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

DRAFT 2019 Annual Report

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EXECUTIVE SUMMARY

Executive Summary to be included in the final report.

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 24 years of SAR data for wild Snake River spring/summer Chinook (1994–2017), 21 years of SAR data for Snake River hatchery spring/summer Chinook (1997–2017), 20 years of SAR data for Snake River wild and hatchery steelhead (1997–2016), and nine years of SAR data for Snake River sockeye (2009–2017). There are nine years of SAR data for Snake River hatchery fall Chinook (2006–2012 and 2015-2016). For mid-Columbia and upper-Columbia fall Chinook there are varying numbers of years available. There are 16 years of SAR data for Hanford Reach wild fall Chinook (2000–2016), seven years of SAR data for wild Deschutes River fall Chinook (2011–2017), and ten years of SAR data for both Spring Creek NFH and Little White Salmon NFH fall Chinook (2008–2017). Spring and summer Chinook and sockeye returns from outmigration year 2017 should be considered preliminary, as they include only 2-salt returns and may change with the addition of 3-salt returns next year. Similarly, 2016 migration year fall Chinook returns include only 2-salt adults. The CSS has actively provided Passive Integrated Transponder (PIT) tags for many of these groups since outmigration year 1997.

The primary purpose of the 2019 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 (2018). In addition, based on comments on the 2018 report, by ODFW, the

CSS report will develop analyses of the relation between CSS annual SARs and the Columbia Basin Partnership Taskforce (CBP) abundance goals for adult returns.

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.

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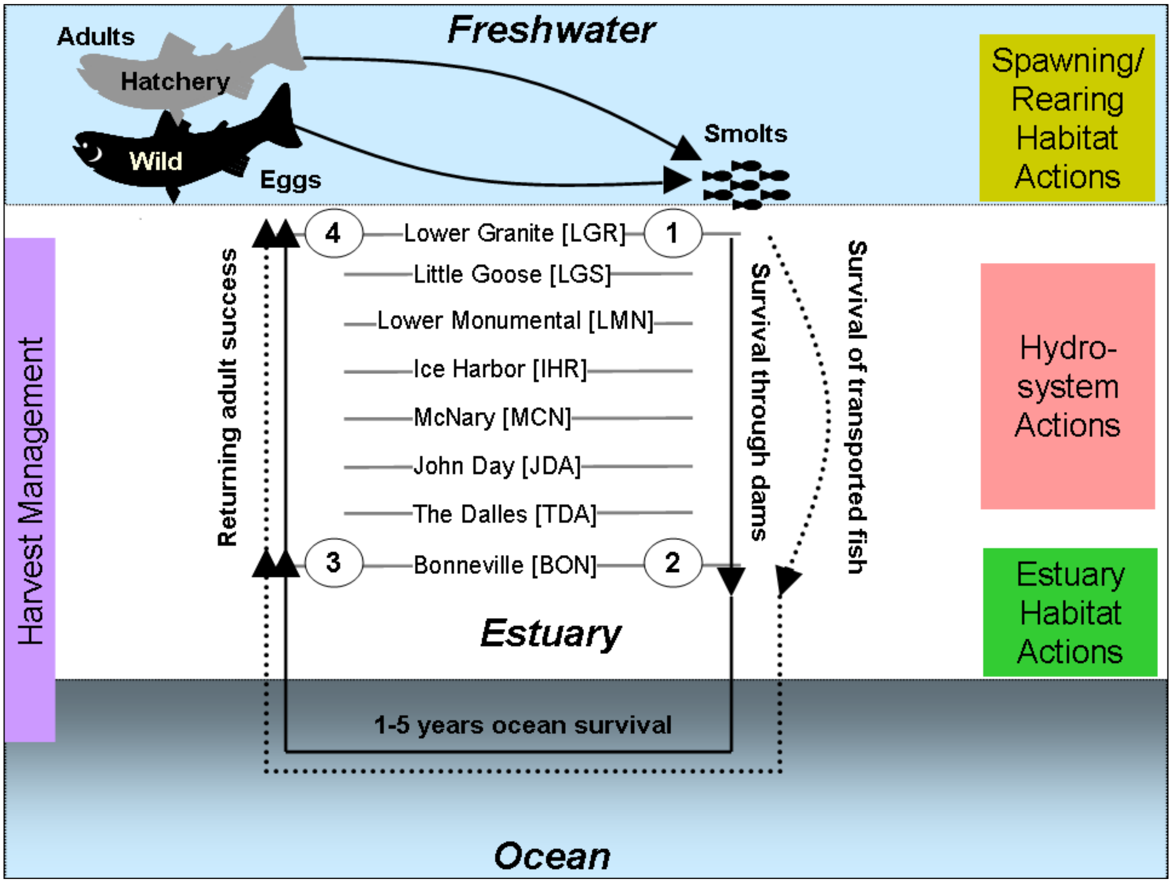


Figure 1.1. A simplified sketch of salmonid life cycle originating in the Snake River basin above LGR. Survival metrics from different portions of the life cycle inform various management questions (e.g., regarding hydrosystem, estuary, or habitat actions, etc.). Both naturally spawned and hatchery produced 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 out-migrating 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 sub basin and main stem out-migrant 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 sub basins 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, sub basins, 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. In 2019 the CSS modified the estimation procedure for reach survivals, incorporating a logit link to constrain survival estimates from zero to one. Appendix A has updated methods to describe this change.

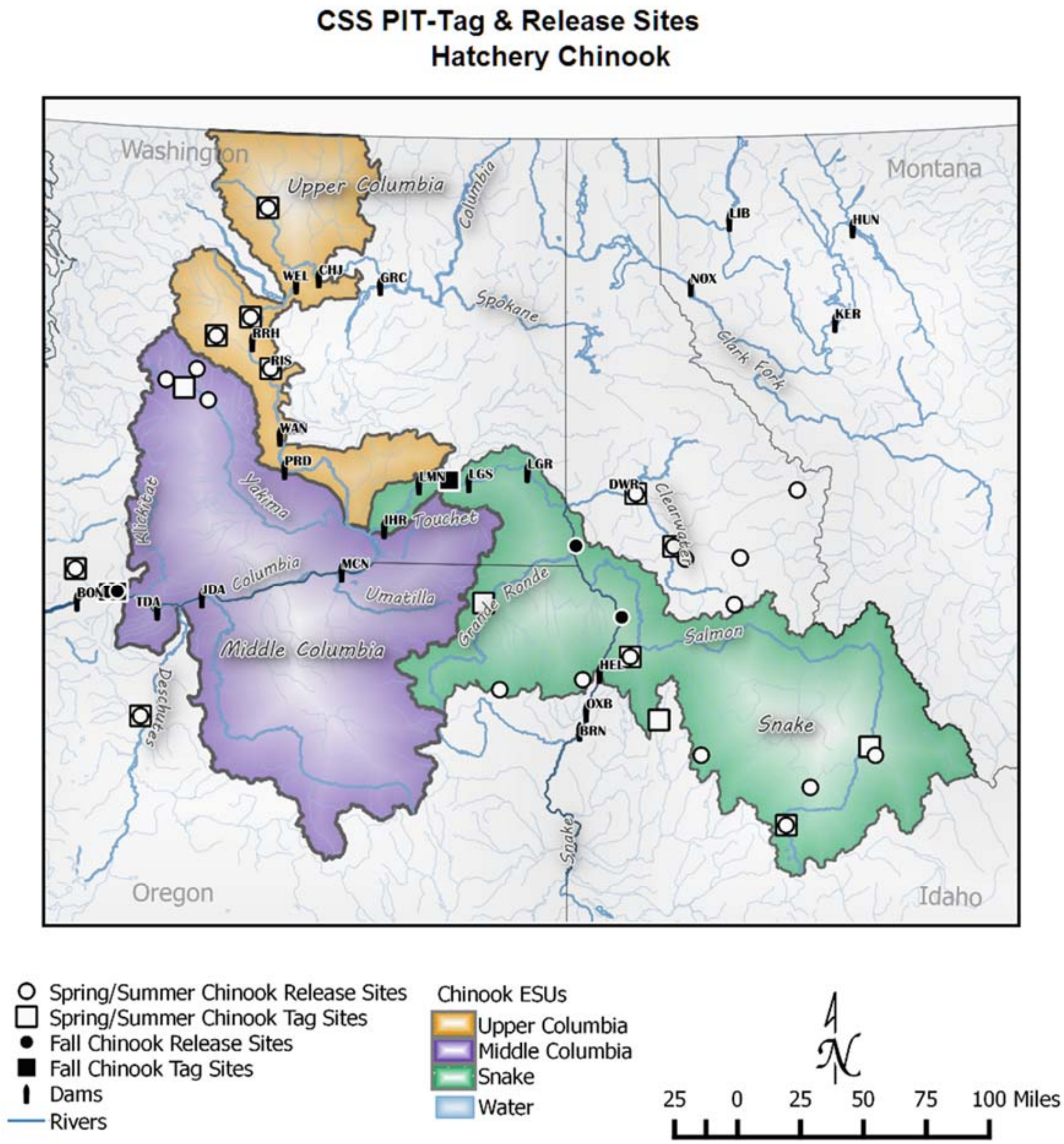


Figure 1.2. CSS PIT-tag release locations for Hatchery spring/summer Chinook and fall Chinook in the Columbia River Basin.

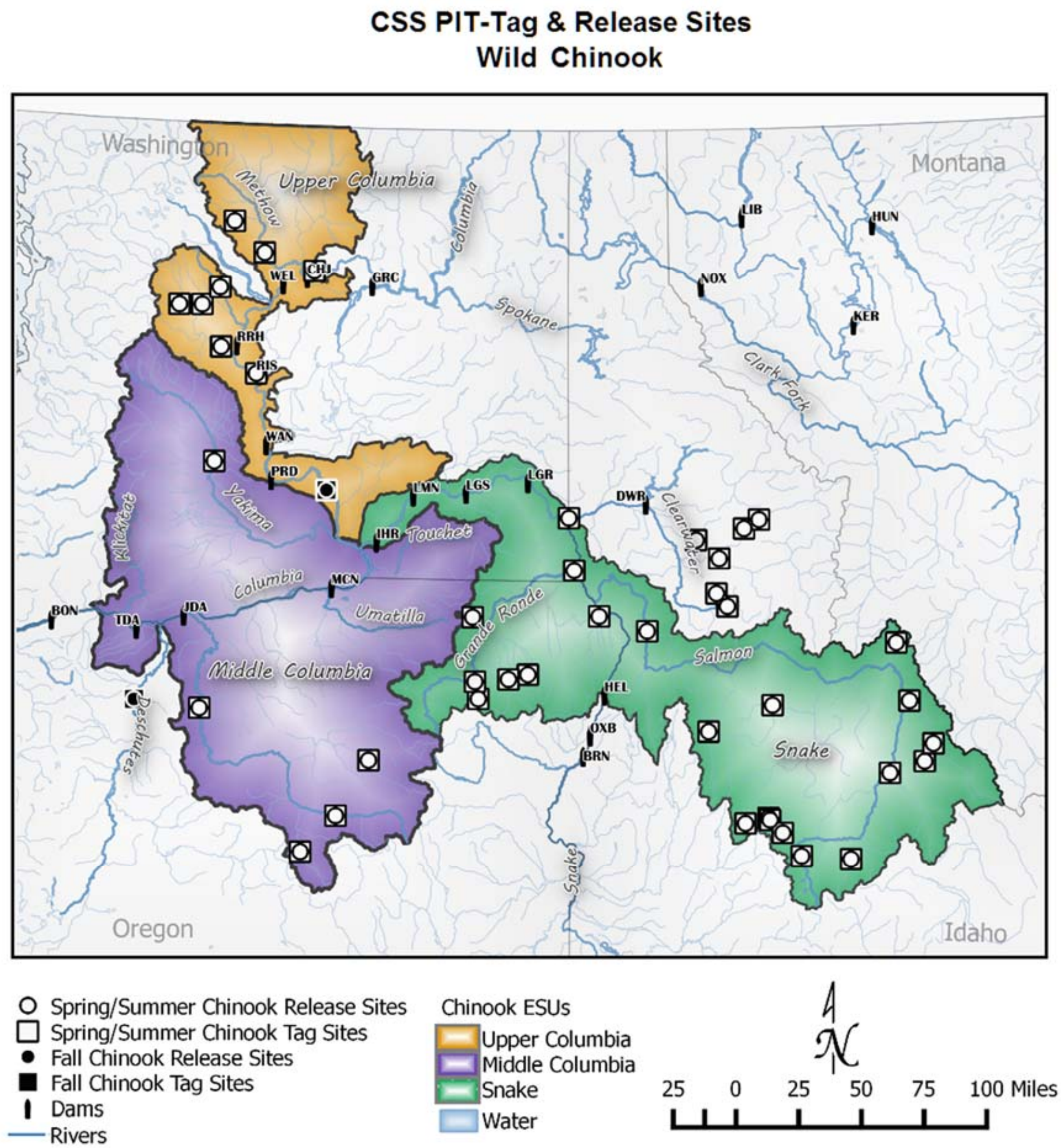


Figure 1.3. CSS PIT-tag release locations for wild spring/summer Chinook and fall Chinook in the Columbia River Basin.

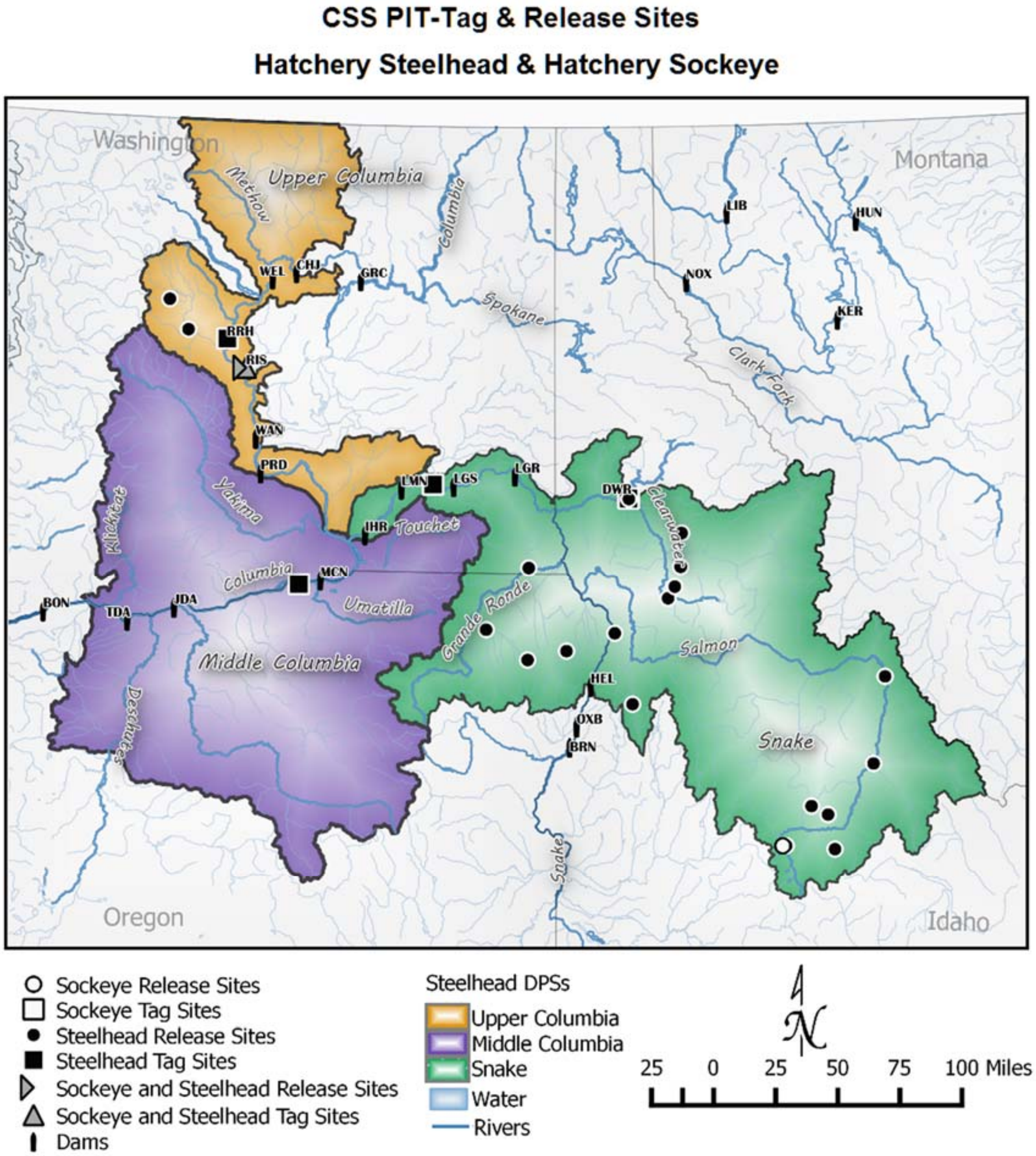


Figure 1.4. CSS PIT-tag release locations for hatchery steelhead and sockeye in the Columbia River Basin.

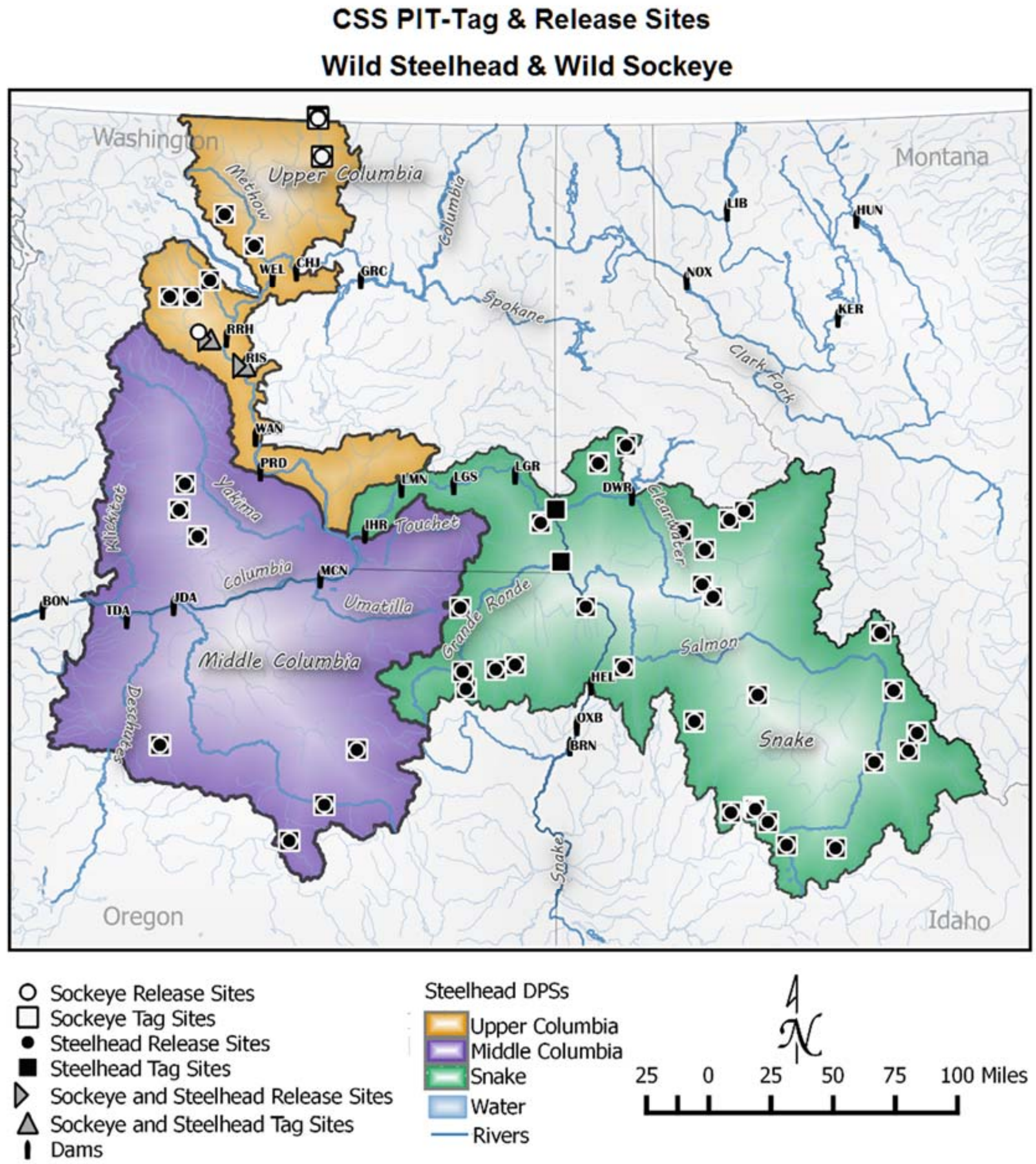


Figure 1.5. CSS PIT-tag release locations for wild steelhead and sockeye in the Columbia River Basin.

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 seven Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), Ice Harbor (ICH), 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, MCN, Ice Harbor (IHR), 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 smolts below BON to adult returns back to LGR (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 three 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 2019. 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. Either fish are assigned to the transport (T) or return to river (R). 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*). Survival from release in tributaries to return as adults at BON or MCN dams have also been evaluated using this method. And in recent years we added adult return data for dams in the upper Columbia (Rock Island, Rocky Reach). 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 2018. The sample sizes for each group with tags provided by the CSS from 1994–2018 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 out-migrated 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 out-migrating 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 6 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 from 2015 to 2018.

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 added 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. In 2018 Umatilla River wild steelhead will be added to the report for the first time.

Coordination and pre-assignments during 2019

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 2019 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). 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 2019 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. Chinook	59,400	27,200						86,600
Kooskia	Sp. Chinook		3,100			4,900			8,000
Pahsimeroi	Su. Chinook		6,400	16,000					22,400
Sawtooth	Sp. Chinook	16,000	6,400						22,400
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		12,900			20,000			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						52,000
Lyons Ferry (Big Canyon Creek)	Fa. Chinook		11,100					5,000	16,100
Grand Total		148,300	362,000	49,000	20,000	24,900	4,000	8,400	616,600

[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 anticipated for marking for the 2019 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 location of marking, species, tag funding sources and tag totals are shown for each. Through cooperative efforts, pre-assignments are carried by either the CSS or the Cooperator for all groups except for the Entiat, Methow, Chiwawa, Wenatchee Tributaries (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 2019 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 anticipated for marking in 2019 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. The location RIS refers to Rock Island Dam.

		PIT-tag Marking Agency[1]								
Location/Hatchery	**Species**	**NPT[2]**	**ODFW**	**USFWS**	**YINN**	**SMP**	**COLV**	**ONA**	**CTUIR**	**Total**
Wild Groups										
Imnaha Trap (Imnaha Basin)	CH/ST	5,600								5,600
Above Wells/Okanogan River	Su. Chinook						25,700			25,700
Okanogan River	Sockeye							9,000		9,000
John Day River	CH/ST		4,000							4,000
Deschutes River	Steelhead		500							500
Deschutes River	Fa. Chinook		0							0
Yakima (Satus, Toppenish, and Ahtanum Creeks)	Steelhead				500					500
Umatilla River	Steelhead		3,500						1,600	5,100
Hatchery Groups										
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				9,000					9,000
Leavenworth NFH	Sp. Chinook					15,000				15,000
Warm Springs NFH	Sp. Chinook			15,000						15,000
Hatchery + Wild										
RIS Yearling	Chinook					4,000				4,000
RIS subyearling	Chinook					4,800				4,800
RIS	Steelhead					4,000				7,000[3]
RIS	Sockeye					3,400				3,400
Grand Total		5,600	8,000	60,000	9,500	31,200	25,700	9,000	1,600	153,600

[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), Okanogan Nation Alliance (ONA), and Confederated Tribes of the Umatilla Indian Reservation (CTUIR). 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.

[3] Additional 3,000 tags provided by Douglas County PUD.

Historic in-river conditions and transportation

The environmental conditions experienced by out-migrating juvenile yearling Chinook and steelhead have varied considerably over the 24-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.

Consistent with the analytical approach CSS has developed over the past several years, we have transitioned to describing flow and spill in terms of water transit time (the time it takes the average particle of water to pass through a reservoir (or series of reservoirs); and PITPH which is a scaled variable that measures the impact of spill proportion on fish passage. The CSS had historically use average spill proportion as an index of the overall proportion of the juvenile salmon population that passed in spill. Based on comments we have received CSS developed a new index variable called PITPH that estimates the proportion of fish passing via the powerhouse at each dam, based on the relationship between spill proportion and proportion of the juvenile population that would pass via the turbines and bypass at the dam. This relationship was derived from PIT-tag data and was described in detail in Appendix J of the 2015 CSS Annual Report. The PITPH variable can vary between 0 and 8 conceptually for populations of fish originating above Lower Granite Dam that have to pass eight dams in their outmigration. Fish passing through spill through the entire reach would encounter zero dams (PITPH of 0) and fish passing through bypasses or turbines at all 8 dams would have a PITPH of 8. As can be seen in Figure 1.6 the range has been generally between two and six for wild Chinook and steelhead cohorts over the years. With 2001, a year when spill was curtailed for most of the year, having the highest PITPH of 6 for wild yearling Chinook. Also, 2001 was a low flow year and water transit time LGR to BON in that year was nearly 36 days while WTT was only 10 days in 1997 a very high flow year for both the Lower Snake River and in the Columbia River.

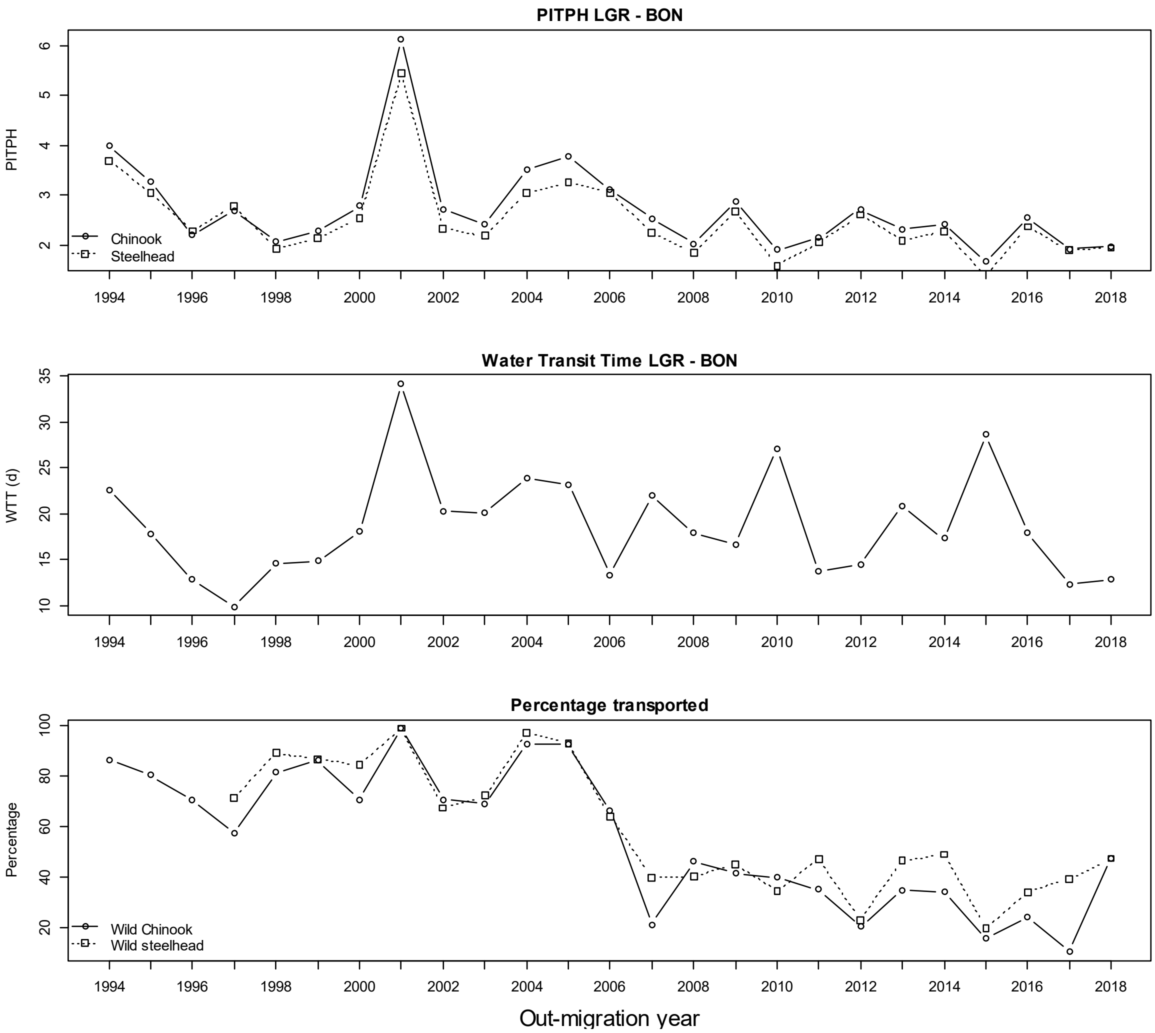


Figure 1.6 The top, middle, and bottom panels are summaries of PITPH, WTT, and the proportion transported over the historical context of the CSS in the reach Lower Granite (LGR) to Bonneville Dam (BON). The top panel shows estimated cumulative PITPH based on flow and spill volumes from April 15 to May 31 at all dams in the LGR to BON reach. The middle panel shows cumulative water transit times LGR to BON. The proportion transported is shown for the wild Snake River stocks involved in the CSS as expressed by population proportion of T0 fish in migration years before 2006 and Tx fish for the years 2006 and beyond (Table 7.7 and Table 7.13 in the 2009 CSS annual report, and Appendix D of 2019 CSS annual report). The proportion transported for migration year 2018 wild Chinook and Steelhead were 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 2012–2017. In 2018 transport began earlier on April 23 at Lower Granite Dam and Little Goose Dam. Transport began on April 24 at Lower Monumental Dam. This earlier start to transportation combined with relatively high flows (i.e. low water transit time) which effectively reduces the spill proportion, increased the percentage of the population that was transported in 2018. Nearly 50% of wild Chinook and wild steelhead were transported in 2018. 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. Typically for years after 2005 about 40 percent of the PIT-tagged Snake River wild stocks were transported.

Note on the use of PITPH

As described above PITPH is an indicator variable, that indexes the relative proportion of fish passing dams via the powerhouse. The variable was developed improve upon the average spill proportion index variable that assumed 1:1 spill volume to fish passage via spill. The PITPH variable accounts for greater than 1:1 spill passage efficiency that occurs at many dams particularly with the implementation of surface passage structures. The PITPH index is calculated based on the average spill proportion, average flow level, and the presence of spillway surface passage structures at each project during the time periods that fish are passing each project. The level of certainty associated with the PITPH index varies by project and the amount of data used to estimate the PITPH index. Particularly at the lower Columbia River projects, the amount of data that was available to estimate the PITPH equations was low, resulting in higher levels of uncertainty in the estimates. For example, at river flow and spill conditions occurring from May 7 – May 9, 2019 at John Day and The Dalles dams, the probability of powerhouse passage (PITPH) is approximately 0.06 at John Day Dam and 0.19 at The Dalles Dam for yearling Chinook and steelhead. However, the levels of uncertainty associated with PITPH at these projects are high, with prediction intervals ranging from 0.01 to 0.22 at John Day Dam and from 0.04 to 0.51 at The Dalles Dam.

The PITPH index is not appropriately applied to tradeoff decisions of spill among projects at a fine scale of hourly or daily spill levels. The PITPH index was primarily derived using average spill proportions and average flow levels occurring over two- or three-week periods at each project or over an entire season. The data necessary to estimate hourly PITPH are not available. The range of available data was highly variable across projects. For example, at The Dalles Dam there is no available PIT-tag data and the PITPH equations were based on a small number of telemetry data sets. Data are not available at all projects for the same years. Very few projects had data available for zero spill or 100% spill conditions. These issues are not problematic when the PITPH index is applied as intended, using weekly, bi-weekly or seasonal average conditions.

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 will be published with the release of the CRSO EIS. The agencies involved have signed a non-disclosure agreement that precludes publication of the results prior to their publication in the EIS. This Chapter will include results of life cycle modeling analysis developed for Snake River spring/summer Chinook in 2013-2017 life cycle analyses. As well as cohort models developed for the CSS and published in Haeseker et al. (2012). Both models have been extensively reviewed regionally, and by the ISAB.

Chapter 3 updates the time series of data on juvenile travel time, instantaneous mortality, and survival with data from 2018. 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. Fall Chinook SARs which previously had been reported in a separate chapter are now incorporated into Chapter 4. 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 a review of current knowledge and research on delayed hydrosystem mortality.

Chapter 7 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 2018.

Chapter 8 Presents continued development of methods to estimate detection probabilities of yearling Chinook salmon at Bonneville Dam, examines environmental factors that influence detection probability across time and incorporates select explanatory variables into a predictive model, and provides preliminary estimates of spring migrant smolt abundance at Bonneville Dam. This is the second year of this effort and the approach will be further developed and evaluated to refine estimation.

Chapter 9 Presents continued development of a life-cycle model for Entiat –Metthow wild Chinook.

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 summarizes the 2017 CSS annual meeting held on April 3, 2017, at the Ambridge Event Center in Portland, Oregon.

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

CHAPTER 2
ANALYSES OF CRSO EIS ALTERNATIVES

The Comparative Survival Study was asked to provide analyses of the responses of salmon populations to alternative hydrosystem operations that were developed as part of the EIS. Because agencies were required to sign non-disclosure agreements these analyses cannot be made available to the public until the draft EIS is released for public review in February 2020. Chapter 2 will be sent to the ISAB for review and comment in February 2020 when the draft EIS is released for review.

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 2018 Annual Report (McCann et al. 2018). 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).

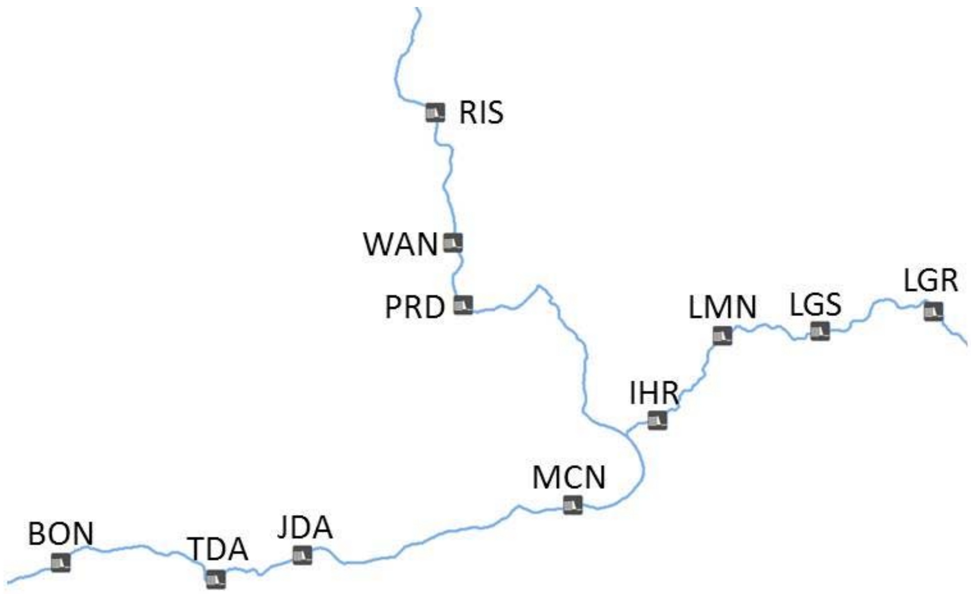


Figure 3.1 Location of dams and river reaches analyzed. Labels refer to Lower Granite Dam (LGR), Little Goose Dam (LGS), Lower Monumental Dam (LMN), Ice Harbor Dam (IHR), Rock Island Dam (RIS), Wanapum Dam (WAN), Priest Rapids Dam (PRD), McNary Dam (MCN), John Day Dam (JDA), The Dalles Dam (TDA), and 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 2019 Annual Report.

Reach	Species	Rearing type	Cohorts	Cohort Period
LGR-MCN	steelhead	hatchery and wild	126	1-week
LGR-MCN	yearling Chinook	wild	164	1-week
LGR-MCN	yearling Chinook	hatchery	161	1-week
LGR-MCN	sockeye	hatchery and wild	20	annual
LGR-MCN	subyearling Chinook	hatchery	68	2-week
RIS-MCN	steelhead	hatchery and wild	57	2-week
RIS-MCN	yearling Chinook	hatchery and wild	56	2-week
RIS-MCN	sockeye	hatchery and wild	19	annual
MCN-BON	steelhead	hatchery and wild	119	1-week
MCN-BON	yearling Chinook	hatchery and wild	120	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 1998–2018. We also estimated annual survival probabilities for sockeye in the LGR–MCN reach over 1998–2018. 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 1999–2018. For hatchery subyearling Chinook in the LGR–MCN reach we developed survival probability estimates for four 2-week release cohorts over migration years 1998–2018. 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 $\hat{c}$ 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 2019 Annual Report.

Reach	Species	Rearing type	Cohorts	Cohort Period
LGR-MCN	steelhead	hatchery and wild	115	1-week
LGR-MCN	yearling Chinook	wild	126	1-week
LGR-MCN	yearling Chinook	hatchery	131	1-week
LGR-MCN	sockeye	hatchery and wild	17	annual
LGR-MCN	subyearling Chinook	hatchery and wild	57	2-week
RIS-MCN	steelhead	hatchery and wild	54	2-week
RIS-MCN	yearling Chinook	hatchery and wild	44	2-week
RIS-MCN	sockeye	hatchery and wild	19	annual
MCN-BON	steelhead	hatchery and wild	31	3-week
MCN-BON	yearling Chinook	hatchery and wild	48	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 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 β_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 improved model fit in some cases 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 β_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 AICc among the three forms evaluated (i.e., the MY + Day, MY, or LR model forms) was selected for use in subsequent analyses.

The models were ranked according to AICc, the model with the minimum AICc was identified, and Akaike weights (w_i) were calculated for each model (Burnham and Anderson 2002). Using the AICc-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 AICc, 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 Instantaneous Mortality Rates

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 (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 that have been collected through the CSS project to evaluate the effects of TDG. Over the 1998-2018 timeframe, there are 115-131 estimates of instantaneous mortality for juvenile yearling Chinook salmon and steelhead in the LGR-MCN reach and 31-48 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 evaluate the effects of TDG on instantaneous mortality rates. If TDG levels are detrimental to salmon and steelhead during their outmigration, we would expect to see higher mortality levels when TDG levels were elevated. We characterized TDG exposure levels in two ways. We characterized the average TDG exposure by calculating the average of the TDG levels measured at each dam during the downstream migration. We characterized the maximum TDG exposure by determining the maximum tailrace TDG level experienced across dams during the downstream migration. In addition to potential TDG effects, several other co-occurring factors have been shown to be associated with mortality rates including seasonality, water transit time, powerhouse passage rates, and water temperatures (McCann et al. 2018).

We developed instantaneous mortality rate models that included TDG as an explanatory variable 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 to evaluate the relative importance of TDG for explaining patterns of variation in mortality rates.

Results

The models that were developed were effective at explaining variation in the observed fish travel times, instantaneous mortality rates, and survival rates (Table 3.4). 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 - 3.7. In the LGR–MCN reach, mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ varied considerably over the period of 1998–2018, 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 1998–2018 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 – 3.7). 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 3.3). 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 3.4 through 3.7). 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 $\hat{S}_i$.

Table 3.3 Coefficient of determination values (R2) in models characterizing yearling and subyearling Chinook salmon, steelhead, and sockeye salmon fish travel times (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 AICC 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	0.80	0.88
LGR-MCN	yearling Chinook	wild	MY + Day	0.97	MY	0.39	0.43
LGR-MCN	yearling Chinook	hatchery	MY + Day	0.95	MY	0.27	0.46
LGR-MCN	sockeye	hatchery and wild	LR	0.62	LR	0.48	0.65
LGR-MCN	subyearling Chinook	hatchery and wild	MY + Day	0.82	LR	0.15	0.64
RIS-MCN	steelhead	hatchery and wild	MY	0.91	LR	0.26	0.44
RIS-MCN	yearling Chinook	hatchery and wild	MY	0.82	LR	0.10	0.11
RIS-MCN	sockeye	hatchery and wild	LR	0.36	LR	0.23	0.29
MCN-BON	steelhead	hatchery and wild	MY + Day	0.97	LR	0.49	0.73
MCN-BON	yearling Chinook	hatchery and wild	MY	0.98	MY	0.17	0.31

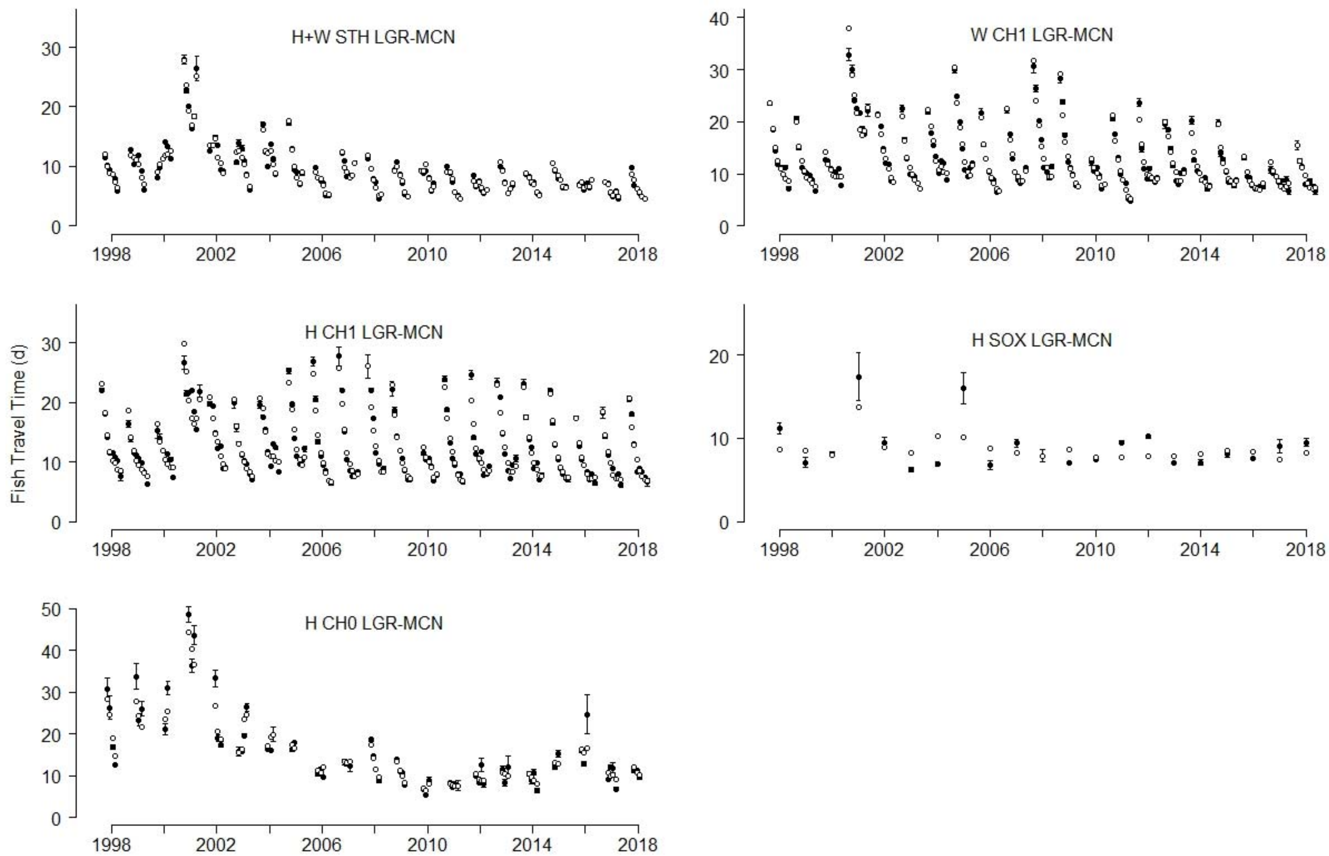


Figure 3.2 Estimates of mean Fish Travel Time (in days, black circles) and predicted mean Fish Travel Time (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the LGR–MCN reach, 1998–2018. The error bars represent +/- 1 SE. For hatchery sockeye in 2015 - 2017, the open circles represent the predicted fish travel times based on environmental conditions in those years and was predicted using models calibrated to 1998-2014 and 2018 data.

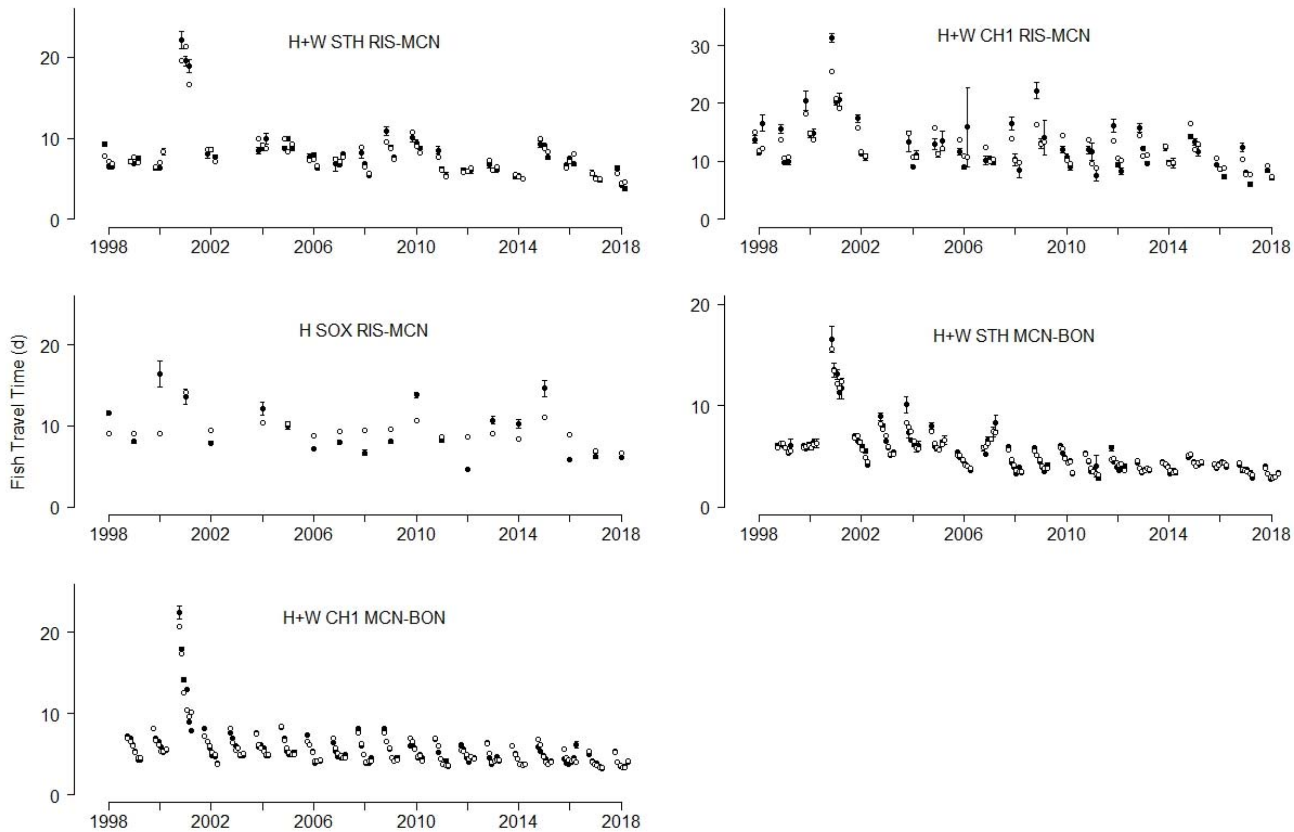


Figure 3.3 Estimates of mean Fish Travel Time (in days, black circles) and predicted mean Fish Travel Time (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the RIS-MCN and MCN-BON reaches, 1998–2018. The error bars represent +/- 1 SE.

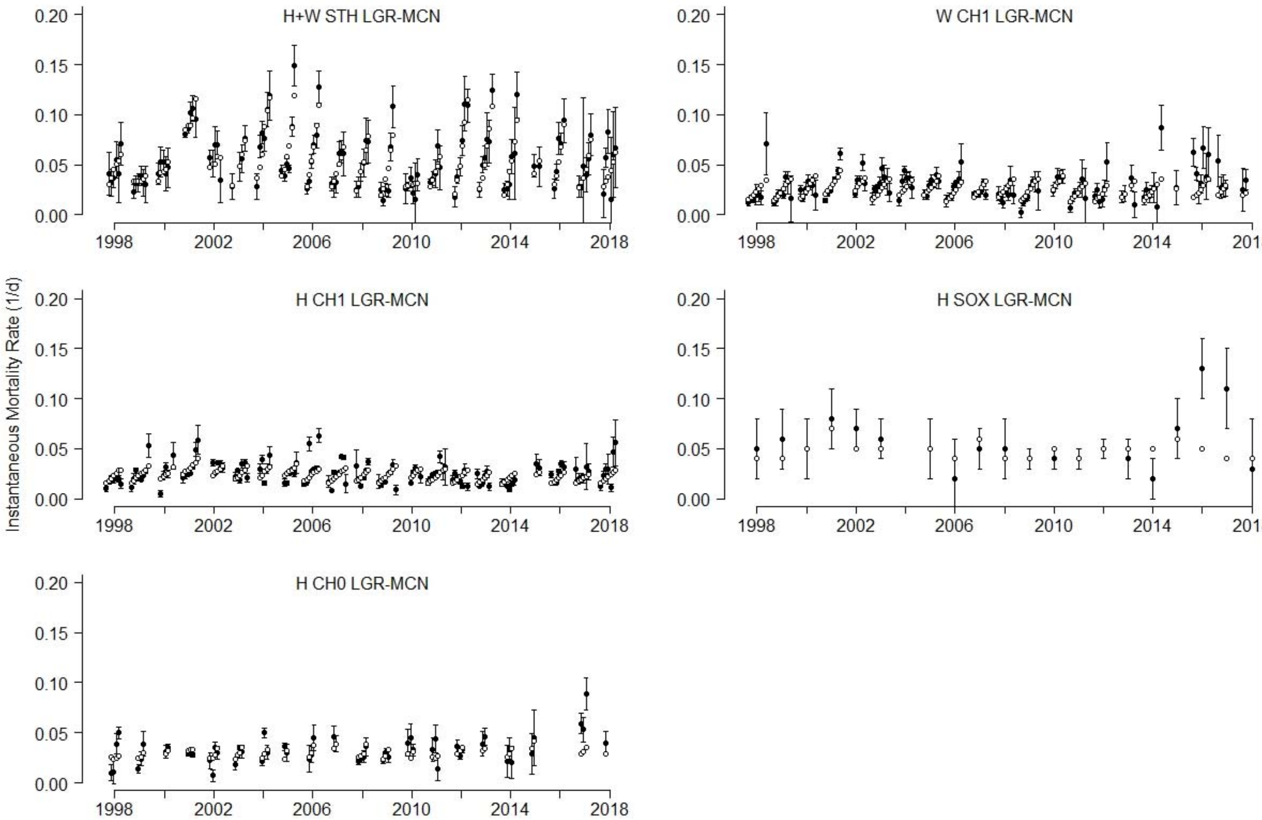


Figure 3.4 Estimates of instantaneous mortality rates, Z (y-axis, d-1, black circles) and predicted Z (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the LGR–MCN reach, 1998–2018. The error bars represent +/- 1 SE. For hatchery sockeye in 2015 - 2017, the open circles represent the predicted instantaneous mortality rates based on environmental conditions in those years and was predicted using a model calibrated to 1998-2014 and 2018 data.

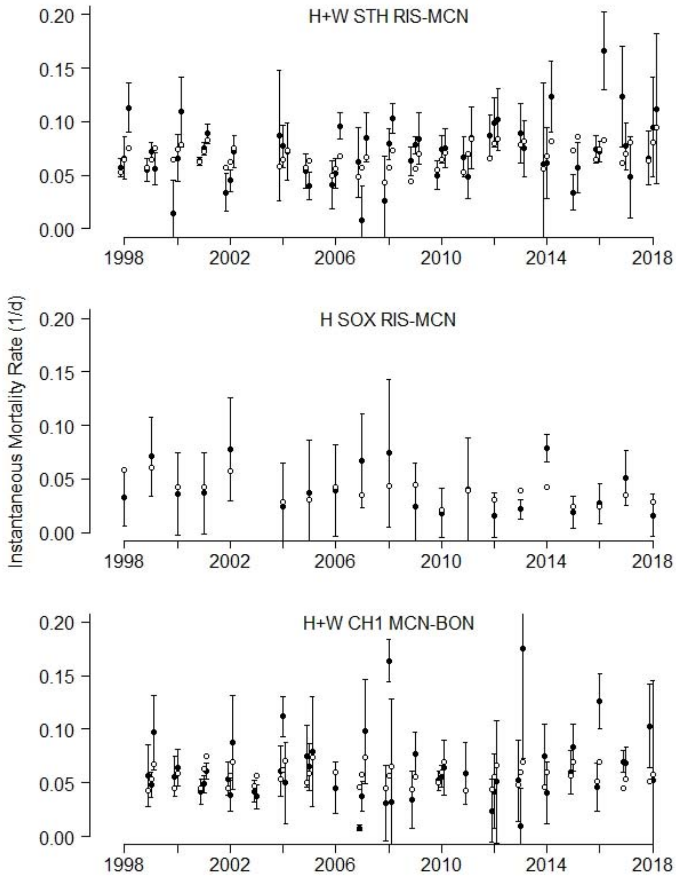


Figure 3.5 Estimates of instantaneous mortality rates, Z (y-axis, d-1, black circles) and predicted Z (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the RIS–MCN and MCN-BON reaches, 1998–2018. The error bars represent +/- 1 SE.

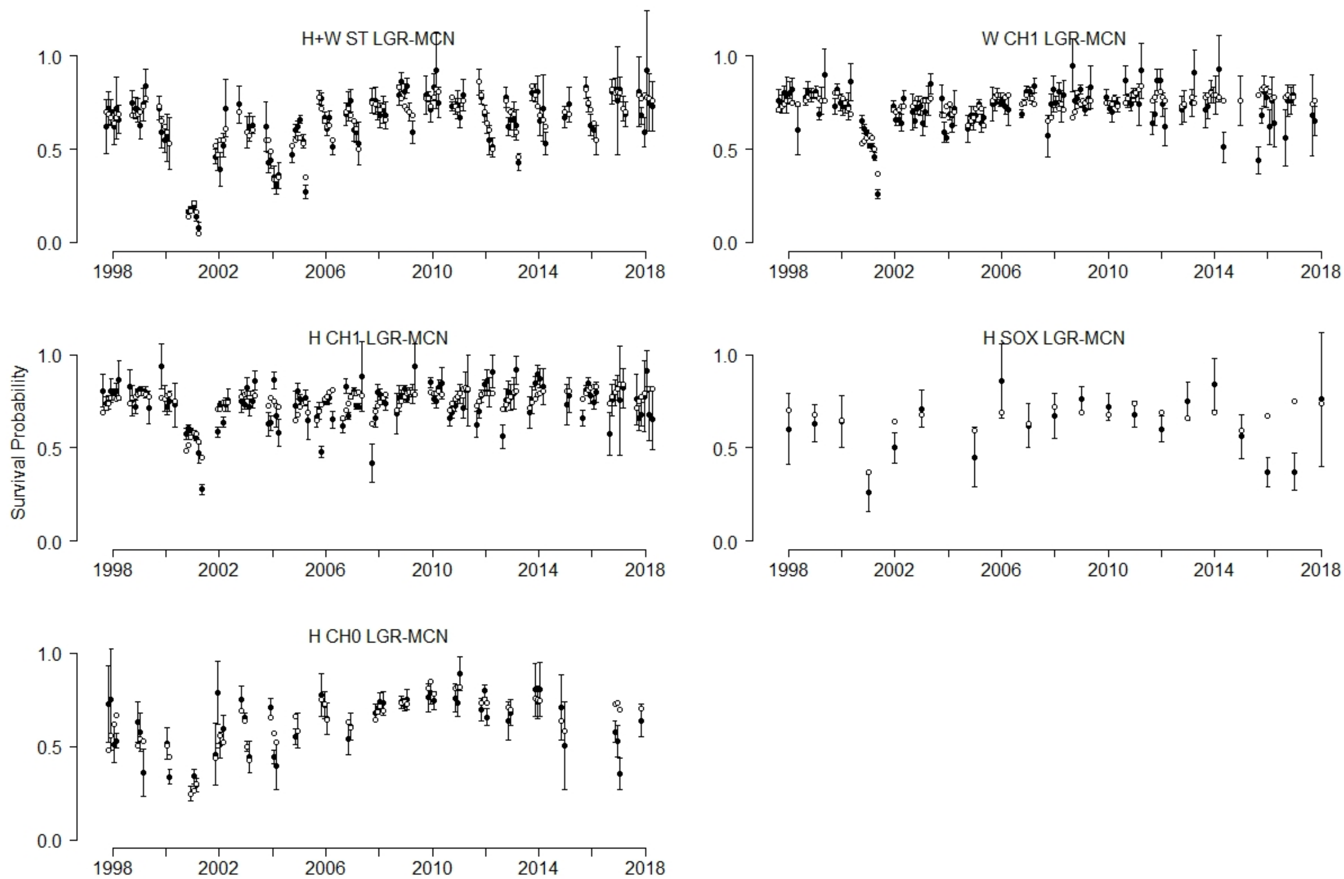


Figure 3.6 Estimates of in-river survival probability (black circles) and predicted in-river survival probability (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN reach, 1998–2018. The error bars represent +/- 1 SE. For hatchery sockeye in 2015 - 2017, the open circles represent the predicted survival probabilities based on environmental conditions in those years and was predicted using models calibrated to 1998-2014 and 2018 data.

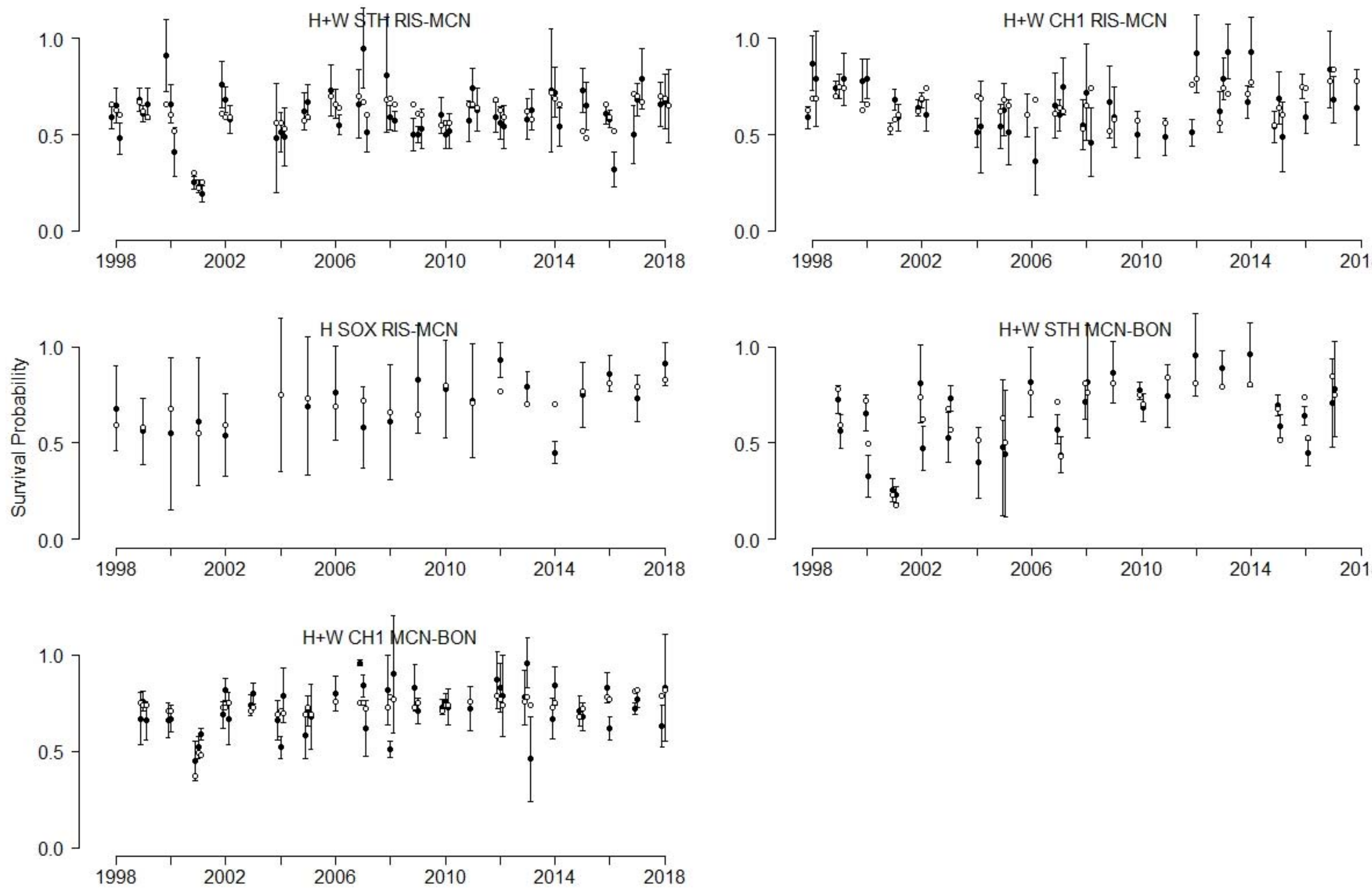


Figure 3.7 Estimates of in-river survival probability (black circles) and predicted in-river survival probability (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the RIS–MCN and MCN-BON reaches, 1998–2018. 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 3.3, 3.5, and 3.7). 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 3.3). 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 3.5 and 3.7). 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, powerhouse passage rates, and the number of dams with spillway surface passage structures frequently were important factors for describing variability in *FTT* (Figure 3.8). 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 high degree of the variation in mean *FTT* for most species and reaches (Table 3.3).

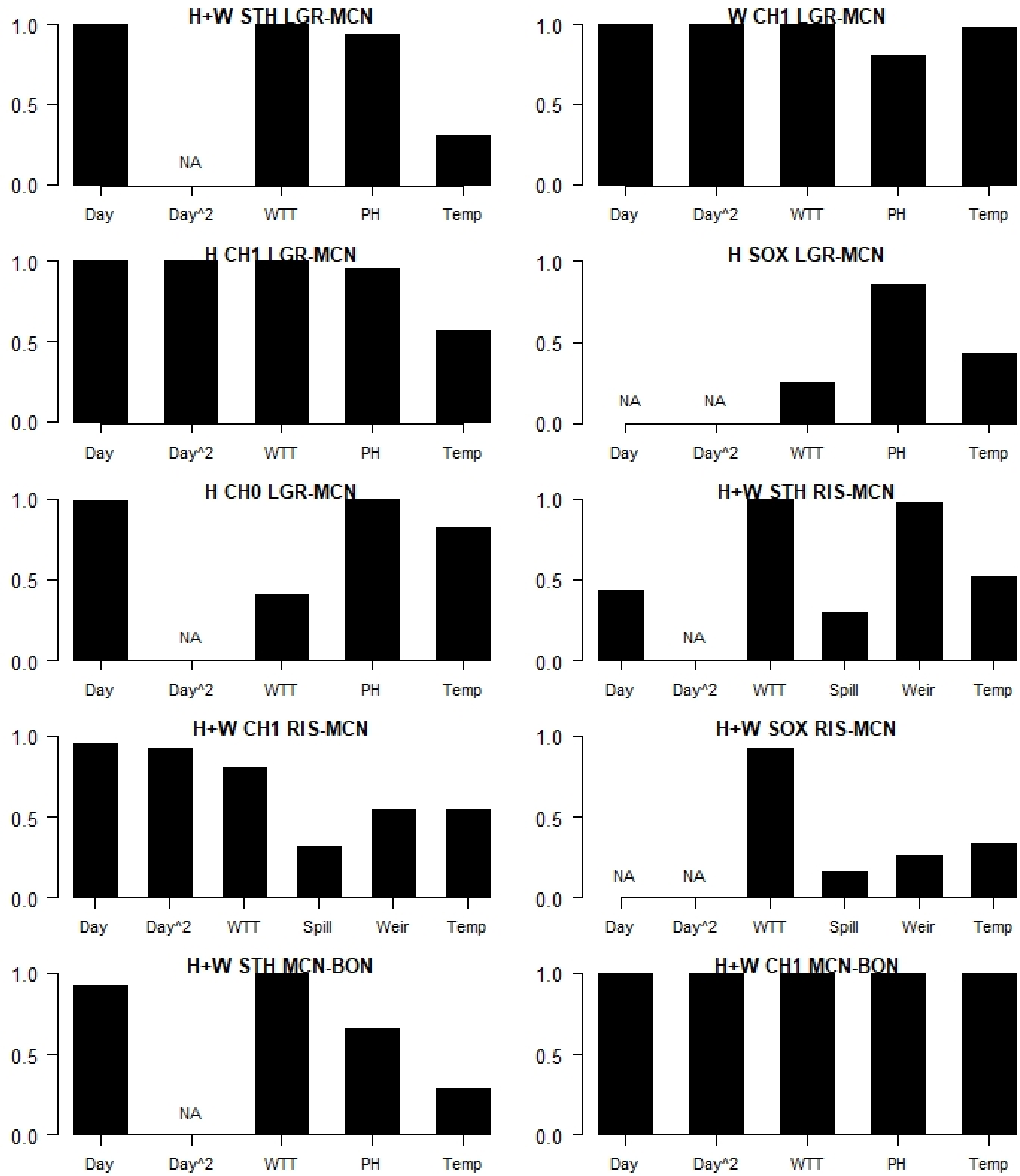


Figure 3.8 Relative variable importance values (y-axis) for fish travel time (FTT) models on release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2018. 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.

Model-averaged coefficients and relative variable importance values indicated that Julian day of release, powerhouse passage rates, and water temperature were frequently the most important factors for characterizing the variability in *Z* (Figure 3.9). 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. The amount of variation in *Z* that was explained using the model-averaged predictions ranged from 10% up to 80% (Table 3.3).

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 3.3). 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 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 through 2017 (Hassemer 2016). Due to these concerns, only data from 1998-2014 and 2018 were used to calibrate models and 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 through 2017 based on the environmental conditions in those years (Figures 3.2, 3.4, and 3.6). Those predictions indicated that fish travel times were consistent with expectations in 2015 through 2017 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 and 2017 were only from the Springfield Hatchery. The instantaneous mortality rate in 2016 ($\hat{Z} = 0.132$) and 2017 ($\hat{Z} = 0.111$) were the highest rates observed, were more than double the average rate during 1998-2014 (average Z = 0.049), and were well above predictions based on the environmental conditions in those years. The survival probabilities in 2016 ($\hat{S}$ = 0.369) and 2017 ($\hat{S} = 0.371$) were about half the average survival probability 1998-2014 (average S = 0.644) and also were well below predictions based on the environmental conditions in those years. These results indicate that the mortality rates were higher than expected and the survival rates were lower than expected based on the environmental conditions that were present in 2016 and 2017. These data suggest that the low survival and high mortality for sockeye in 2016 and 2017 was not due to the environmental conditions in those years, but rather some other factor. Estimated fish travel times ($\widehat{FTT} = 9.5\ days$), instantaneous mortality rates ($\hat{Z} = 0.029$), and survival probabilities $(\hat{S} = 0.756)$ from the 2018 releases were all consistent with model predictions based on the environmental conditions that were present in

2018, indicating that the issues that impacted Snake River hatchery sockeye during 2015-2017 did not appear to affect sockeye performance in 2018.

Results of TDG Evaluations

Instantaneous mortality rate models that included average or maximum TDG along with Julian Day, water transit time, water temperature, and powerhouse passage rates (Figure 3.11-3.12) showed similar results to models without the TDG variables (Figure 3.9). 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 3.10-3.11). Consistent with these Relative Variable Importance results, the model-averaged coefficients of the effects of average and maximum TDG were all near zero and confidence intervals overlapped zero for all species and reaches (Figure 3.12), indicating that there was little association between TDG levels and instantaneous mortality rates.

The majority of the observations were collected under TDG levels of less than 120%, which is the current tailrace limit (Figure 3.13). However, a number of observations were collected under involuntary spill levels where the TDG levels were above 120% and up to a maximum of 136%. Those observations that were collected when TDG levels were over 120% or 125% also showed no indications that TDG was having a detrimental effect on instantaneous mortality rates based on residual plots. Combined, these results show no evidence of detrimental effects of TDG on instantaneous mortality rates for steelhead and Chinook salmon in the Snake and Columbia rivers over the range of TDG levels that have been observed during 1998-2018 (Figure 3.13).

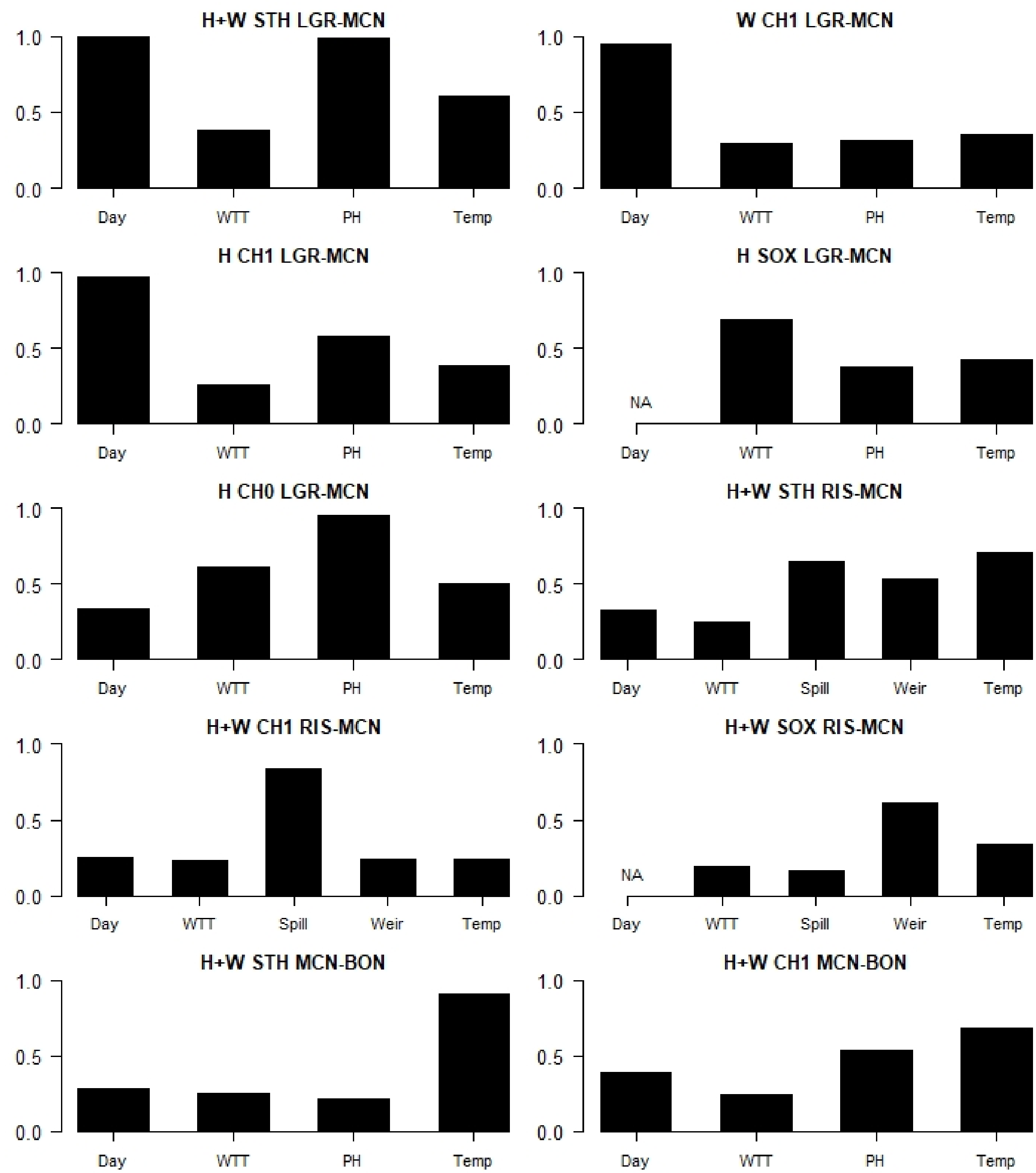


Figure 3.9 Relative variable importance values (y-axis) for instantaneous mortality rate (Z) models on release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2018. 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.

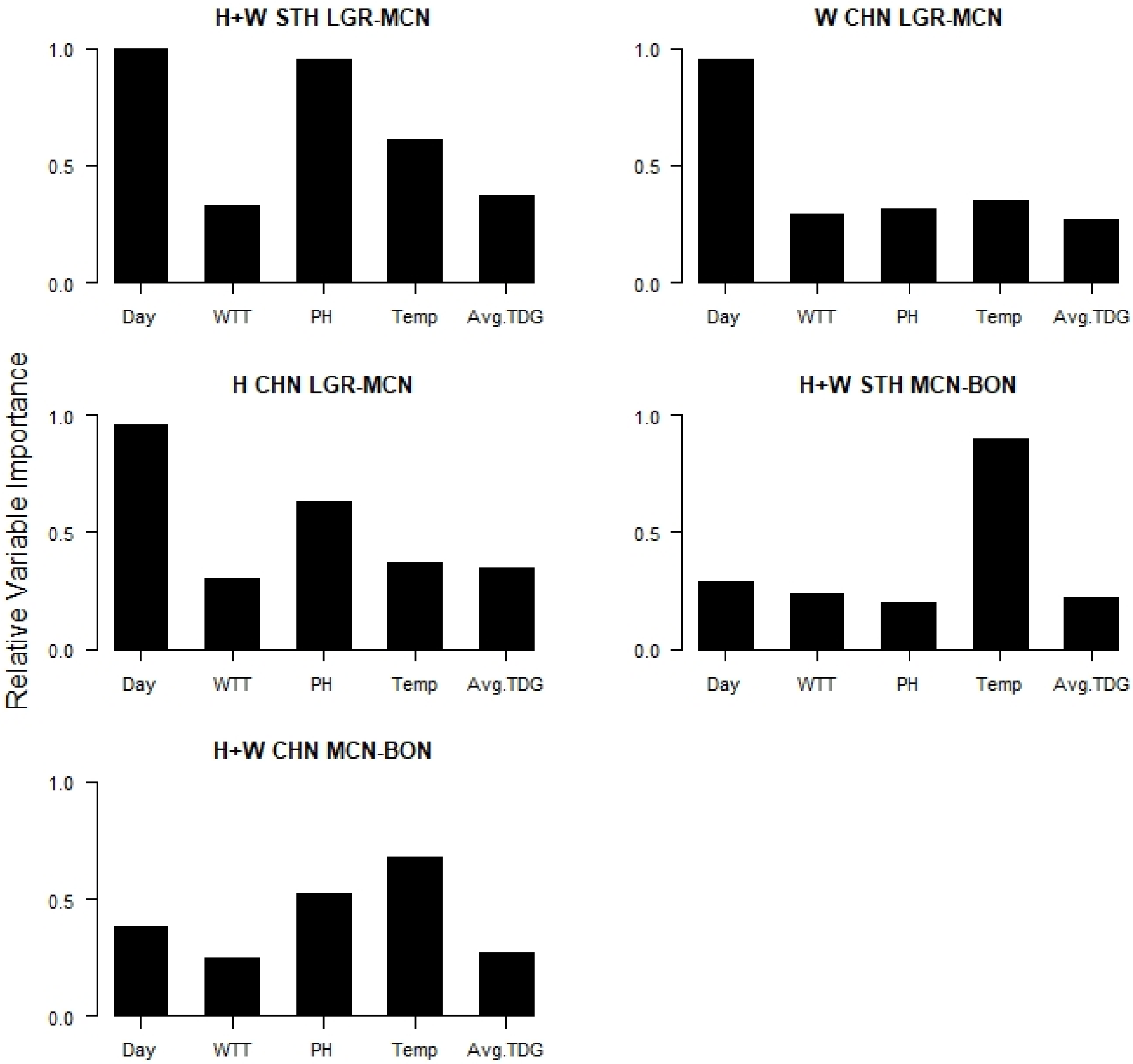


Figure 3.10 Relative variable importance values (y-axis) for instantaneous mortality rate models for hatchery (H) and wild (W) steelhead (STH) and yearling Chinook salmon (CHN) in the LGR–MCN and MCN–BON reaches, 1998–2018. Model variables included: Julian day of cohort release (Day), water transit time (WTT), powerhouse passage (PH), water temperature (Temp), and average Total Dissolved Gas (Avg.TDG).

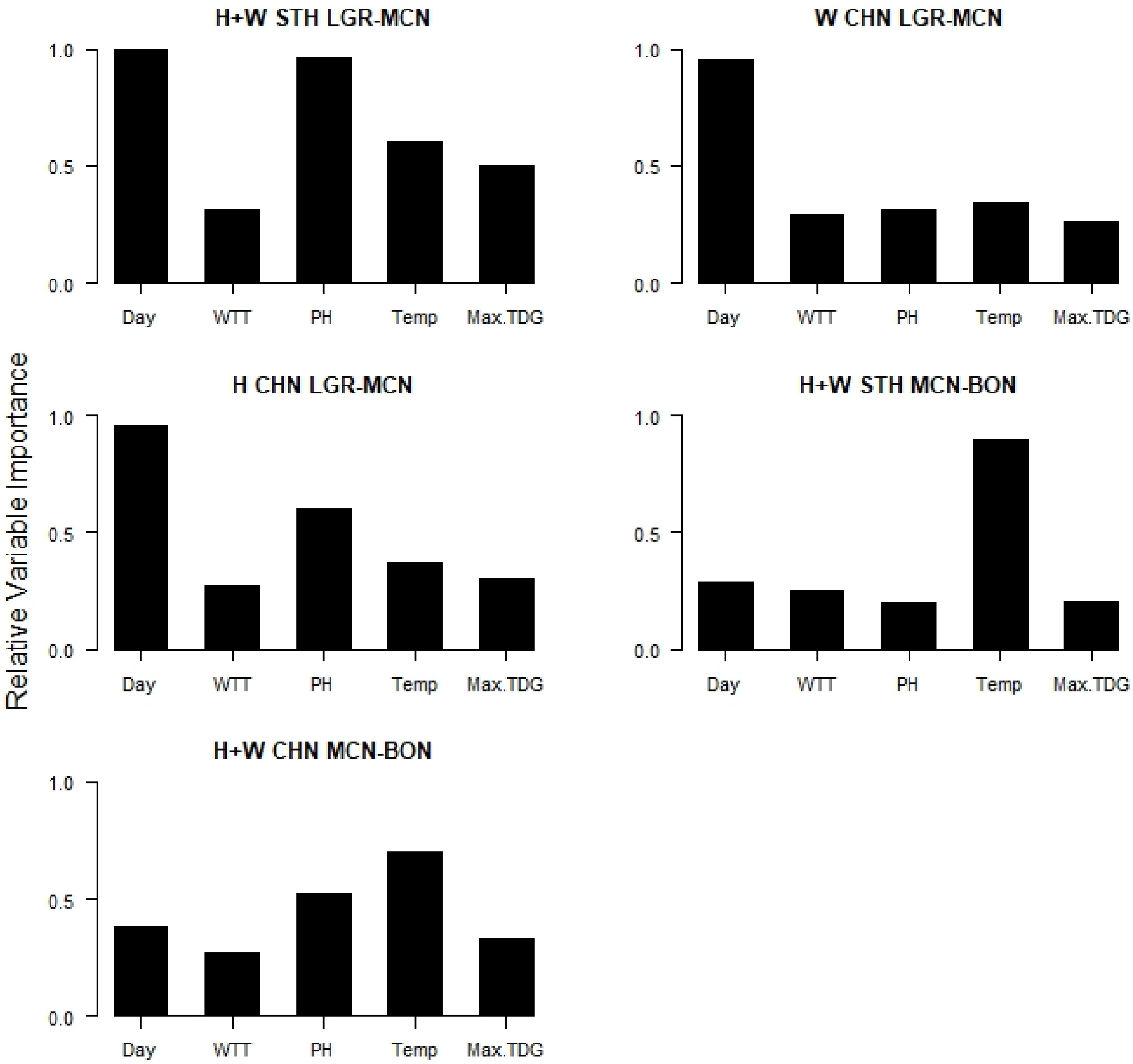


Figure 3.11 Relative variable importance values (y-axis) for instantaneous mortality rate models for hatchery (H) and wild (W) steelhead (STH) and yearling Chinook salmon (CHN) in the LGR–MCN and MCN–BON reaches, 1998–2018. Model variables included: Julian day of cohort release (Day), water transit time (WTT), powerhouse passage (PH), water temperature (Temp), and maximum Total Dissolved Gas (Max.TDG).

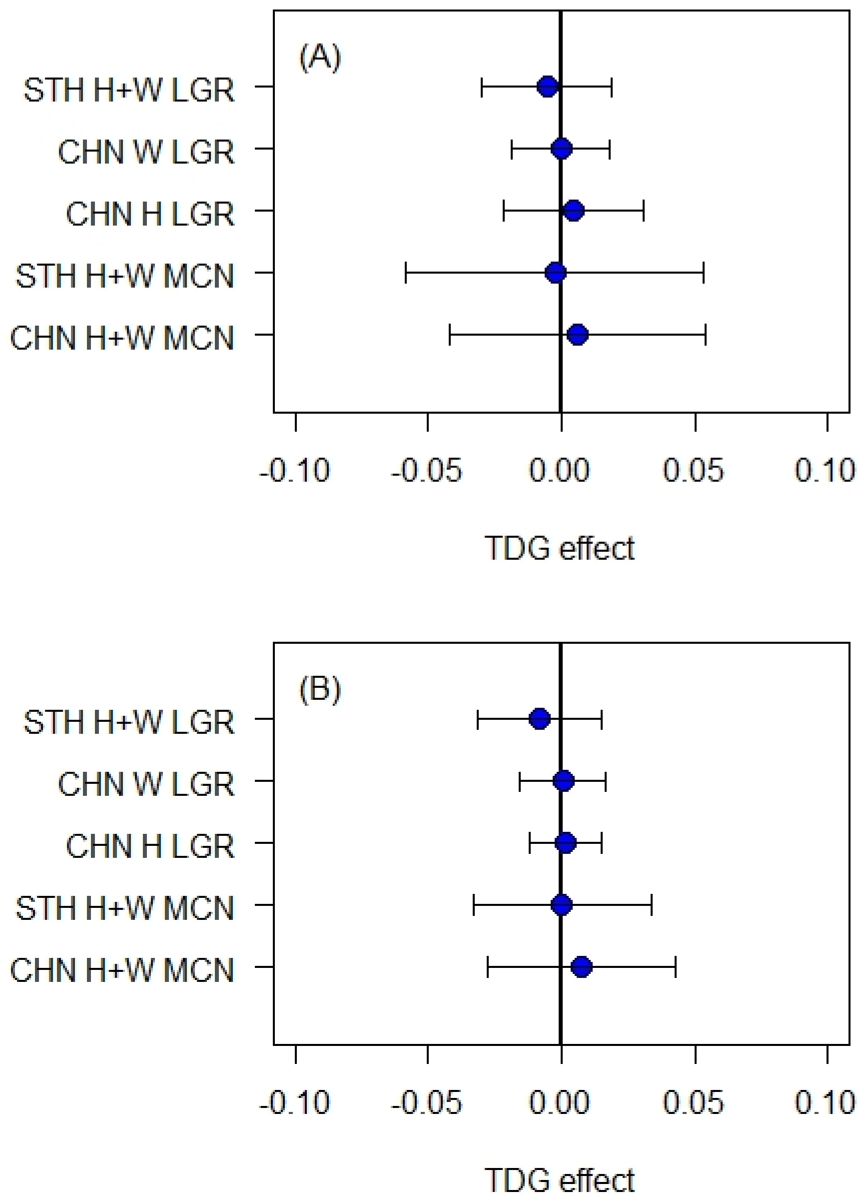


Figure 3.12 Model-averaged coefficients (blue circles) and confidence intervals (horizontal black lines) for the effect of average (panel A) and maximum (panel B) Total Dissolved Gas (TDG) on instantaneous mortality rates of hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN (LGR) and MCN-BON (MCN) reaches.

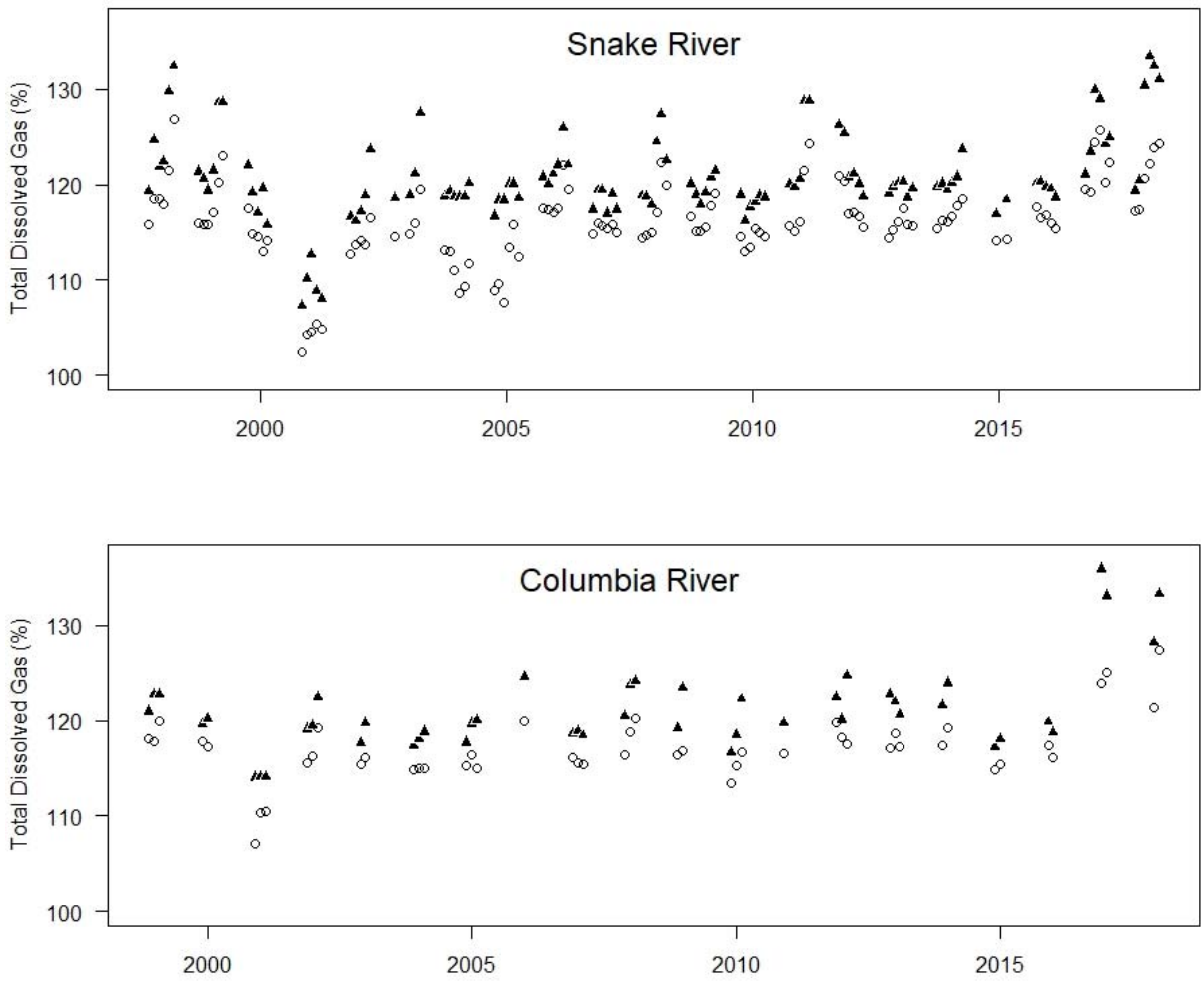


Figure 3.13 Average (open circles) and maximum (filled triangles) Total Dissolved Gas levels measured in the Snake River (upper panel) and Columbia River (lower panel), 1998-2018.

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 variable incorporates 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 increasing water temperature could include (1) declining smolt energy reserves or physiological condition over the migration season and with increasing water temperature, (2) increasing predation rates on smolts over the migration season and with increasing water temperature, (3) increases in disease susceptibility or disease-related mortality over the migration season and with increasing 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 3.8 and 3.9).

Generally, models for *FTT* accounted for more of the variation 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, 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. Based on the comprehensive analysis of TDG effects, we found no evidence of detrimental effects on instantaneous mortality rates of high TDG levels, with observations that ranged up to 136% TDG. Analyses indicate that substantial improvements in fish travel time, in-river survival, ocean survival, and Smolt-to-Adult Return rates (SARs) are expected under a 125% TDG spill operation compared to historical operations (CSSOC 2017, McCann et al. 20017).

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 increasing spill levels up to the dissolved gas limits on a 24-hour basis, could reveal similarly dramatic improvements for yearling and subyearling Chinook, steelhead and sockeye.

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. There currently are plans to install a spillway PIT detector at Lower Granite Dam in 2019 or 2020.

Conclusions

- The data collected and analyzed over 1998-2018 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, spill proportions, and powerhouse passage rates, 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, increase spill percentages, and reduce powerhouse passage rates.
- Concerns have been raised over the poor condition and survival of sockeye released from the Springfield Hatchery in 2015 through 2017. Snake River hatchery sockeye released in 2016 and 2017 had the highest instantaneous mortality rates observed over the time series and survival probabilities were about half of average. However, the estimated fish travel time, instantaneous mortality rate, and survival probability from the 2018 releases were all consistent with model predictions based on the environmental conditions that were present in 2018, indicating that the issues that impacted Snake River hatchery sockeye during 2015-2017 did not appear to affect sockeye performance in 2018.

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 out-migrating 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, Yakima River, and Upper Columbia River fish (e.g., Lower Granite Dam, GRA; McNary Dam, MCA, Rocky Reach Dam, RRA, and Wells Dam, WEA). 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 (e.g., Lower Granite, McNary, John Day, Bonneville, Rocky Reach), and adults at either Bonneville Dam or the uppermost dam with adequate adult detection capability. 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 and Okanogan — 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 some Upper Columbia populations, we estimate SARs from Rocky Reach Dam (RRE), where applicable.

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. For wild groups we compare estimated SARs to the NPCC 4% average SAR objective and report the frequency with which SARs have exceeded the 2% minimum objective. 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 2016 (steelhead) or 2017 (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 (Appendix B). 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 this 2019 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 2006–2017. (Note: we further subdivided SARs into subbasin for the Grande Ronde/Imnaha MPG in this report). The overall SARs are presented for all 24 years of PIT-tagged wild spring/summer Chinook data and 21 years of PIT-tagged hatchery spring/summer Chinook data. Overall SARs for Snake River aggregate wild and aggregate hatchery steelhead are presented for 20 years beginning in 1997. We also calculated SARs for Snake River wild steelhead at an MPG level (Clearwater, Grande Ronde, Imnaha, and Salmon) and for A-run and B-run wild steelhead for smolt migration years 2006–2016. We have also begun to report SARs of Asotin Creek (Lower Snake River MPG) wild steelhead for smolt migration years 2014-2016. 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 2000–2017 are presented for wild spring Chinook from the John Day and Yakima rivers. For hatchery spring Chinook, overall SARs from 2000 to 2017 are presented for Carson and Cle Elum hatcheries and for Warm Springs Hatchery spring Chinook during 2007–2017. Overall SARs are also presented for wild steelhead from the John Day River (2004–2016), Deschutes River (2007–2016), Yakima River (2002–2016), and Umatilla River (2011-2016). The Umatilla group was a new addition for the 2018 CSS Annual Report. In the 2018 report, we added two release sites (Buckhollow and Bakeoven creeks) to the Deschutes wild steelhead group, which was previously represented by the Trout Creek release site. Steelhead in these three tributaries are in the Deschutes Eastside steelhead MPG. 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 Priest Rapids Dam, PRD) wild and hatchery spring and summer Chinook, 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 (2006–2017) and Wenatchee River (2007–2017); Leavenworth hatchery spring Chinook (2000–2017); wild steelhead (Wenatchee, Entiat and Methow rivers from 2006 to 2016); and hatchery steelhead released into the Wenatchee River (2003–2016). There is limited ability to detect PIT-tagged juvenile out-migrants in the Columbia River upstream of MCN. However, for some groups, 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 2008–2016 (through 2017 for spring Chinook and sockeye). In the 2017 report, we also added three new groups in the Upper Columbia region: Entiat hatchery summer Chinook (2011-2017); Winthrop hatchery spring Chinook (2009-2017); and Wenatchee wild sockeye (2014-2017). We also 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. Similar to past years, SARs for Upper Columbia groups are calculated as adult returns to Bonneville Dam (BOA). However, for this year's report, we have added SARs calculated as adult returns to the uppermost dam with adequate adult PIT-tag detection capabilities (Appendix B). For groups originating from the Wenatchee River or tagged and released at RIS, these SARs are estimated as adult returns to McNary Dam (MCA). For groups originating from the Entiat River, these SARs are estimated as adult returns to Rock Reach Dam (RRA). For groups originating from the Methow, Okanogan, or Columbia River above Wells Dam, these SARs are estimated as adults returning to Wells Dam (WEA).

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 2017 report was the sixth 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. 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, over 60,000 fall Chinook tagged in 2017 and again, over 60,000 in 2018. These efforts were 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 and one in the Clearwater 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 (Appendix A).

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 methods below 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. 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

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. Methods to estimate SARs for Snake River subyearling fall Chinook have been described previously (McCann et al. 2015).

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. In the cases when zero adults returned (i.e., SAR point estimates of 0.0), 90% confidence intervals were based on the Clopper-Pearson binomial methodology (Clopper and Pearson 1934). Reported correlations are based on a minimum ten SAR point estimates, except as noted.

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:

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

where,

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

and,

$$C_1^* = (T_0 + C_1) - T_0^*$$

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,

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

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

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

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 draft report represent adult returns through June 28, 2019 for Snake River spring or spring/summer Chinook groups, Upper and Mid-Columbia spring Chinook groups, and all steelhead groups and July 31, 2019 for Snake River summer Chinook groups, Upper Columbia summer Chinook groups, and all sockeye groups.

Characterizing the relationship between $\log_e$(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 2015 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 and Wenatchee populations, Rocky Reach Dam for Entiat populations, and Wells Dam for Methow and Okanogan 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 Umatilla River wild steelhead are estimated at JDA, and those of Deschutes River wild steelhead are estimated at BON. PIT-tagged smolt numbers of salmon and steelhead originating in the upper Columbia, upstream of the Wenatchee River are estimated at RRE as well as at MCN. 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. For most mid-Columbia and Upper Columbia groups, nonparametric 90% confidence intervals are estimated with the same bootstrapping protocol as was used for the Snake River stocks. The only exception to this is for fish tagged and released at Rock Island Dam or when zero adults returned (i.e., SAR point estimates of 0.0). In these cases, 90% confidence intervals were based on the Clopper-Pearson binomial methodology (Clopper and Pearson 1934). SARs for this draft report represent adult returns through June 28, 2019 for Snake River spring or spring/summer Chinook groups, Upper and Mid-Columbia spring Chinook groups, and all steelhead groups and July 31, 2019 for Snake River summer Chinook groups, Upper Columbia summer Chinook groups, and all sockeye groups.

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 1994–2016 and 1997–2016, 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 1993–1999, 1.1% during 2000-2009, and 0.8% during 2010-2016.

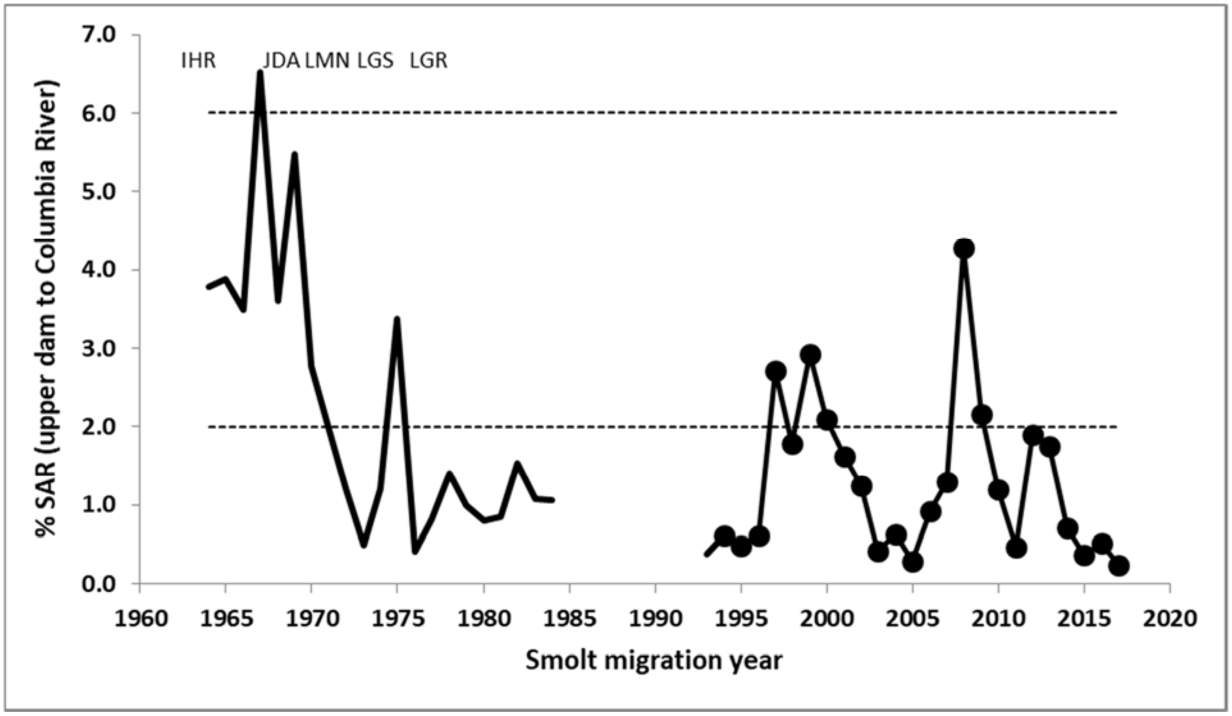


Figure 4.1 SARs from smolts at uppermost Snake River dam to Columbia River returns (including jacks) for Snake River wild spring/summer Chinook, 1964-2017. Dam construction sequence was: 1961-IHR, 1968-JDA, 1969-LMN, 1970-LGS, and 1975-LGR. SARs based on run reconstruction (1964-1984 and 1993, solid line) and CSS PIT tags (1994-2017, dots and solid line). The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference; SAR for 2017 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 0.76%; annual SARs never met the NPCC 4% SAR objective during the period 1994-2017. Annual SARs exceeded the NPCC's minimum SAR objective of 2% in only two migration years (1999 and 2008) during this period (Table B.1; Figure 4.2 top left plot). LGR-GRA SARs with jacks included were about 10% 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 27% 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 2006–2017 smolt migration years (Figure 4.3, Tables B.3-B.14). 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 0.46%) than the range of SARs for the other MPGs (0.67% to 0.94% Tables B.3–B.14; Figure 4.3). SARs were highest in 2008 and very low in 2006, 2011 and 2014-2017 for all MPGs.

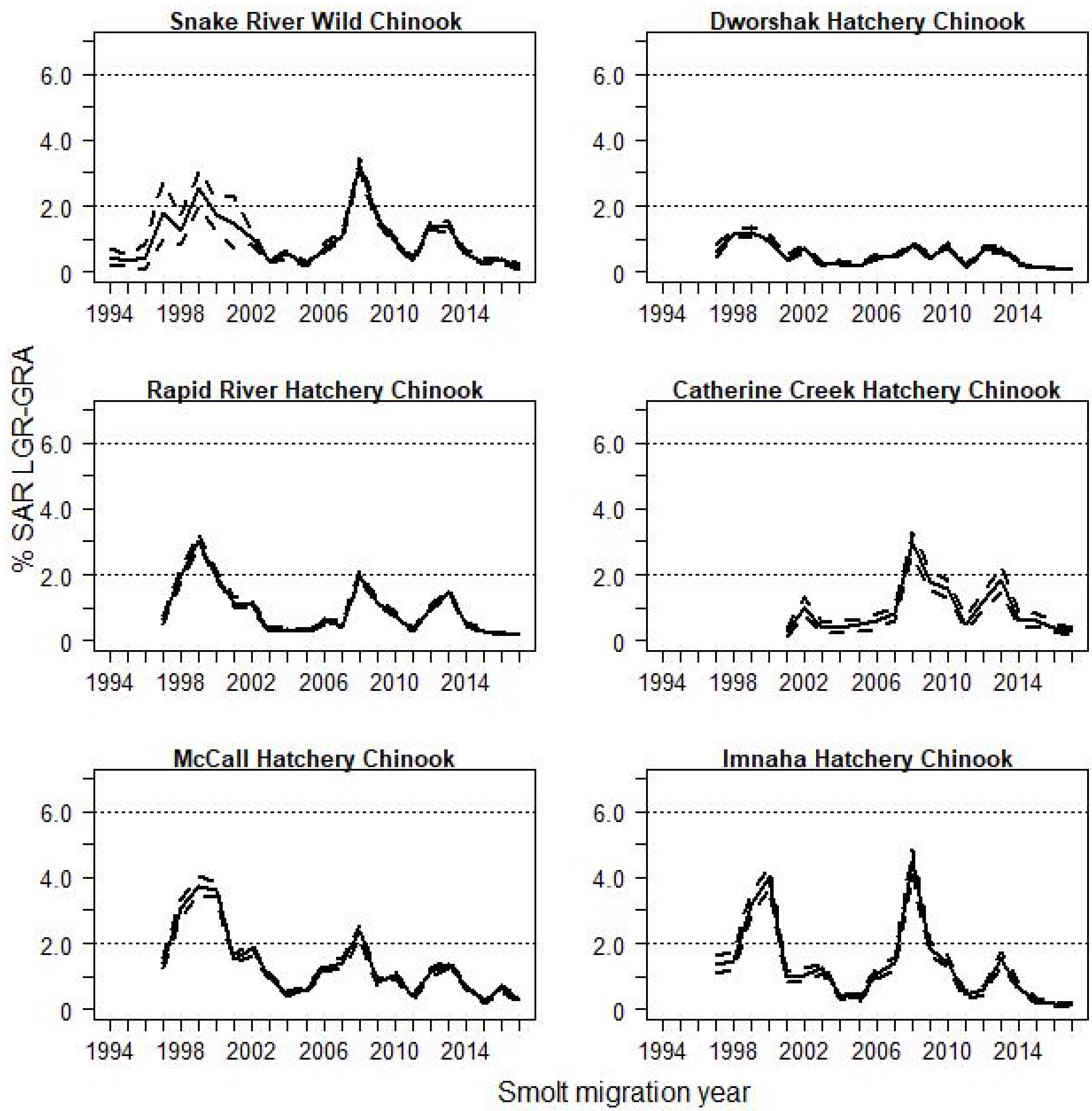


Figure 4.2. Bootstrapped LGR-to-GRA SAR (with jacks included) and upper and lower CI for Snake River wild spring/summer Chinook and five Snake River hatchery groups for migration years 1994–2017. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019 for wild spring/summer and hatchery spring Chinook and July 31, 2019 for hatchery summer Chinook. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.1 (wild spring/summer Chinook), B.15 (Dworshak Hatchery), B.17 (Rapid River Hatchery), B.19 (Catherine Creek Hatchery), B.21 (McCall Hatchery), and B.23 (Imnaha Hatchery).

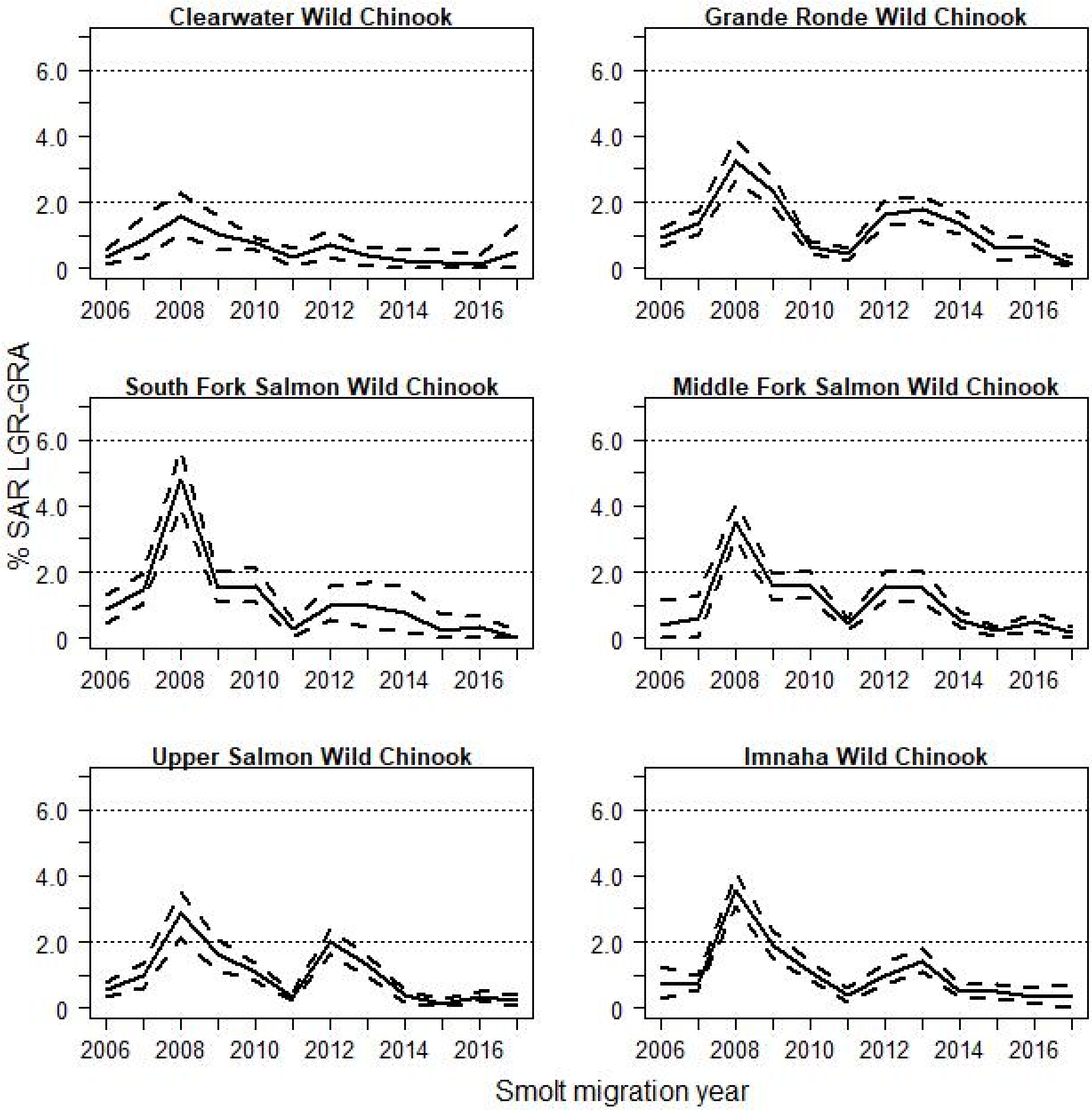


Figure 4.3. Bootstrapped LGR-to-GRA SAR (with jacks included) Snake River wild spring/summer Chinook Major Population Groups for smolt migration years 2006–2017. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019 for Clearwater and Grande Ronde spring/summer Chinook and July 31, 2019 for South Fork Salmon, Middle Fork Salmon, Upper Salmon, and Imnaha spring/summer Chinook. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.3 (Clearwater wild), B.5 (Grande Ronde wild), B.7 (Imnaha wild), B.9 (South Fork Salmon wild), B.11 (Middle Fork Salmon wild), and B.13 (Upper Salmon wild).

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) 0.40% and did not exceed 2% in any year during 1997–2017 (Table B.15). LGR-GRA SARs for Rapid River hatchery spring

Chinook averaged 0.69% and exceeded 2% in a single year (1999; Table B.17). Catherine Creek hatchery Chinook SARs from 2001 through 2017 averaged 0.72% 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) 1.06% and exceeded 2% in four years (1998–2000 and 2008; Table B.21). LGR-GRA SARs for Imnaha hatchery summer Chinook averaged 0.90% 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 = 0.84) during 1997–2017.

The estimated overall SARs for additional Snake River hatchery spring and summer Chinook groups for migration years 2006–2017 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, Kooskia 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. The estimated LGR-to-GRA SARs for all Snake River hatchery spring/summer Chinook were very low in 2014-2017.

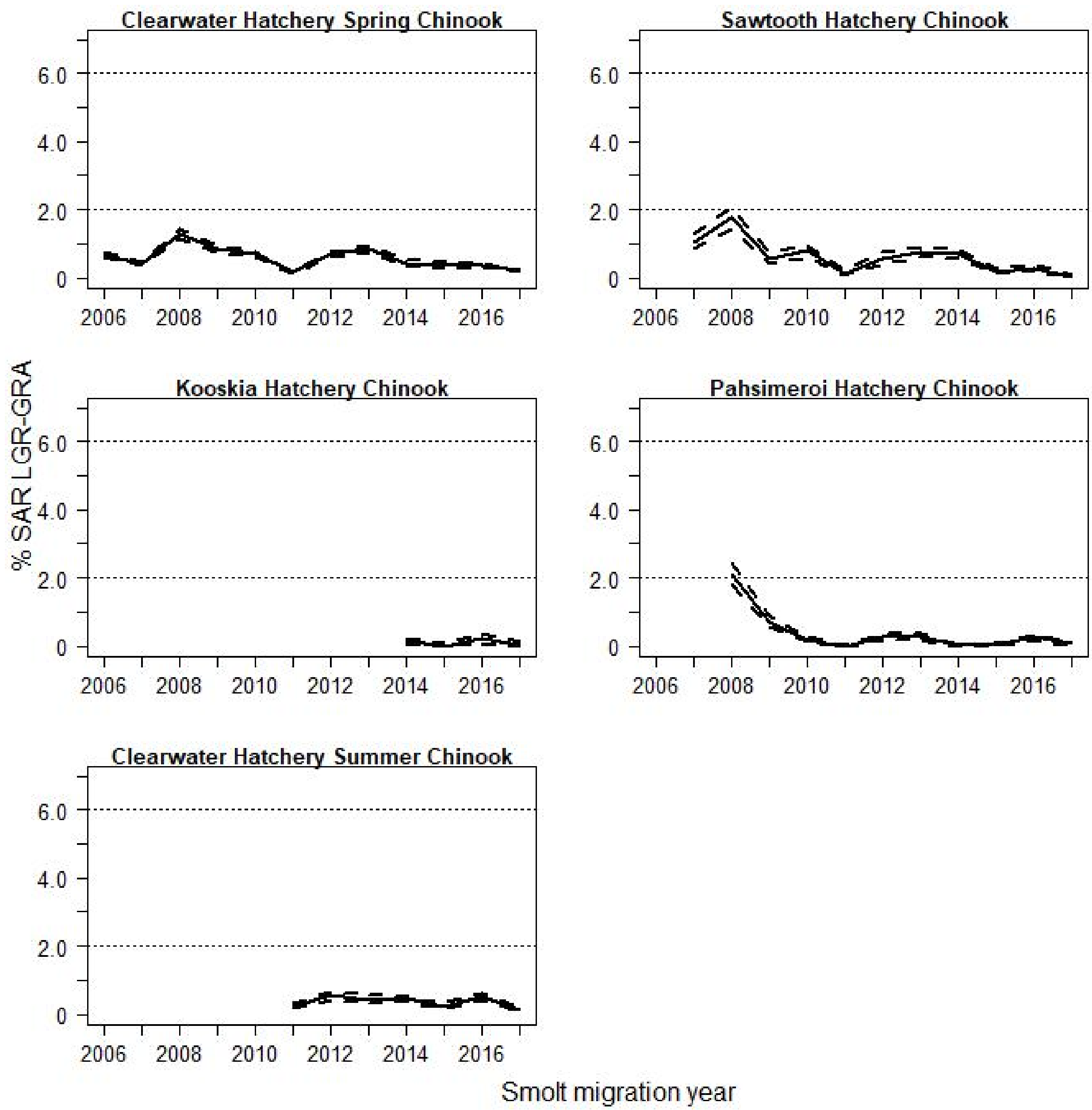


Figure 4.4. Bootstrapped LGR-to-GRA SAR (with jacks included) and upper and lower CI for five additional Snake River hatchery groups for migration years 2006-2017. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019 for hatchery spring Chinook and July 31, 2019 for hatchery summer Chinook.. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.25 (Clearwater Hatchery spring Chinook), B.27 (Sawtooth Hatchery), B.29 (Kooskia Hatchery), B.31 (Pahsimeroi Hatchery), and B.33 (Clearwater Hatchery summer Chinook).

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, 2.5% during 2000–2009, and 1.5% during 2010-2016. Snake River wild steelhead and wild spring/summer Chinook SARs were highly correlated (r = 0.74) during the 1964–2016 period when aligned by smolt migration year.

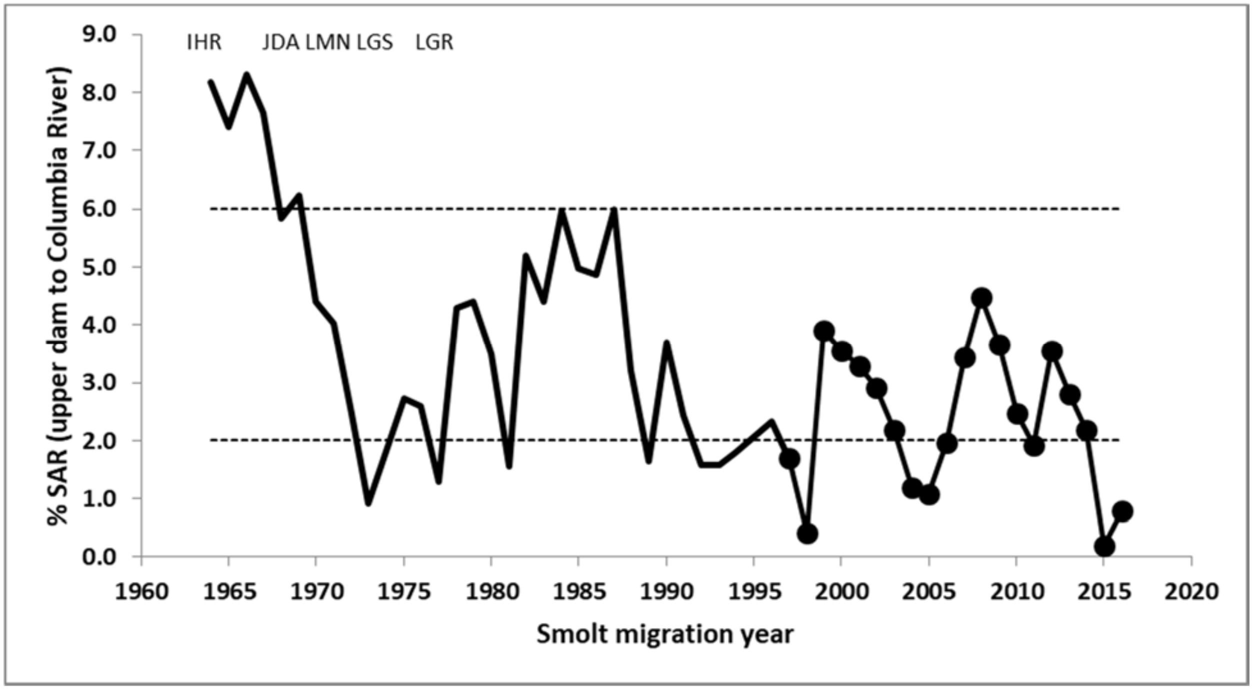


Figure 4.5. SARs from smolts at uppermost Snake River dam to Columbia River returns for Snake River wild steelhead, 1964–2016. Dam construction sequence was: 1961-IHR, 1968-JDA, 1969-LMN, 1970-LGS, and 1975-LGR. SARs based on run reconstruction (1964-1996, solid line) and CSS PIT tags (1997–2016, dots 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 1.35% during the period 1997–2016 (Table B.35; Figure 4.6 top plot); annual SARs never met the NPCC 4% SAR objective. SAR point estimates exceeded the NPCC's minimum SAR objective of 2% in eight of 20 migration years (statistically significant in four years). The 2015 SAR estimate of 0.10% is the lowest among the CSS 20-year dataset. SARs based on adult returns to BOA were about 40% 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.

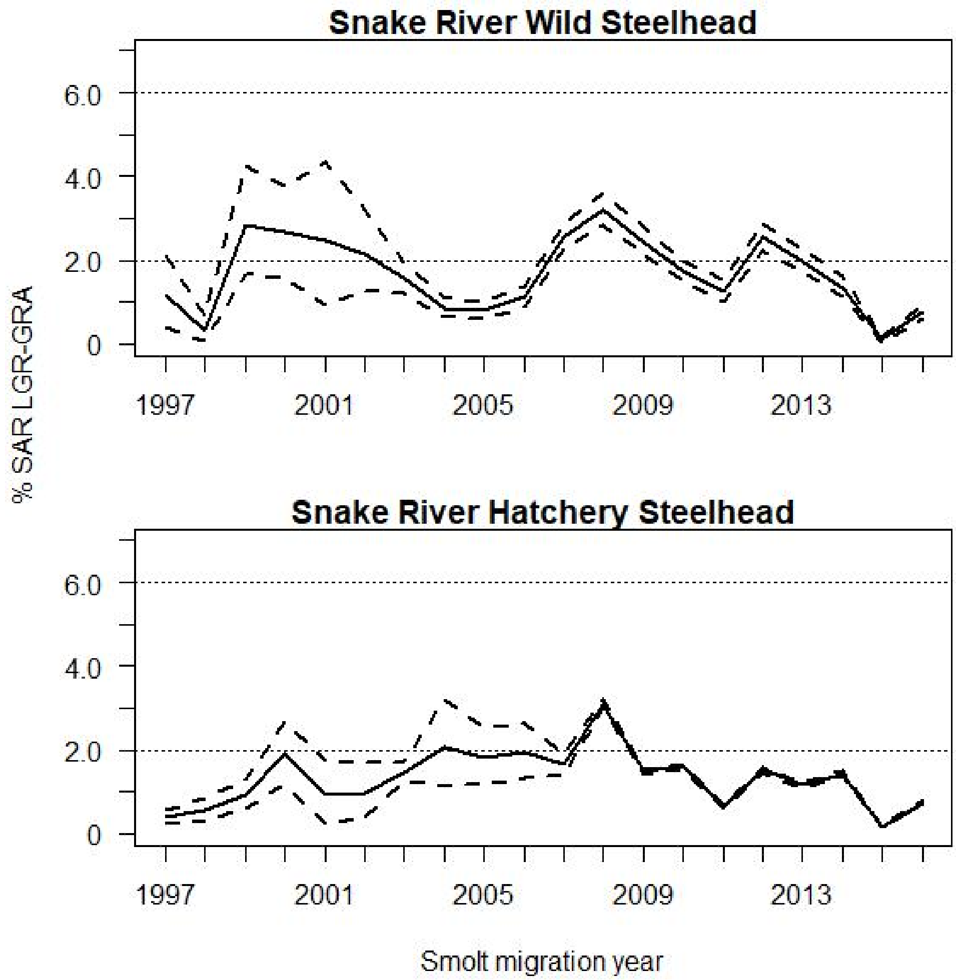


Figure 4.6. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River wild and hatchery steelhead for migration years 1997–2016. The 2008-2016 hatchery steelhead estimates represent the weighted mean for the 5 groups. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.35 (wild steelhead) and B.43 (hatchery steelhead).

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; Figures 4.7-4.8) for juvenile migration years 2006–2016. SARs were correlated (average r = 0.78) 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. Wild steelhead SARs were very low for all MPGs in 2015; no PIT tagged adults returned from the 2015 outmigration of the Salmon River and Asotin Creek groups. The geometric mean LGR–GRA SAR for the aggregate wild A-run group (1.49%) was about 27% higher than for the B-run group (1.17%) during 2006–2016.

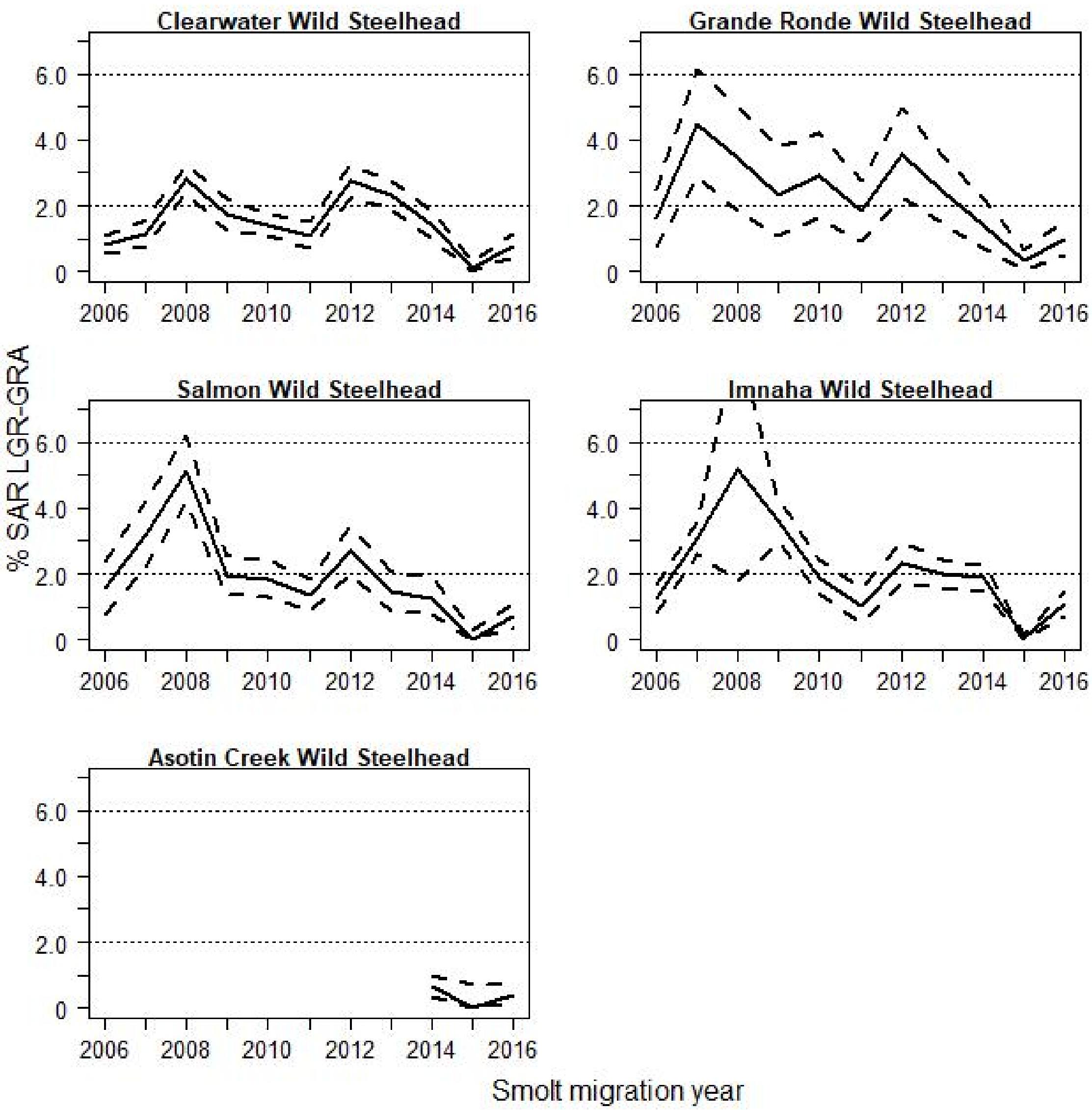


Figure 4.7. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River wild steelhead MPGs and aggregate wild A-run and wild B-run steelhead for migration years 2006–2016. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.36 (Clearwater wild), B.37 (Grande Ronde wild), B.38 (Imnaha wild), B.39 (Salmon wild), and B.40 (Asotin Creek wild).

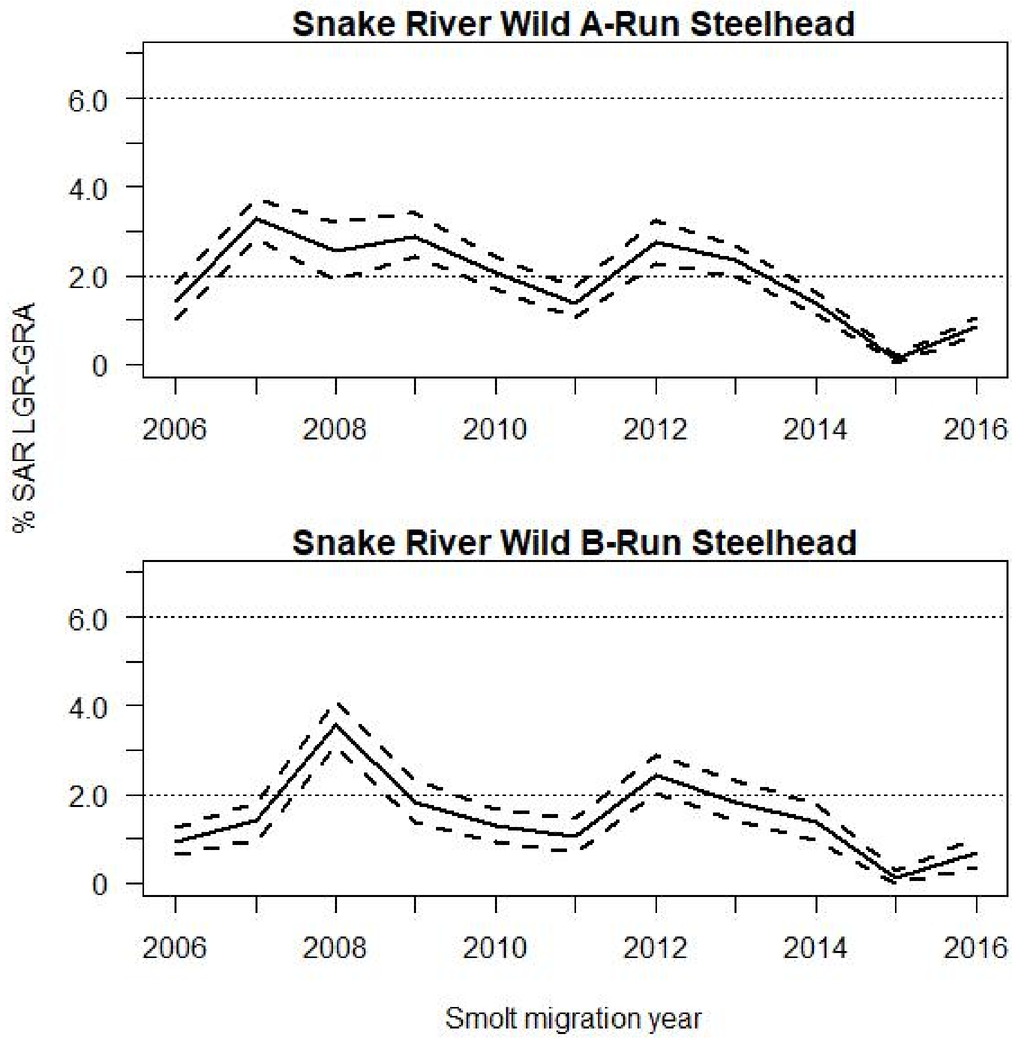


Figure 4.8. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River aggregate wild A-run and wild B-run steelhead for migration years 2006–2016. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.41 (Snake River wild A-run) and B.42 (Snake River wild B-run).

The estimated overall SARs (LGR-to-GRA) for Snake River hatchery steelhead averaged 1.11% (geometric mean for 1997–2016) 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 = 0.47) during 1997–2016, although wild and hatchery SARs are tracking more closely (r = 0.88) in the nine 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 2008–2015; SARs of Clearwater River B-run hatchery steelhead exceeded those from the Salmon River (Table B.44–B.49; Figure 4.9).

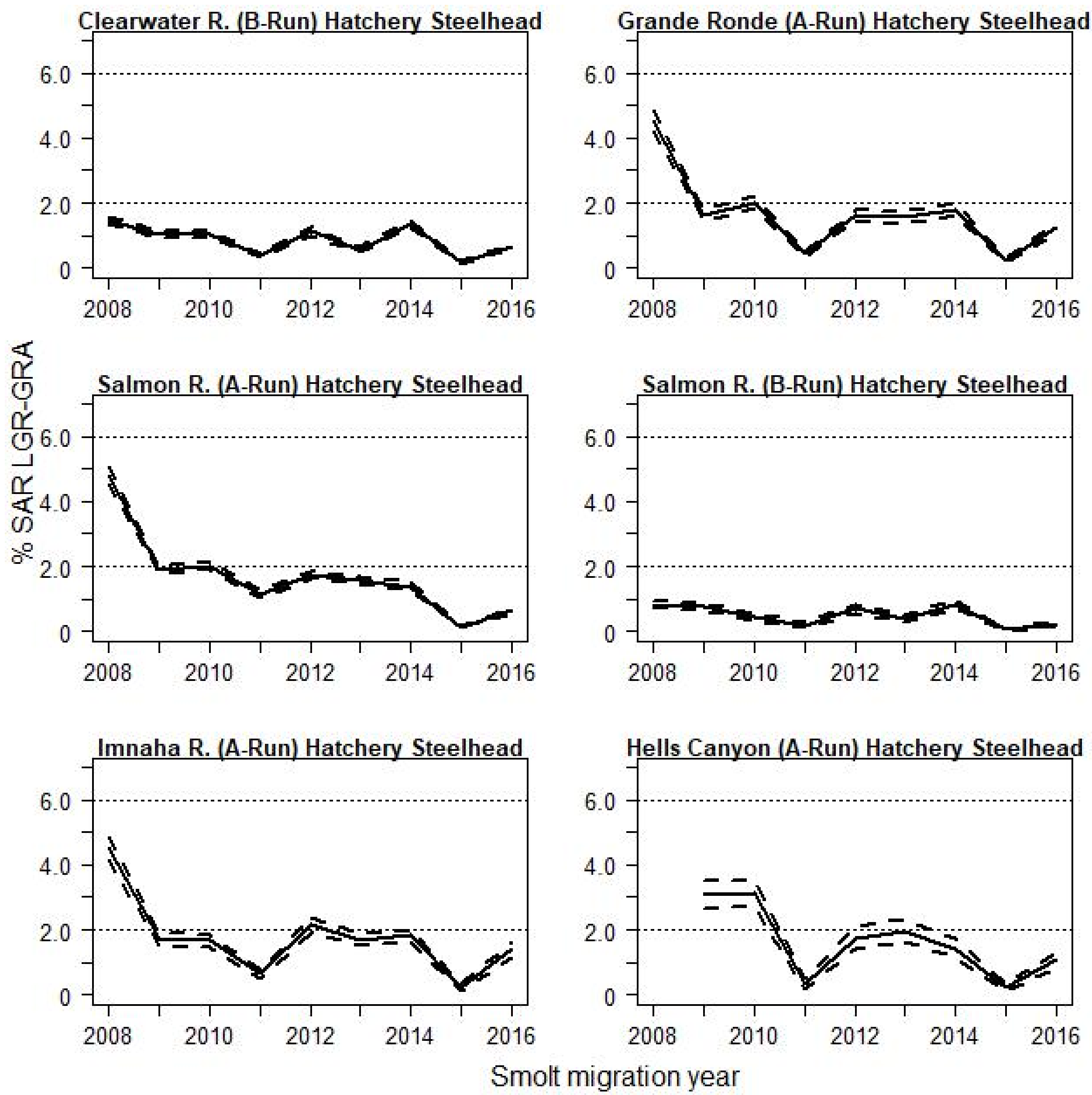


Figure 4.9. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River hatchery steelhead groups for migration years 2006–2016. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.49 (Clearwater B-run), B.44 (Grande Ronde A-run), B.47 (Salmon A-run), B.48 (Salmon B-run), B.45 (Imnaha A-run), and B.46 (Hells Canyon A-run).

SARs of Snake River hatchery sockeye varied by year and hatchery group during smolt migration years 2009–2017 (Table B.50; Figure 4.10). 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 2.31% (2009–2012); the SAR LGR-GRA for Springfield Hatchery was 0.0% in 2015-2017. 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. 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 2015-2017 Springfield hatchery releases experienced several fish health problems that affected juvenile survival and SARs. Observations by IDFG personnel during the 2015 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). Pre-release assessment in 2016 indicated heavy descaling across all release groups and may have been associated with releasing fish during a sensitive period of peak or post-smoltification. These issues were addressed in 2016 but survival of the Springfield release group remained low (Johnson et al. 2016). Survival of the Springfield release to LGR was poor again in 2017 (IDFG, unpublished data). In 2017 and 2018, studies were undertaken to evaluate smoltification and transport stress; water quality differences between Springfield Hatchery and Redfish Lake Creek were shown to cause high levels of stress and poor survival. In 2018, two acclimation strategies were used in an adaptive management framework that resulted in good survival to LGR (Eric Johnson, IDFG, personal communication) and higher estimates of S_R than recent years (Table A.7). However, SARs from the 2018 release will not be available until the 2020 CSS Report.

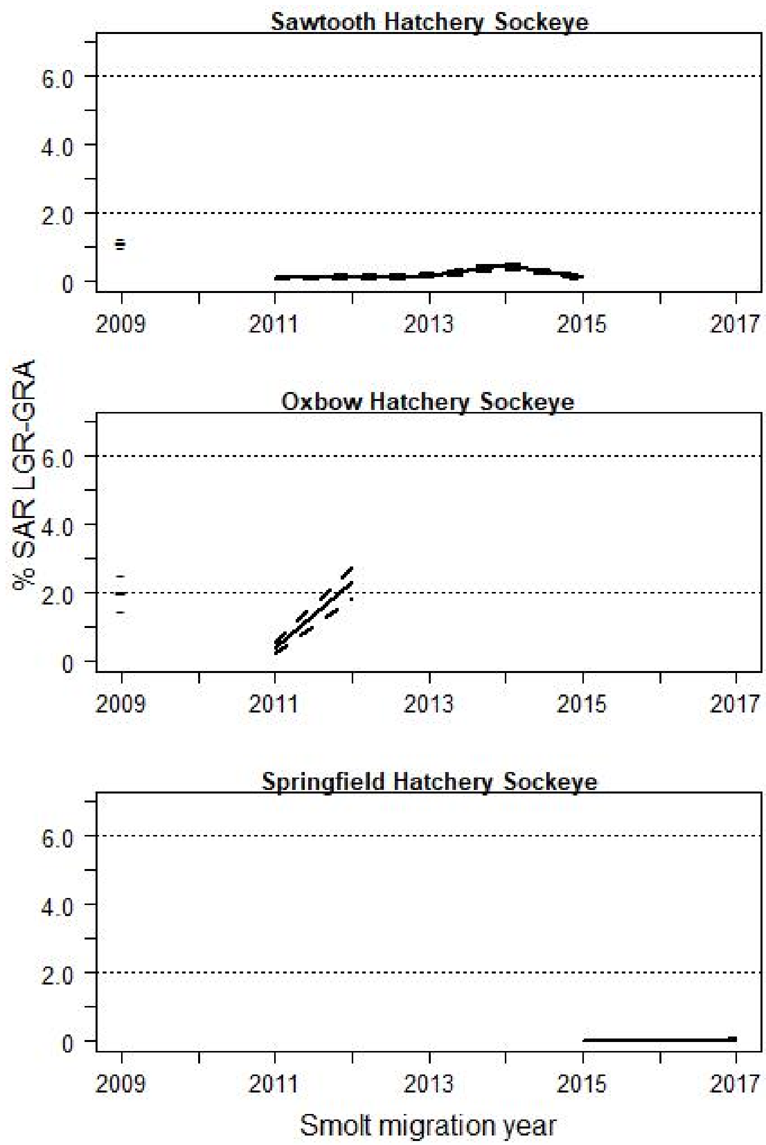


Figure 4.10. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River hatchery sockeye groups for migration years 2009–2019. Migration year 2017 is incomplete with 2-salt returns through July 31, 2019. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Table B.50.

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 including 1-salt (or jacks) ranged from 0.24% to 0.89% for releases in 2006, 0.0% to 0.36% 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. For the more recent years (2015 and beyond), there were 3-salt returns for 2015 and only 2-salt returns from migration year 2016 available for analysis for this report. And only two hatchery release groups were available to analyze for those years; Captain John Rapids and Pittsburgh Landing. In 2015 and 2016 SARs for those two release groups were 0.31% and 0.15% for Captain John Rapids (2015 and 2016 respectively) and were 0.39% and 0.25% for Pittsburgh Landing releases. For all the years, the highest SAR LGR to GRA was for Hells Canyon – Umatilla/Irrigon Hatchery release in 2008 at 2.3%.

As requested by ISAB and consistent with other species reported in the CSS, SARs are also reported for adults at Bonneville Dam in contrast to returns to Lower Granite Dam (See Appendix B for complete SAR tables). 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 (to BON as adults) in a few cases approached or exceeded 3% and without jacks surpassed 2%.

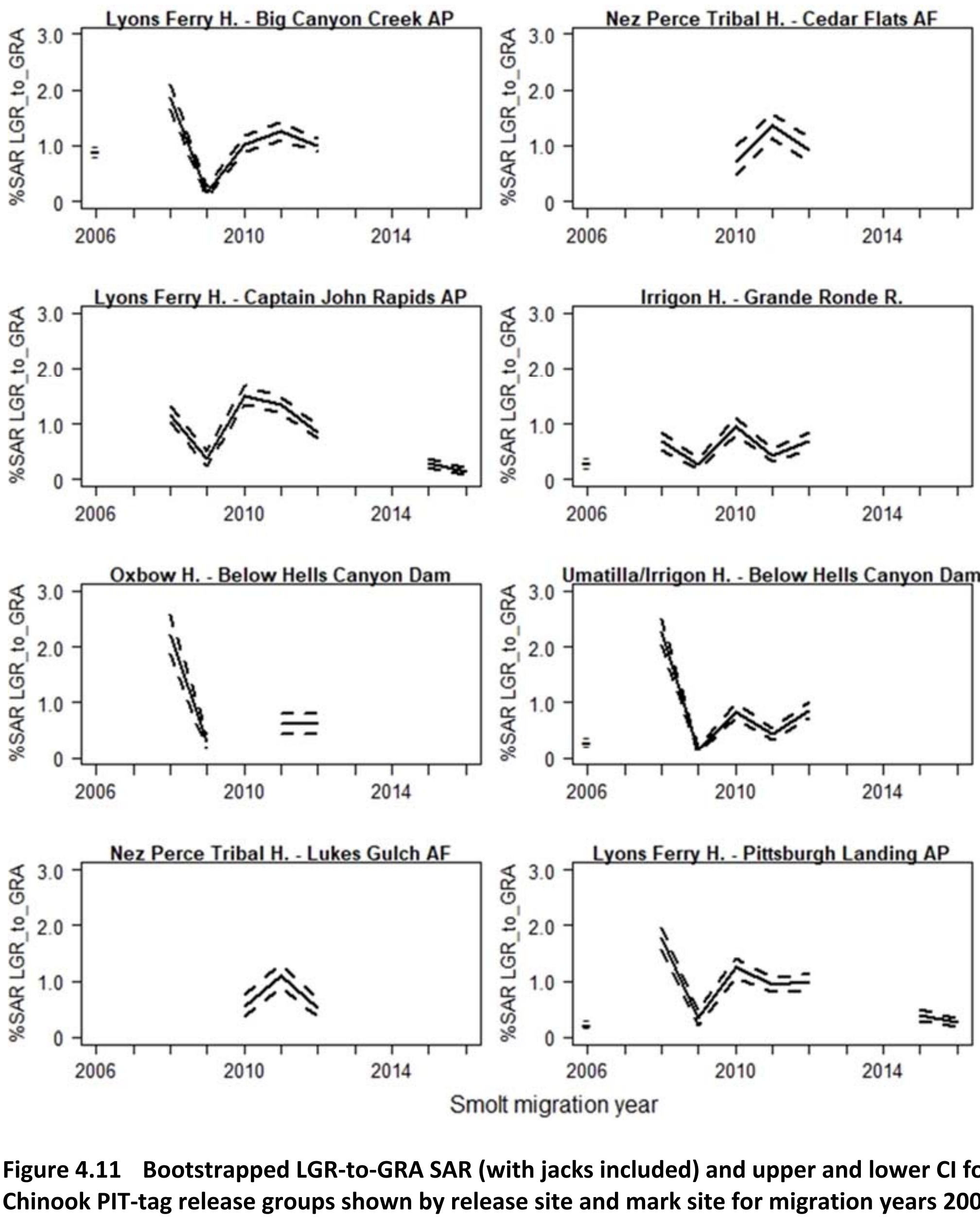


Figure 4.11 Bootstrapped LGR-to-GRA SAR (with jacks included) and upper and lower CI for subyearling Chinook PIT-tag release groups shown by release site and mark site for migration years 2006 to 2016. Only groups with 3 or more migration years of returns are included. Migration year 2016 is incomplete with 3-salt returns through July 31, 2019. Data for this figure can be found in Tables B.53 (Big Canyon Creek), B.69 (Cedar

Flats), B.55 (Captain Johns Rapids), B.61 (Grande Ronde River), B.65 (Oxbow Hatchery below Hells Canyon Dam), B.63 (Umatilla/Irrigon Hatchery below Hells Canyon Dam), B.71 (Lukes Gulch), and B.57 (Pittsburgh Landing).

Characterizing the relationship between $\log_e$(TIR) and in-river survival (S_R)

We fitted all models of the ratio of transport SARs to in-river SARs $\log_e$(TIR) with in-river survival and species as the two covariates. We estimated AICc weights (Burnham and Anderson 2002) for all models (Table 4.1). The top ranked model contained only the S_R covariate. Based on comments from the ISAB, we used model averaging to predict the relationship between S_R and $\log_e$(TIR). The resulting model averaged coefficients are shown in Table 4.2. We used the model averaged predictions to illustrate the relationship between $\log_e$ (TIR) and reach survival (Figure 4.11).

Table 4.1. Information theoretic ranking of models predicting loge(TIR) with summaries of attributes of the models considered.

Model	AIC_C	ΔAIC_C	w_i
$\log_e(S_R)$	85.0	0.00	0.419
$\log_e(S_R) + \log_e(S_R)$:Species	85.9	0.85	0.273
$\log_e(S_R)$ + Species	86.2	1.17	0.233
$\log_e(S_R)$ * Species	88.5	3.43	0.075
Species	113.5	28.45	0.000

Table 4.2. Parameter estimates from the model averaging.

Parameter	Estimate
Intercept	-0.479
$\log_e(S_R)$	-1.189
Species(ST)	-0.100
$\log_e(S_R)$:Species(ST)	0.054

As noted in Chapter 1 and described in Appendix A, reach survival estimates were re-estimated, in 2019 using a new method that included a logit link that constrained individual reach estimates to between 0 and 1, as well as universally adding estuary bird island mortalities and adult returns to Bonneville Dam to bolster estimates of detection probability at Bonneville Dam. Despite this new method, and some subsequent small changes to reach survivals, the overall relationship between reach survival and TIR observed in past years analyses did not change noticeably. Reach survival had a negative effect on $\log_e$ (TIR). As survival increased, $\log_e$ (TIR) decreased. The model predictions were used to estimate the reach survival at which $\log_e$ (TIR) would decrease below zero indicating a negative effect of transportation on SAR. Based on the model predicted steelhead, $\log_e$ (TIR) would drop below zero when juvenile reach survival increased above 0.72, indicating that transport would no longer mitigate for hydrosystem effects when in-river survival was above that point. For yearling Chinook the model predicted that at reach survivals above 0.67 the $\log_e$ (TIR) would drop below zero.

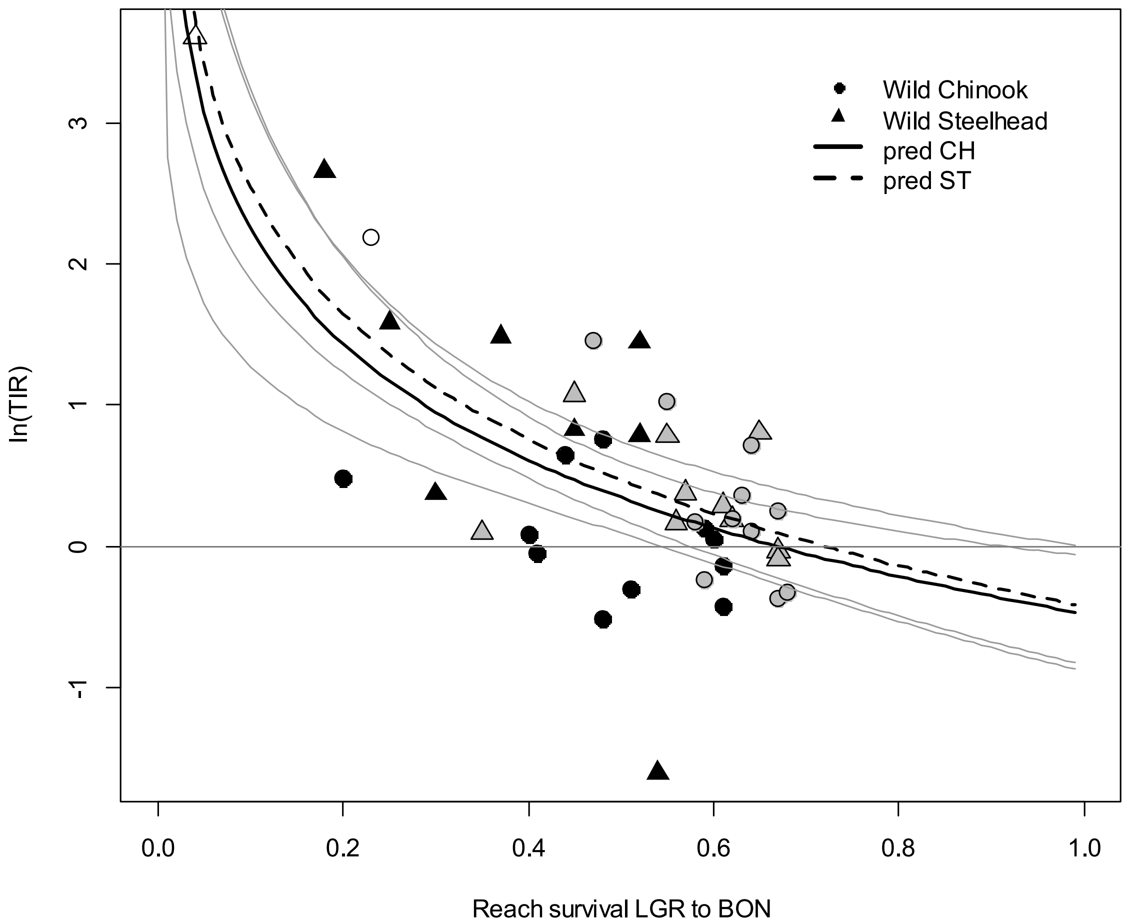


Figure 4.11. Plot of loge(TIR) versus reach survival (SR) for wild yearling Chinook for the juvenile migration years 1994 to 2016 and wild steelhead from the Snake River for the juvenile migration years 1997 to 2015. The two open symbols are migration year 2001, which had low flow and zero spill. The gray data points are migration years with court-ordered spill and delayed start to transportation (2006–2016). Curves shown are predictions from the model average prediction using loge(SR) shown in Table 4.2. Thinner lines represent the 95% confidence intervals for the model. The model predicts that TIR will be less than one when juvenile Chinook survival is 0.65 or higher and juvenile steelhead survival is 0.70 or higher.

Figure 4.12 shows patterns in $\log_e$(TIR) 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 above in Figure 4.11), a trend of decreasing transport benefit with increasing reach survival is apparent. Wild Chinook and wild steelhead annual estimates of $\log_e$(TIR) versus juvenile reach survival, were plotted for comparison purposes. The prediction line in Figure 4.12 has a negative slope and was estimated to intersect the $\log_e$(TIR) line at about 0.42 reach survival. For fall Chinook the point at which the $\log_e$(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 2015 (See Figure 4.10 above). 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 4.12 had multiple data points per year, and included only the years 2006 through 2016, in contrast to the wild steelhead and wild yearling Chinook data points that show only one annual TIR and begin with migration year 1994 for wild yearling Chinook and 1997 for wild steelhead.

Figure 4.12 shows that in-river survival for subyearling fall Chinook has generally been in the same range as yearling Chinook and steelhead. But that $\log_e$(TIR) values have been lower indicating poorer performance of transported fish relative to their in-river counterparts, at similar survivals.

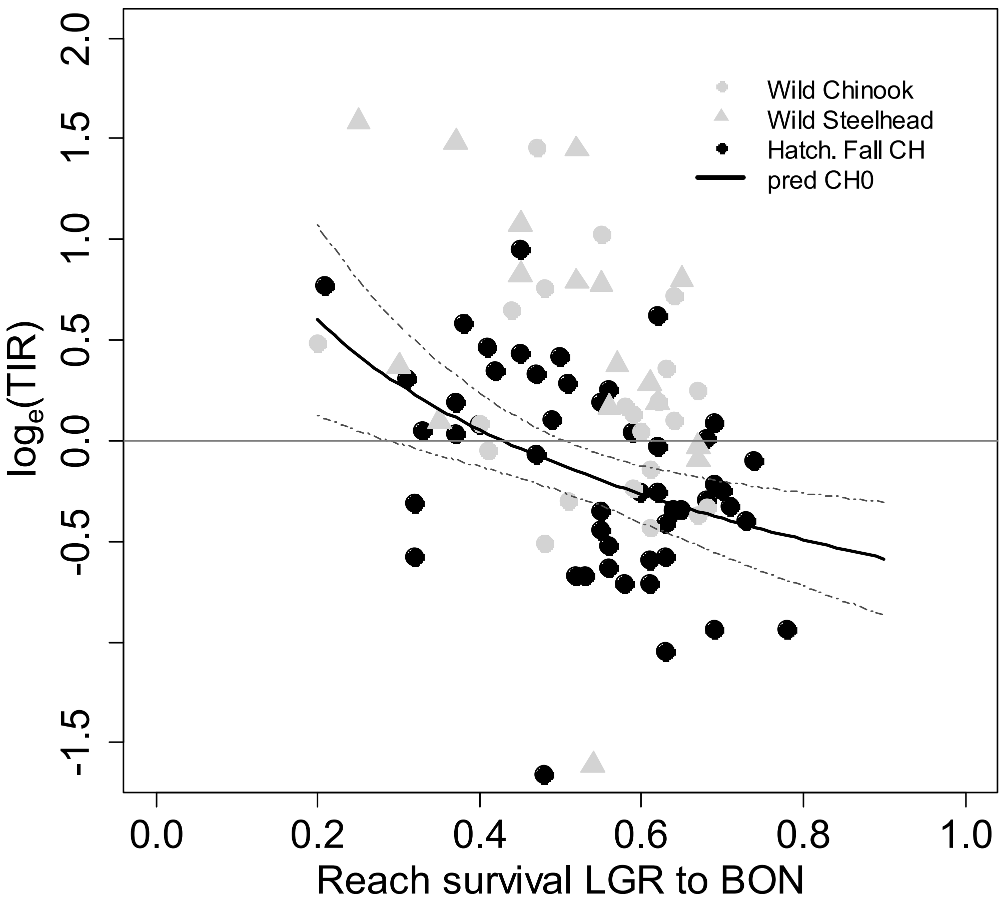


Figure 4.12. Log of Transport/in-river ratio of adult returns versus juvenile survival from LGR to BON for production releases of subyearling fall Chinook with regression line and 95% prediction intervals. All release groups from migration years 2006 to 2015, were included. Wild yearling Chinook and wild Steelhead annual TIR estimates were also plotted for comparison.

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 3.582% during the 18-year period 2000–2017 (Table B.73; Figure

4.13); annual SARs met the NPCC 4% SAR objective in nine of 18 years. John Day wild spring Chinook SAR point estimates exceeded the NPCC's minimum SAR objective of 2% in all migration years except 2011 and 2017, and were significantly greater than 2% in all but four years (2005, 2006, 2011, and 2017). 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 2.49% during 2000–2017 (no PIT-tagged smolts were released in 2010 or 2014 and too few were released in 2016 and 2017 to reliably estimate MCN smolt numbers). Annual SARs of Yakima River wild spring Chinook met the NPCC 4% SAR objective in three of 14 years. Yakima wild spring Chinook SAR point estimates exceeded the minimum 2% in eight of 14 migration years, and were significantly greater than 2% in six years (Table B.74). Yakima River wild Chinook SARs based on BOA returns were 8% greater than those observed 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) 3.9 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 = 0.71) between regions during the period 2000–2017.

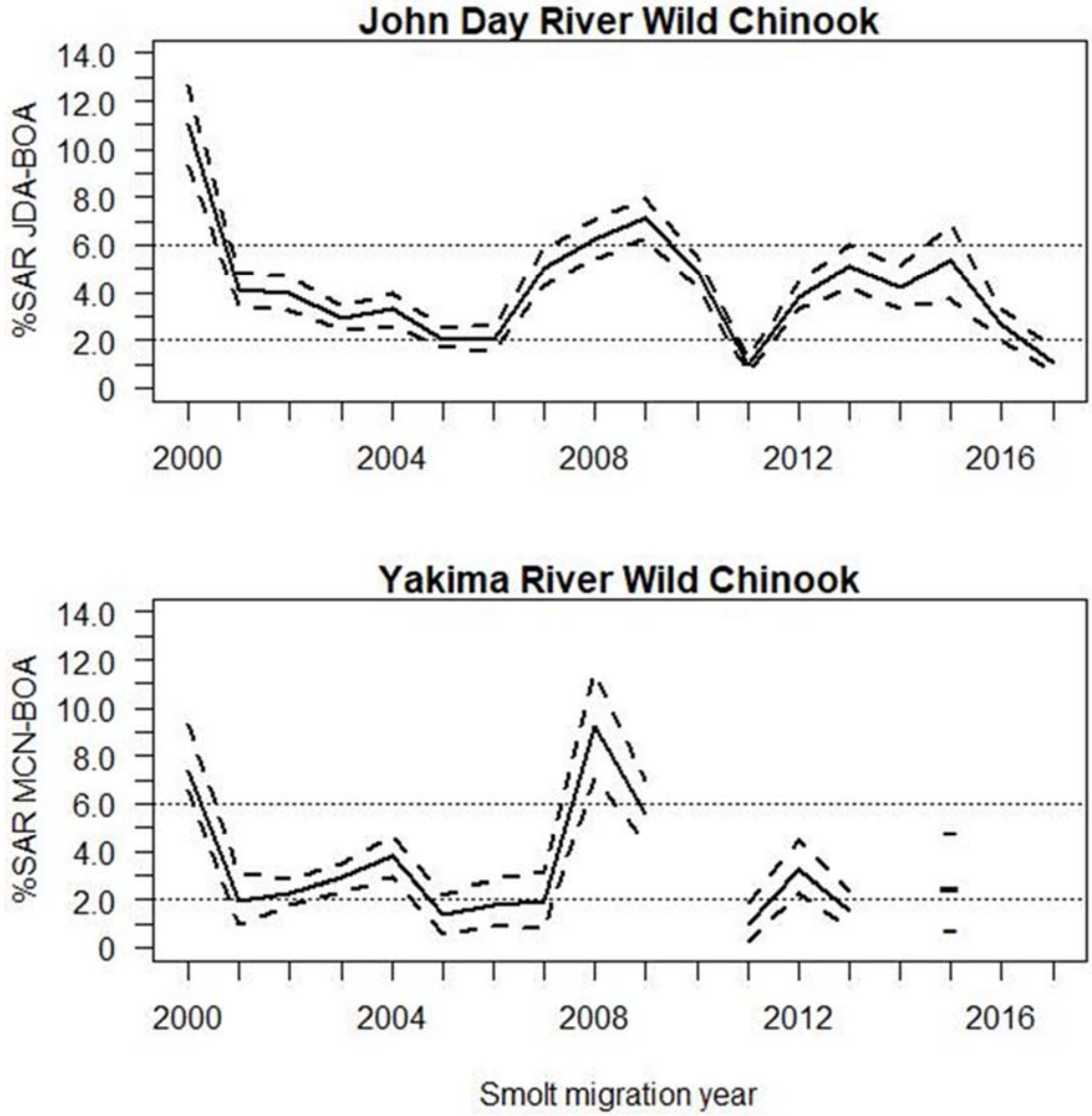


Figure 4.13. Bootstrapped SAR (including jacks) and upper and lower CI for wild spring Chinook from the John Day and Yakima rivers in the mid-Columbia region for migration years 2000–2017. Smolts are estimated at upper dam; adults are enumerated at BOA. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019. No PIT tagged smolts were released in the Yakima River in 2010 and 2014, and too few were released in 2016 and 2017 for reliable MCN smolt estimates. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.73 (John Day wild) and B.74 (Yakima wild).

The estimated overall SARs (including jacks) for mid-Columbia River hatchery spring Chinook varied by hatchery and year (Tables B.76-B.81; Figure 4.14). BON-to-BOA SARs for Carson Hatchery spring Chinook averaged (geometric mean) 0.87% during 2000–2017 (Table B.76). Estimated BON-BOA SARs for Warm Springs National Fish Hatchery spring Chinook 2010–2017 averaged 0.79% (Table B.78). MCN-BOA SARs for Cle Elum Hatchery spring Chinook averaged 1.49% and were 11% higher than MCN-MCA SARs (Tables B.80 and B.81). 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 = 0.77) between populations during 2000–2017.

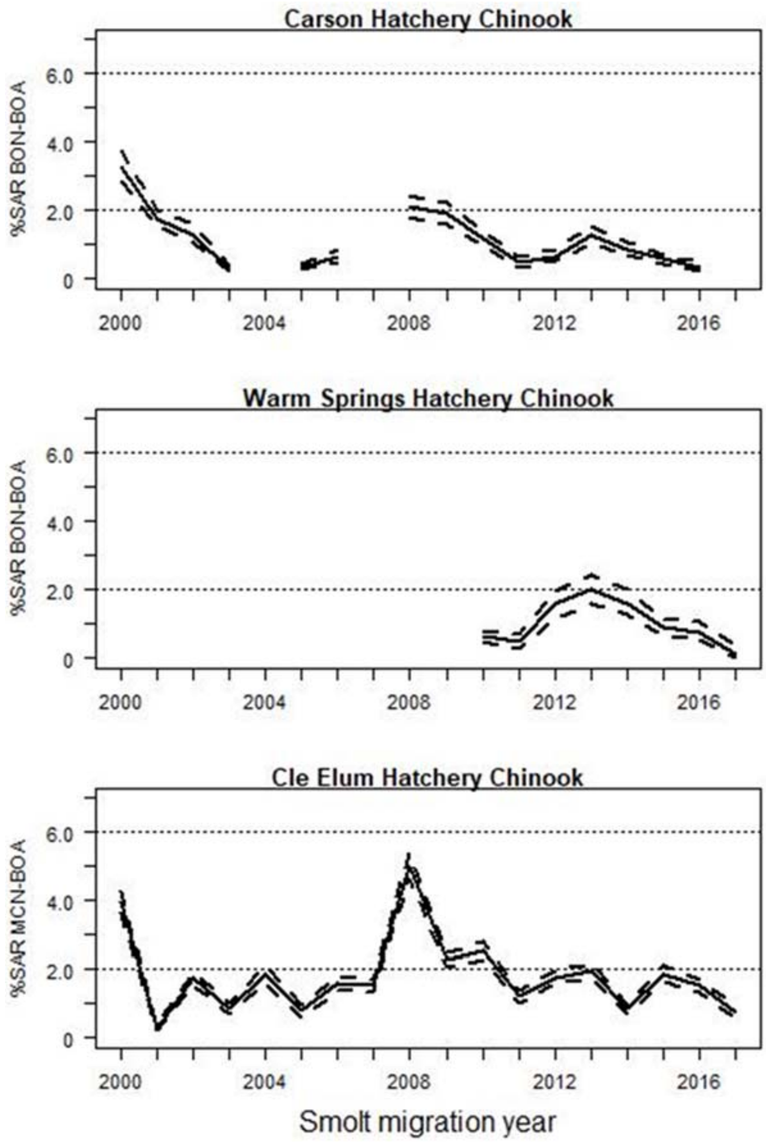


Figure 4.14. Bootstrapped SAR (including jacks) and upper and lower CI for hatchery spring Chinook in the mid-Columbia region for migration years 2000–2017. Smolts are estimated at upper dam; adults are enumerated at BOA. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019. SAR for Carson Hatchery not calculated for 2004, 2007, and 2017 because release to BON survival estimate = 1.0. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.76 (Carson Hatchery), B.78 (Warm Springs Hatchery), and B.80 (Cle Elum Hatchery).

The CSS estimated SARs and confidence intervals for mid-Columbia wild steelhead from the Umatilla River beginning with juvenile migration year 2011, the John Day River beginning with migration year 2004, from Deschutes River tributaries (Trout, Buckhollow and Bakeoven creeks) beginning with migration year 2006, and from the Yakima River beginning with migration year 2002 (Tables B.82–B.85; Figure 4.15). The geometric mean SAR (JDA-BOA) of Umatilla wild steelhead was 2.79% during 2011-2016; annual SARs met the NPCC 4% SAR objective in three of six years and significantly exceeded the 2% minimum SAR objective in four of six years (Table 82; Figure 4.15). The geometric mean SAR (JDA-BOA) of John Day River wild steelhead was 4.87% during 2004-2016; annual SARs met the NPCC 4% SAR objective in nine of 13 years. JDA-BOA SAR estimates of John Day wild steelhead significantly exceeded the NPCC's minimum SAR objective of 2% in 11 out of 12 years (Table 83; Figure 4.15); the 2011 and 2015 SARs were the exceptions. 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. The geometric mean SAR (BOA-BOA) of Deschutes wild steelhead was 5.03% during 2006-2016 (Table B-84); annual SARs met the NPCC 4% SAR objective in eight of 11 years. Deschutes River wild steelhead SARs (BON-to-BOA) significantly exceeded the NPCC's minimum SAR objective of 2% in nine of 11years (Table B.84; Figure 4.15). The geometric mean SAR (MCN-MCA) of Yakima River wild steelhead was 4.01% during 2002-2016; annual SARs met the NPCC 4% SAR objective in ten of 15 years. Yakima River wild steelhead SARs significantly exceeded the NPCC's minimum SAR objective of 2% in nine out of 15 years (Table B.85; Figure 4.15); MCN-to-BOA SARs were 22% 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 = 0.75) 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 and 2015.

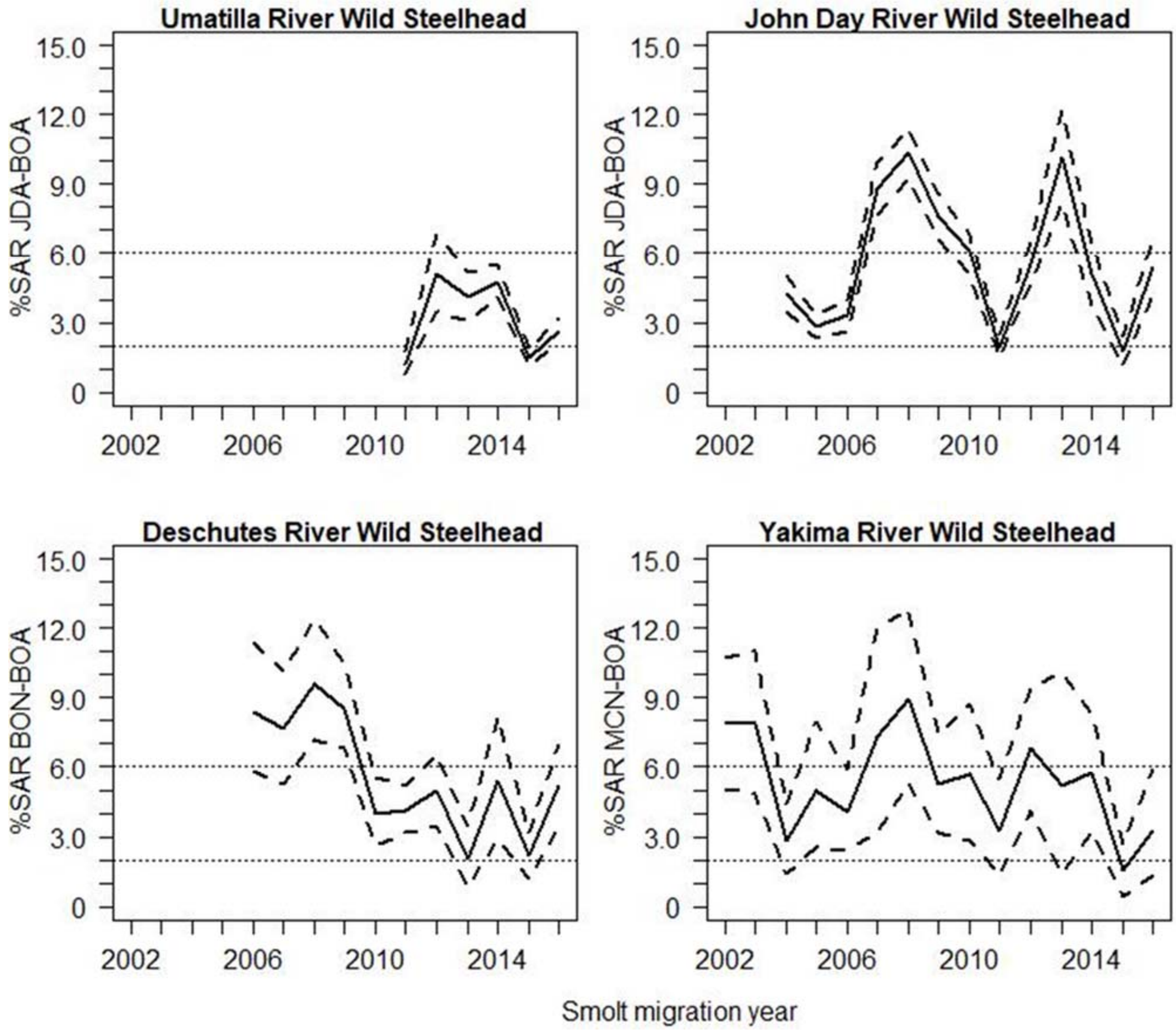


Figure 4.15. Bootstrapped SAR and upper and lower CI for wild steelhead from mid-Columbia region for migration years 2002–2016. Smolts are estimated at upper dam; adults are enumerated at BOA. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.82 (Umatilla wild), B.83 (John Day wild), B.84 (Deschutes wild), and B.85 (Yakima wild).

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.

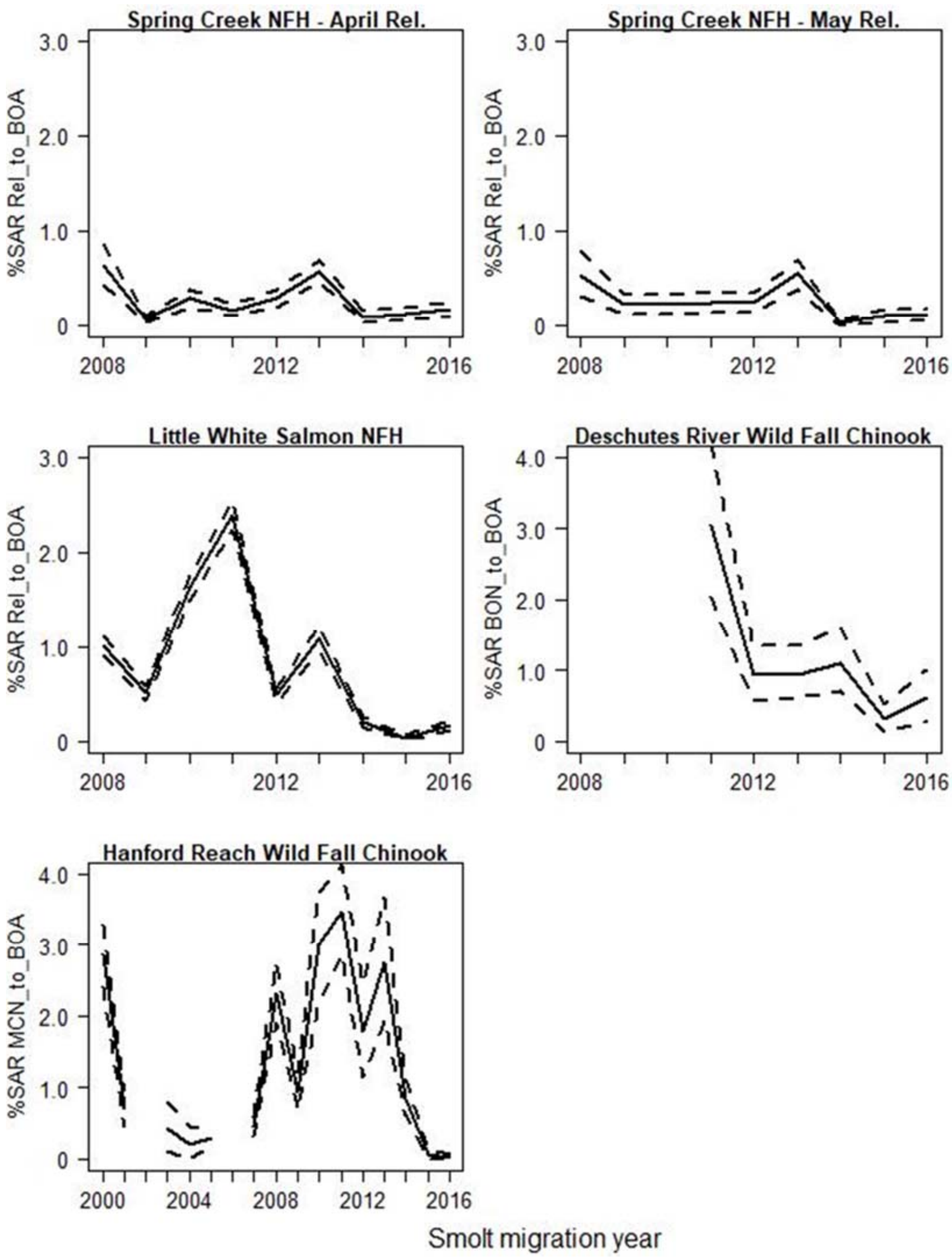


Figure 4.16. Bootstrapped SAR and upper and lower CI for Mid-Columbia hatchery and wild fall Chinook (either release to BOA for hatchery groups or upper most dam to BOA for wild groups). Fall Chinook PIT-tag release groups shown by release site. Note that hatchery SARs are without jacks and wild SARs are with jacks, the wild SARs are on a scale of 1 to 4 which differs from hatchery plots, and the x-axis for Hanford Reach fall Chinook differs from the other groups. Migration year 2016 is incomplete with 3-salt returns through July 31, 2019. Data for this figure can be found in Tables B.91 (Spring Creek Hatchery – April and May), B.93 (Little White Salmon Hatchery), B.88 (Deschutes wild), and B.86 (Hanford Reach wild).

In the Mid-Columbia, the highest SARs for fall Chinook were the McNary Dam to Bonneville Dam SARs for Hanford Reach PIT-tag release groups (Figure 4.16). SARs for Hanford wild PIT-tag groups exceeded 3% in 2011 (without jacks). Including jacks the highest SAR for Hanford wild fall Chinook was 3.5% also in 2011. Spring Creek NFH releases have shown the lowest SARs for the fall Chinook release groups in the Mid-Columbia River, with SARs generally below 1% with jacks included. Little White Salmon NFH releases have had SARs as high as 2.4% from release to BON. Individual SAR estimates for all of these PIT-tag groups are available in Appendix B.

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) 1.20% during 2007–2017 (Table B.95; Figure 4.17). MCN-BOA SARs did not meet the NPCC 4% SAR objective in any year and significantly exceeded 2% in only one of eleven 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. SARs based on jack and adult returns to BOA were about 21% greater (geometric mean of SAR ratios) than SARs based on returns to MCA (Table B.94) because of the combined effect of dam passage loss, straying and Zone 6 harvest.

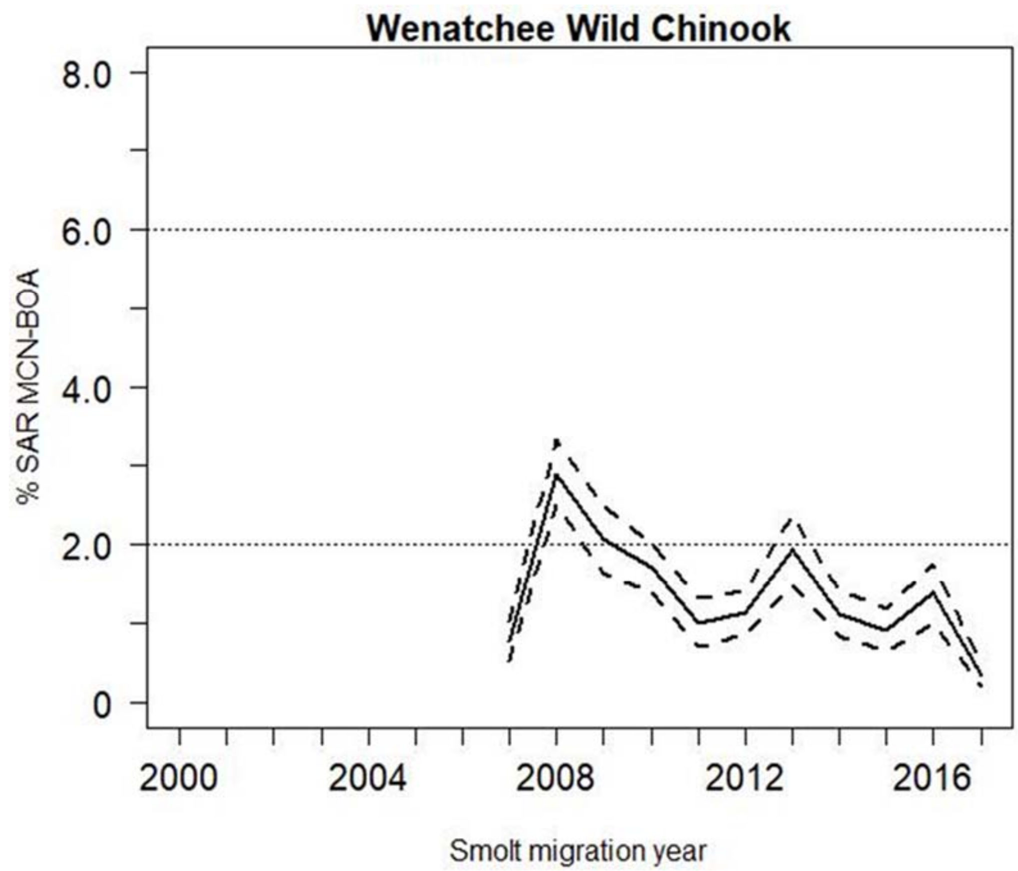


Figure 4.17. Bootstrapped SAR (MCN-to-BOA, including jacks) and upper and lower CI for Wenatchee River wild spring Chinook from Upper Columbia region for migration years 2007–2017. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Table B.95.

We have estimated SARs for wild spring Chinook from the Entiat and Methow rivers for the MCN-BOA reach for 2006-2017 and the RRE-BOA reach for 2008-2017 (Tables B.97 and B.99; Figure 4.18). SAR estimates for the RRE-BOA reach averaged 0.75%, well short of the NPCC 4% objective, and were less than the NPCC 2% minimum SAR objective in all ten years. SARs based on jack and adult returns to BOA were about 42% greater (geometric mean of SAR ratios) than SARs based on returns to RRA (Table B.96) because of the combined effect of dam passage loss, straying and harvest. Wild spring Chinook SARs based on smolts at RRE were 53% (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 RRE-BOA reaches for 2011-2016 (Tables B.100 and B.103, Figure 4.18). SAR estimates for the RRE-BOA reach averaged 0.37% and exceeded 2% in one of six years. Wild summer Chinook SARs based on smolts at RRE were 66% (geometric mean of ratio) those based on smolts at MCN. Note that Okanogan summer Chinook originate above Wells Dam (WEL) and that the RRE-BOA SAR estimate does not include mortality in the WEL-RRE reach.

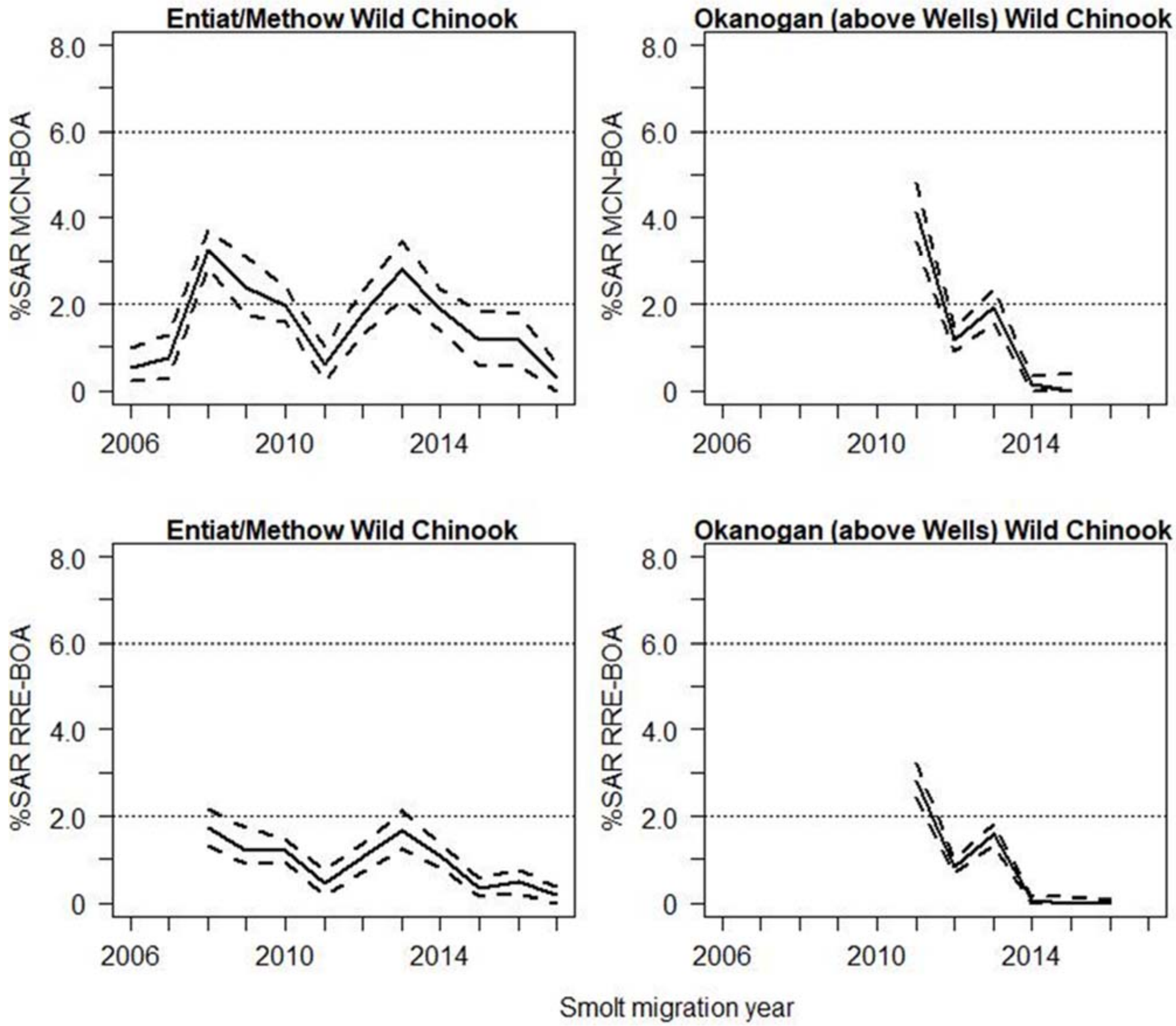


Figure 4.18. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA, including jacks) and upper and lower CI for Methow/Entiat wild spring Chinook for migration years 2006–2017 and Okanogan wild summer Chinook for migration years 2011-2017, upper Columbia River region. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.97 (Entiat/Methow MCN-BOA), B.99 (Entiat/Methow RRE-BOA), B.101 (Okanogan MCN-BOA), and B.103 (Okanogan RRE-BOA).

The geometric mean SAR (MCN-BOA) for Leavenworth hatchery spring Chinook (Wenatchee River) was 0.48% during 2000-2017 (Table B.105; Figure 4.19). SARs based on jack and adult returns to BOA were about 24% greater (geometric mean of SAR ratios) than SARs based on returns to MCA (Table B.104) because of the combined effect of dam passage loss, straying and harvest. 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 = 0.76) and with wild and hatchery spring/summer Chinook SARs from the Snake River (average r = 0.80) during 2000–2017.

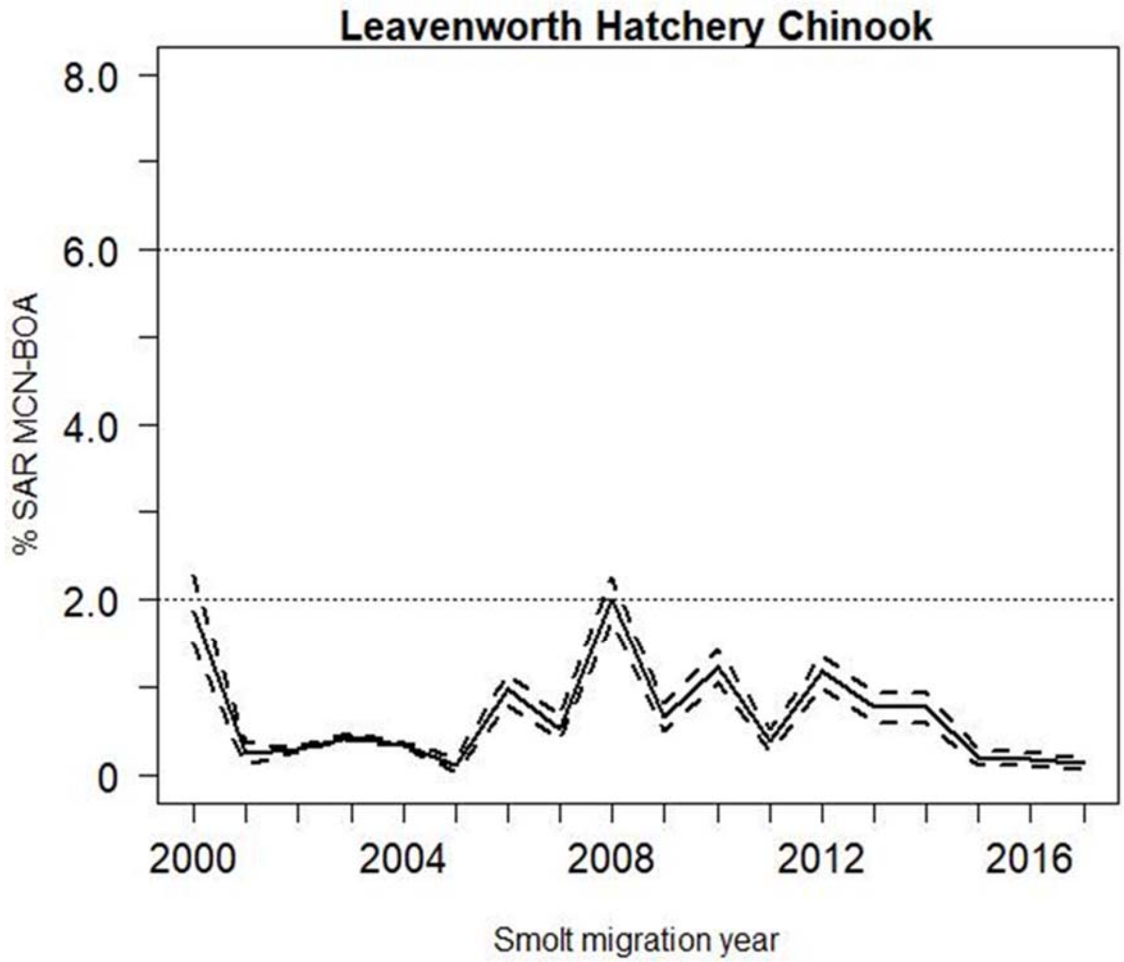


Figure4.19. Bootstrapped SAR (MCN-to-BOA, including jacks) and upper and lower CI for Leavenworth hatchery spring Chinook from Upper Columbia region for migration years 2000–2017. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Table B.105.

We have also estimated SARs for the MCN-WEA, MCN-BOA, RRE-WEA, and RRE-BOA reaches for hatchery spring Chinook from Winthrop hatchery for 2009-2017 (Tables B.106-B.109; Figure 4.20). In addition, we have estimated SARs for the MCN-RRA, MCN-BOA, RRE-RRA, and RRE-BOA reaches for hatchery summer Chinook from the Entiat River for 2011-2017 (Tables B.110-113; Figure 4.20). SAR estimates for the RRE-BOA reach averaged 0.70% and 0.92% for the Winthrop and Entiat hatchery groups, respectively. For Winthrop Hatchery spring Chinook, SARs based on jack and adult returns to BOA were about 21% greater (geometric mean of SAR ratios) than SARs based on returns to WEA (Table B.108). For Entiat Hatchery summer Chinook, SARs based on jack and adult returns to BOA were about 45% greater (geometric mean of SAR ratios) than SARs based on returns to RRA (Table B.112).

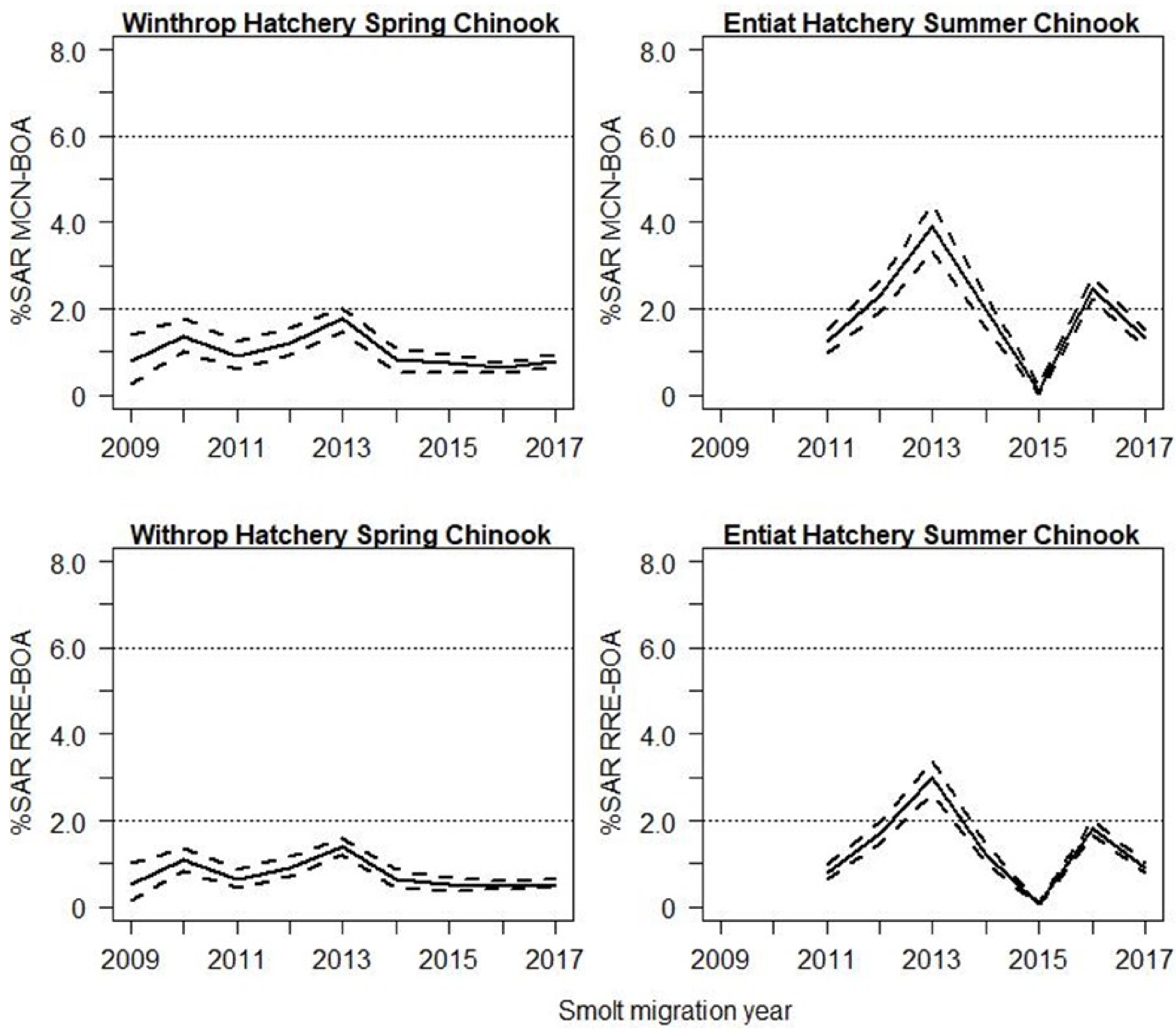


Figure 4.20. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA, including jacks) and upper and lower CI for Winthrop hatchery spring Chinook for migration years 2009-2017 and Entiat hatchery summer Chinook for migration years 2011-2017, upper Columbia River region. Migration year 2017 is incomplete with 2-salt returns through June 28, 2019 for Winthrop Hatchery and July 31, 2019 for Entiat Hatchery. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.107 (Winthrop MCN-BOA), B.109 (Winthrop RRE-BOA), B.111 (Entiat MCN-BOA), and B.113 (Entiat RRE-BOA).

Overall SARs (MCN–BOA) for Upper Columbia River wild steelhead from the Wenatchee, Entiat and Methow rivers averaged 2.72% during 2006–2016 (Table B.114; Figure 4.21). Overall SARs from RRE to BOA were also estimated in 2008–2016 for Upper Columbia River wild steelhead from the Entiat and Methow rivers (Table B.115; Figure 4.21). This represents a subgroup of the wild steelhead aggregate reported in Table B.114 (i.e., excludes Wenatchee River steelhead). Wild steelhead SARs based on smolts at RRE averaged 1.74%; SARs met the NPCC 4% SAR objective in one year (2008) and significantly exceeded 2% in three out of nine years. The 2015 SAR estimate was very low (0.25%), an observation consistent with SARs in the Snake and mid-Columbia regions. Wild steelhead SARs based on smolts at

RRE were 65% (geometric mean of ratio) those based on smolts at MCN in 2008–2016, again demonstrating the need to monitor SARs for the complete smolt migration path through the hydrosystem.

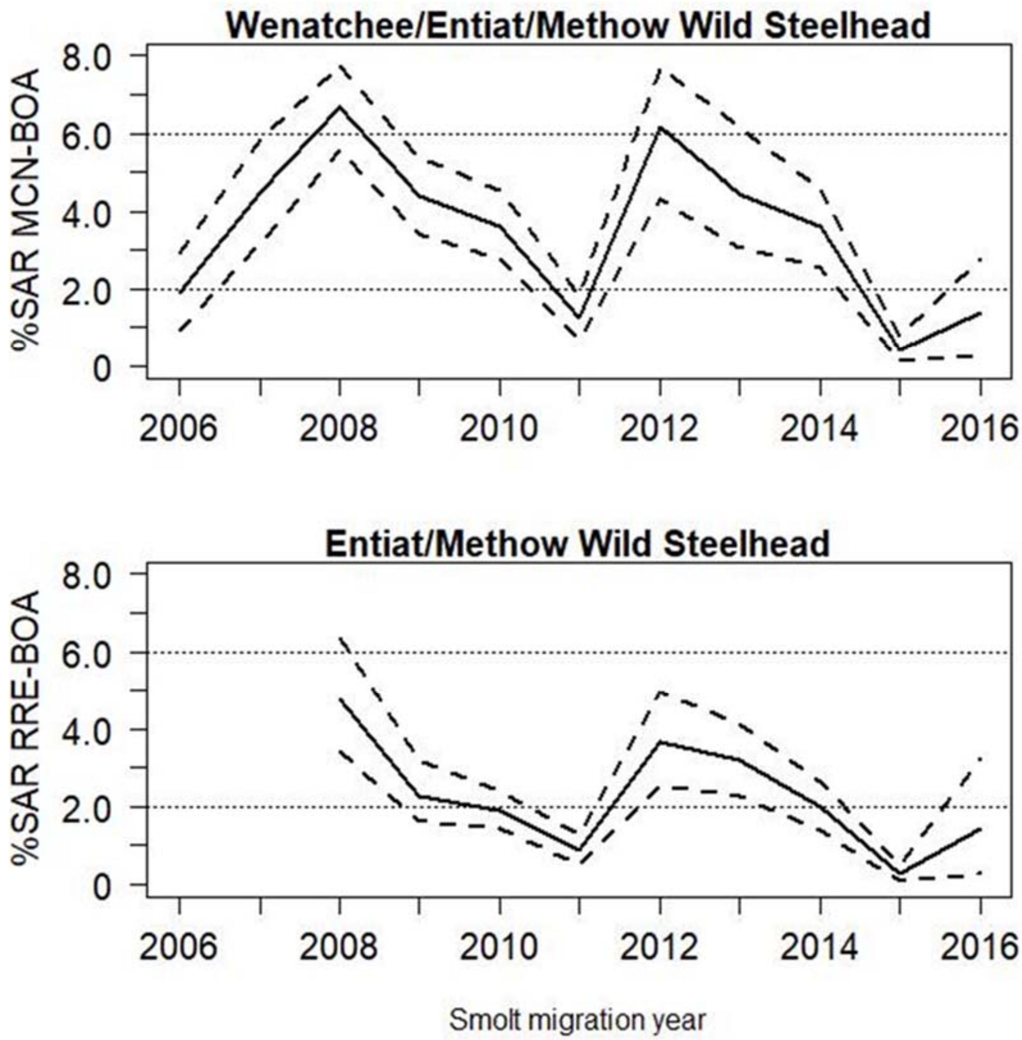


Figure 4.21. Bootstrapped SAR and upper and lower CI for wild steelhead from the Upper Columbia region through the 2016 migration year. MCN-BOA SARs are estimated for the Wenatchee/Entiat/Methow group; RRE-BOA SARs are estimated for the Entiat/Methow subgroup. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.114 (Wenatchee/Entiat/Methow MCN-BOA) and B.115 (Entiat/Methow RRE-BOA).

SARs (MCN–BOA) for Upper Columbia River hatchery steelhead released into the Wenatchee River (Eastbank and Chelan hatcheries) averaged 1.54% and ranged from 0.04% to 5.75% during 2003–2016 (Table B.116; Figure 4.22). SARs based on adult returns to BOA were about 22% greater (geometric mean of SAR ratios) than SARs based on returns to MCA (Table B.116). Consistent with other the Upper Columbia River wild steelhead groups, the lowest point estimate for Upper Columbia hatchery steelhead SARs was in 2015.

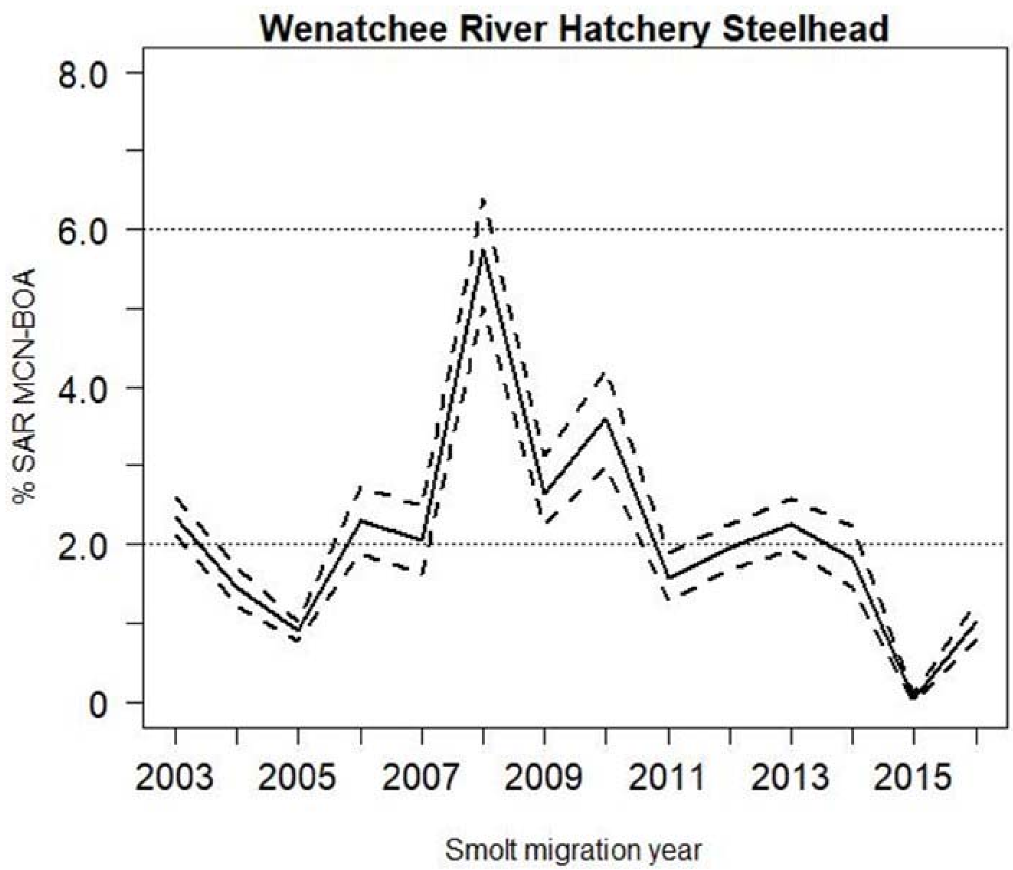


Figure 4.22. Bootstrapped SAR (MCN-to-BOA) and upper and lower CI for Wenatchee River hatchery steelhead from Upper Columbia region through the 2016 migration year. The hatchery steelhead group is a wild x wild cross released in the Wenatchee basin (reared at Chelan, East Bank, or Turtle Rock hatcheries depending on year). The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Table B.116.

The estimated overall SAR (MCN–BOA) for Wenatchee River wild sockeye ranged from 0.18% to 2.77% in 2014-2017 (Table B.117; Figure 4.23). The estimated overall SAR (MCN–BOA) for Okanogan River wild sockeye ranged from 0.12% to 7.66% in 2013-2017 (Table B.118; Figure 4.23). The estimated overall SAR (RRE–BOA) ranged from 0.12% in 2017 to 8.05% in 2013 (Table B.119; Figure 4.23).

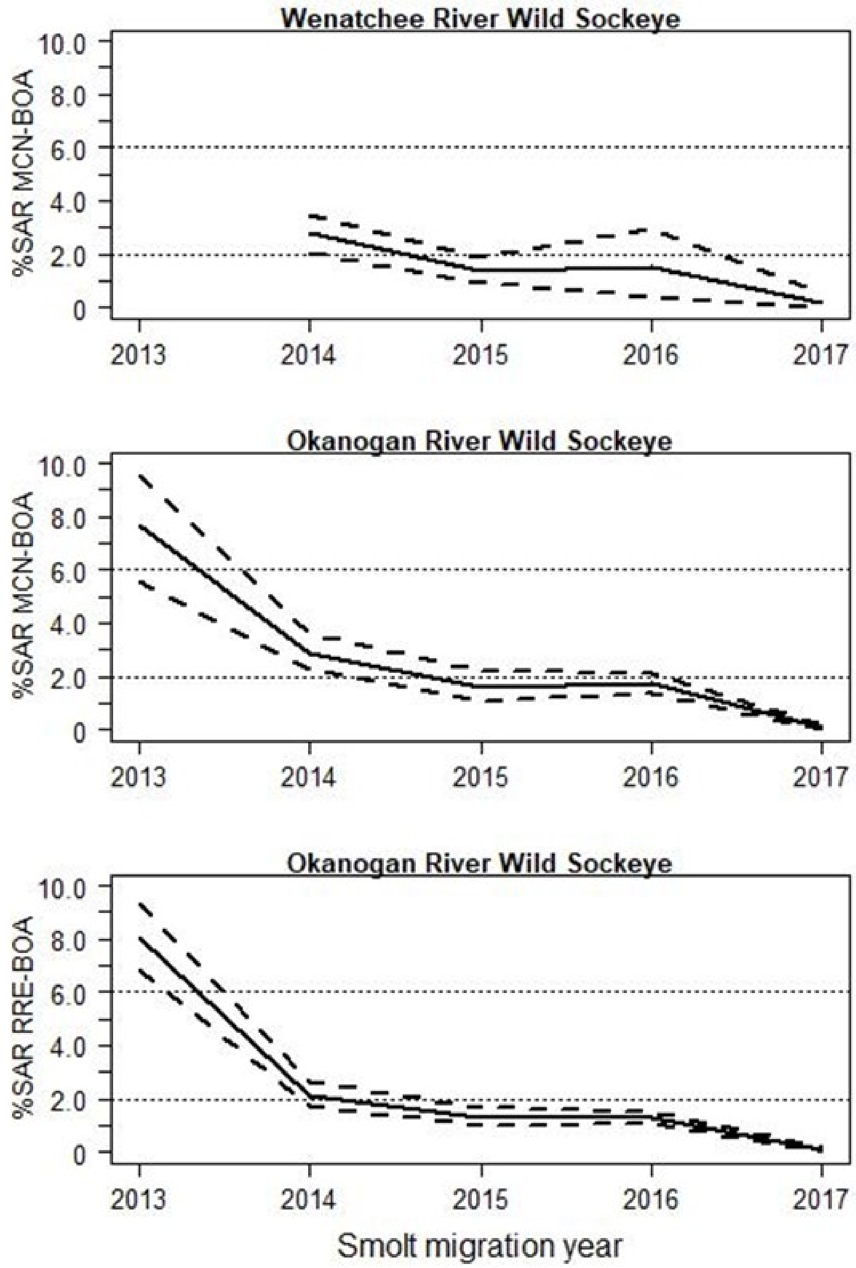


Figure 4.23. Bootstrapped SAR (MCN-to-BOA and RRE-BOA) and upper and lower CI for Okanogan River and Wenatchee River wild sockeye from Upper Columbia region, 2013-2017 migration years. Migration year 2017 is incomplete with 2-salt returns through July 31, 2019. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. Data for this figure can be found in Tables B.117 (Wenatchee), B.118 (Okanogan MCN-BOA), and B.119 (Okanogan RRE-BOA).

Because the component of Upper Columbia SARs upstream of McNary Dam is missing for many 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

(2018 FPC Annual Report). Survival estimates through this 360-kilometer reach are estimated in 2-week periods across several migration years when sample size is available (Figure 4.24). 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 yearling Chinook and steelhead (arithmetic mean survival ~ 0.60 for steelhead and 0.65 for yearling Chinook). For the Wenatchee stocks, this implies that if estimating SARs similarly to other CSS groups were possible, they would average about 60-65% of that indicated by the MCN to BOA SAR. For example, the geometric mean MCN to BOA SAR for Wenatchee hatchery steelhead (Table B.116) would change from 1.54% to 0.92%.

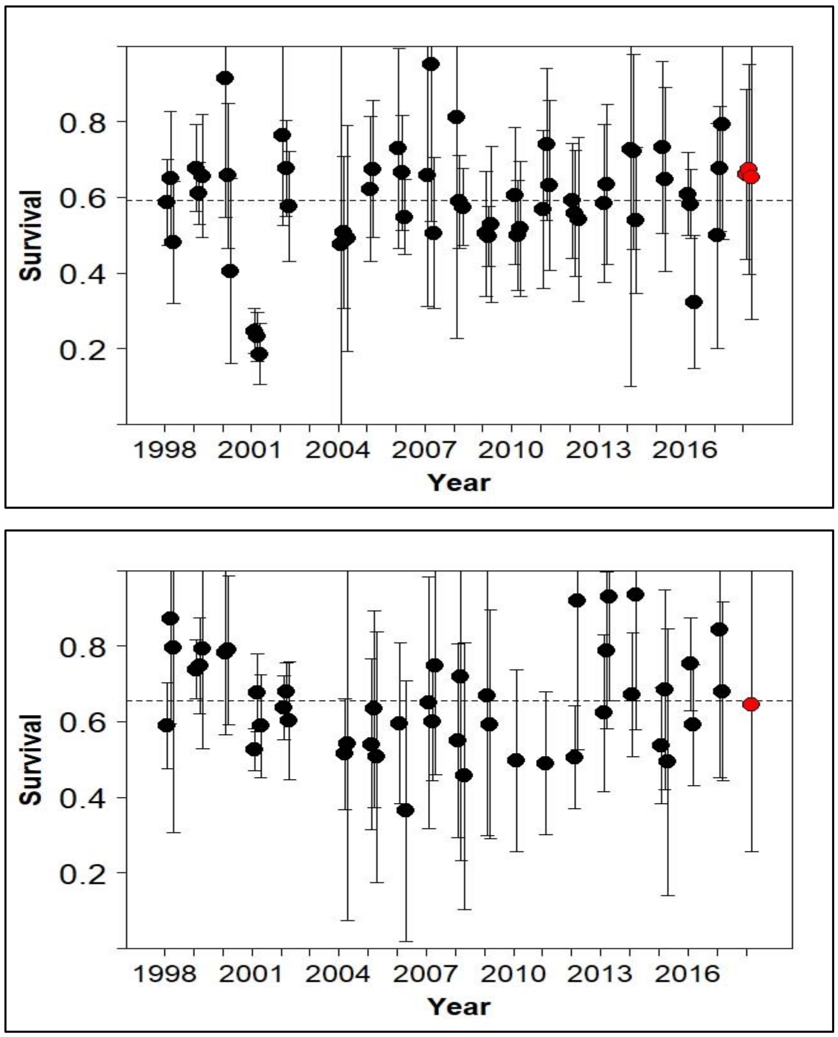


Figure 4.24. Spring out-migrants' juvenile survival from RIS to MCN. The top panel is hatchery + wild steelhead and the bottom panel is hatchery + wild yearling Chinook. These are 2-week CJS estimates for smolts captured, PIT-tagged, and released at RIS as part of the SMP project (FPC 2018 Annual Report). The confidence interval plotted is 95%. The arithmetic means (through 2017) are noted by the horizontal dashed line were 0.60 and 0.65 for steelhead and yearling Chinook, respectively.

SARs from smolts tagged at RIS to adults at BOA are summarized in Tables B.120 to B.125 and Figure 4.25 for the SMP PIT tag groups of Upper Columbia wild and hatchery yearling (primarily spring) Chinook, subyearling (primarily summer) 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 yearling Chinook and steelhead groups are 79% and 43% of those for tributary-tagged wild groups (Tables B.99, B.115, B.121 and B.124), 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, 17- to 18-year time series of survival rates that, except for Leavenworth hatchery spring Chinook, is otherwise lacking in this region.

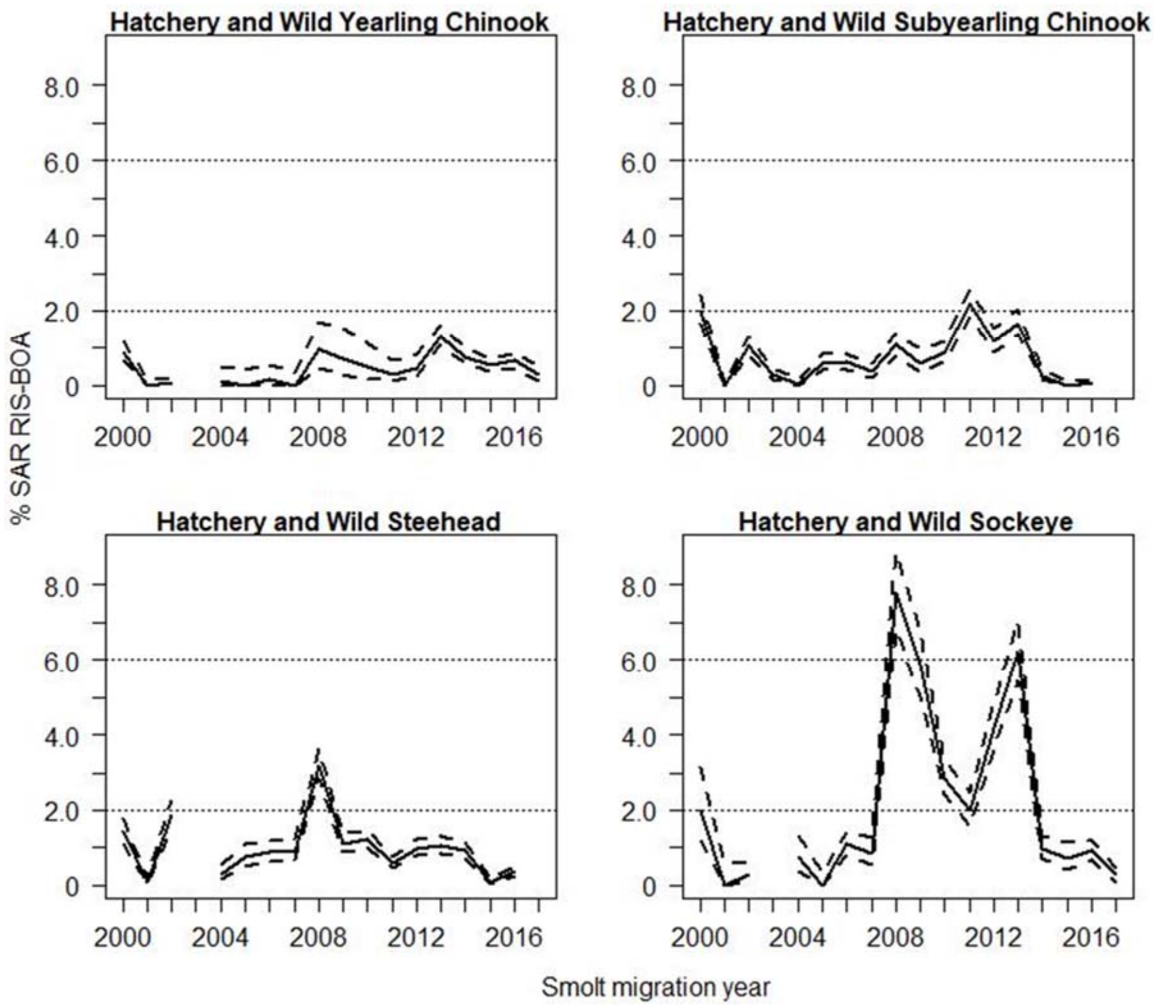


Figure 4.25. SAR (RIS-to-BOA) and upper and lower CI for Upper Columbia wild and hatchery yearling Chinook (with jacks included), subyearling Chinook (with jacks included), steelhead, and sockeye tagged at Rock Island Dam for the Smolt Monitoring Program, 2000–2017. Migration year 2017 is incomplete with 2-salt returns through July 31, 2019. Smolts were tagged at Rock Island Dam; adults are enumerated at BOA. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference. **Data for this figure can be found in Tables B.121 (yearling Chinook), B.123 (subyearling Chinook), B.124 (steelhead), and B.125 (sockeye).**

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. Whether a bias existed in the RR SARs, PIT-tag SARs, or both, is unclear 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. 2018) were 46% greater (geometric mean of ratio) than those based on PIT tags, during migration years 1996–2014 (Figure 4.26). 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.

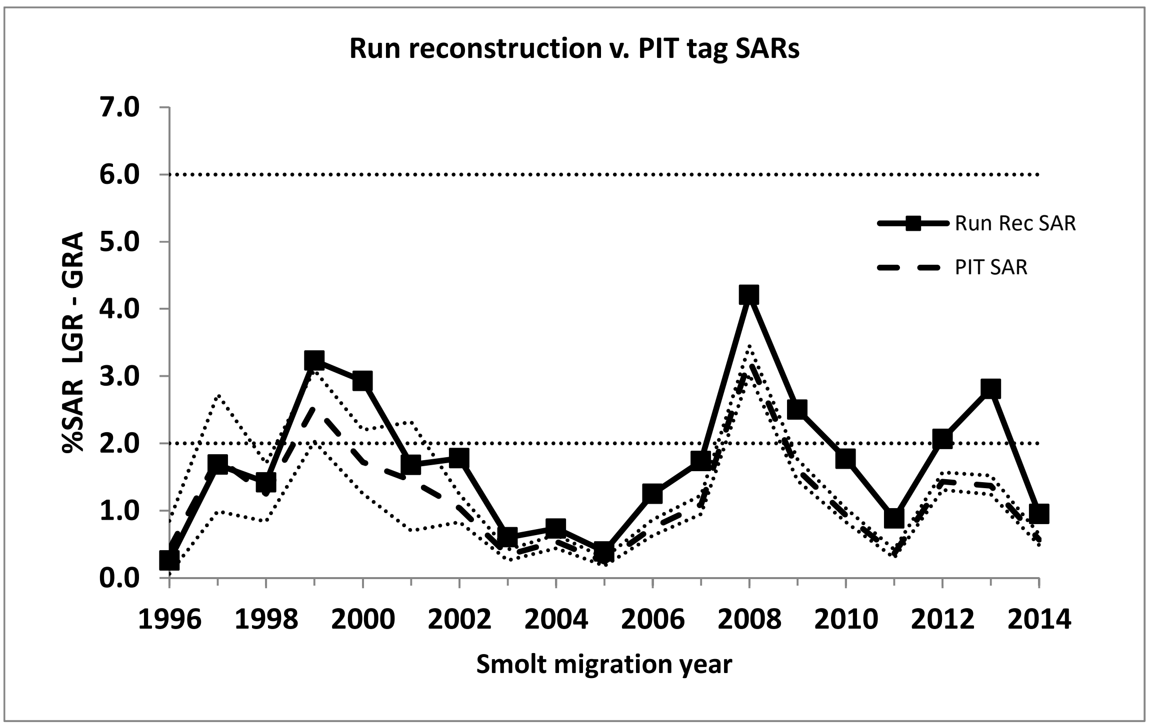


Figure 4.26. IDFG run reconstruction SARs (including jacks) compared to CSS PIT-tag SARs and 90% CI, Snake River wild spring/summer Chinook, migration years 1996–2014. NPCC (2014) 2%–6% SAR objectives for listed wild populations are shown for reference.

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.

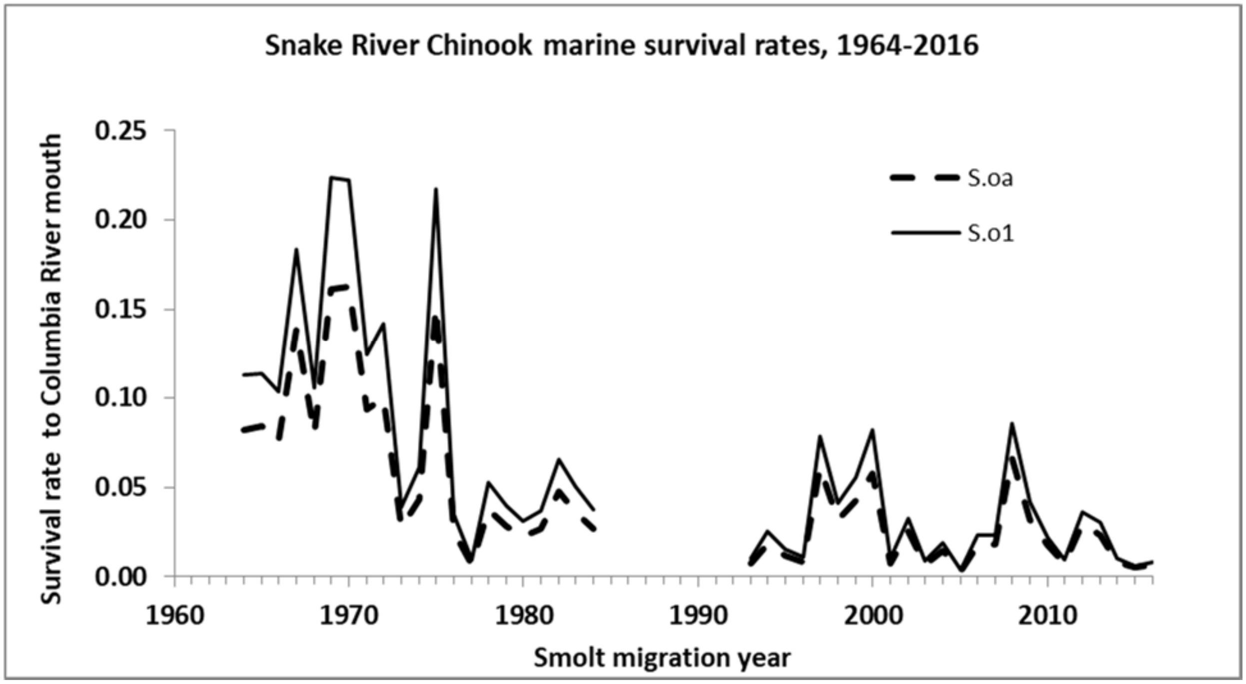
The following factors could potentially bias PIT-tag SARs: (1) non-representative tagging; (2) post-tagging mortality; (3) tag loss (shedding or damaged tags); (4) weighting schemes from different passage routes (before 2006); and (5) adult detection efficiency. Tuomikoski et al. (2010) concluded that 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 Chapter 8 of McCann et al. 2018).

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 1994–2016 ranged from 0.003 to 0.067 and the 23-year geometric mean was 0.016 (Table B.126). These recent *S.oa* rates for spring/summer Chinook were more than six-fold lower than the geometric mean of 0.099 for the 1964–1969 period (Figure 4.27). Similarly, *S.oa* for wild steelhead declined more than 7-fold from a geometric mean of 0.175 during 1964–1969 to 0.028 during 1997–2016 (Table B.127; Figure 4.27).



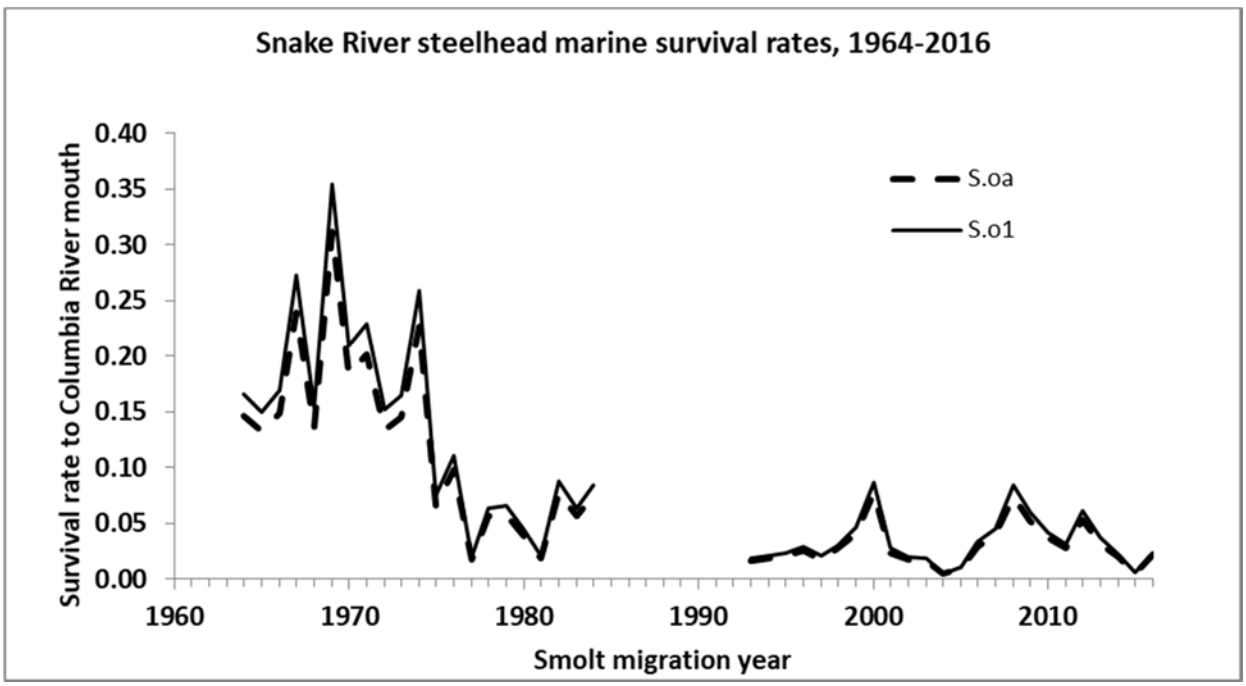


Figure 4.27 Marine survival rates for Snake River wild spring/summer Chinook and steelhead, 1964–2016.

Estimated first year ocean survival rates, *S.o1*, for Snake River wild spring/summer Chinook during 1994-2016 ranged from 0.004 in 2005 to 0.086 in 2008 and the 23-year geometric mean was 0.021 (Figure 4.27, Table B.126). Estimated *S.o1* for wild steelhead during 1997–2016 ranged from 0.005 in 2004 to 0.087 in 2000 and the 20-year geometric mean was 0.028 (Table B.127). Over the same 20-year period as shown for wild steelhead, the geometric mean of *S.o1* was 0.022 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 out-migrants is more limited.

Discussion

Neither Snake River wild spring/summer Chinook nor wild steelhead populations appear to consistently meet the NPCC 2%–6% SAR objective. Geometric mean SARs (LGR-to-GRA) were 0.76% and 1.35% for PIT-tagged wild spring/summer Chinook and steelhead, respectively. In the 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 similar levels of differential delayed mortality (*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). Survival rates differ 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 the highest SARs within a year.

Reasons for the relative lack of correlation between Snake River wild and hatchery steelhead SARs during 1997–2016 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 ($r = 0.88$) in the nine 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.

SARs of Snake River wild spring/summer Chinook and steelhead were correlated (r = 0.74) during the 1997-2016 out-migrations.

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 2015-2017 Springfield Hatchery releases experienced severe fish health problems, which were reflected in poor juvenile survival and low SARs (no adult PIT tag returns from any of these years).

Mid-Columbia River wild spring Chinook populations, as represented by the John Day and Yakima rivers, 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 3.58% and 2.69%, respectively, during 2000–2017. Most wild steelhead SARs for the Umatilla, John Day, Deschutes and Yakima rivers met or exceeded 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 2000–2017. SARs for Carson Hatchery were less than those observed 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 established 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 2000–2017. The SARs for the MCN-BOA reach exclude much of the migration corridor for upper Columbia populations, which pass an additional three (Wenatchee River), four (Entiat River) or five (Methow and Okanogan rivers) 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 65-66% of those based on smolts at MCN for these populations and years, reflecting the level of mortality that occurs between the point at which out-migrating juveniles first encounter mainstem dams and subsequent survivors are detected at MCN. 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.

The USFWS (in collaboration with the CSS oversight committee) implemented an independent study of PIT-tag bias to evaluate and test the repeatability of Knudsen et al. (2009) results, with double tagging experiments for Carson Hatchery spring Chinook. Final results from this study were presented in the 2019 CSS Annual Report (McCann et al. 2018, see Chapter 8). The study detected no difference between the PIT-tag-based and CW-tag-based SARs up to the point of return to Carson Hatchery. The study detected a reduction in PIT-tag retention over time after fish entered the hatchery holding ponds, likely due to females expelling PIT tags as eggs ripened.

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, upper Columbia, and other Columbia Basin 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 (Umatilla, 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 wild spring Chinook and steelhead have fallen short of the NPCC 2%-6% objectives since CSS monitoring began in 2006. 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 overstated 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.
- 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.
- 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).
- These continuing analyses respond to annual ISAB reviews and provide a sound foundation to continue and develop quantitative planning SAR objectives for the next amended NPCC Columbia River Basin Fish and Wildlife Program.

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 SAR objectives (see Chapter 4). 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%) 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. 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 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). In that work, 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 (2014) SAR objectives did not specify the points in the life cycle where Chinook smolt and adult numbers should be estimated, but the original PATH analysis for Snake River spring/summer Chinook was based on SARs calculated from adult and jack returns to the uppermost dam (Marmorek et al. 1998). The PATH analyses did not identify specific SARs necessary for steelhead survival and recovery but noted that steelhead SARs were somewhat higher than those of spring/summer Chinook before completion of the FCRPS (Marmorek et al. 1998). Additional SAR objectives may be associated with the objectives identified in Fish and Wildlife Program subbasin plans, other State and Tribal fishery management plans, and future amendments to the NPCC Columbia River Basin Fish and Wildlife Program. 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.

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. The ISAB (2017-2; 2018-3) extensively reviewed the 2-6% SAR objective, noted that the objective has been subject to extensive analyses by the CSS, and found *"…SAR objectives provide a readily measured, first-order objective for restoring stocks"*.

In its 2018 report (McCann et al. 2018), the CSS conducted a graphical summary of SARs and realized population productivity (spawning ground recruits) at the finest geographic scales possible, consistent with the ISAB (2013) review comments on the CSS draft 2013 annual report. Results illuminate the SARs necessary for John Day River spring Chinook and Snake River steelhead population abundance to stabilize or increase, given the depressed wild abundance levels in recent years. These analyses were complementary to the previous analyses for the Snake River spring/summer Chinook ESU. Notably, patterns in the John Day spring Chinook populations were similar to those observed in the Snake River. However, we found higher SARs are needed for population replacement in John Day Chinook (>3%) than in Snake River Chinook (1-2%), likely reflecting the higher relative spawner abundance and influence of density dependence in the John Day populations. In addition, historical levels of productivity were achieved with pre-harvest SARs in the range of 4% to 6% for John Day River wild spring Chinook. We also explored the relationship of steelhead SARs to population productivity for four Snake River spawning tributaries. Similar to our observations for Chinook Salmon, we observed steelhead population declines associated with brood year SARs less than 1%, and increased life-cycle productivity for Snake River steelhead populations in the years that brood year SARs exceeded 2%. These observations were generally consistent with the NPCC (2014) 2%–6% SAR objectives.

For this report, we extend the previous steelhead analyses. In 2016, the CSS began a comparison of Snake River steelhead SARs to population productivity for Fish Creek (Clearwater Major Population Group (MPG)), Rapid River (Salmon MPG). Pahsimeroi River (Salmon River MPG) was added in 2017 and Joseph Creek (Grande Ronde River MPG) in 2018.

Methods

Recent SARs and Population Replacement

In the 2019 annual report, we continue to investigate the relation between SAR and realized population productivity of Snake River steelhead. We add another year of data to the series from Fish Creek (a major tributary of the Lochsa River Population, Clearwater River MPG), Rapid River (a major tributary in the Lower Salmon Population, Salmon River MPG), Pahsimeroi River (Salmon River MPG), and Joseph Creek (Grande Ronde River MPG). Hatchery influence is minimized in the first three drainages by exclusion of any hatchery production or strays at the weirs (Copeland et al. 2015). Data from Fish Creek and Joseph Creek included brood years 1996-2012 and data from Rapid River and Pahsimeroi River included brood years 2003-2012. In this report, we add data series from two other populations: Big Bear Creek (in the Potlatch River drainage, part of the Lower Clearwater population, Clearwater MPG) and Big Creek (a major spawning area in the Lower Middle Fork Salmon population, Salmon MPG). Hatchery fish are not released in Joseph Creek, Big Bear Creek, or Big Creek and available data indicates stray rates into those drainages are low (<5%). Steelhead from Fish Creek and Big Creek are classified as B-run; steelhead from Rapid River, Pahsimeroi River, Joseph Creek and Big Bear Creek are classified as A-run (Copeland et al. 2017). Steelhead run reconstruction data for the Idaho populations were obtained from Dobos et al. (2019) to include data collected in 2018.

Data for Joseph Creek steelhead were derived differently. Spawning abundance 1996-2010 was estimated based on redd counts conducted by Oregon Department of Fish and Wildlife (Carmichael et al. 2015). Annual single-pass index surveys of redds were used to estimate average redd density in major spawning areas. Observed redd density was extrapolated to unsurveyed areas based on the reach-specific intrinsic productivity index (ICTRT 2007). The estimate of total redds was expanded to spawning adults (fish per redd) based on data from a weir near the mouth of Deer Creek, a tributary of the Wallowa River in the Grande Ronde River drainage. Number of adults passed was divided by a redd census to calculate an annual fish per redd estimate. Prior to 2002, an average 2.1 adults per redd was assumed based on the 2002 – 2005 observations. Starting in 2011, a resistance board weir was operated near the mouth (rkm 3.4) by the Nez Perce Tribe (Kucera 2012). For abundance in spawning years 2011-2013 and 2015-2016, we used a mark-recapture population estimate based on fish handled at the weir, assuming that this estimate is more accurate and precise than the redd expansion. The weir was compromised by flooding in 2014 and 2017. We used the redd count expansion for 2014 and an estimate based on PIT detections for 2017. Weir operation protocol is to remove known hatchery fish marked with a CWT. The number of hatchery-origin fish should be low, subject to CWT mark rate and weir efficiency, and we assumed hatchery fraction was the average (3%) for years when the weir was operable. We used the estimates reported by Nez Perce Tribe staff (Kucera 2012; Kucera et al. 2013, 2014; Watry et al. 2017a, 2017b; Orme and Kinzer 2018; Robbins et al. 2018). The composition of the spawning fish (age, percentage of hatchery fish) was inferred from fish handled at this weir. Number of natural-origin recruits was based on total spawning abundance discounted for hatchery percentage. The age composition of the natural-origin spawners was based on scale patterns; otherwise, an average of the 2011-2016 data was applied. The spawning abundance based on mark-recapture methods may be biased high because the estimate reflects the number of adults released at the weir and does not include upstream pre-spawning mortalities.

We defined the realized steelhead population productivity as the natural logarithm of recruits to spawning grounds divided by number of spawners (ln R_{sg}/S). Steelhead cohorts produce smolts ranging in age from one to five (or more) years old. Therefore, to calculate SARs by brood year we weighted multiple years of SARs by the juvenile outmigrant age structure. The SARs are defined as survival from smolt at Lower Granite Dam to adult back to Lower Granite Dam (LGR-GRA). We used CSS estimates of LGR-GRA SARs for wild A-run (Rapid River, Pahsimeroi River, Big Bear Creek) or B-run (Fish Creek, Big Creek) steelhead for smolt migration years 2006-2012 (Tables B.41, B.42). For Joseph Creek, we used LGR-LGR SARs for Grande Ronde basin steelhead (Table B.37). Prior to smolt migration year 2006, we used SAR estimates for the wild aggregate steelhead (Table B.35). For the Idaho populations, we used the age composition of spring migrants at rotary screw traps from Copeland et al. (2015) to index average smolt age composition. 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. For Big Bear Creek and Big Creek, we used average age composition of spring migrants from data reported by Apperson et al. (2017). Average age composition for Big Bear Creek steelhead was 28.3% one-year, 66.1% two-year and 5.6% three-year. Average age composition for Big Creek steelhead (excluding 2007 because of a late trap installation, Copeland and Putnam 2008) was 23.1% one-year, 26.9% two-year, 39.1% three-year, 10.8% four-year, and 0.1% five-year. Absent availability of age structure information collected from emigrating juvenile steelhead in Joseph Creek, we used the freshwater ages observed from scales collected from the returning adult spawners to infer smolt age composition. Average out-migrant age composition for Joseph Creek steelhead was 1.0% one-year, 93.7% two-year and 5.2% three-year.

We completed two graphical analyses. First, we plotted individual brood year productivity estimates against brood year SARs by population. A logarithmic trend line was plotted for each population. We then compared distributions of observed productivity over all populations by brood year SAR category: <1.0% SAR, 1.0 - 1.9% SAR, and ≥ 2.0% SAR using boxplots.

Results

The Fish Creek steelhead analysis was based on R_{sg}/S estimates for brood years 1996-2012; age 1-4 smolts from these brood years migrated during 1997-2016. Weighted brood year SARs for 1996-2012 averaged 1.71% and ranged from 0.87% to 2.62% (Table 5.1). Spawning ground recruits per spawner of Fish Creek steelhead ranged from 0.34 for brood year 2011 to 10.25 for brood year 1997 (Table 5.1). A few more recruits from brood year 2012 may return in 2019 but substantial changes in the R_{sg}/S estimate are unlikely.

The Joseph Creek steelhead analysis was based on R_{sg}/S estimates for brood years 1996-2012: age 1-3 year smolts from these brood years migrated during 1997-2015. Weighted brood year SARs for 1996-2011 averaged 2.21% and ranged from 0.44% to 4.40% (Table 5.1). Spawning ground recruits per /spawner of Joseph Creek steelhead ranged from 0.27 for brood year 2002 to 3.09 for brood year 1997 (Table 5.1). The brood year 1996 SAR-R_{sg}/S pair is an outlier but is included in the subsequent summaries.

The Pahsimeroi River steelhead analysis was based on R_{sg}/S estimates for brood years 2003-2012; age 1-3 year smolts from these brood years migrated during 2004-2015. Weighted brood year SARs for 2003-2012 averaged 2.04% and ranged from 0.84% to 3.14% (Table 5.1). Spawning ground recruits per spawner of Pahsimeroi River steelhead ranged from 0.18 for brood year 2003 to 9.86 for brood year 2007 (Table 5.1).

The Rapid River steelhead analysis was based on R_{sg}/S estimates for brood years 2003-2012; age 1-5 year smolts from these brood years migrated during 2004-2017 (approximately 1% migrated in 2017). Weighted brood year SARs for 2003-2012 averaged 2.01% and ranged from 0.62% to 2.70% (Table 5.1). Spawning ground recruits per spawner of Rapid River steelhead ranged from 0.22 for brood year 2012 to 2.13 for brood year 2007 (Table 5.1). A few more recruits from brood year 2012 may return in 2019 but substantial changes in the R_{sg}/S estimate are unlikely.

The Big Bear Creek steelhead analysis was based on R_{sg}/S estimates for brood years 2005-2012; age 1-3 year smolts from these brood years migrated during 2006-2015. Weighted brood year SARs for 2005-2012 averaged 2.31% and ranged from 1.58% to 2.78% (Table 5.1). Spawning ground recruits per spawner of Big Bear Creek steelhead ranged from 0.43 for brood year 2012 to 4.16 for brood year 2006 (Table 5.1). Technical problems prevented estimation of abundance in Big Bear Creek in 2018 but very few, if any, fish from brood year 2012 should have been present;therefore, substantial changes in the R_{sg}/S estimate are unlikely.

The Big Creek steelhead analysis was based on R_{sg}/S estimates for brood years 2010-2012; age 1-5 year smolts from these brood years migrated during 2011-2017 (<1% migrated in 2017). Weighted brood year SARs for 2010-2012 averaged 1.41% and ranged from 0.84% to 2.70% (Table 5.1). Spawning ground recruits per spawner of Big Creek steelhead ranged from 0.14 for brood year 2012 to 0.58 for brood year 2010 (Table 5.1). A few more recruits from brood year 2012 may return in 2019 but substantial changes in the R_{sg}/S estimate are unlikely.

Table 5.1. Estimates of weighted SAR and spawning ground recruits/spawner (Rsg/S) by brood year for six Snake River steelhead populations.

Brood year	Population											
	Fish Creek		Joseph Creek		Pahsimeroi R		Rapid River		Big Bear Cr		Big Creek	
	SAR	R_{sg}/S	SAR	R_{sg}/S	SAR	R_{sg}/S	SAR	R_{sg}/S	SAR	R_{sg}/S	SAR	R_{sg}/S
1996	1.35	2.95	0.44	2.18								
1997	2.45	10.25	2.80	3.09								
1998	2.60	3.45	2.65	0.96								
1999	2.35	2.65	2.45	0.90								
2000	1.94	3.45	2.11	0.87								
2001	1.37	0.89	1.54	0.58								
2002	0.93	0.37	0.86	0.27								
2003	0.87	0.78	0.85	0.81	0.84	0.18	1.50	0.84				
2004	1.18	0.94	1.76	1.73	0.94	0.76	2.47	0.99				
2005	2.08	2.99	4.40	1.29	1.81	0.86	2.69	1.69	2.72	0.76		
2006	2.62	2.43	3.39	1.24	3.14	2.72	2.70	1.46	2.78	4.16		
2007	1.83	1.41	2.36	1.32	2.62	9.86	2.23	2.13	2.74	2.65		
2008	1.33	0.43	2.84	0.85	2.71	5.82	1.90	0.34	2.25	1.46		
2009	1.58	0.81	1.93	0.38	1.93	6.00	2.26	0.35	1.66	0.93		
2010	2.02	2.27	3.49	2.11	1.66	1.03	2.19	0.35	2.33	0.72	1.77	0.58
2011	1.69	0.34	2.39	1.26	2.65	0.71	1.55	0.34	2.39	1.81	1.61	0.31
2012	0.96	0.43	1.37	0.47	2.13	0.34	0.62	0.22	1.58	0.43	0.84	0.14

An association is evident between R_{sg}/S and brood year SAR for steelhead from the study populations. Generational declines in abundance ($R_{sg}/S < 1$; $\ln[R_{sg}/S < 0]$) occurred in 25 out of 32 cases where brood year SARs were less than 2% (Table 5.1; Figure 5.1). Trends of R_{sg}/S and brood year SAR for all populations were positive and similar in slope, except that the trend for Joseph Creek was much flatter than the others.

SARs less than 1% resulted in generational decreases in steelhead abundance ($\ln[R_{sg}/S] < 0$; Figure 5.2). The single exception to this was Joseph Creek brood year 1996. Conversely, SARs greater than 2% usually resulted in generational increases in steelhead abundance. Observed productivity was frequently negative (median $\ln(R_{sg}/S) < 0$) 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.

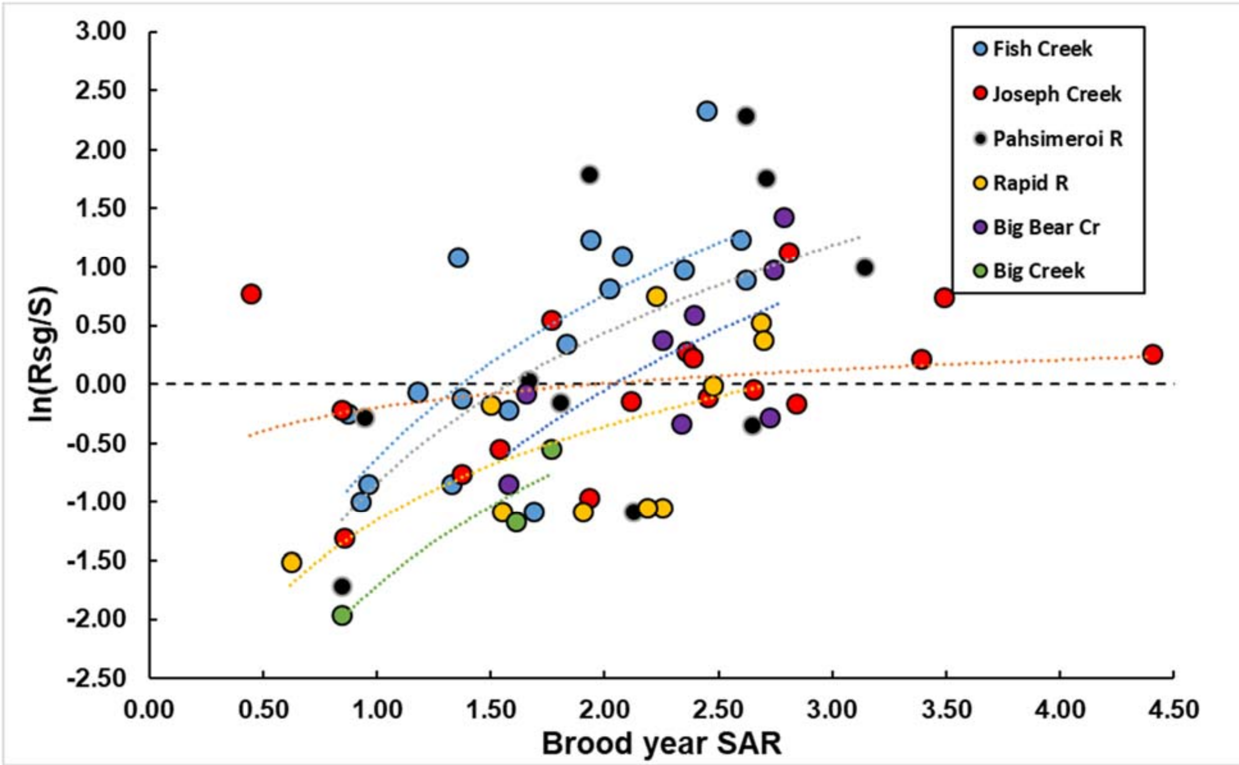


Figure 5.1. Association of spawning ground recruits/spawner, ln(Rsg/S), and brood year SAR for six Snake River steelhead populations. Brood years represented are 1996–2012 for Fish Creek and Joseph Creek; 2003-2012 for Rapid River and Pahsimeroi River, 2005-2012 for Big Bear Creek; and 2010-2012 for Big Creek. Brood year SARs represent LGR-GRA survival. Note the left-most point represents the brood year 1996 outlier from Joseph Creek. The dashed line indicates ln(Rsg/S) values of zero. Dotted lines represent logarithmic population trends.

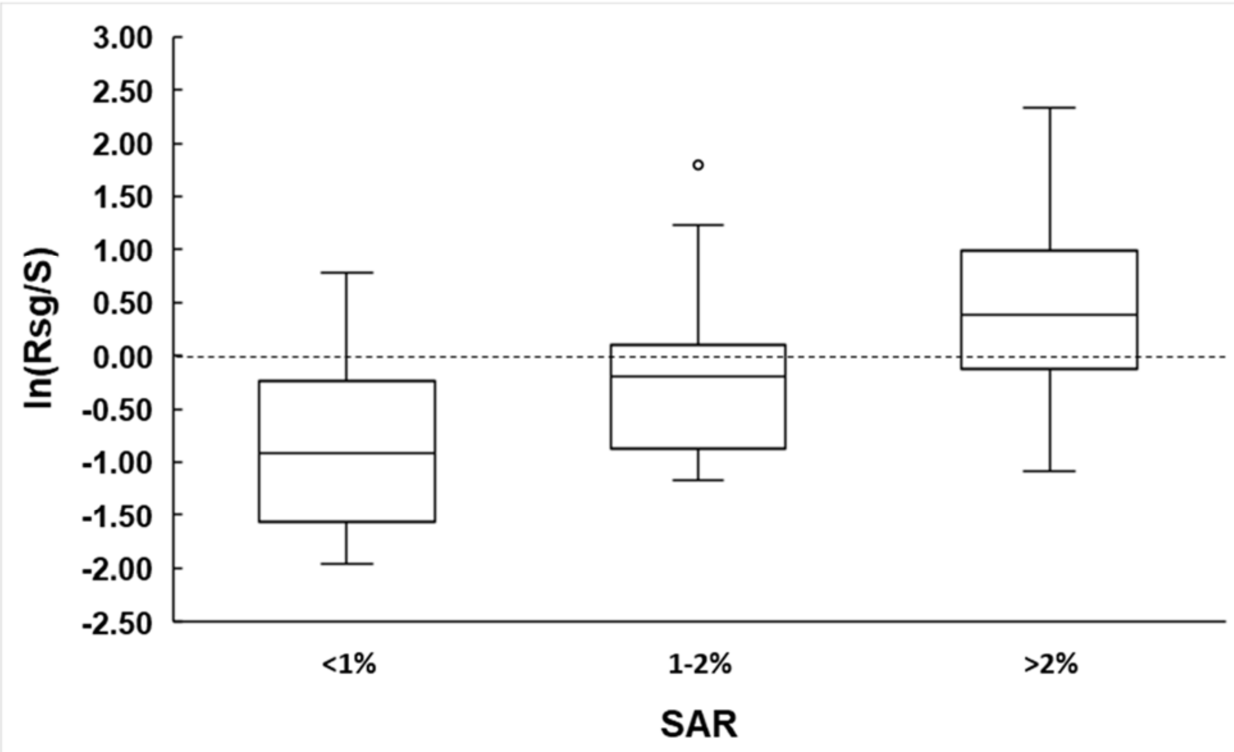


Figure 5.2. Boxplots of Snake River steelhead population productivity (ln[Rsg/S]) by brood year SAR category for six Snake River steelhead populations. Boxes show 25th percentile, median, and 75th percentile of ln(Rsg/S); whiskers show 1.5 times the interquartile range or the range of the data, whichever is least; outliers beyond 1.5 times the interquartile range are shown as single dots. Brood year SARs represent LGR-GRA survival. The dashed line indicates ln(Rsg/S) values of zero.

Discussion

The graphical summary of SARs and realized population productivity (spawning ground recruits) presented in this chapter show the SARs necessary for Snake River steelhead population abundances to stabilize or increase, given the abundance levels of wild fish in recent years. Our analysis addresses the ISAB (2012) review comments on the CSS draft 2012 annual report and supports the objectives of the amended Columbia River Basin Fish and Wildlife Program (NPCC 2014), which encourages a regional review of the NPCC SAR objectives. Additionally, it continues recent years' reporting at finer geographic and MPG scales as observed in the ISAB (2013) review of the CSS draft 2013 annual report.

We explored the relationship of SARs to population productivity for six Snake River spawning tributaries. Steelhead smolts from the same brood year emigrate over several years, unlike Chinook Salmon. To align population productivity (spawning ground recruits/spawner) with SARs, we calculated a weighted brood year SAR, based on average smolt age composition. Similar to our observations for Snake River Chinook Salmon (McCann et al. 2017), we 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%.

Demographic data for steelhead populations are more limited compared to Chinook Salmon populations in the Columbia River basin. In this report, we expanded the number of steelhead populations analyzed from four to six populations, including two B-type populations. Potential exists to expand this analysis again in the future. New data series are emerging for other Snake River steelhead populations. Incorporating these data will help achieve a broader representation of populations, even if individual data series are shorter than desired. However, populations that have relatively long spawner abundance time series estimates and a history of consistent sampling for fresh- and saltwater age would likely have greater range and add sensitivity to this analysis.

We expected variation for steelhead populations in their productivity response to SARs due to their complex life history. The variation is likely caused by changes in survival and productivity during periods when the fish are residing upstream of Lower Granite Dam. Snake River steelhead may smolt from ages 1-5. Adults leave the ocean and remain in freshwater for up to 6-8 months and must survive the winter before spawning. Some populations (e.g., Fish Creek, Feeken et al. 2019) have a substantial proportion of spawners spending winter downstream of LGR, so SAR may encompass more adult variability in them than for populations in which most adults spend winter upstream of Lower Granite Dam. Further, we are using an aggregated SAR, which is then allocated across migratory years to produce a weighted brood year SAR. This SAR may not track the smaller scale productivity as well as if one could be estimated for the local population.

There are some obvious differences among populations in the relationship of SAR to $\ln(R_{sg}/S)$ but all populations exhibit a positive correlation. For example, expected $\ln(R_{sg}/S)$ of Rapid River steelhead increases with SAR but a higher SAR is needed to achieve replacement than other populations. The differences could be due to effects of additional juvenile mortality as it takes more years in freshwater for a brood year to smolt in Rapid River than in the other populations. Differences in adult prespawn mortality and sex ratio could also explain differences as well as other population-specific factors. Given the range in life history characteristics exhibited by Snake River steelhead (see Copeland et al 2017), adding more populations to this analysis will help understand the scope in response of population productivity to changes in SARs.

Continuing these investigations supports development of SAR planning objectives during the ongoing NPCC FWP amendment process and fulfills the ISAB's suggestion to refine SAR objectives at finer demographic scales. Because Snake River spring/summer Chinook run reconstructions are updated on a five-year schedule for ESA status assessments, we did not repeat them for this report. Updates to the Chinook analysis will be done as run reconstructions are completed. A manuscript has been submitted for peer-reviewed publication that compares SAR to population productivity for Snake River spring/summer and John Day River spring Chinook Salmon, based on data shown in previous CSS reports.

The observations reported in this chapter to date are relevant to, and generally support, the NPCC (2014) 2%–6% SAR objectives. We observed major population declines associated with SARs (LGR-GRA) less than 1%, and increased life-cycle productivity as SARs exceeded 2%.

Conclusions

- Declines in wild Snake River steelhead population were associated with brood year SARs less than 1%, and increased life-cycle productivity occurred when brood year SARs exceeded 2%.
- Relationship of SAR with steelhead population productivity is less precise than for Chinook Salmon and varies among populations.

CHAPTER 6
DELAYED MORTAILTY REVIEW

Populations of Columbia and Snake River salmon and steelhead have substantially declined since the completion of the Federal Columbia River Power System (FCRPS) in the 1970's. While extensive study of the FCRPS has been undertaken to ascertain and quantify the specific causes for this decline, a number of populations have declined to such an extent to warrant listing under the US Endangered Species Act in the 1990's. Some operational and systematic changes throughout the years have yielded improvements in some survival metrics, however, many populations are still performing at well below pre-dam levels of productivity and abundance. Snake River and Upper Columbia populations may pass as many as eight or nine large hydroelectric projects on their seaward migration. The resultant deleterious effects on survival from passage through the hydrosystem can be broadly categorized into two types of effects; (1) direct mortality, which is defined as mortality that occurs in immediate proximity and is causal to the dam, and (2) delayed or latent mortality, which occurs subsequent to dam passage in the estuary and early ocean residence, but is directly related to their hydrosystem passage history. While direct mortality is relatively easily studied and quantified, delayed mortality is much more difficult to measure as it is expressed subsequent to passage of the most downstream dam. As such, this chapter will attempt to summarize some of the major findings surrounding delayed mortality in relation to the FCRPS, as well as quantify their relative magnitude of effects on life stage specific survival, and resultant productivity.

A number of hypotheses have been proposed for possible mechanistic explanations for delayed mortality in relation to hydrosystem passage experience. A review by Budy et al. (2002) discussed the possibility that delayed mortality associated with passage of the FCRPS may be due to injuries and stress events accumulated during migration through the hydrosystem by turbines, juvenile bypass systems, and spillways. Cumulatively, these stress events may increase smolts vulnerability to predators and disease and/or reduce their energetic condition. Evidence of this has been illustrated by Mesa (1994), showing that increased stress events in juvenile Chinook resulted in increased predation by northern pikeminnow and Hostetter et al. (2012), which found that steelhead that were in poorer condition associated with disease or injury, were subsequently more vulnerable to predation by piscivorous birds in the Columbia River estuary. Similarly, juvenile salmonids undergoing transport, while avoiding most of the direct mortality associated with migration through the FCRPS, experience considerable stress and injury during collection in the juvenile bypass system (JBS) at dams on the lower Snake River (Budy et al. 2002, Van Gaest et al. 2011). Crowding in the JBS of collection dams, exposure to pathogens in barges and trucks, and altered estuary arrival timing have all been proposed as possible explanations linking poorer than expected subsequent survival in transported fish (Budy et al. 2002, Muir et al. 2006, Schaller et. al. 2007, Tuomikoski et al. 2011).

The evidence that arrival timing in the estuary is also linked to differential survival in Columbia River Chinook and steelhead has been found by a number of studies. Specifically, the 'match/mismatch' hypothesis has been studied extensively as a possible mechanism for the observed delayed mortality. Starting from the assumption that juvenile salmonids are evolutionarily adapted in timing their migration to optimize in-river and subsequent ocean survival (Percy 1992), the extensive changes in flow regimes, temperature, and migration duration associated with the installation of mainstem hydropower dams has significantly altered estuary arrival timing (Anchor et al. 2007, Muir et al. 2006). Scheuerell and Williams (2005) demonstrated that intra-annual variability in early ocean conditions during the period of ocean entry had substantial predictive ability on subsequent smolt-to-adult survival rates. Additionally, inter-annual variability in estuary arrival timing has been shown to correlate well to smolt to adult survival rates, with earlier arrivals generally associated with higher survival (Scheuerell et al. 2009, Schreck et al. 2006). Specifically, Scheuerell et al. (2009) found that SAR's for Snake River steelhead and spring Chinook were strongly associated with date of migration as defined by detection at Lower Granite Dam. They found the highest SARs in Chinook were 4-50 times higher in individuals migrating in early to mid-May than in mid-June, although magnitude and timing of this effect was variable between years. This differential mortality has been attributed to both predator density in the Columbia River estuary and plume increasing with time on an annual basis, as well as variability in food availability (Roby et al. 2003, Scheuerell et al. 2009). Muir et al. (2006) found that Snake River Chinook took on average between 2-4 weeks to migrate from Lower Granite to Bonneville Dam. The match/mismatch hypothesis suggests that increased delay associated with passage through the FCRPS is strongly correlated with sub-optimal estuary arrival timing, and subsequent differential delayed hydrosystem mortality.

Finally, the fish size hypothesis assumes that differential post hydrosystem mortality is best explained by differences in size at the time of estuary arrival, with smaller fish surviving at lower rates than larger fish. This hypothesis is based on the idea that high mortality rates in the estuary and early ocean are largely attributable to size selective predation (Pearcy 1992). Muir et al. (2006) proposed that size selectivity due to lost growth opportunities for transported fish might be a plausible explanation for the poor performance in comparison to in-river migrants. With in-river migrants taking between 2-4 weeks to reach Bonneville, and up to 7 weeks in low flow years, additional growth opportunities for transported fish would be absent in the 2 days it takes to reach the estuary. This was apparent in their finding that in-river migrants grew an additional 5-8mm on average, while there was no observed growth in transported fish between Lower Granite and Bonneville dams. They contend this differential in size between the two groups exposed a larger number of transported fish to possible predation by northern pikeminnow in the Columbia River estuary, and Pacific hake in the Columbia River plume.

While direct evidence of precisely where delayed hydrosystem mortality is occurring is difficult to ascertain, a number of lines of evidence suggest it is during the estuary and early ocean residence periods (Williams et. al. 2005, Marmorek et.al. 2011, Schaller et al. 2014). Differential mortality has been observed between both transported and in-river fish, as well as in-river migrants exposed to variable hydrosystem passage experiences (Deriso et al. 2001, Buchannon et al. 2011, Ferguson et al. 2006, Muir et al. 2006, Haeseker et al. 2012, Sanford and Smith 2002, Schaller et al. 2007, Schaller et al. 2014, Scheurelle et al. 2009, Tuomikoski et al. 2010, Williams et al. 2005). While this represents a weight of evidence indicating that delayed mortality is associated with a history of transport and in-river conditions relating to the FCRPS, not all studies have detected this effect (Rechinsky et al. 2013). Delayed mortality in relation to the hydrosystem has been evaluated in a number of ways, from direct experiments (Ferguson 2006), to spatial comparisons (Schaller et al. 1999, Schaller and Petrosky 2007), and time series evaluations that include environmental covariates (Schaller et al. 2014, Haeseker et al. 2012, Scheuerelle et al. 2009). Most of these have found evidence that there is some component of delayed mortality as a result of FCRPS passage, even though precisely what causes this effect, and exactly where it is manifest has not been conclusively determined.

Delayed mortality from FCRPS dam passage has been quantified by a number of studies, both directly, at specific dams, as well as indirectly using post-Bonneville SARs. Ferguson et al. (2006) conducted an experiment evaluating direct mortality at the face of McNary dam, in addition to subsequent delayed mortality as observed at an array 46km downstream. They found that direct mortality as a result of dam passage through the turbines accounted for only 30-54% of the observed mortality at the downstream array. Meaning that for in-river migrants passing turbine routes, between 46-70% of the observed mortality at the dam was attributable to delayed hydrosystem effects. Similarly, Tuomikoski et al. (2010) and McCann et al. (2016) evaluated a suite of survival models assessing how well detection at an FCRPS bypass system predicted subsequent ocean survival for Snake River spring Chinook and steelhead. For both species, there was evidence that as the number of bypass experiences increased, the subsequent post-Bonneville SARs correspondingly decreased. Specifically, for spring Chinook, they found that each bypass event at an FCRPS dam resulted in a 10% decrease in expected post-Bonneville SARs when compared to non-detected fish. While this study didn't differentiate between specific bypass events, there is also some evidence that specific combinations of bypass events at FCRPS projects can also have synergistic delayed effects. Buchannon et al. (2011) observed that specific combinations of bypass events at particular dams appeared to exacerbate the decline in subsequent post-Bonneville SARs. They found that on average, fish that were bypassed at Little Goose dam would consistently return at rates between 27-33% lower than would be expected of non-detected fish. But at Lower Monumental, the range was between a 2-36% decrease, depending on if and where they were subsequently bypassed downstream. Finally, Schaller et al. (2014) compared Snake River populations to John Day populations of Chinook and steelhead that must pass 4 fewer dams during their migration. They found that historically, Snake River populations have survived at about 25% the rate than the downstream reference population since the completion of the FCPRS dams in the mid 1970's. While also incorporating environmental variables associated with in-river and ocean conditions, Schaller et al. (2014) also concluded that approximately 76% of Snake River Chinook smolts died shortly after entering the marine environment as a direct result of their FCRPS migration experience.

While a large number of studies have identified lower SARs in fish that use bypass and turbine routes of passage, lending credibility to cumulative stress and injury hypothesis of Budy et al. (2002), some have argued that delayed mortality is simply the natural manifestation of smaller, weaker fish having size selective powerhouse and bypass entrainment (Zabel et al. 2005). Zabel et al. (2005) found that smaller fish had an increased probability of re-entering an FCRPS smolt bypass system at Little Goose and Lower Monumental dams. The implication being that "perceived" FCRPS hydrosystem delayed mortality may simply be the manifestation of these weaker fish having a higher propensity for ending up in the powerhouse, and their subsequent poor survival is unrelated to the resultant FCRPS bypass system events. While this is a parsimonious explanation for the observed delayed mortality effects in bypassed fish, Buchannon et al. (2011) examined this relationship at a wider array of dams and found much more variability in the effect, and it was less conclusively directional. While acknowledging the differences in methodologies, they concluded that variability in the relationship between fish length and bypass probability suggests that it is likely complicated by a number of unknown factors.

While specific metrics pertaining to magnitude of effect can be useful for understanding long-term viability of a population, from a managerial perspective, it is useful to at least pinpoint some proximate causes for an observed effect. To this end, defining exactly which mechanism is causal to delayed mortality may be less important than determining the indices that are strongly correlated with its deleterious effects. In addition to bypass and turbine experiences, water travel time and delayed migration due to the FCRPS have been consistently identified as parameters of importance when evaluating and quantifying the effects of delayed mortality as it relates to passage through the hydrosystem (Haeseker et al. 2012, Scheurelle et al. 2009, Tuomikoski et al 2010, Schaller et al. 2014). Haeseker et al. (2012) examined both freshwater and marine environmental covariates in an attempt to explain variability in multiple life stages of Snake River Chinook and steelhead populations. They found that the most important covariates in characterizing outmigration survival in Chinook and steelhead were spill percentage and water travel time. Spill percentage was also one of the most influential variables in describing ocean survival. Haeseker et al. (2012) also demonstrated that increasing SARs were highly correlated with increased spill and decreased water transit time through the hydrosystem. Similarly, Scheuerelle et al. (2009) concluded that, based on their findings of decreasing SARs with increasing date of Bonneville arrival, management actions should focus on increased flow from reservoirs and increased spill to minimize the delay in estuary arrival caused by FCRPS projects (Tuomikoski et al. 2010, Zabel et al. 2008). Schaller et al. (2014) came to the same conclusion, arguing that reductions in fish travel time through the FCRPS through draw downs, increased spill, and minimizing bypass encounters could have a substantial effect on curtailing both direct and delayed mortality in Columbia River stocks. While the evidence for competing hypotheses of causal mechanisms for delayed mortality are still somewhat confounded, there does seem to be consensus on some of the management actions that are likely to minimize their relative effects. With new spill agreements being negotiated in the near future, decreased water transit times, increased spill, and the associated decrease in bypass probabilities during the spring migration may provide a useful experiment to observe and evaluate delayed mortality under a new flow management regime.

CHAPTER 7
CSS CHAPTER FOR ADULT SALMON AND STEELHEAD UPSTREAM MIGRATION

Introduction

When assessing adult salmon and steelhead survivals during their upstream migration, past analyses have mainly treated fish travel time as a proxy for measuring migratory costs (e.g. Crozier et al. 2017, Crozier et al. 2018, FPC 2016, FPC 2019). Prolonged travel time may increase energy expenditure for fish and possibly amplify their exposure to high water temperatures, diseases, predators, and fishery harvest. When it comes to improving adult fish passage within the Federal Columbia River Power System, managers have typically controlled spills with a primary goal to minimize travel time for adult salmon and steelhead. However, there have been concerns that reducing spills to facilitate adult salmon passage may direct more juvenile fish through the powerhouse. A complete solution for fish passage issues is complicated and beyond the scope of this chapter. Yet, what has been lacking among the discussion about fish passage is a more comprehensive understanding of adult fish survival in relation to travel time.

An important consideration is that travel times of fish that die en route are not directly observed in the reach where mortality occurs. This has been an obstacle for bridging the knowledge gap in understanding the survival-travel time relationship. In the previous Comparative Survival Study (CSS) analysis, we developed a preliminary method to impute the unobserved travel time with expected travel time, so we could directly assess the relationship between survival and travel time (McCann et al. 2018). This year, we are continuing to build on this effort and further our understanding of the survival-travel time relationship.

Travel time is often modeled as a proxy for migratory cost. The assumption is that a longer travel time is related to a higher exposure to mortality agents and higher energy expenditure. A researcher in this case will assess how fish survival changes due to environmental and biological costs. Nevertheless, for the current CSS analysis, we have been investigating the relationship from a different perspective. Instead, we model travel time as a process where fish survival progresses over time as they travel upstream. We do not assume a relationship between travel time and migratory costs. We merely estimate the overall survival and daily mortality.

Survival Process

Our main focus is to investigate the change in fish survival over time as they travel upstream. First, we define travel time as the time spent for a fish to travel from one detection point to the next. In the context of this analysis, the detection points are dams, and the time spent between dams is measured in days. Then we define a travel time cohort as a group of fish that spend the same amount of days traveling between two dams. As they travel, the survival on a particular day t is S_t, where $S_t \in (0,1)$. The cumulative survival up to day t is $S_0 \cdot S_1 \cdot S_2 \cdot \ldots \cdot S_t = \prod_{x=0}^{t} S_x$. The initial survival ($S_0$) of the cohort before they leave the first dam is one, or 100%, and the cumulative survival decreases as they experience mortality on the way to the second dam[1]. Mathematically, the product of cumulative survival ($\prod_{x=0}^{t} S_x$) is monotonically decreasing (always decreasing or remaining constant) with each additional day.

Travel Time/Migration Rate as Response

In the previous section, we treated fish travel time as a time process in relation to survival. Still, to place a fish in a particular travel time cohort, first we need to know its travel time. For fish that have been detected at both the first and the second dams, it is straightforward to measure their travel time. However, for fish that die before being detected at the second dam, we have to estimate their travel time with an indirect approach.

Fish travel time is dynamic but can be predicted by biological and environmental factors with reasonable accuracy (e.g. Crozier et al. 2017, FPC 2018a). Particularly, fish that possess similar biological traits and/or encounter similar environmental conditions will likely make similar progress in migration. For example, variables such as water temperature, river flow volume, arrival time, juvenile transport history, and distance to the tagging origin can all affect migration rate of a fish. From a modeling perspective, if we know the relationship between fish travel time and biological/environmental conditions, we can use this information to estimate unobserved travel times.

Special procedures have often been needed when modeling fish travel time. Because distribution of travel time is often skewed to the right, it requires a transformation to better approximate normality of the residuals and reduce heteroscedasticity during modeling (Chapter 3 in McCann et al. 2017, FPC 2018a, FPC 2018b). A simple transformation is to divide distance between dams by travel time to yield velocity, or migration rate (km/day). However, even after a transformation, additional assumptions such as modeling with a log-normal or a mixture distribution may be necessary to better approximate migration rate (e.g. Crozier et al. 2017, Chapter 7 in McCann et al. 2018).

Integrated Model

Survival has a binary outcome, so we model the probability for survival over time with a binomial distribution. Depending on the species, run type, or the reach of focus, we model transformed travel time, or migration rate, following a log-normal or a normal-normal mixture distribution. Putting the two components together, we evaluate survival and migration rate at the same time as an integrated model (Figure 7.1).

[1] The concept of survival at a certain instant in time is analogous to the theory for instantaneous mortality (Quinn & Deriso 1999). Particularly, the relationship between survival and instantaneous mortality can be described in an equation: $S_t = e^{-Z_t}$, where Z_t is the instantaneous mortality, or the death rate at an instant time t.

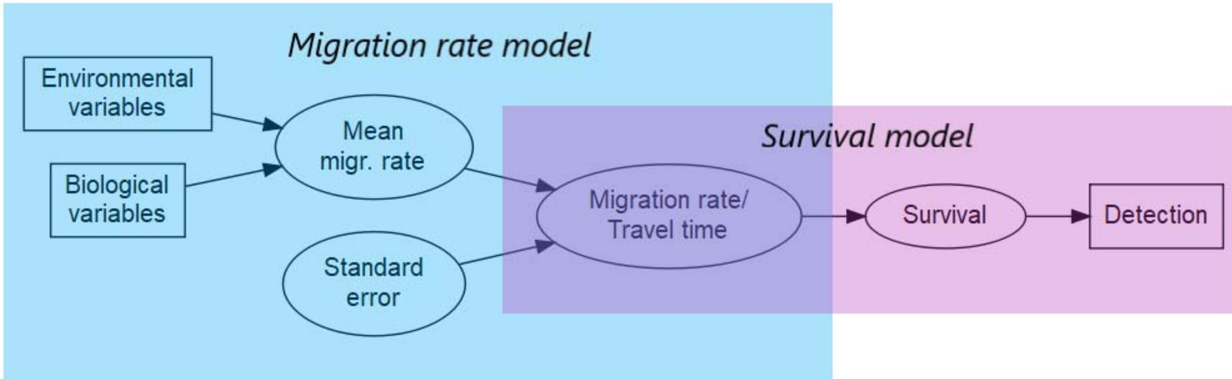


Figure 7.1. Simplified directed acyclic graph for the intergrated model. Square boxes represent data, and oval boxes parameters. In the model, migration rates are observed for the surviving fish but are unobserved and thus estimated for the dead fish.

Methods

Data Selection

For each species and run type in this analysis (Snake River spring/summer Chinook, fall Chinook, sockeye, and steelhead), we included PIT-tagged adults that were detected at Bonneville Dam during return years 2003 to 2018 (unless noted otherwise) and originated upstream of Lower Granite Dam as juveniles. For each fish in the data set, we included detection history at Bonneville, McNary and Lower Granite Dams. For the Bonneville to McNary reach, we matched each fish with McNary tailrace temperature (°C) and river flow volume (Kcfs, thousand cubic feet per second) at the time of its detection at Bonneville Dam. For the McNary to Lower Granite reach, we matched each fish with Ice Harbor Dam tailrace temperature (°C) and river flow volume (Kcfs) at the time of its detection at McNary Dam. Temperatures at Ice Harbor Dam were more representative for the Lower Snake River because Ice Harbor Dam is located upstream of the confluence of Snake and upper Columbia Rivers. Also, temperatures at McNary Dam tracked reasonably well with temperatures at Ice Harbor Dam, with Pearson's correlation coefficient = 0.96 (Figure 7.2). We also included juvenile migration history (transported or not) and distance (km) to tagging origin from Lower Granite Dam. We did not distinguish between hatchery and wild fish in this analysis.

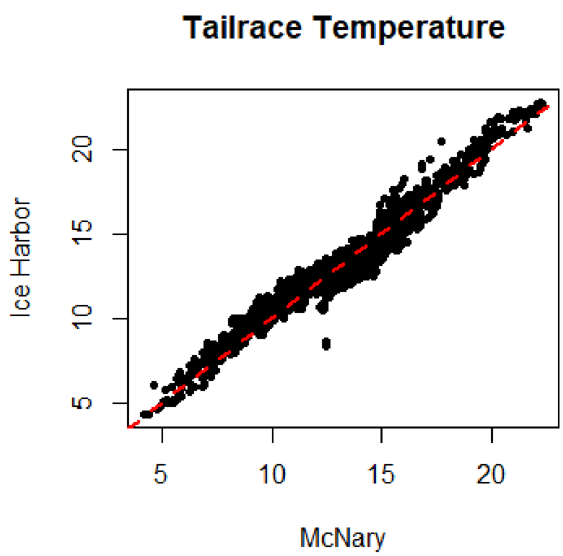


Figure 7.2. Comparison between tailrace water temperature at McNary and Ice Harbor dams, 2003 to 2018. Red dash line represents 1-1 relationship.

Snake River Spring/Summer Chinook: in the data set, we only included adults with known origin (PTAGIS species codes of 11H, 11W, 12H and 12W) and those who spent at least two years at sea (no jacks). We excluded fish that originated from the Tucannon River and Lyons Ferry Hatchery.

Snake River Fall Chinook: the same criteria as spring/summer Chinook. Except that the PTAGIS species codes for fall Chinook were 13H and 13W.

Snake River Sockeye: the same criteria as both spring/summer and fall Chinook. There were very few PIT-tagged sockeye prior to 2010 in our data set, so we combined all fish from 2003 to 2010 into one year group. 2018 also had very few records, so we combined fish from 2017 and 2018. Criteria for Tucannon River and Lyons Ferry Hatchery origin did not apply to sockeye.

Snake River Steelhead: we included PIT-tagged wild and hatchery steelhead that were detected as adults at Bonneville Dam during return years 2003 to 2017 (June to September). We did not include steelhead that returned in 2018 because, for steelhead, the returning adult cohort would not be complete until the winter of 2019. We excluded both wild and hatchery B-run fish due to their later migration timing. We also excluded overwintering steelhead because they had a different migration process compared to other steelhead that did not overwinter.

Model Formulation

For the survival process component of the integrated model, we utilized a logistic regression model in a Bayesian framework. For the Bonneville-McNary reach, the model included detection at McNary Dam as the binary response variable. Fish travel time between Bonneville and McNary Dams was the continuous explanatory variable. For the McNary-Lower Granite reach, the model included detection at Lower Granite Dam as the binary response variable. Fish travel time between McNary and Lower Granite Dams was the continuous explanatory variable. Adult migration year was included in the model as the random effects explanatory variable to account for year to year variations. We set up the random year effects to only adjust the slope of the survival process model based on migration year. We fixed the intercept so the initial survival would be close to 100% for all migration years. Our survival component had the following form:

$$det_i \sim Bernoulli(S_i)\ , \qquad [1]$$
$$logit(S_i) = \gamma_0 + (\gamma_{ftt} + \alpha_{year[i]}) \cdot Ftt_i\ ,$$

where det_i was the binary detection at McNary or Lower Granite Dam for ith individual fish, and S_i was the conversion probability for fish i. α_{year} were the year adjustment for the slope, from year 2003 to 2018. Conversion did not account for misdetection and was only a minimal estimate of apparent survival. However, detection probabilities at the adult fishways were close to 100% throughout Lower Columbia and Snake Rivers. Thus, adult fish conversion probabilities should be reasonably close to apparent survivals even without accounting for misdetection.

In our earlier discussion regarding the survival process, at time 0, the initial survival (S_0) should be approximately one. If we plotted fish survival over time ($S = logit^{-1}(\gamma_0 + \gamma_{ftt} \cdot Ftt)$), the survival curve would intercept the y-axis at $S \approx 1$. That is, $S_0 = logit^{-1}(\gamma_0 + \gamma_{ftt} \cdot 0) \approx 1$. We restricted γ_0 to be greater than three, so $logit^{-1}(\gamma_0)$ would be close to one. In addition, we assumed a $t(3{,}5{,}2.5)$ prior distribution that would put more weight on values around five for γ_0. On the other hand, we imposed no restriction and assumed a weakly informative $t(3{,}0{,}2.5)$ prior distribution for γ_{ftt}. We assigned α_{year} a $t(3{,}0, \sigma_{year})$ distribution, where $\sigma_{year} \sim t(3{,}0{,}2.25)$. We assigned the weakly informative priors based on recommendations by Gelman et al. (2008) and Broms et al. (2016).

For the migration rate component of the integrated model, we utilized a generalized linear model. Depending on the reach, the response variable could be the migration rate (km/day) between Bonneville and McNary Dams or McNary and Lower Granite Dams. The explanatory variables included seasonality (arrival at Bonneville or McNary Dam in Julian date), McNary or Ice Harbor tailrace water temperature, river flow volume at McNary or Ice Harbor, quadratic terms for seasonality, temperature, and flow volume, juvenile transport history (e.g. transported or in-river), distance from the tagging origin, and "migration continuity" (see details below).

For the McNary-Lower Granite reach, we identified migration continuity for each fish. Migration continuity was an indicator categorizing fish migration into two groups: fish with a continuous travel and fish with an interrupted, delayed travel. We assigned fish to the interrupted, delayed group based on either 1) they were identified by PIT detectors at locations other than mainstem river between McNary and Lower Granite dams, and/or 2) they had an erratic migration rate from reach to reach. For the first criterion, we examined the detection histories of all fish in our data for records in the upper Columbia River or tributaries between McNary and Lower Granite Dams. For the second criterion, we compared migration rate of each fish between McNary-Ice Harbor and Ice Harbor-Lower Granite reaches, to see if their ratios were close to 1:1. For this analysis, we considered ratios that were smaller than 0.2 or greater than five to be too erratic. The second criterion was based on what seemed reasonable for our data set. We have tried other ranges such as 0.1 to 10, and it did not seem to dramatically affect the model results nor alter the conclusions.

For each species in the analysis, we selected a suitable suite of variables before fitting it in a Bayesian framework. We began with a full model by including all explanatory variables. Next, we eliminated a less important term and compared the model AIC values (Akaike 1973) before and after the elimination. We reduced the model one term at a time using a sequence of AIC comparisons until no more could be excluded without losing significant model fit. As a rule of thumb, we considered an increase in AIC value more than two per degree of freedom as a loss of significant model fit. We evaluated the model fit in the program *R* (*R* Core Team 2019). After identifying a final model, we formulated the model in a Bayesian framework.

For Bonneville-McNary reach, our Bayesian migration rate model had the following form:

$$R_i \sim Lognormal(\mu_i, \sigma^2) \ , \tag{2}$$

where $\mu_i = \mathbf{X_i}\beta$,
and $\sigma \sim t(3{,}0{,}2.25)$.

For McNary-Lower Granite reach,

$$R_i \sim Normal(\mu_i, \sigma_1^2) \cdot I_i^{continuous} + Normal(\mu_i, \sigma_2^2) \cdot (1 - I_i^{continuous}) \ , \tag{3}$$

where $\mu_i = \mathbf{X_i}\beta$,
and $\sigma_1, \sigma_2 \sim t(3{,}0{,}2.25)$.

$$R_i = \begin{cases} R_i^{obs} & \text{if observed} \\ E[R_i^{mis} | R^{obs}, \beta, \gamma] & \text{if missing/unobserved} \end{cases}$$

$\mathbf{X_i}$ was fish i's covariates vector. R^{obs} was the observed fish migration rate, and R^{mis} was the missing/unobserved migration rate. $I^{continuous}$ was the indicator function for fish with a continuous migration. That is, $I^{continuous} = 1$ if fish i had a continuous migration, 0 if not. We assumed a weakly informative $t(3{,}0{,}2.5)$ prior distribution for all β except β_0, for which we assigned a $t(3{,}0{,}10)$ prior distribution.

We utilized the program *Stan* (Carpenter et al. 2017) in an *R* environment through package `rstan` (Stan Development Team 2018) to perform Hamiltonian Monte Carlo (HMC) sampling. To facilitate a better convergence for HMC sampling, we standardized all continuous variables except migration rates/travel times. We included details of computation and model fit assessment in Supplemental Materials A.

During HMC sampling, we specified stochastic nodes for the unobserved migration rates, and *Stan* would estimate the missing variable based on the joint posterior distribution. Put differently, we imputed the unobserved migration rates using information from both the survival and migration rate components of the integrated model.

To summarize the results, we plotted the estimated conversion probability over time and the daily mortality rate for each species and run type. We estimated the daily mortality rate by converting daily conversion probability with the following equation:

$$Z_t = -ln(S_t) \ , \tag{4}$$

where Z_t is the exponential mortality rate per day and $S_t = \prod_{x=0}^{t} S_x \,/\, \prod_{x=0}^{t-1} S_x$.

Moreover, we identified the estimated conversion probability at median travel time. We also identified the time it took for conversion probability to fall below a certain value. These conversion values were selected based on the model results for each species and were intended for illustration purposes only.

Results

Spring/Summer Chinook

Our final model for spring/summer Chinook migration rate between Bonneville and McNary Dams included temperature and its quadratic term, total river flow volume, juvenile transport history, and distance from the tagging origin. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{flow}Flow_i + \beta_{trans}Trans_i + \beta_{orig.dist}Dist_i \ ,$$

where $Trans_i$ was an indicator variable for individual i. That is, $Trans_i$ = 1 if fish i was transported as a juvenile and 0 if it migrated in-river. Model estimates can be found in Supplemental Materials A (Table 7.1).

The median travel time between Bonneville and McNary Dams was approximately six days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.865 (95% credible interval, or CrI = 0.844 to 0.885). It would take 4.224 days (95% CrI = 3.679 to 5.044 days) for the conversion probability to fall below 0.9 (Figure 7.3). Daily mortality increased with travel time (Figure 7.4).

For the reach between McNary and Lower Granite Dams, our final model included temperature and its quadratic term, juvenile transport history, migration continuity, and distance from the tagging origin. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{trans}Trans_i + \beta_{migr.cont}MC_i + \beta_{orig.dist}Dist_i \ ,$$

where $Trans_i$ and MC_i were indicator variables for individual i. MC_i = 1 if fish i strayed from the mainstem migration route or had an erratic migration progress and 0 if not. $Trans_i$ is the same as previously stated. Model estimates can be found in Supplemental Materials A (Table 7.2).

The median travel time between McNary and Lower Granite Dams was approximately seven days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.949 (95% CrI = 0.944 to 0.954). It would take 25.092 days (95% CrI = 19.901 to 36.252 days) for the conversion probability to fall below 0.9 (Figure 7.3). Daily mortality increased very modestly with travel time (Figure 7.4).

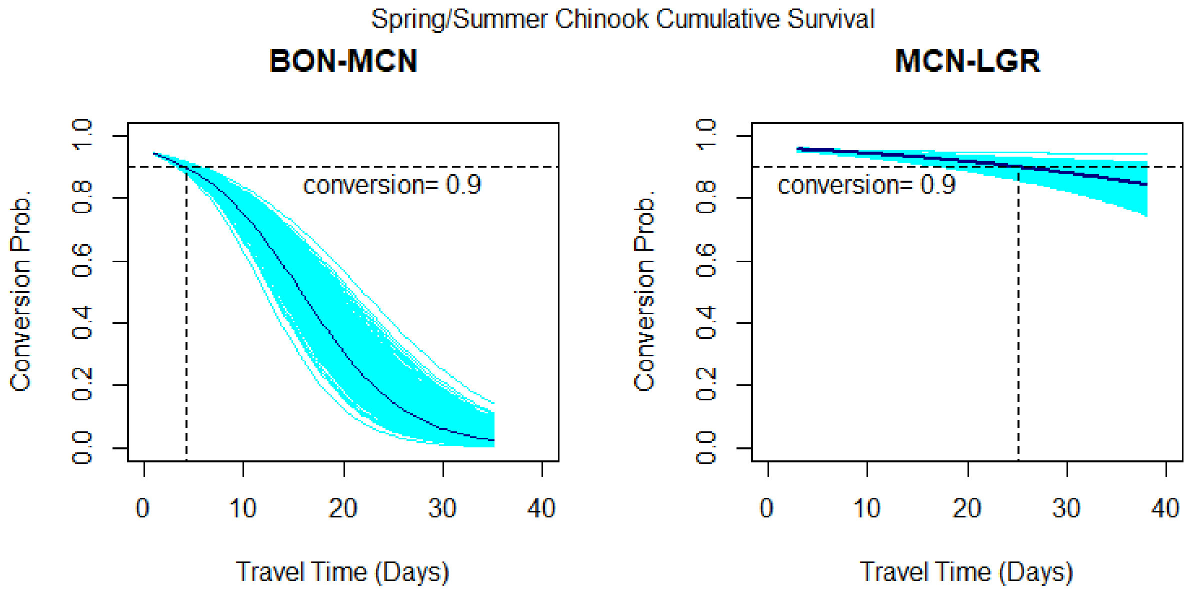


Figure 7.3. Estimated conversion probability of spring/summer Chinook over time for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (right). Light color areas represent model uncertainties. Dash lines indicate the estimated time required for conversion probability to fall below 0.9.

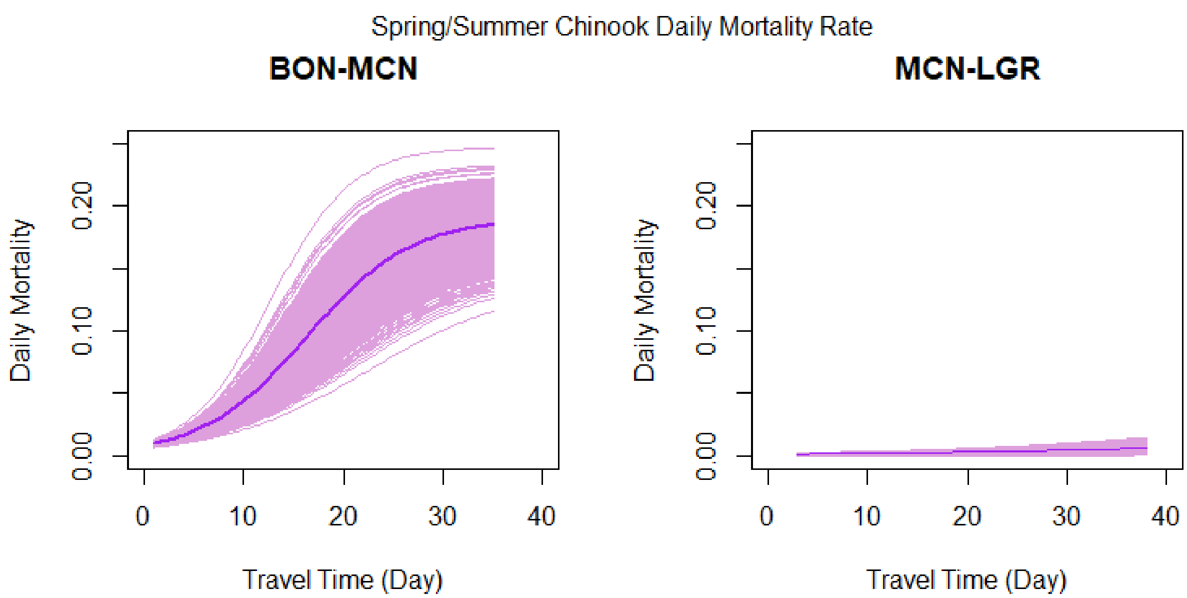


Figure 7.4. Estimated daily mortality rate of spring/summer Chinook for the Bonneville to McNary reach (left) and the McNary **to Lower** Granite reach (right). Light color areas represent model uncertainties.

Fall Chinook

Our final model for fall Chinook migration rate between Bonneville and McNary Dams included temperature and its quadratic term, total river flow volume, arrival in Julian date, juvenile transport history, and distance from the tagging origin. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{flow}Flow_i + \beta_{arr}Arrival_i + \beta_{trans}Trans_i + \beta_{orig.dist}Dist_i \ ,$$

where $Trans_i$ was an indicator variable for individual i. Model estimates can be found in Supplemental Materials A (Table 7.3).

The median travel time between Bonneville and McNary Dams was approximately six days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.799 (95% CrI = 0.771 to 0.823). It would take 4.687 days (95% CrI = 4.253 to 5.198 days) for the conversion probability to fall below 0.85 (Figure 7.5). Daily mortality increased with travel time (Figure 7.6).

For the reach between McNary and Lower Granite Dams, our final model included temperature and its quadratic term, total river flow and its quadratic term, arrival in Julian date and its quadratic term, juvenile transport history, and migration continuity. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{flow}Flow_i + \beta_{flow^2}Flow_i^2 + \beta_{arr}Arrival_i + \beta_{arr^2}Arrival_i^2 + \beta_{trans}Trans_i + \beta_{migr.cont}MC_i \ ,$$

where $Trans_i$ and MC_i were indicator variables for individual i. Model estimates can be found in Supplemental Materials A (Table 7.4).

The median travel time between McNary and Lower Granite Dams was approximately seven days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.945 (95% CrI = 0.939 to 0.951). It would take 27.661 days (95% CrI = 21.961 to 38.052 days) for the conversion probability to fall below 0.85 (Figure 7.5). Daily mortality increased modestly with travel time (Figure 7.6).

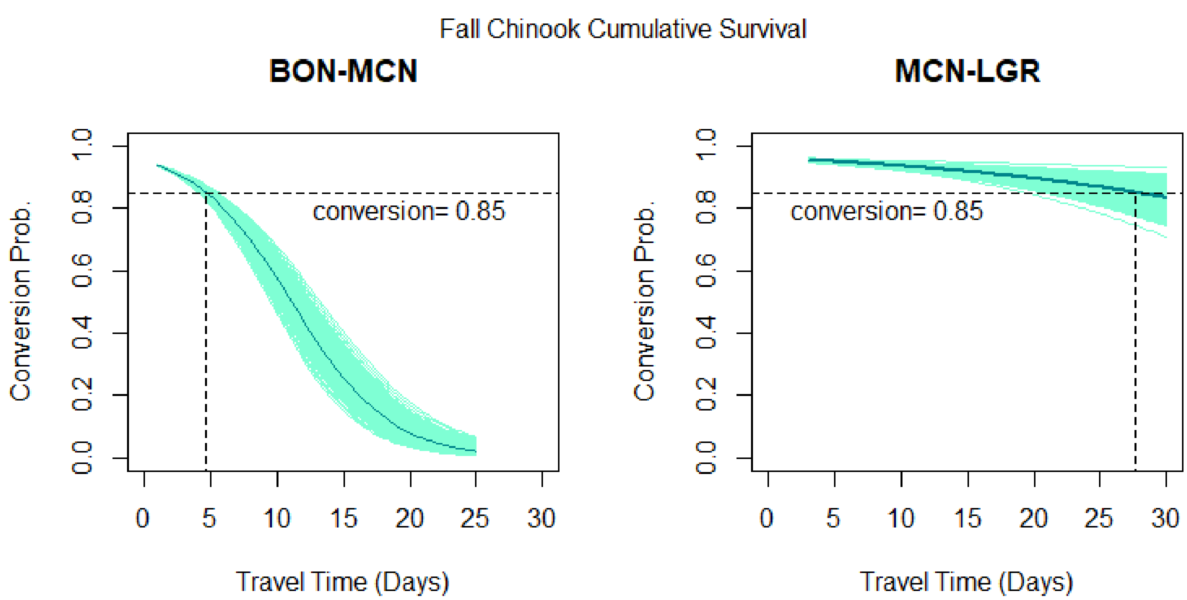


Figure 7.5. Estimated conversion probability of fall Chinook over time for the Bonneville to McNary reach (left) and

the McNary to Lower Granite reach (right). Light color areas represent model uncertainties. Dash lines indicate the estimated time required for conversion probability to fall **below** 0.85.

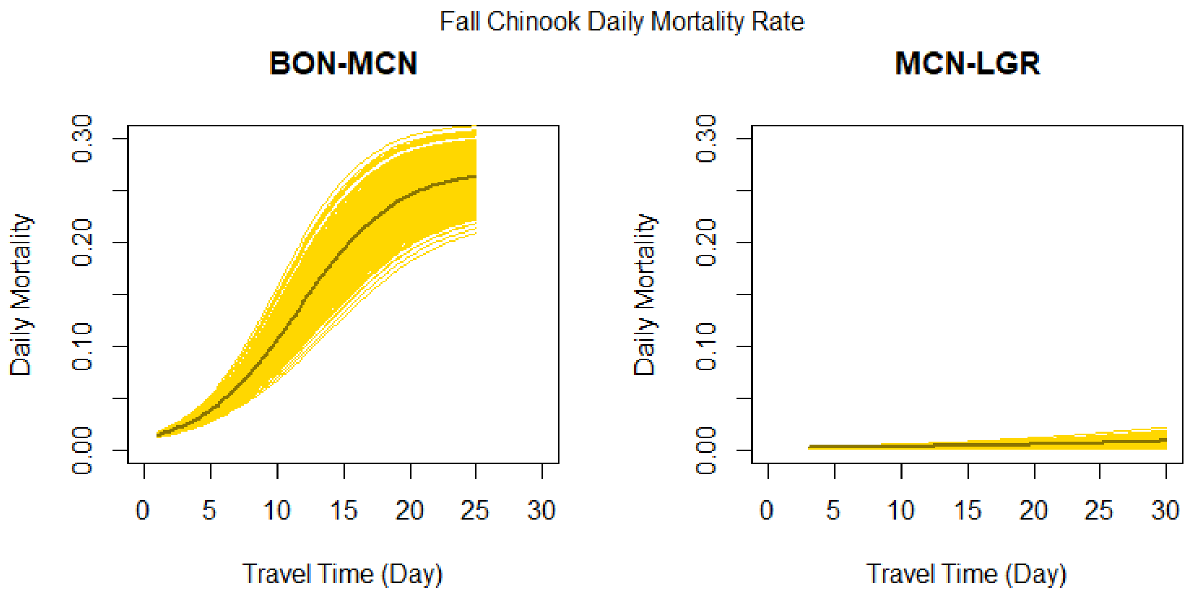


Figure 7.6. Estimated daily mortality rate of fall Chinook for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (right). Light color areas **represent** model uncertainties.

Sockeye

Our final model for sockeye migration rate between Bonneville and McNary Dams included temperature and its quadratic term, and juvenile transport history. The model contained no interaction terms. The linear predictor had the form:

$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{trans}Trans_i$,

where $Trans_i$ was an indicator variable for individual i. Model estimates can be found in Supplemental Materials A (Table 7.5).

The median travel time between Bonneville and McNary Dams was approximately 5.5 days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.75 (95% CrI = 0.67 to 0.806). It would take 6.217 days (95% CrI = 5.169 to 7.459 days) for the conversion probability to fall below 0.7 (Figure 7.7). Daily mortality increased with travel time (Figure 7.8).

For the reach between McNary and Lower Granite Dams, our final model included temperature and its quadratic term, total river flow volume, arrival date, juvenile transport history, and migration continuity. The model contained no interaction terms. The linear predictor had the form:

$\mu_i = \beta_0 + \beta_{temp}Temp_i + \beta_{temp^2}Temp_i^2 + \beta_{flow}Flow_i + \beta_{arr}Arrival_i + \beta_{trans}Trans_i + \beta_{migr.cont}MC_i$, where $Trans_i$ and MC_i were indicator variables for individual i. Model estimates can be found in Supplemental Materials A (Table 7.6).

The median travel time between McNary and Lower Granite Dams was approximately seven days, excluding fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.92 (95% CrI = 0.884 to 0.943). It would take 26.328 days (95% CrI = 14.991 to 65.15 days) for the conversion probability to fall below 0.7 (Figure 7.7). Daily mortality increased modestly with travel time (Figure 7.8).

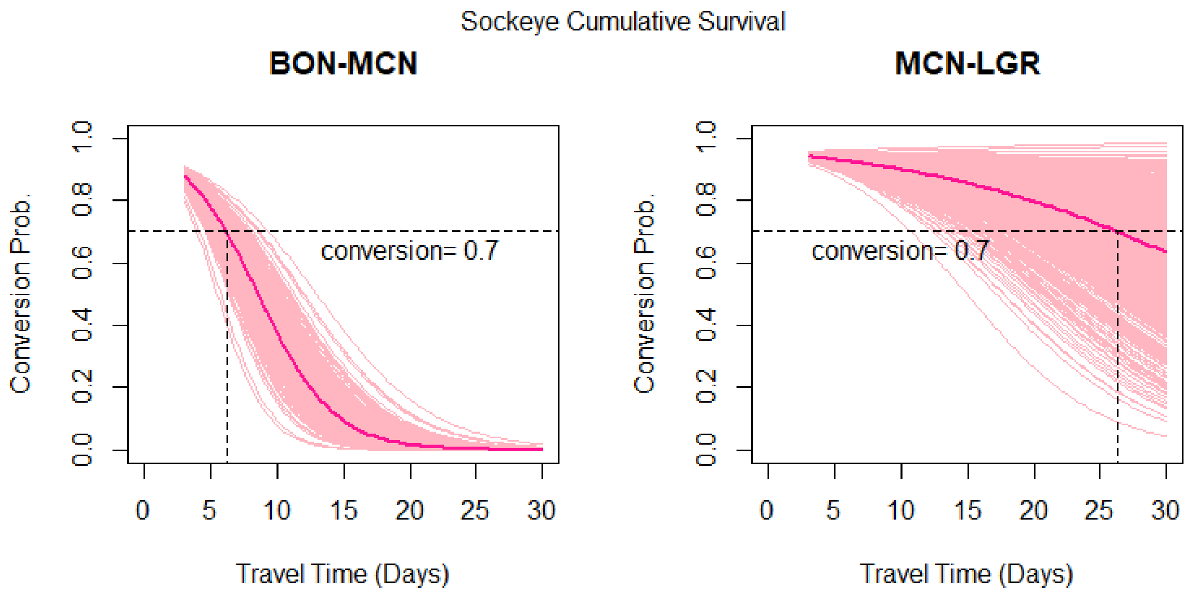


Figure 7.7. Estimated conversion probability of sockeye over time for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (right). Light color areas represent model uncertainties. Dash lines indicate the estimated time required for conversion **probability** to fall below 0.7.

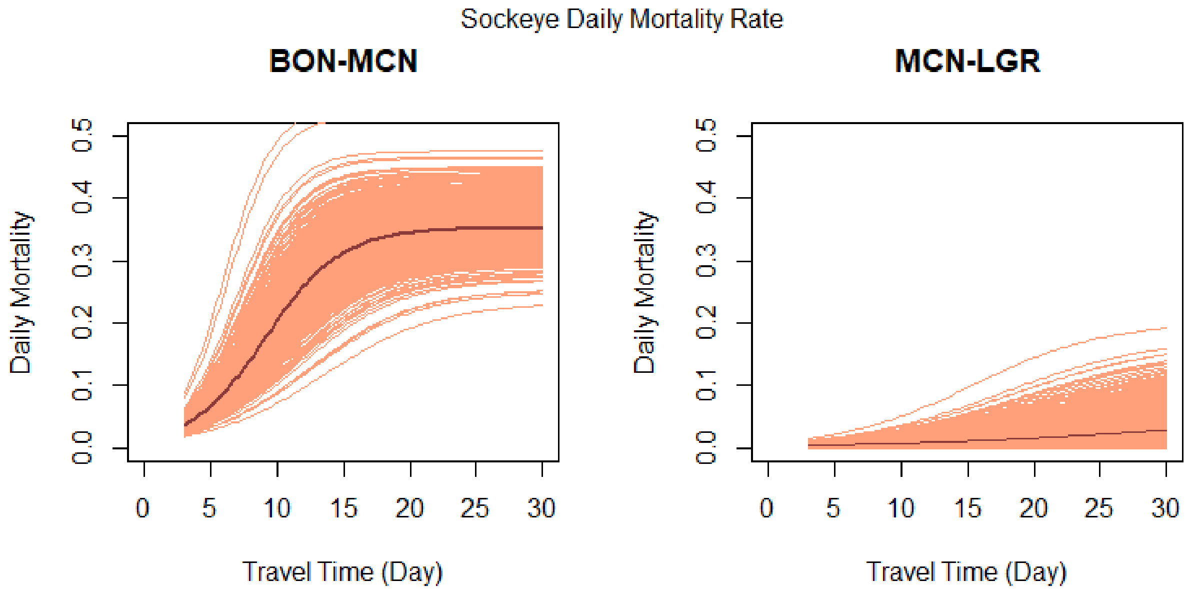


Figure 7.8. Estimated daily mortality rate of sockeye for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (right). Light color areas represent model uncertainties.

Steelhead

Our final model for steelhead migration rate between Bonneville and McNary Dams included temperature and its quadratic term, arrival in Julian date and its quadratic term, juvenile transport history, and distance to the tagging origin. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp} Temp_i + \beta_{temp^2} Temp_i^2 + \beta_{arr} Arrival_i + \beta_{arr^2} Arr_i^2 + \beta_{trans} Trans_i + \beta_{orig.dist} Dist_i \ ,$$

where $Trans_i$ was an indicator variable for individual i. Model estimates can be found in Supplemental Materials A (Table 7.7).

The median travel time between Bonneville and McNary Dams for steelhead was approximately 25 days, excluding overwintering fish and fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.891 (95% CrI = 0.884 to 0.897). It would take 22.272 days (95% CrI = 20.767 to 24.095 days) for the conversion probability to fall below 0.9 (Figure 7.9). Daily mortality increased modestly with travel time (Figure 7.10).

For the reach between McNary and Lower Granite Dams, our final model included temperature and its quadratic term, total river flow volume, arrival date and its quadratic term, juvenile transport history, migration continuity, and distance to the tagging origin. The model contained no interaction terms. The linear predictor had the form:

$$\mu_i = \beta_0 + \beta_{temp} Temp_i + \beta_{temp^2} Temp_i^2 + \beta_{flow} Flow_i + \beta_{arr} Arrival_i + \beta_{arr^2} Arrival_i^2 + \beta_{trans} Trans_i + \beta_{migr.cont} MC_i + \beta_{orig.dist} Dist_i \ ,$$

where $Trans_i$ and MC_i were indicator variables for individual i. Model estimates can be found in Supplemental Materials A (Table 7.8).

The median travel time between McNary and Lower Granite Dams was approximately 10 days, excluding overwintering fish and fish without direct travel time measurements. The estimated conversion probability at median travel time was 0.944 (95% CrI = 0.942 to 0.945). It would take 43.458 days (95% CrI = 37.718 to 52.698 days) for the conversion probability to fall below 0.9 (Figure 7.9). Daily mortality increased modestly with travel time (Figure 7.10).

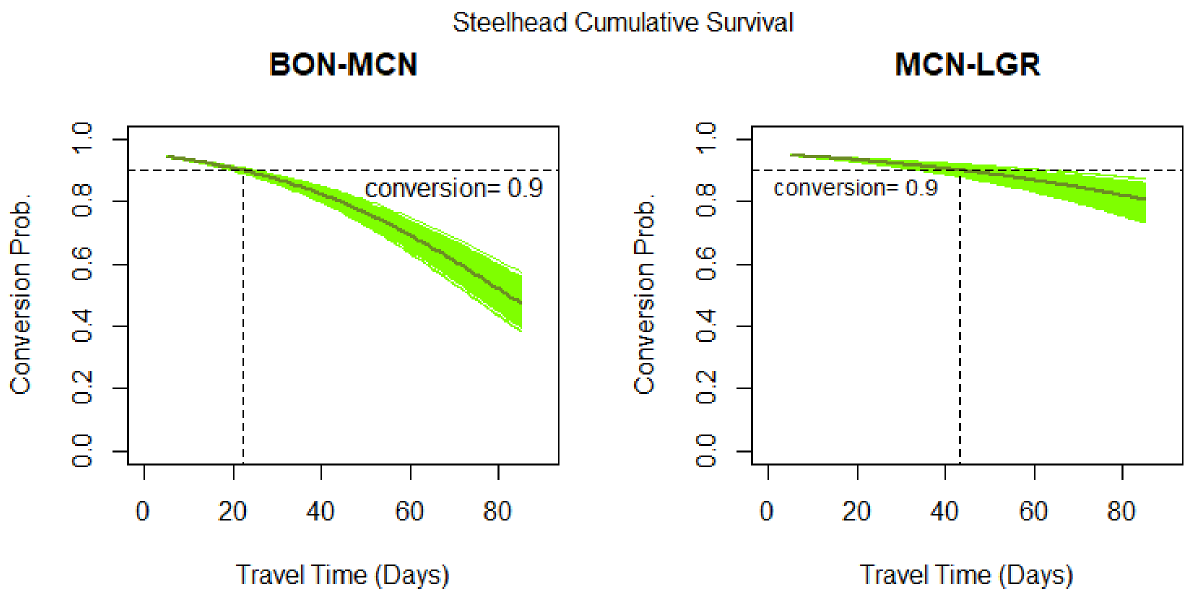


Figure 7.9. Estimated conversion probability of steelhead over time for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (**right**). Light color areas represent model uncertainties. Dash lines indicate the estimated time required for conversion probability to fall below 0.9.

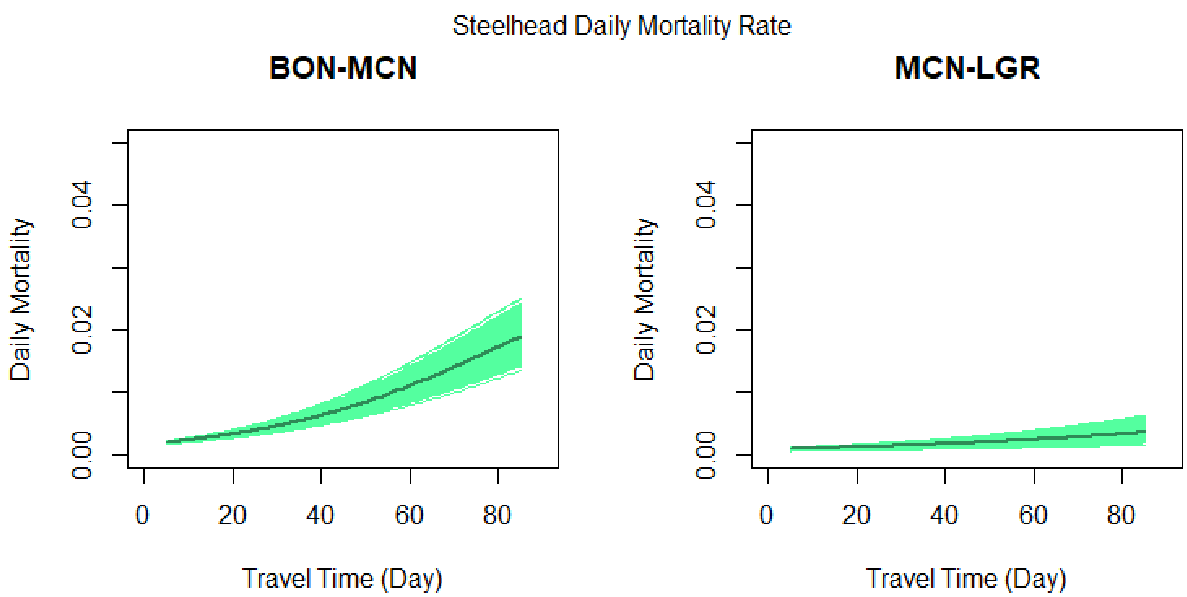


Figure 7.10. Estimated daily mortality rate **of** steelhead for the Bonneville to McNary reach (left) and the McNary to Lower Granite reach (right). Light color areas represent model uncertainties.

Discussion

For all species and run types in this analysis, our model estimated a faster decline in conversion probability while traveling from Bonneville to McNary Dam, compared to traveling from McNary to Lower Granite Dam. Put another way, adult fish migrants were subjected to a higher migratory cost between Bonneville and McNary Dams compared to McNary and Lower Granite Dams.

We did not assume a relationship between travel time and migratory cost, but our model showed that a higher mortality was associated with longer travel times (Figure 7.4; Figure 7.6; Figure 7.8; Figure 7.10). Our model assumptions have most likely directed the results. We assumed that initial fish survival was at approximately 100% and decreased or stayed constant overtime; hence, our model would show a higher mortality over time based on that assumption. Nonetheless, the magnitude of daily mortality would reflect the extents of migratory cost in that reach. For example, our model suggested a high migratory cost in the Bonneville-McNary reach. And a relationship between prolonged travel time and a higher mortality was most pronounced in that reach for all species. Contrarily, in the McNary-Lower Granite reach, our model suggested a low migratory cost for some species. Prolonged travel time seemed mostly inconsequential to mortality in that reach for Chinook and steelhead. For sockeye, prolonged travel time was associated with a higher mortality compared to other species, in both reaches.

Steelhead have a unique natural history and migratory behavior compared to other species in this analysis. Straying and overwintering behaviors are well documented for steelhead (e.g. Chapter 5 in Tuomikoski et al. 2010, Keefer et al. 2015a, Keefer et al. 2015b, Keefer et al. 2016). In previous CSS analyses, we found it difficult to distinguish behaviors such as straying, fallback/re-ascension, overshoot, or temporary thermal refuge in steelhead with the information available to us (McCann et al. 2018). Although we have made some progress this year, it remains a challenge to model steelhead migration rates. Our model was capable of capturing the general pattern of the survival process, yet it failed to fully explain the complexity of steelhead migratory behaviors (e.g. the bimodal travel time distribution between Bonneville and McNary Dams).

We relied heavily on our model assumptions when estimating unobserved migration rates. A main assumption for the survival process was that the cumulative survival had a value = 1 when travel time = 0. And the value of cumulative survival would remain constant or decrease over time. We assigned an informative prior and applied restrictions on the parameter so that our estimation would adhere to this assumption. By imposing *ad hoc* conditions on the model, we introduced subjectivity in the results and possibly biased the estimates. Therefore, we had to limit our scope of inference to comparisons between reaches and between species. The differences in results between reaches and species were not confounded by potential biases, because all estimates in this analysis were subjected to the same biases.

We did not identify the migratory costs affecting survival of adult fish migrants in this analysis. But we plan to further investigate the main factors causing the difference in survivals between the Bonneville-McNary and the McNary-Lower Granite reaches. Also, we plan to invest more efforts to analyze individual fish behaviors such as straying and fallback, especially for steelhead. It would enable us to rely more on observed information instead of model assumptions in our analysis. Also, we plan to develop a more comprehensive assessment of our model fit. In particular, we would use a simulation study to quantify potential bias and help us understand the limitation of our scope of inference.

Conclusions

- Our model indicated that adult fish migrants were subjected to a higher migratory cost between Bonneville and McNary Dams compared to McNary and Lower Granite Dams.
- In the McNary-Lower Granite reach, where migratory cost was modest for Chinook and steelhead, prolonged travel time seemed mostly inconsequential to conversion probability.
- Sockeye had a higher mortality compared to other species in both reaches; prolonged travel time could have a devastating effect on conversion probability.

Supplemental Materials A: Model Details

Spring/Summer Chinook

Table 7.1. Model estimates for spring/summer Chinook between Bonneville and McNary Dams.

	Median	SD	95% CRI	$\hat{R}$	Eff size
β_0 (Int)	3.573	0.003	(3.566, 3.579)	1879	1
Temperature	0.905	0.023	(0.861, 0.951)	1889	1
$Temp^2$	-0.898	0.023	(-0.942, -0.853)	1896	1
Flow	-0.156	0.003	(-0.162, -0.15)	1911	1
Transported	-0.077	0.006	(-0.088, -0.067)	2031	1
Origin	0.009	0.003	(0.004, 0.015)	1817	1
σ_{year}	3.545	0.003	(3.54, 3.55)	1853	1
$\mu_{ln(R)}$	0.382	0.002	(0.379, 0.386)	1863	1
Yr 2003	0.090	0.016	(0.058, 0.122)	932	1
Yr 2004	0.029	0.017	(-0.003, 0.063)	955	1
Yr 2005	0.057	0.018	(0.021, 0.093)	1028	1
Yr 2006	0.017	0.018	(-0.02, 0.05)	1050	1
Yr 2007	0.071	0.020	(0.034, 0.11)	1104	1
Yr 2008	0.023	0.016	(-0.009, 0.055)	944	1
Yr 2009	0.005	0.017	(-0.027, 0.037)	962	1
Yr 2010	-0.049	0.016	(-0.082, -0.017)	861	1
Yr 2011	-0.012	0.016	(-0.044, 0.017)	889	1
Yr 2012	-0.002	0.016	(-0.034, 0.03)	921	1
Yr 2013	0.059	0.018	(0.025, 0.096)	993	1
Yr 2014	-0.056	0.017	(-0.089, -0.025)	924	1
Yr 2015	-0.095	0.017	(-0.128, -0.062)	971	1
Yr 2016	-0.032	0.017	(-0.067, 0.001)	932	1
Yr 2017	-0.046	0.018	(-0.084, -0.012)	1014	1
Yr 2018	-0.038	0.018	(-0.073, -0.004)	953	1
$\sigma_{ln(R)}$	0.048	0.012	(0.031, 0.079)	2051	1
γ_0 (Int)	3.001	0.002	(3, 3.006)	1955	1
Travel Time	-0.190	0.015	(-0.219, -0.16)	858	1

Table 7.2. Model estimates for spring/summer Chinook between McNary and Lower Granite Dams.

	Median	SD	95% CRI	$\hat{R}$	Eff size
β_0 (Int)	32.103	0.100	(31.9, 32.295)	1354	1
Temperature	5.855	0.554	(4.743, 6.87)	1498	1
Temp^2	-5.940	0.557	(-6.958, -4.805)	1483	1
Transported	-0.230	0.152	(-0.53, 0.056)	1840	1
Migr Cont	-22.686	0.189	(-23.057, -22.306)	1800	1
Origin	0.217	0.078	(0.07, 0.37)	2145	1
μ_R	31.321	0.084	(31.157, 31.49)	1209	1
$\sigma_{R.1}$	11.496	0.063	(11.374, 11.622)	1027	1
$\sigma_{R.2}$	4.236	0.115	(4.023, 4.471)	1780	1
Yr 2003	0.013	0.010	(-0.003, 0.038)	855	1
Yr 2004	0.003	0.010	(-0.015, 0.023)	1286	1
Yr 2005	0.010	0.015	(-0.01, 0.049)	797	1
Yr 2006	-0.010	0.009	(-0.03, 0.007)	1437	1
Yr 2007	-0.006	0.010	(-0.028, 0.012)	1721	1
Yr 2008	0.010	0.009	(-0.005, 0.031)	1293	1
Yr 2009	-0.005	0.009	(-0.025, 0.013)	1328	1
Yr 2010	-0.006	0.007	(-0.02, 0.006)	1191	1
Yr 2011	0.015	0.007	(0.002, 0.028)	857	1
Yr 2012	-0.013	0.008	(-0.03, 0.001)	1050	1
Yr 2013	-0.003	0.010	(-0.023, 0.017)	1777	1
Yr 2014	0.020	0.012	(0.002, 0.05)	791	1
Yr 2015	-0.029	0.008	(-0.046, -0.014)	1237	1
Yr 2016	-0.015	0.010	(-0.036, 0.002)	1362	1
Yr 2017	0.011	0.011	(-0.008, 0.036)	1355	1
Yr 2018	0.001	0.010	(-0.019, 0.022)	1489	1
σ_{year}	0.014	0.005	(0.007, 0.026)	1276	1
γ_0 (Int)	3.207	0.062	(3.084, 3.327)	436	1
Travel Time	-0.040	0.007	(-0.053, -0.026)	516	1

We set up *Stan* to conduct multiple independent HMC sampling processes that were referred to as "sampling chains." Our HMC sampling included four chains of 4,000 iterations, with burn-in of 50% each. Burn-in was referred to as the "warm-up" sampling session and later discarded. For the rest of HMC sampling, we kept every fourth draw of the sample (i.e. "thinning" of four), which yielded a total of 2,000 sample draws from the joint posterior distribution at the end. To summarize, we started with four chains of 4,000 ($4 \times 4000 = 16000$), discarded half (8000) for the warm-up, kept every fourth draw (divided by 4), and ended up with 2,000 samples.

Gelman's diagnostics provided a general approach to monitor HMC convergence (Gelman & Rubin 1992). The main statistics for diagnostics were $\hat{R}$ ("r-hat") and n_{eff} (effective sample size). $\hat{R}$ estimated the potential decrease in the between-chains variability and ideally should be close to one. n_{eff} was an estimate of the number of independent draws from the posterior distribution of the parameters. Diagnostics showed that all parameters in our model had an $\hat{R}$ close to one and an adequate effective sample size. Which indicated no major concerns overall for model convergence.

Another convergence diagnostic tool was traceplot, which showed the history of HMC sampling for each parameter. We plotted our HMC sampling processes, or sampling chains, in different shades of grey overlapping each other (Figure 7.11; Figure 7.12). A good "convergence," or completed sampling process, would show all chains overlapping in paths and range of values (e.g. a "grassy" look). In our case, traceplots showed reasonably well mixing for all parameters in the model.

Although showing no problem in sampling convergence, posterior distribution of γ_0 for the Bonneville-McNary reach showed a clear sign of truncation because we limited the values to be greater than three (Figure 7.11).

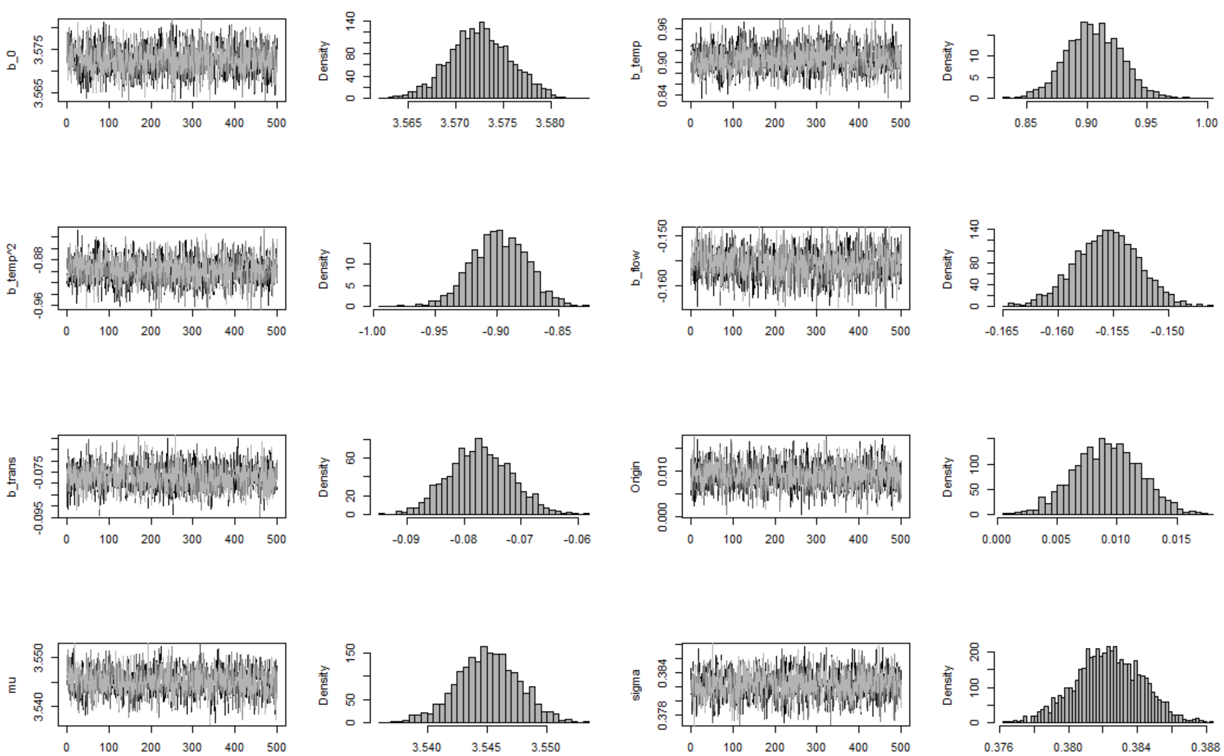


Figure 7.11. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

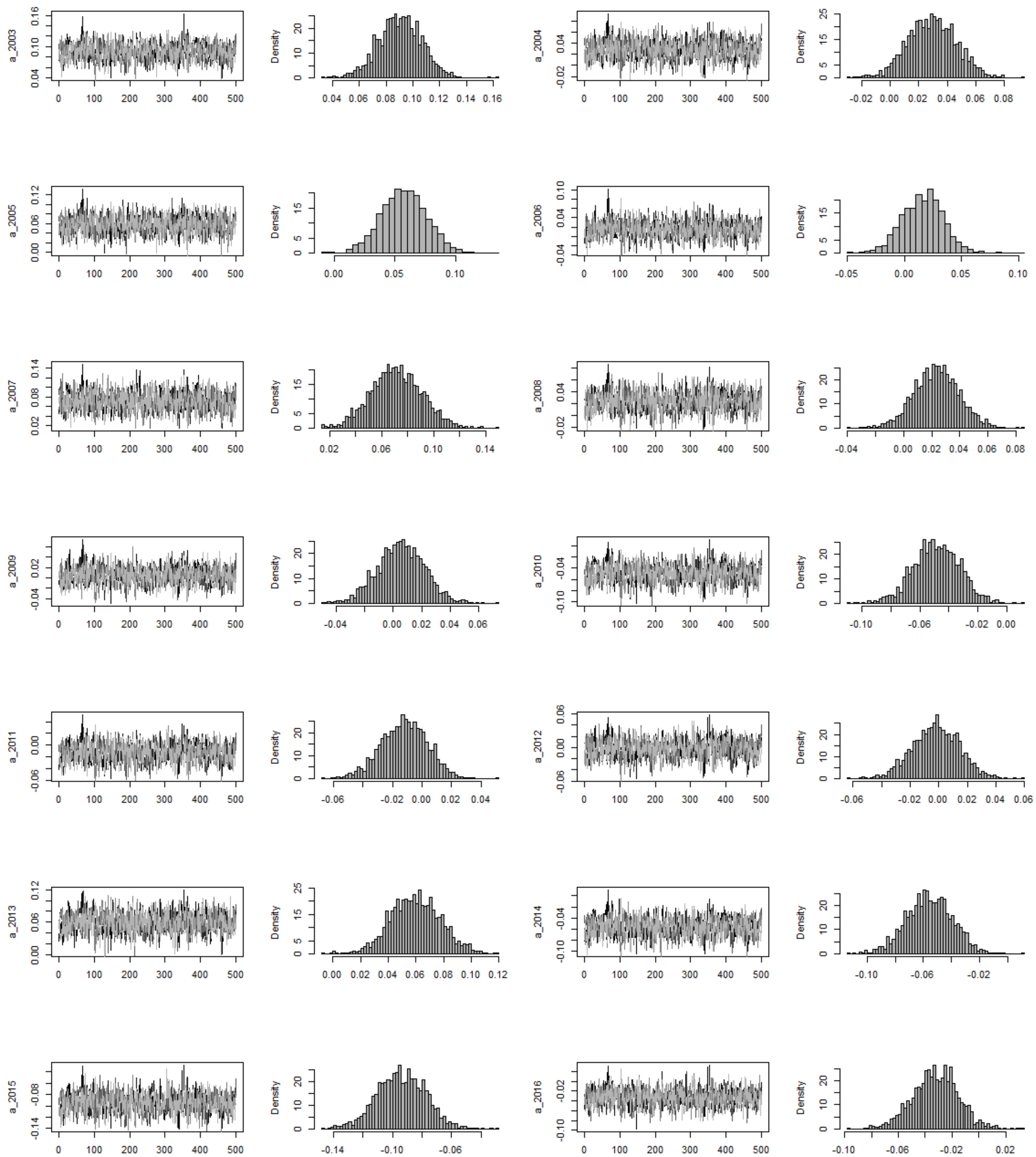


Figure 7.11 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

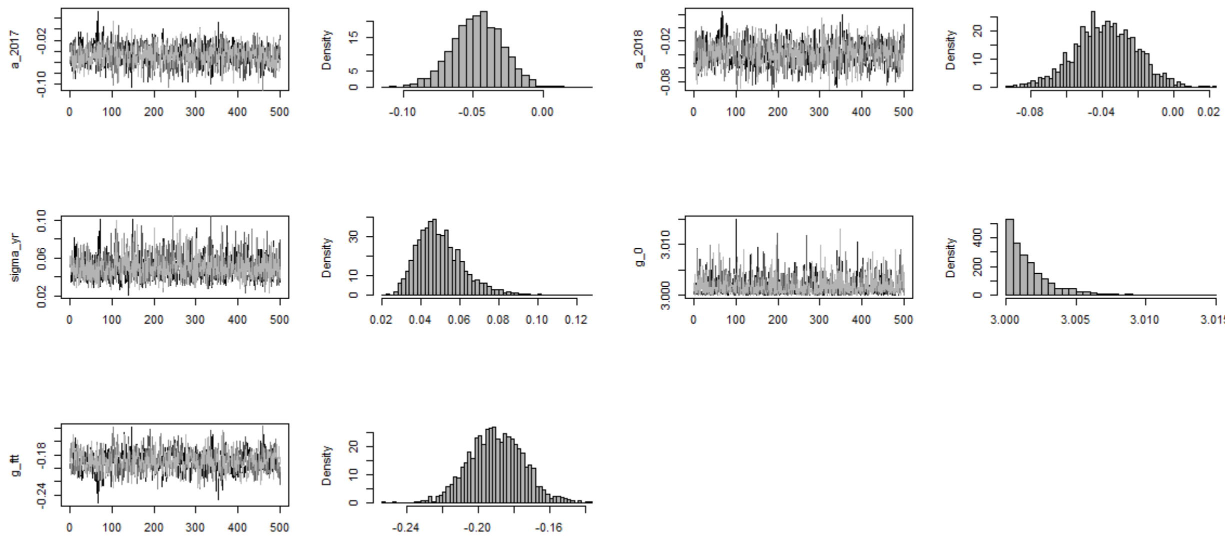


Figure 7.11 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

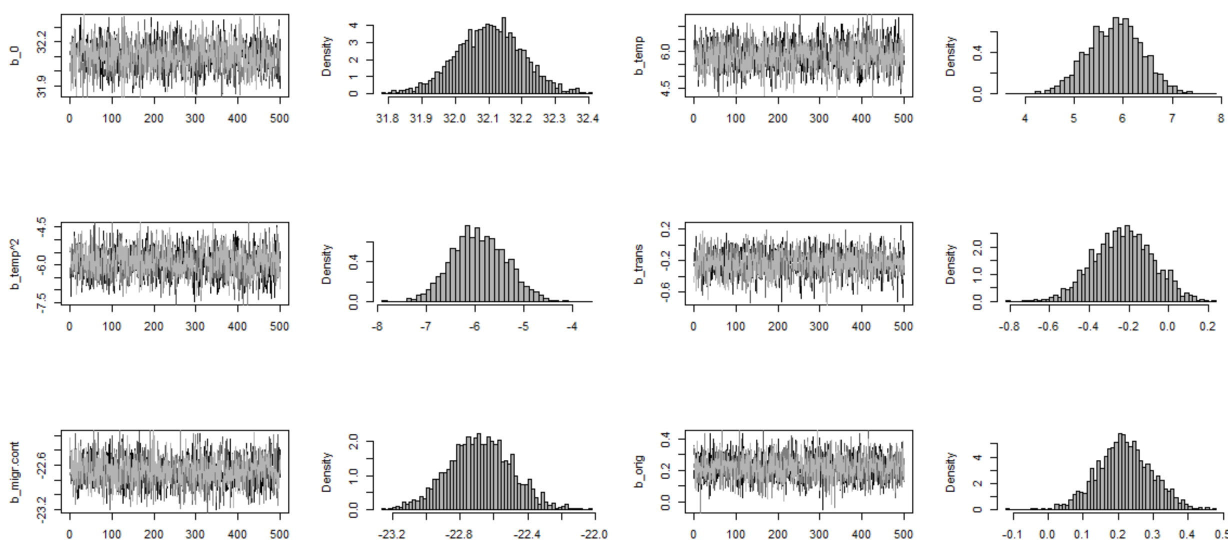


Figure 7.12. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

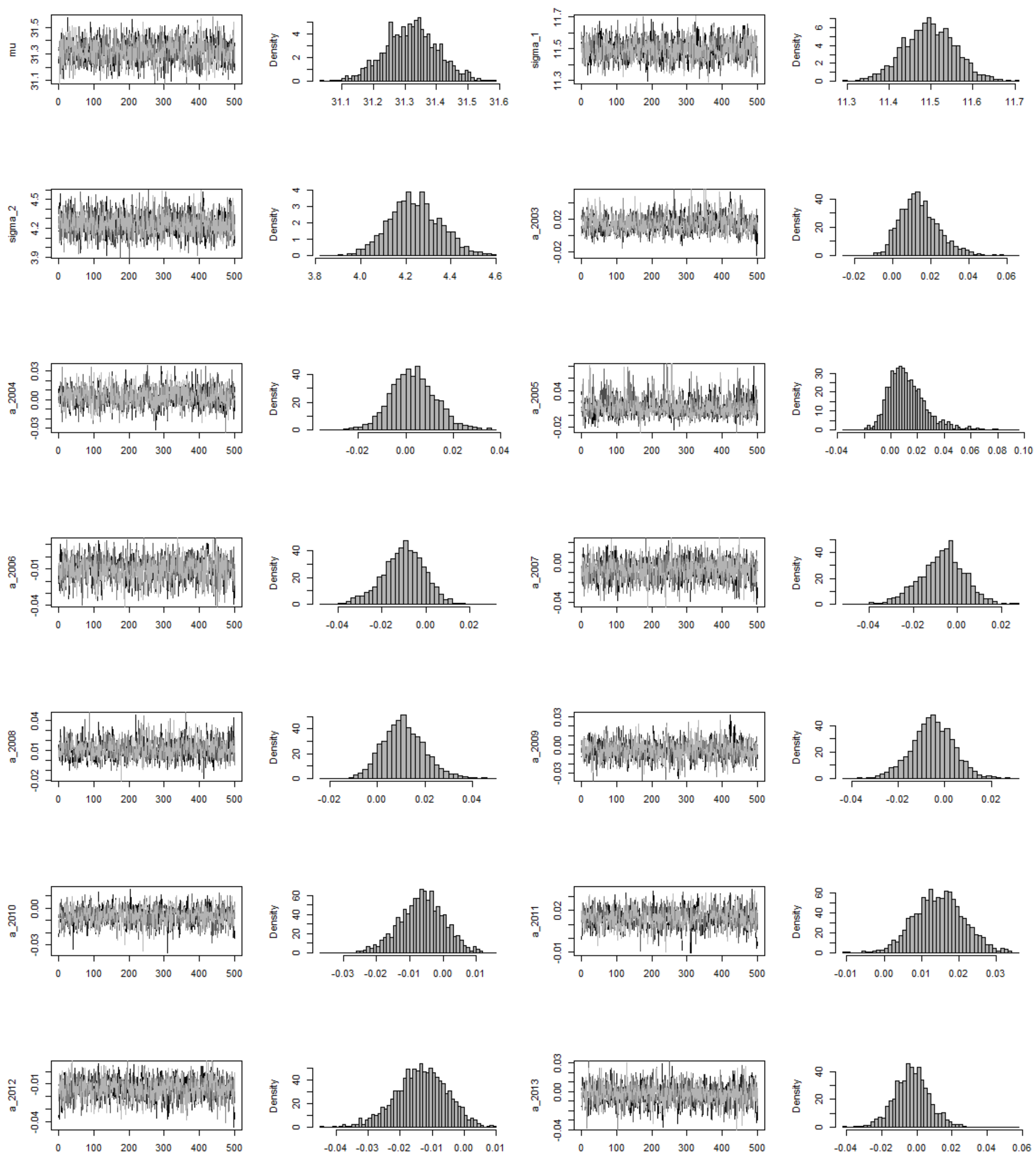


Figure 7.12 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

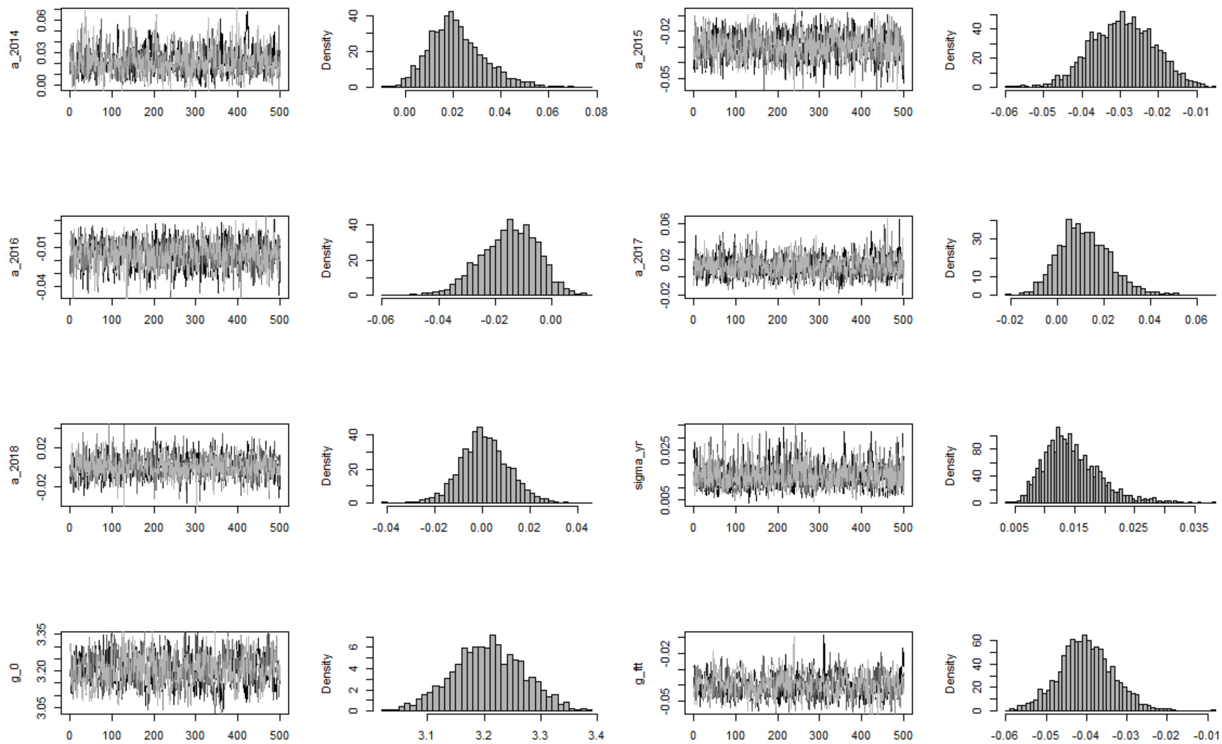


Figure 7.12. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach spring/summer Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

In addition, we simulated fish migration rates under a log-normal distribution for the Bonneville-McNary reach and a normal-normal mixture distribution for the McNary-Lower Granite reach. The values for the parameters were based on our model estimates. We transformed each migration rate (km/day) to travel time (days) and compared the predicted travel time distribution to the observed (Figure 7.13). In our modeling fitting process, each HMC sampling yielded a predicted distribution that contained imputed travel time. With 2,000 iterations, we produced 2,000 posterior predictive distributions of travel time. Of course we could not display all 2,000 predicted distributions here, so we randomly selected one to plot in Figure 7.13. Results showed predictions underestimated the peak of travel time distribution for the Bonneville-McNary reach. However, for the McNary-Lower Granite reach, predicted travel time distribution overlapped closely with the observed distribution.

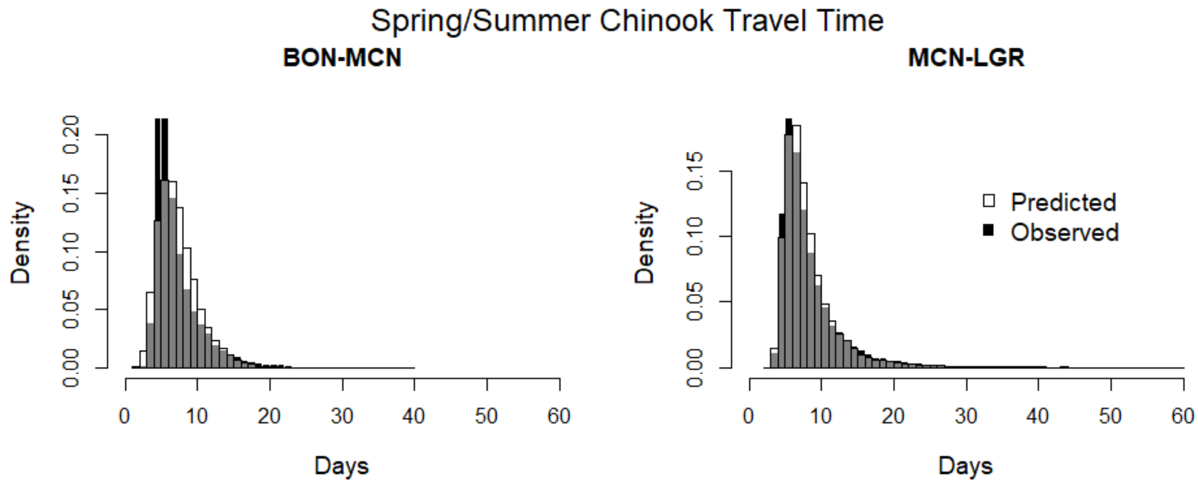


Figure 7.13. Examples comparing distributions for predicted and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right). "Density" referred to probability densities that are plotted so that the histogram has a total area of one.

We also examined the assignment of imputed travel time by plotting the combined distribution for imputed and observed travel time. Again, we randomly selected one example from the 2,000 iterations of the sampling process. It showed that imputed travel time were mostly greater than seven days for the Bonneville-McNary reach and between four to 12 days for the McNary-Lower Granite reach (Figure 7.14).

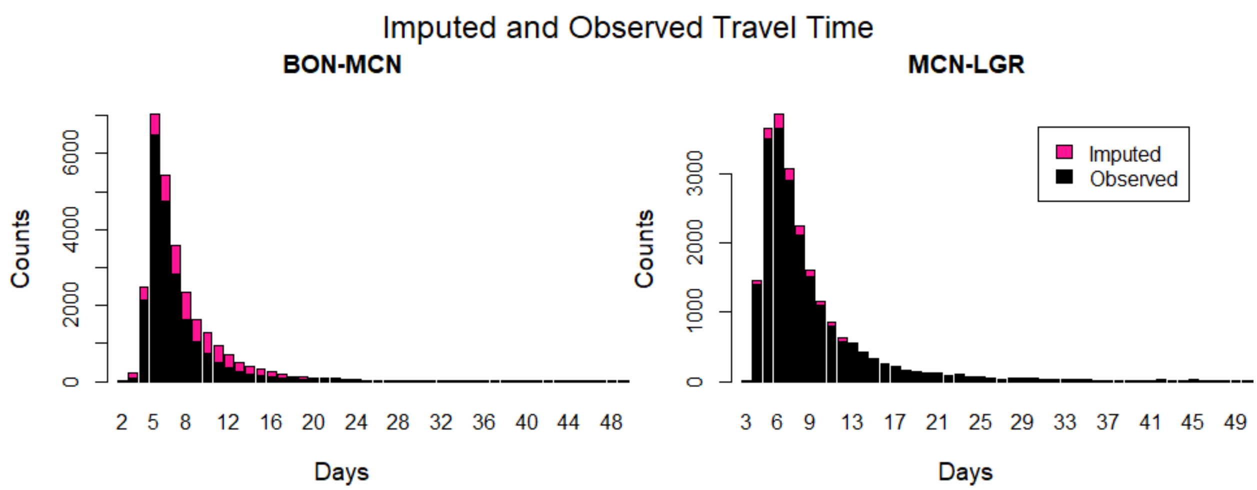


Figure 7.14. Examples of distribution for imputed and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right), randomly selected from multiple iterations of the sampling process. The pink bars represent imputed travel time.

Fall Chinook

Table 7.3. Model estimates for fall Chinook between Bonneville and McNary Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	3.565	0.004	(3.557, 3.573)	3247	1
Temperature	1.049	0.080	(0.891, 1.204)	2952	1
$Temp^2$	-1.126	0.080	(-1.281, -0.967)	2949	1
Flow	-0.005	0.005	(-0.014, 0.004)	3185	1
Arrival	0.042	0.005	(0.031, 0.052)	3287	1
Transported	-0.140	0.009	(-0.157, -0.123)	3396	1
Origin	0.014	0.003	(0.007, 0.021)	3433	1
$\mu_{ln(R)}$	3.533	0.004	(3.525, 3.539)	3145	1
$\sigma_{ln(R)}$	0.384	0.003	(0.378, 0.389)	2535	1
Yr 2003	0.096	0.034	(0.034, 0.167)	2504	1
Yr 2004	0.027	0.027	(-0.021, 0.087)	2663	1
Yr 2005	-0.032	0.024	(-0.082, 0.012)	2486	1
Yr 2006	-0.056	0.039	(-0.144, 0.006)	3009	1
Yr 2007	0.043	0.037	(-0.019, 0.125)	2781	1
Yr 2008	0.012	0.016	(-0.021, 0.045)	1442	1
Yr 2009	0.014	0.016	(-0.018, 0.047)	1367	1
Yr 2010	-0.029	0.015	(-0.059, 0)	1243	1
Yr 2011	-0.071	0.016	(-0.102, -0.041)	1311	1
Yr 2012	0.016	0.015	(-0.013, 0.046)	1329	1
Yr 2013	0.056	0.014	(0.028, 0.085)	1205	1
Yr 2014	-0.039	0.015	(-0.067, -0.01)	1217	1
Yr 2015	-0.011	0.015	(-0.04, 0.018)	1213	1
Yr 2016	0.030	0.018	(-0.003, 0.069)	1802	1
Yr 2017	-0.012	0.023	(-0.061, 0.032)	2510	1
Yr 2018	-0.018	0.028	(-0.079, 0.032)	3000	1
σ_{year}	0.040	0.013	(0.023, 0.072)	2951	1
γ_0 (Int)	3.002	0.002	(3, 3.009)	3388	1
Travel Time	-0.271	0.014	(-0.298, -0.244)	1148	1

Table 7.4. Model estimates for fall Chinook between McNary and Lower Granite Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	33.274	0.102	(33.074, 33.464)	3071	1
Temperature	24.611	2.232	(20.257, 29.12)	2847	1
$Temp^2$	-25.580	2.248	(-30.115, -21.156)	2835	1
Flow	0.038	0.228	(-0.414, 0.485)	2855	1
$Flow^2$	0.403	0.234	(-0.055, 0.871)	2920	1
Arrival	1.175	0.137	(0.91, 1.453)	2888	1
Transported	-1.277	0.225	(-1.705, -0.816)	2913	1
Migr Cont	-21.330	0.387	(-22.093, -20.57)	3605	1
Origin	0.466	0.087	(0.295, 0.638)	3373	1
μ_R	32.532	0.091	(32.354, 32.707)	2568	1
$\sigma_{R.1}$	9.484	0.065	(9.363, 9.616)	2324	1
$\sigma_{R.2}$	5.484	0.258	(5.001, 6.018)	3219	1
Yr 2003	-0.001	0.018	(-0.044, 0.032)	3022	1
Yr 2004	0.004	0.025	(-0.027, 0.071)	765	1
Yr 2005	0.000	0.016	(-0.034, 0.035)	3090	1
Yr 2006	0.000	0.019	(-0.039, 0.039)	2745	1
Yr 2007	0.002	0.022	(-0.035, 0.058)	2206	1
Yr 2008	0.005	0.012	(-0.015, 0.032)	2889	1
Yr 2009	0.002	0.011	(-0.02, 0.026)	2951	1
Yr 2010	0.014	0.012	(-0.004, 0.042)	2228	1
Yr 2011	0.007	0.010	(-0.009, 0.029)	2256	1
Yr 2012	-0.008	0.010	(-0.031, 0.009)	2536	1
Yr 2013	-0.025	0.009	(-0.044, -0.007)	1956	1
Yr 2014	-0.008	0.009	(-0.028, 0.007)	2298	1
Yr 2015	0.003	0.009	(-0.014, 0.023)	2487	1
Yr 2016	-0.001	0.013	(-0.029, 0.023)	3299	1
Yr 2017	0.001	0.015	(-0.03, 0.033)	3198	1
Yr 2018	-0.001	0.014	(-0.032, 0.025)	3091	1
σ_{year}	0.012	0.006	(0.005, 0.027)	1639	1
γ_0 (Int)	3.215	0.071	(3.08, 3.356)	1612	1
Travel Time	-0.053	0.008	(-0.07, -0.037)	1501	1

The sampling for fall Chinook included four chains of 4,000 iterations, with burn-in of 50% each. We kept every other draw of our HMC sampling (thinning of two), which yielded a total of 4,000 sample draws from the joint posterior distribution. Gelman's diagnostics showed that all parameters had an $\hat{R}$ close to one and an adequate effective size. Traceplots showed reasonably well mixing for all parameters (Figure 7.15; Figure 7.16). Diagnostics indicated no major concerns overall for model convergence.

Posterior distribution of γ_0 for the Bonneville-McNary reach showed left truncation because we censored the values to be greater than three (Figure 7.15).

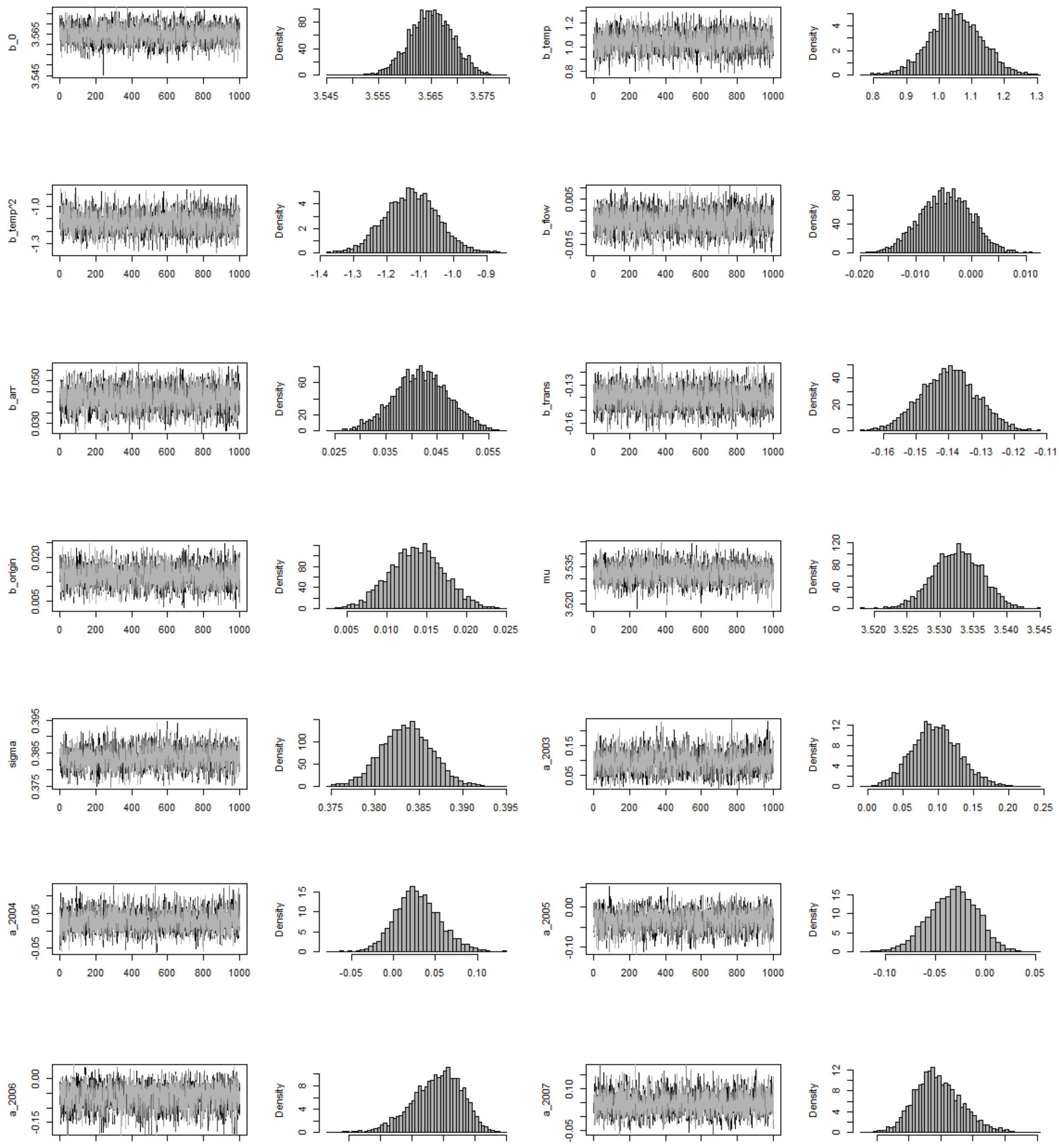


Figure 7.15. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach fall Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

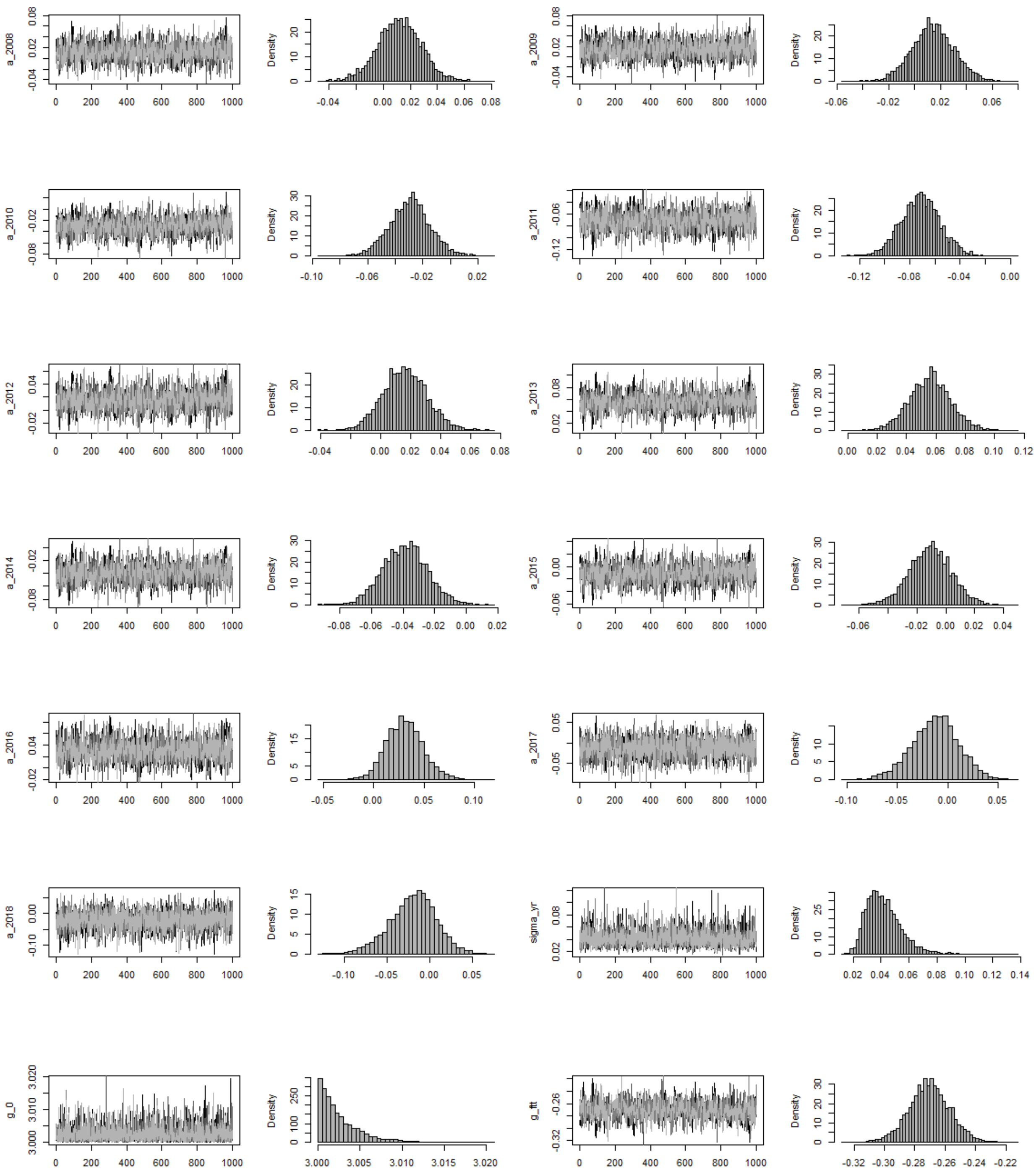


Figure 7.15 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach fall Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

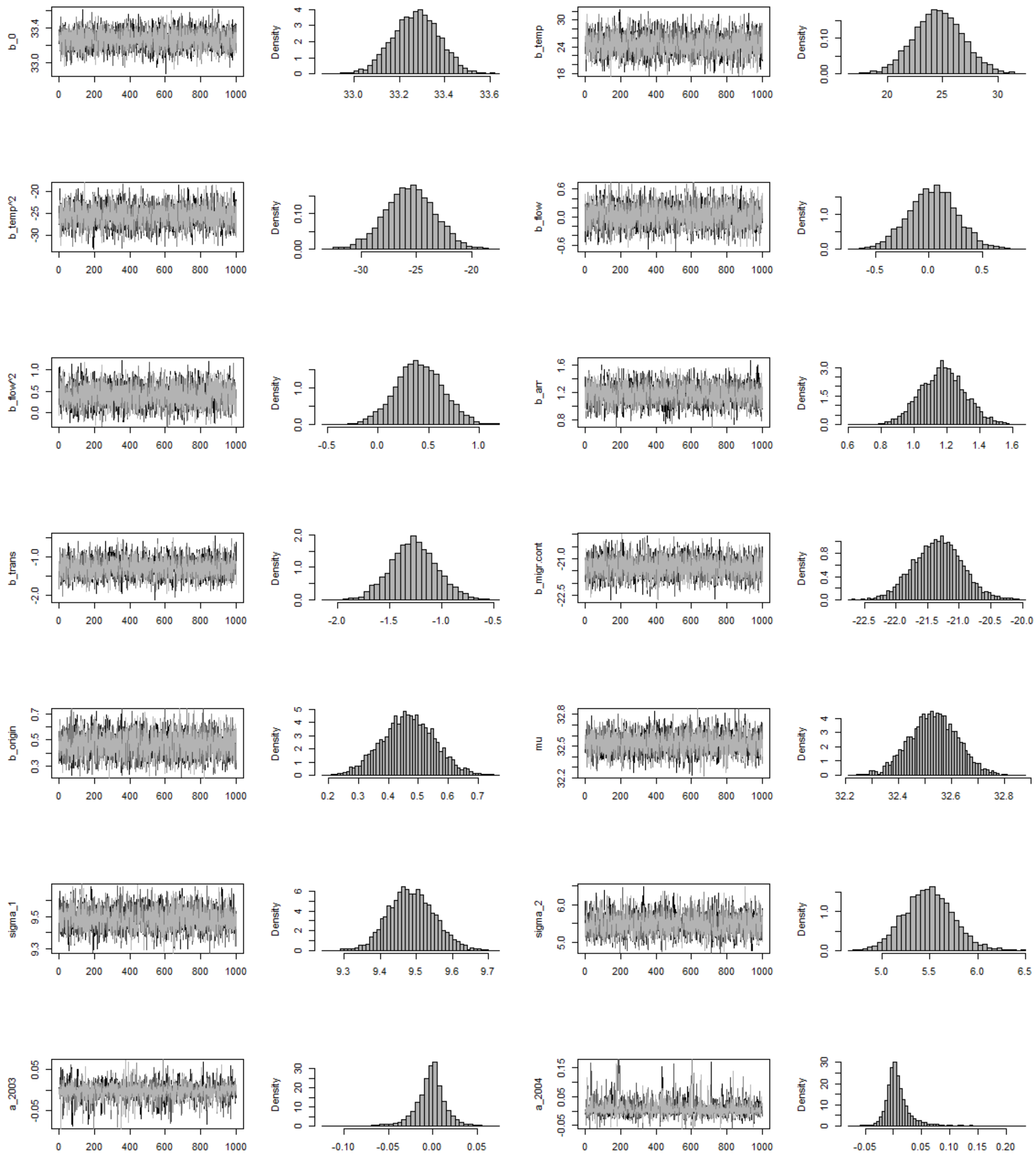


Figure 7.16. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach fall Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

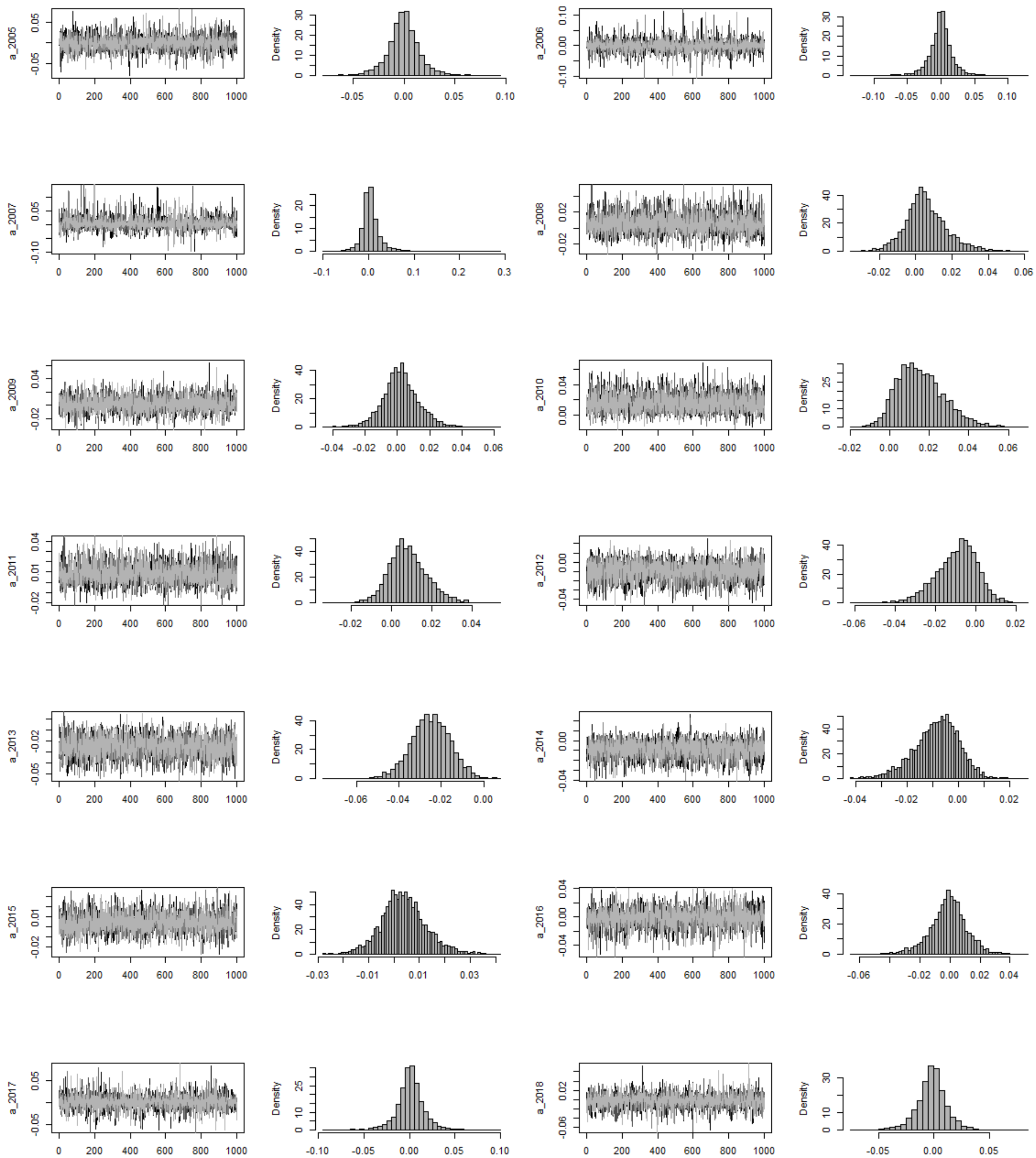


Figure 7.16 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach fall Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

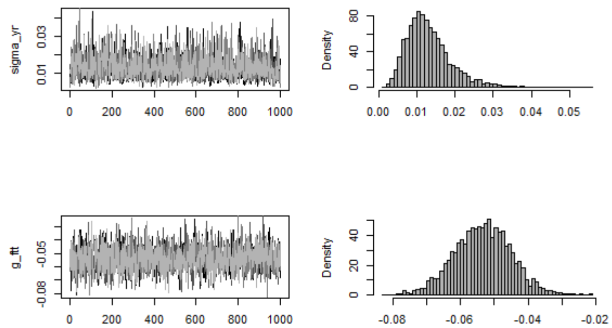


Figure 7.16 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach fall Chinook model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

We simulated fall Chinook migration rates under a log-normal distribution for the Bonneville-McNary reach and a normal-normal mixture distribution for the McNary-Lower Granite reach. The values for the parameters were based on our model estimates. We transformed each migration rate (km/day) to travel time (days) and compared the predicted travel time distribution to the observed (Figure 7.17). We randomly selected one to plot in Figure 7.17. Results for the Bonneville-McNary reach showed that predictions did not capture the peak of travel time distribution quite exactly. However, for the McNary-Lower Granite reach, predicted travel time distribution overlapped closely with the observed distribution.

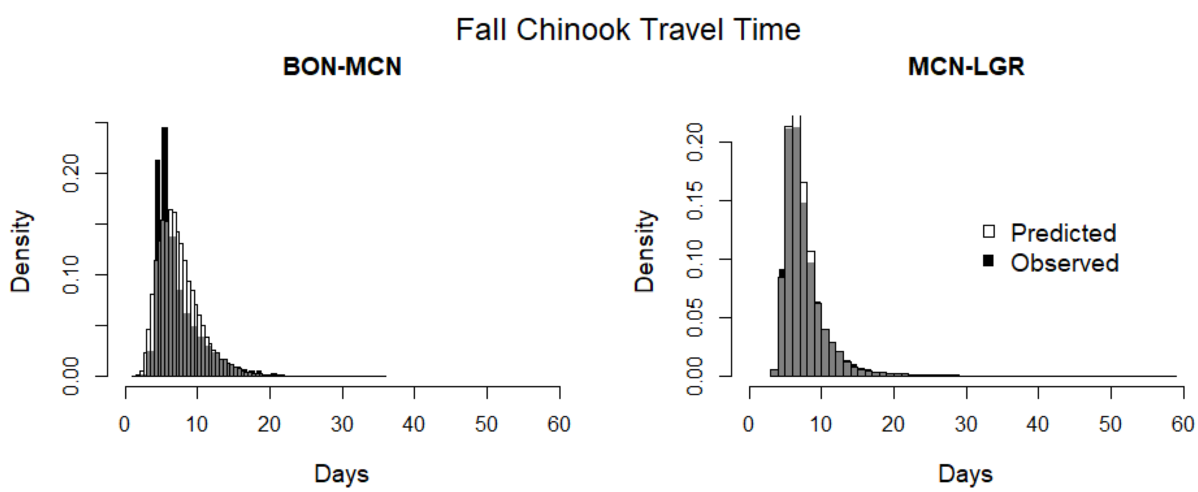


Figure 7.17. Examples comparing distributions for predicted and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right). "Density" referred to probability densities that are plotted so that the histogram has a total area of one.

We also displayed a randomly selected example for imputed and observed travel time distribution for fall Chinook. It showed that imputed travel times were mostly greater than seven days for the Bonneville-McNary reach and between five to 12 days for the McNary-Lower Granite reach (Figure 7.18).

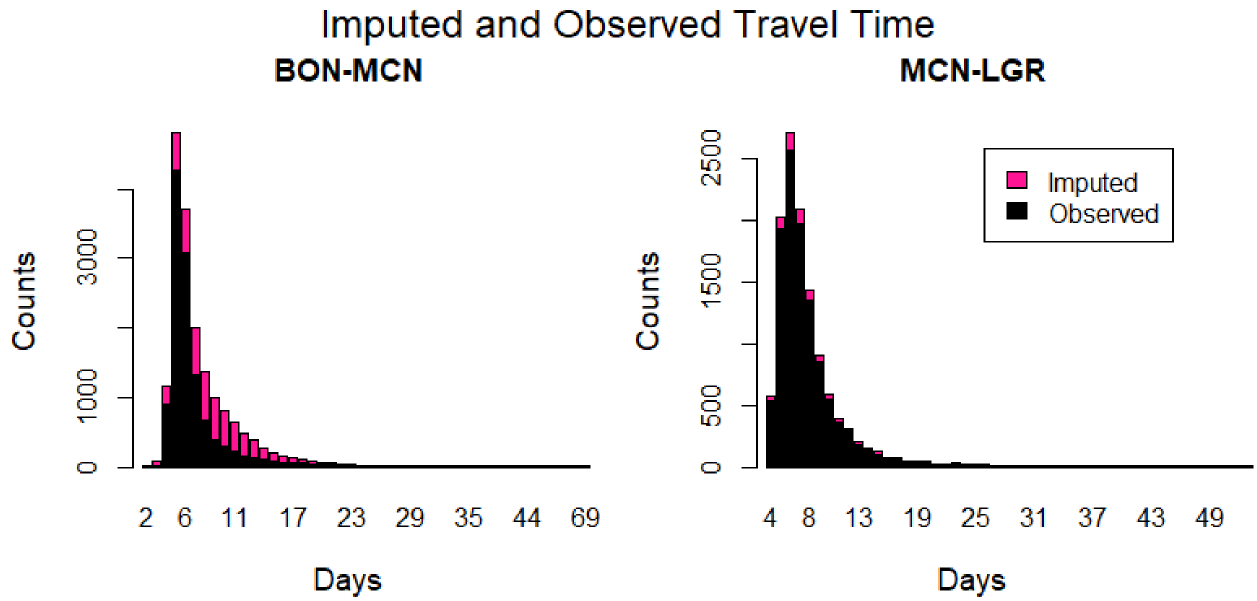


Figure 7.18. Examples of distribution for imputed and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right), randomly selected from multiple iterations of the sampling process. The pink bars represent imputed travel time.

Sockeye

Table 7.5. Model estimates for sockeye between Bonneville and McNary Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	3.503	0.017	(3.47, 3.535)	1384	1
Temperature	2.998	0.237	(2.547, 3.472)	1521	1
Temp^2	-3.256	0.248	(-3.752, -2.783)	1435	1
Transported	-0.266	0.023	(-0.312, -0.221)	2989	1
$\mu_{ln(R)}$	3.402	0.016	(3.37, 3.434)	962	1
$\sigma_{ln(R)}$	0.355	0.009	(0.338, 0.374)	1626	1
Yr 2003-10	0.023	0.042	(-0.054, 0.112)	2209	1
Yr 2011	0.014	0.033	(-0.047, 0.086)	1715	1
Yr 2012	-0.038	0.039	(-0.118, 0.035)	2067	1
Yr 2013	0.038	0.037	(-0.027, 0.121)	1759	1
Yr 2014	0.006	0.034	(-0.058, 0.079)	1610	1
Yr 2015	-0.123	0.037	(-0.193, -0.047)	1630	1
Yr 2016	0.091	0.040	(0.019, 0.176)	1865	1
Yr 2017-18	-0.047	0.044	(-0.14, 0.029)	2209	1
σ_{year}	0.064	0.033	(0.027, 0.15)	2805	1
γ_0 (Int)	3.028	0.039	(3.001, 3.148)	3392	1
Travel Time	-0.352	0.033	(-0.423, -0.293)	1585	1

Table 7.6. Model estimates for sockeye between McNary and Lower Granite Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	29.095	0.854	(27.487, 30.841)	2172	1
Temperature	36.559	14.281	(1.858, 59.926)	1950	1
Temp^2	-43.440	14.735	(-67.957, -8.127)	1961	1
Flow	-1.411	0.851	(-3.195, 0.137)	2660	1
Arrival	0.439	0.387	(-0.334, 1.209)	3426	1
Transported	0.783	0.678	(-0.544, 2.128)	3659	1
Migr Cont	-23.313	1.124	(-25.307, -20.908)	2527	1
μ_R	31.519	0.324	(30.87, 32.142)	3335	1
$\sigma_{R.1}$	9.412	0.252	(8.949, 9.93)	2982	1
$\sigma_{R.2}$	4.153	0.901	(2.783, 6.173)	2194	1
Yr 2003-10	0.026	0.040	(-0.037, 0.123)	3193	1
Yr 2011	0.039	0.035	(-0.018, 0.119)	2743	1
Yr 2012	0.008	0.034	(-0.055, 0.081)	3061	1
Yr 2013	-0.038	0.030	(-0.099, 0.022)	2850	1
Yr 2014	0.033	0.030	(-0.023, 0.097)	2679	1
Yr 2015	-0.097	0.034	(-0.164, -0.031)	2764	1
Yr 2016	0.024	0.034	(-0.032, 0.105)	2883	1
Yr 2017-18	-0.042	0.047	(-0.147, 0.034)	3414	1
σ_{year}	0.051	0.028	(0.021, 0.127)	3250	1
γ_0 (Int)	3.015	0.022	(3.001, 3.083)	3893	1
Travel Time	-0.082	0.028	(-0.142, -0.032)	2559	1

The sampling for the Bonneville-McNary reach sockeye model included four chains of 4,000 iterations, with burn-in of 50% each. We kept every other draw of our HMC sampling (thinning of two), which yielded a total of 4,000 sample draws from the joint posterior distribution. The sampling for the McNary-Lower Granite reach included four chains of 8,000 iterations, with burn-in of 50% each. We kept every fourth draw of our HMC sampling (thinning of four), which yielded a total of 4,000 sample draws from the joint posterior distribution.

Gelman's diagnostics showed that all parameters had an $\hat{R}$ close to one and an adequate effective size. Traceplots showed reasonably well mixing for all parameters (Figure 7.19; Figure 7.20). Diagnostics indicated no major concerns overall for model convergence.

Posterior distribution of γ_0 for both Bonneville-McNary and McNary-Lower Granite reaches showed left truncation because we limited the values to be greater than three (Figure 7.19; Figure 7.20).

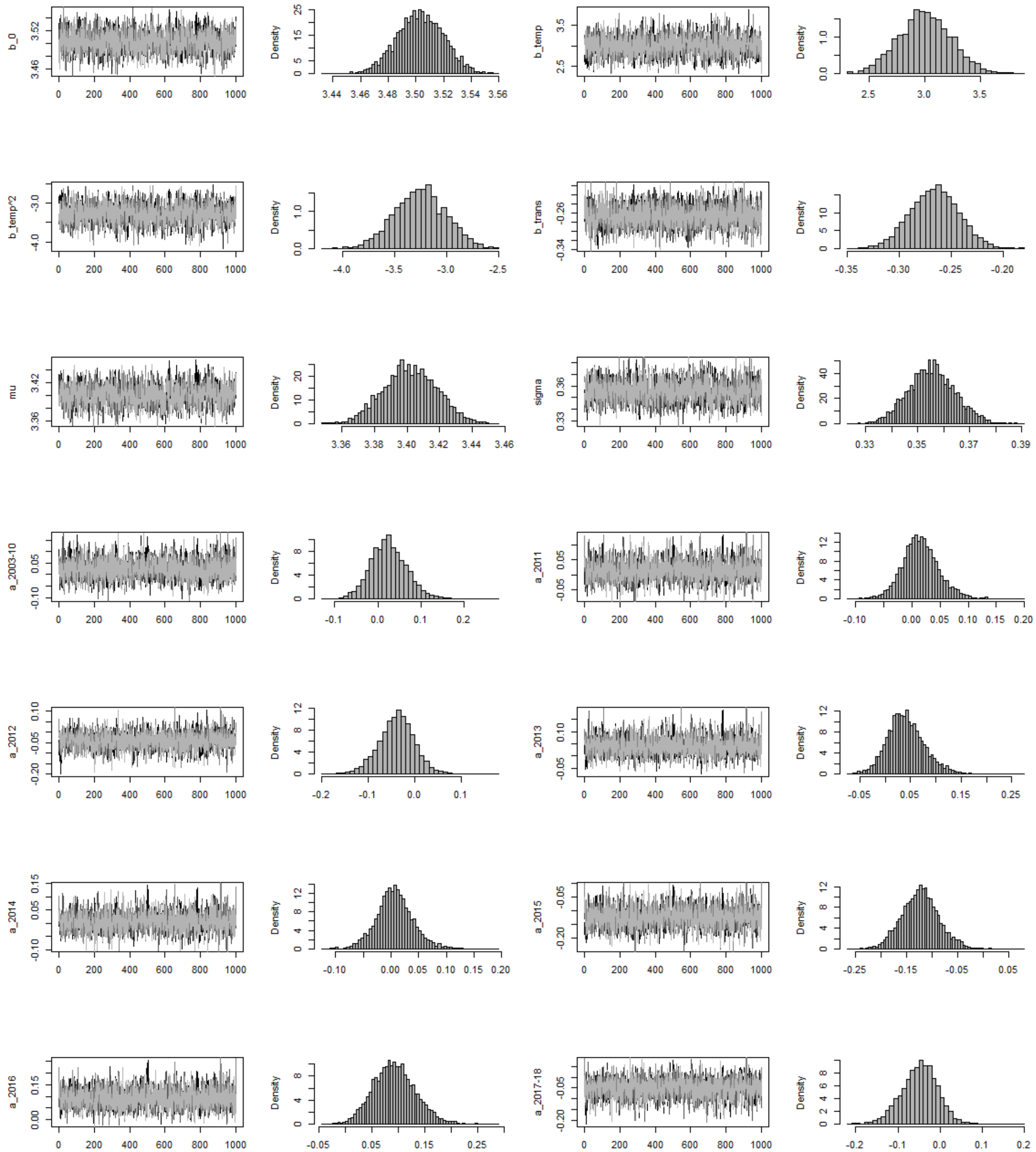


Figure 7.19. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach sockeye model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

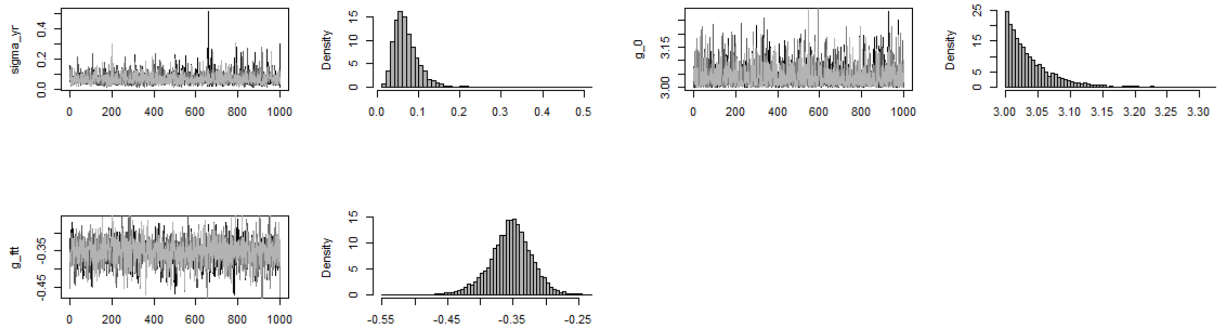


Figure 7.19 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach sockeye model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

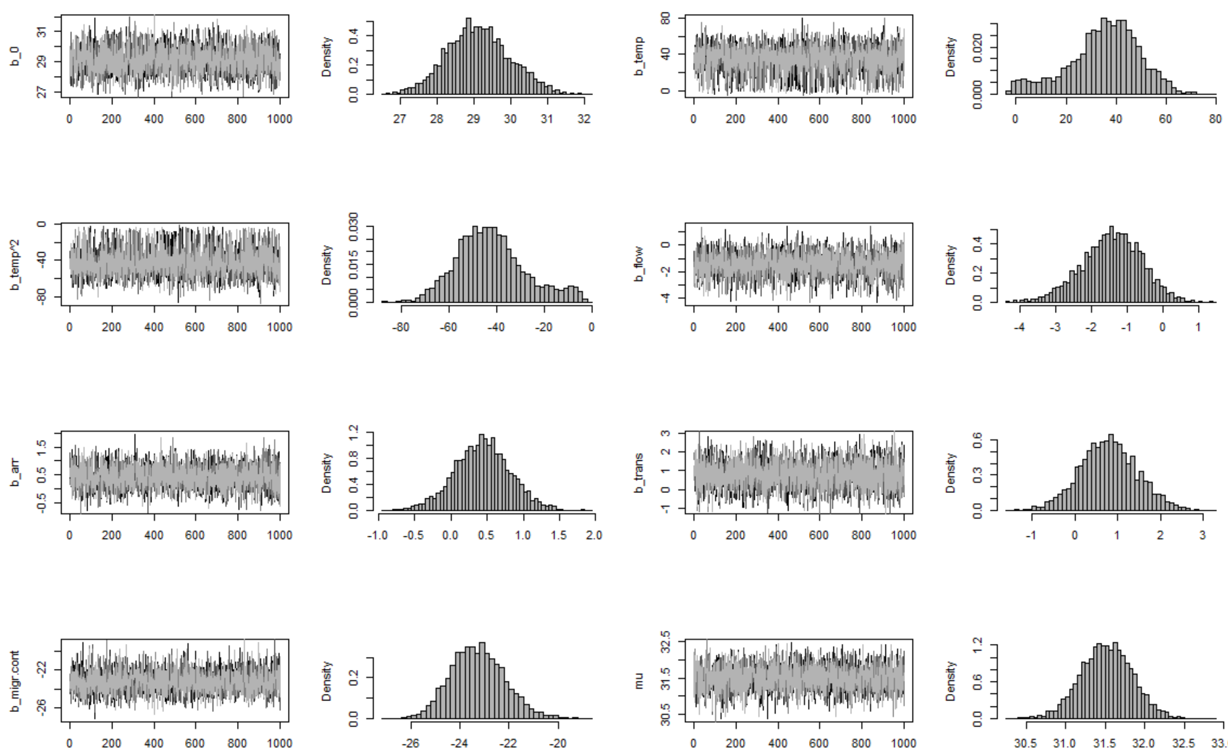


Figure 7.20. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach sockeye model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

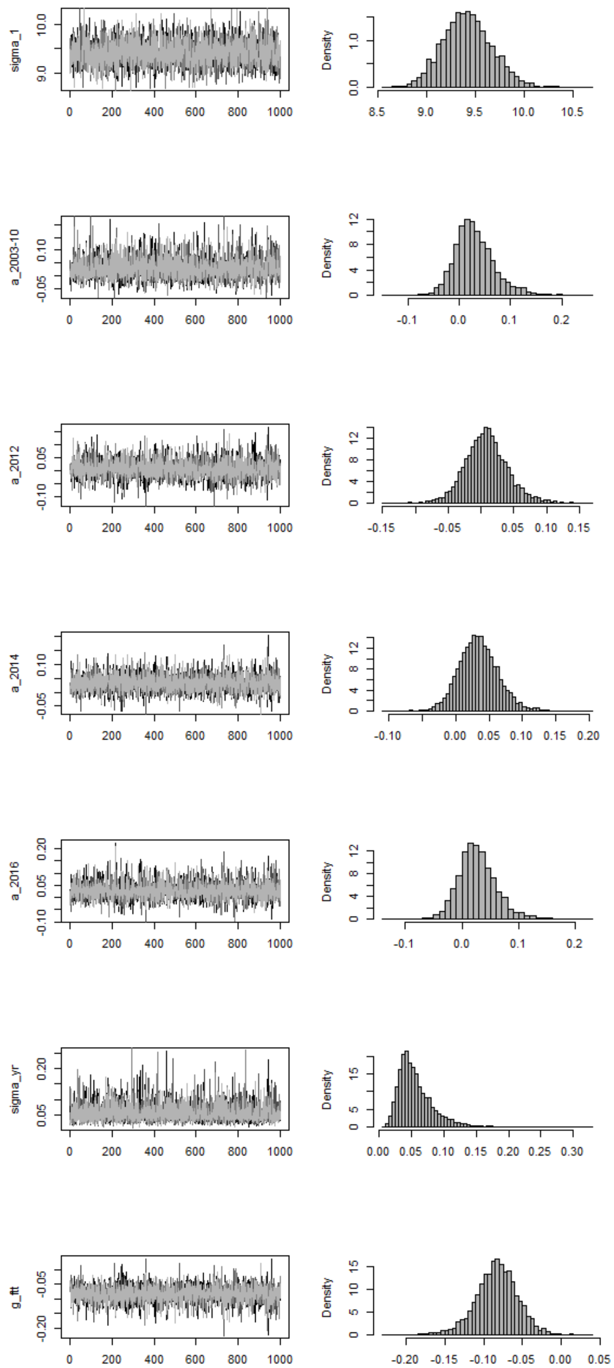


Figure 7.20 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach sockeye model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

We simulated sockeye migration rates under a log-normal distribution for the Bonneville-McNary reach and a normal-normal mixture distribution for the McNary-Lower Granite reach. Parameter values for the simulation were based on our model estimates. We transformed each migration rate (km/day) to travel time (days) and compared the predicted travel time distribution to the observed (Figure 7.21). We randomly selected one to plot in Figure 7.21. Results for the Bonneville-McNary reach showed that predictions underestimated the peak and the tail of travel time distribution. For the McNary-Lower Granite reach, we seemed to over-predict the number of fish with travel time between seven to 15 days.

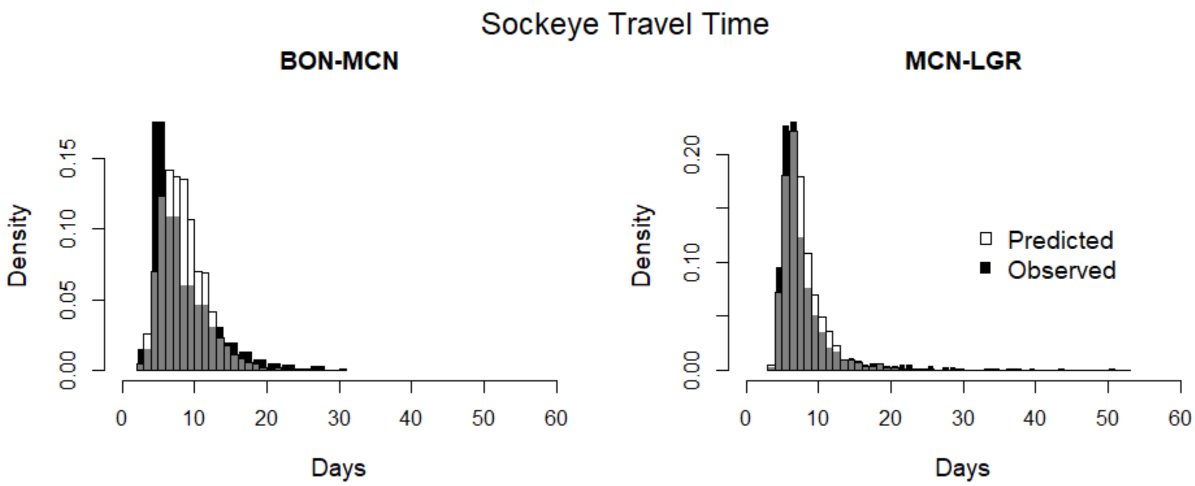


Figure 7.21. Examples comparing distributions for predicted and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right). "Density" referred to probability densities that are plotted so that the histogram has a total area of one.

We also showed a randomly selected example for imputed and observed travel time distribution for sockeye. It showed that imputed travel time were mostly greater than seven days for Bonneville-McNary reach. For McNary-Lower Granite reach, imputation seemed to be evenly distributed throughout all time steps (Figure 7.22).

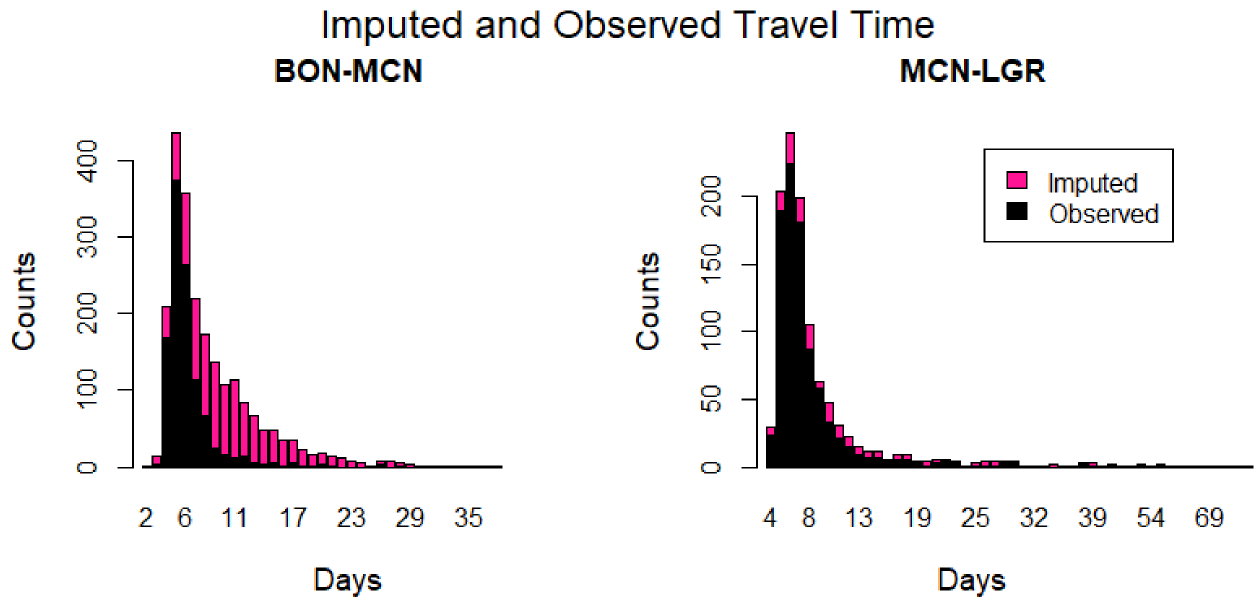


Figure 7.22. Examples of distribution for imputed and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right), randomly selected from multiple iterations of the sampling process. The pink bars represent imputed travel time.

Steelhead

Table 7.7. Model estimates for steelhead between Bonneville and McNary Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	2.243	0.008	(2.226, 2.259)	3801	1
Temperature	-0.537	0.165	(-0.857, -0.209)	3802	1
$Temp^2$	0.275	0.163	(-0.047, 0.591)	3793	1
Arrival	-2.159	0.164	(-2.473, -1.836)	3786	1
$Arrival^2$	2.410	0.162	(2.088, 2.719)	3775	1
Transported	-0.212	0.014	(-0.24, -0.185)	3821	1
Origin	-0.001	0.007	(-0.014, 0.012)	3598	1
$\mu_{ln(R)}$	2.165	0.007	(2.152, 2.179)	3785	1
$\sigma_{ln(R)}$	0.826	0.006	(0.815, 0.837)	3927	1
Yr 2003	0.007	0.004	(0, 0.015)	3613	1
Yr 2004	0.004	0.003	(-0.001, 0.011)	3903	1
Yr 2005	0.002	0.003	(-0.003, 0.008)	3818	1
Yr 2006	0.000	0.003	(-0.005, 0.005)	4029	1
Yr 2007	0.003	0.003	(-0.001, 0.009)	3649	1
Yr 2008	0.003	0.002	(-0.001, 0.008)	3643	1
Yr 2009	-0.002	0.002	(-0.005, 0.001)	3711	1
Yr 2010	0.001	0.002	(-0.002, 0.004)	3852	1
Yr 2011	-0.008	0.002	(-0.011, -0.004)	3615	1
Yr 2012	-0.001	0.002	(-0.005, 0.002)	3871	1
Yr 2013	-0.006	0.002	(-0.01, -0.003)	3608	1
Yr 2014	-0.002	0.002	(-0.005, 0.001)	3714	1
Yr 2015	0.001	0.002	(-0.002, 0.004)	3584	1
Yr 2016	-0.003	0.002	(-0.007, 0)	3758	1
Yr 2017	0.000	0.002	(-0.004, 0.004)	4054	1
σ_{year}	0.004	0.001	(0.002, 0.007)	3980	1
γ_0 (Int)	3.008	0.012	(3, 3.042)	4045	1
Travel Time	-0.037	0.001	(-0.039, -0.034)	3546	1

Table 7.8. Model estimates for steelhead between McNary and Lower Granite Dams.

	Median	SD	95% CRI	Eff size	$\hat{R}$
β_0 (Int)	22.656	0.080	(22.497, 22.81)	3100	1
Temperature	-5.021	1.106	(-7.182, -2.812)	2365	1
$Temp^2$	5.241	1.094	(3.031, 7.357)	2397	1
Flow	-0.076	0.075	(-0.226, 0.069)	2601	1
Arrival	-1.450	0.255	(-1.944, -0.957)	2458	1
$Arrival^2$	3.814	0.273	(3.282, 4.351)	2497	1
Transported	0.061	3.862	(-7.733, 7.95)	3225	1
Migr Cont	-15.170	0.123	(-15.405, -14.93)	3078	1
Origin	0.364	0.051	(0.267, 0.467)	3669	1
$\mu_{migr.rate}$	20.784	0.070	(20.646, 20.92)	3137	1
$\sigma_{R.1}$	8.606	0.057	(8.496, 8.727)	2005	1
$\sigma_{R.2}$	2.766	0.051	(2.666, 2.869)	1617	1
Yr 2003	0.000	0.004	(-0.007, 0.009)	2774	1
Yr 2004	0.001	0.011	(-0.004, 0.032)	399	1
Yr 2005	0.001	0.006	(-0.003, 0.017)	497	1
Yr 2006	0.000	0.004	(-0.011, 0.006)	2048	1
Yr 2007	0.000	0.003	(-0.005, 0.007)	2672	1
Yr 2008	0.001	0.003	(-0.004, 0.009)	2359	1
Yr 2009	-0.003	0.003	(-0.01, 0.001)	1158	1
Yr 2010	0.002	0.002	(-0.001, 0.007)	1490	1
Yr 2011	-0.003	0.003	(-0.009, 0.001)	1279	1
Yr 2012	0.001	0.002	(-0.003, 0.005)	2603	1
Yr 2013	0.000	0.002	(-0.006, 0.003)	2639	1
Yr 2014	0.000	0.002	(-0.004, 0.004)	2490	1
Yr 2015	-0.001	0.002	(-0.007, 0.003)	2410	1
Yr 2016	0.000	0.002	(-0.005, 0.005)	2974	1
Yr 2017	0.000	0.003	(-0.006, 0.008)	2975	1
σ_{year}	0.002	0.002	(0, 0.007)	588	1
γ_0 (Int)	3.004	0.005	(3, 3.02)	3471	1
Travel Time	-0.019	0.002	(-0.021, -0.015)	2254	1

The sampling for Bonneville-McNary reach steelhead model included four chains of 4,000 iterations, with burn-in of 50% each. We kept every other draw of our HMC sampling (thinning of two), which yielded a total of 4,000 sample draws from the joint posterior distribution. The sampling for McNary-Lower Granite reach included four chains of 4,000 iterations, with burn-in of 50% each. We kept every draw of our HMC sampling (no thinning), which yielded a total of 8,000 sample draws from the joint posterior distribution.

Gelman's diagnostics showed that all parameters had an $\hat{R}$ close to one and an adequate effective size. Traceplots showed reasonably well mixing for all parameters (Figure 7.23; Figure 7.24). Diagnostics indicated no major concerns overall for model convergence.

Posterior distribution of γ_0 for both Bonneville-McNary and McNary-Lower Granite reaches showed left truncation because we limited the values to be greater than three (Figure 7.23; Figure 7.24).

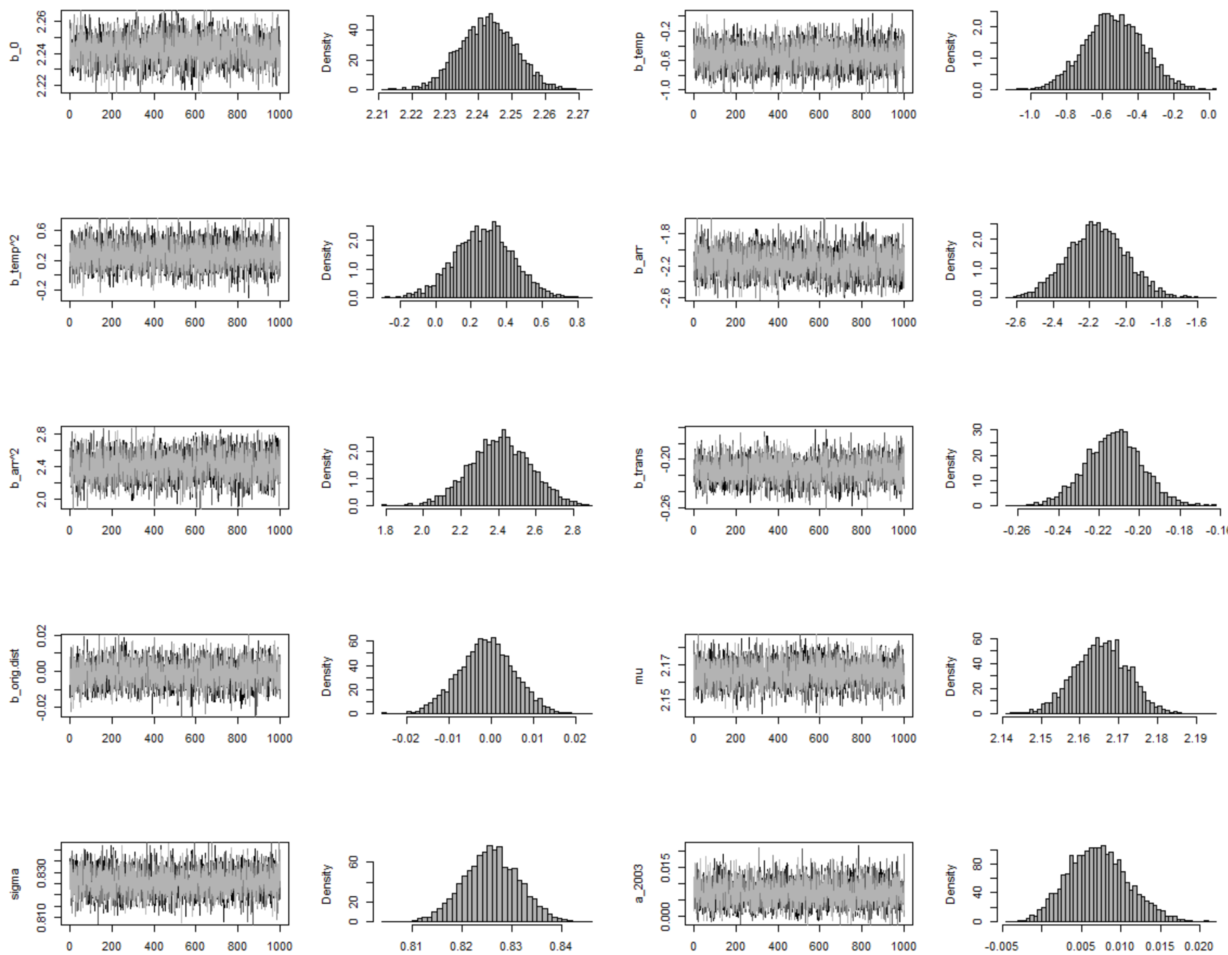


Figure 7.23. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

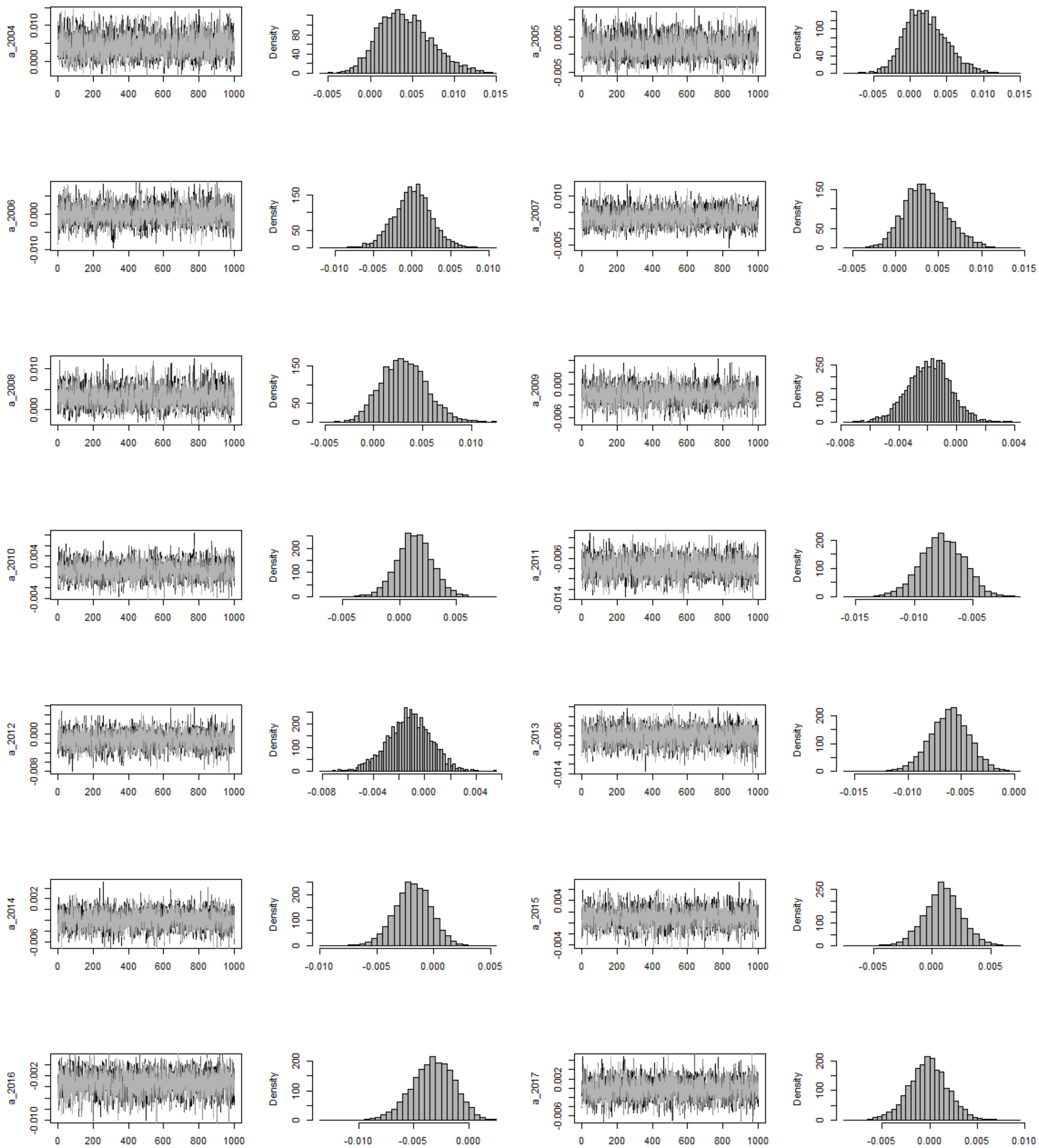


Figure 7.23 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

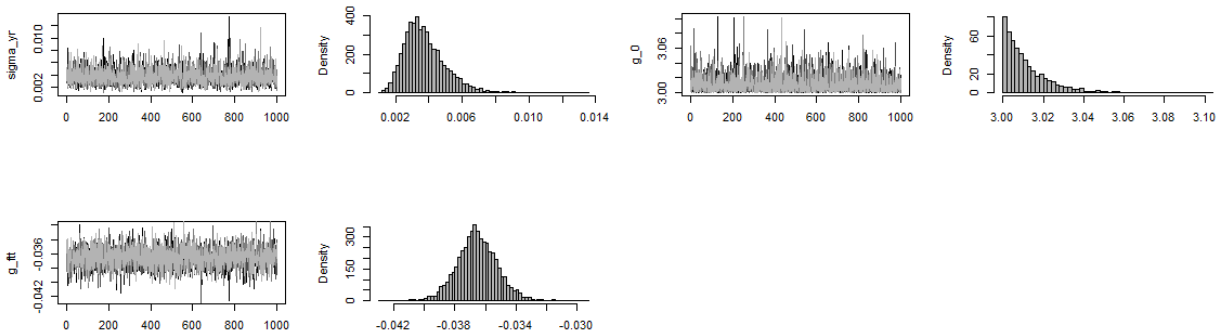


Figure 7.23 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our Bonneville-McNary reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

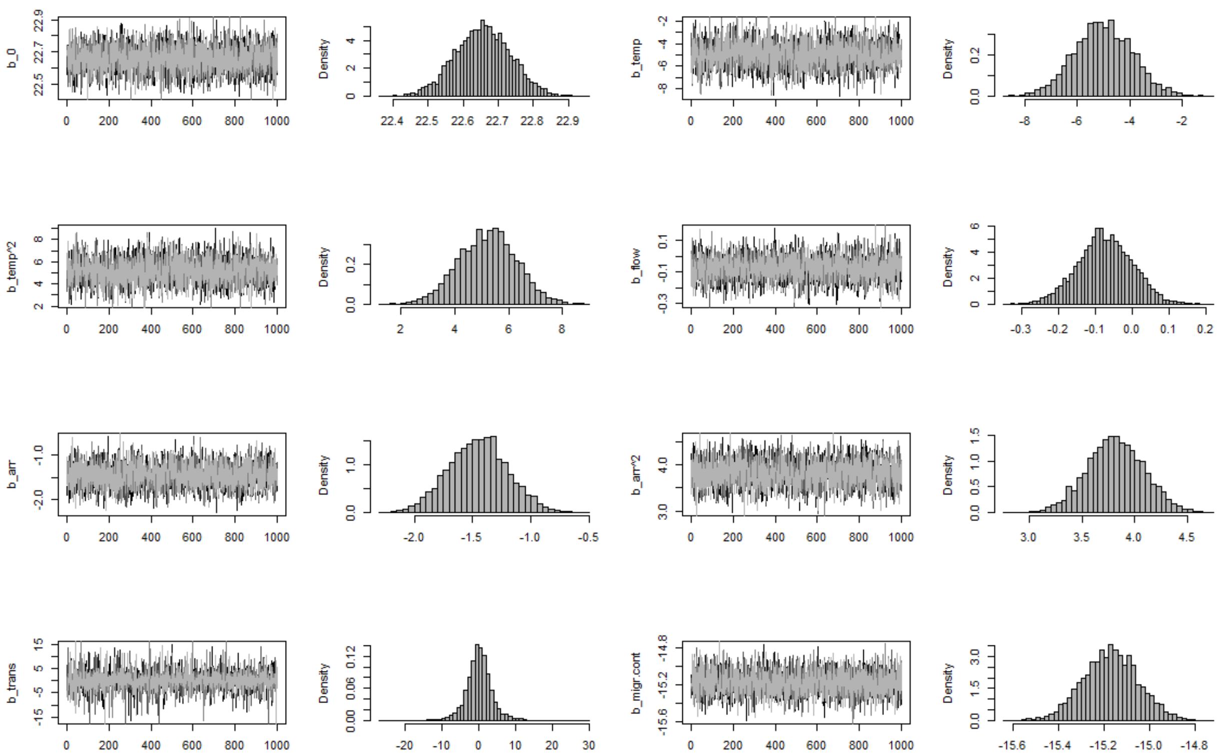


Figure 7.24. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

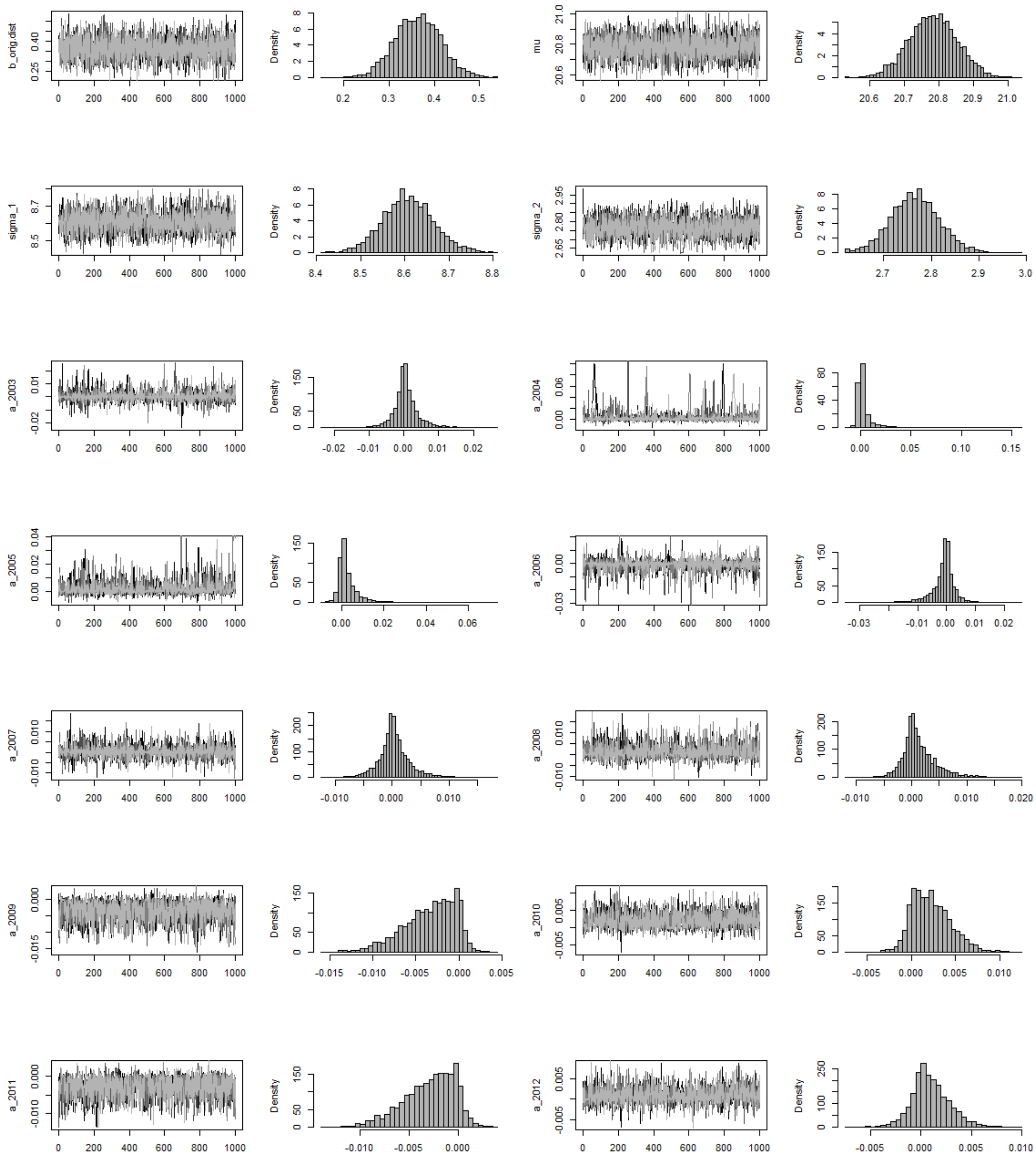


Figure 7.24 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

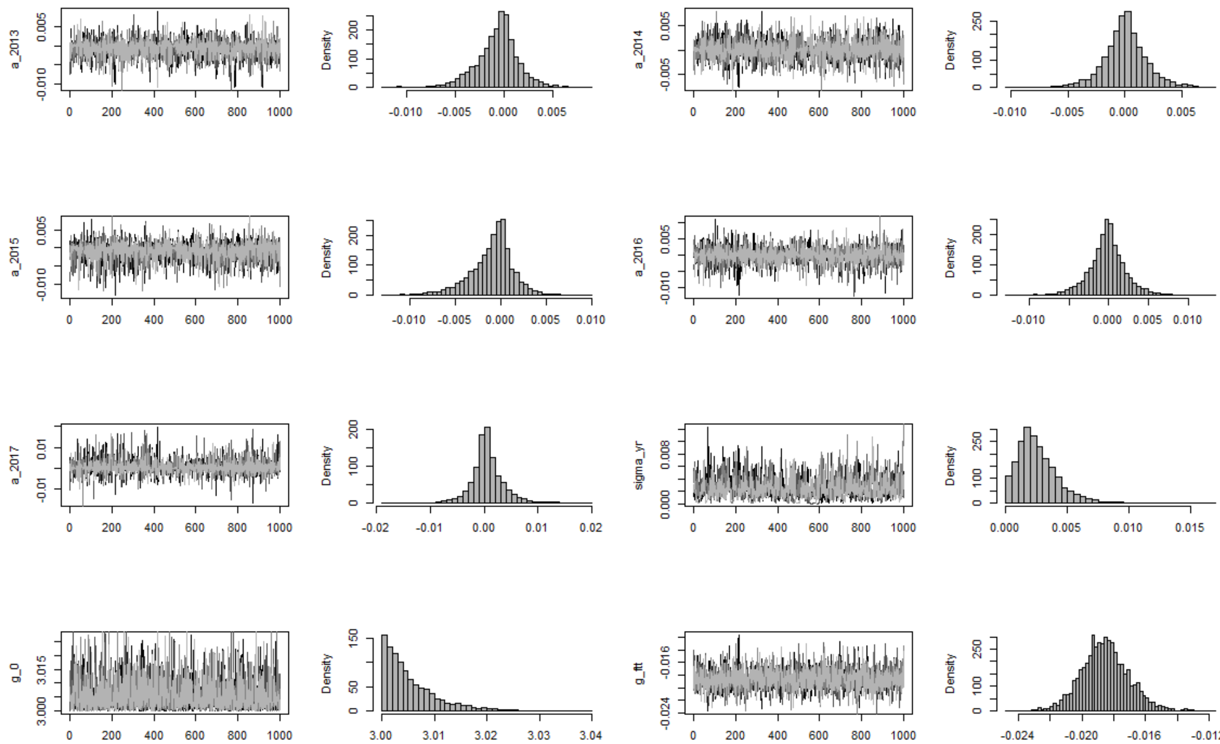


Figure 7.24 continued. Traceplots (columns 1 and 3) show well mixing and indicated no major concerns for convergence of our McNary-Lower Granite reach steelhead model. Histograms (columns 2 and 4) indicate that posterior distributions generally follow prior assumptions of student's t distributions.

We simulated steelhead migration rates under a log-normal distribution for Bonneville-McNary reach and a normal-normal mixture distribution for McNary-Lower Granite reach. The parameter values for the simulation were based on our model estimates. We transformed each migration rate (km/day) to travel time (days) and compared the predicted travel time distribution to the observed (Figure 7.25). We randomly selected one to plot in Figure 7.25. Results showed that predictions for steelhead travel time between Bonneville and McNary Dams did not quite capture the bimodal shape of the observed distribution. For the McNary-Lower Granite reach, we seemed to over-predict travel time between seven to 15 days compared to the observed distribution.

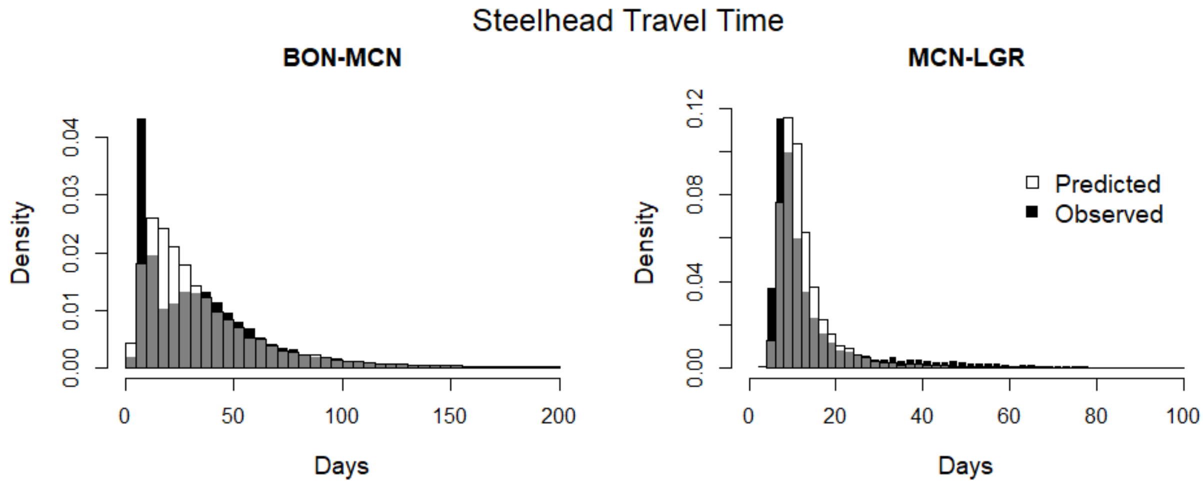


Figure 7.25. Examples comparing distributions for predicted and observed travel time for the Bonneville-McNary reach (left) and the McNary-Lower Granite reach (right). "Density" referred to probability densities that are plotted so that the histogram has a total area of one.

We also showed randomly selected examples for imputed and observed travel time distribution for steelhead. It showed that imputed travel time were evenly distributed across travel time for the Bonneville-McNary reach. For the McNary-Lower Granite reach, imputations seemed to be mostly distributed among travel time less than 30 days (Figure 7.26).

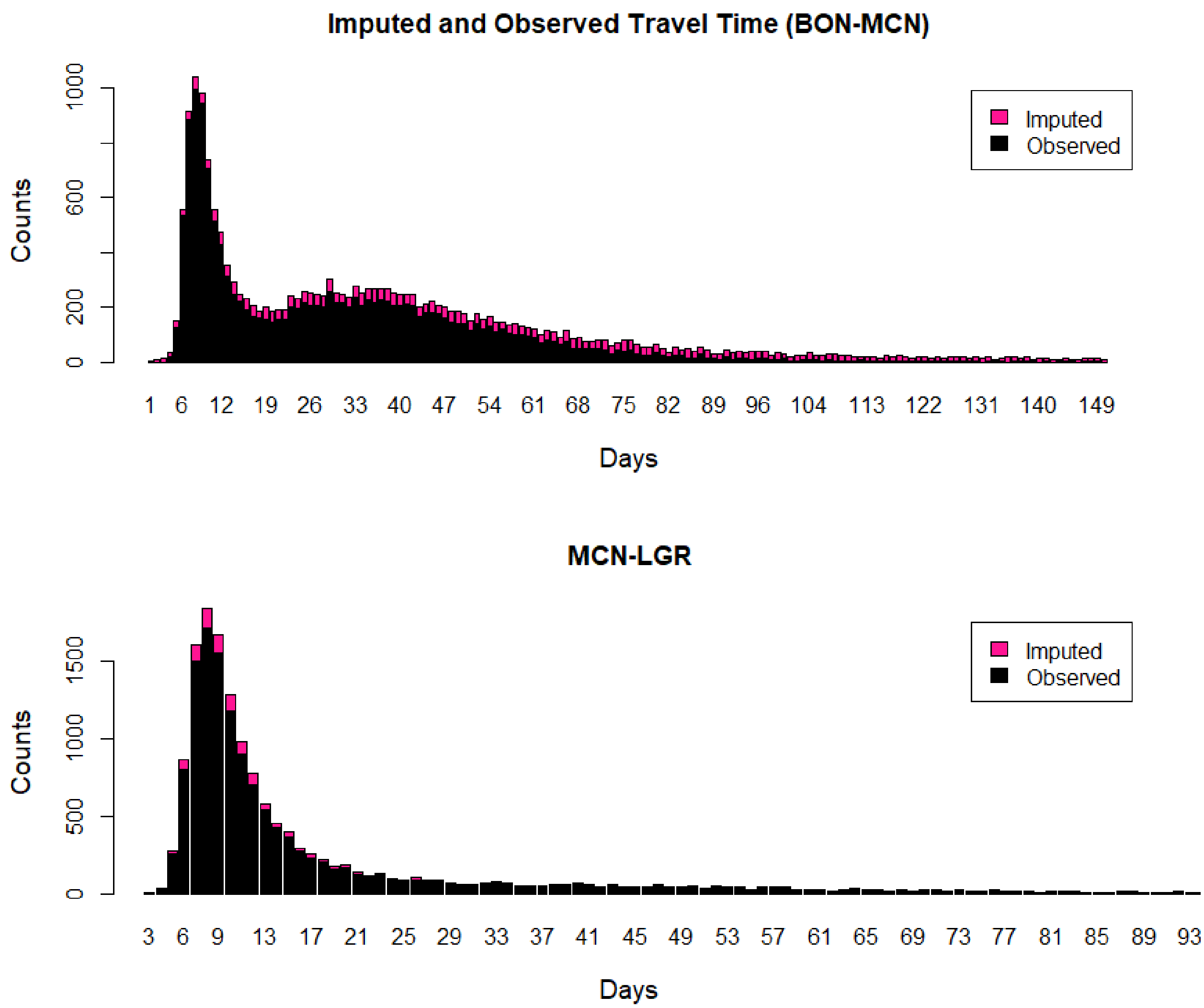


Figure 7.26. Examples of distribution for imputed and observed travel time for the Bonneville-McNary reach (top) and the McNary-Lower Granite reach (bottom), randomly selected from multiple iterations of the sampling process. Travel time between Bonneville and McNary Dams was censored at 150 days for plotting purpose. The pink bars represent imputed travel time.

Chapter 8

Preliminary development of an approach to estimate daily detection probability and total passage of spring-migrant yearling Chinook salmon at Bonneville Dam

Since its inception, the Comparative Survival Study (CSS) has developed and refined metrics to assess an array of questions related to, for example, the effects of hydrosystem operational decisions on route-of-passage proportions (PITPH; McCann et al. 2015, Appendix J) and variation in life-cycle productivity across a range of hydrosystem operations and configurations (e.g., SRI; Schaller et al. 2014). Taken alone, these metrics provide valuable information to characterize the influence of various dynamic elements of the hydrosystem. Yet, some of those metrics (e.g., PITPH) have been applied more broadly; such as to project population performance in response to potential varying future conditions. In response to the 2016 CSS Annual Report (McCann et al. 2016), the Independent Scientific Advisory Board (ISAB 2016) commented:

Some of the recommendations [from the ISAB]*…will become increasing important in the future. For example, is there evidence of density dependence during the smolt out-migration and early marine periods…? Could the CSS estimate total smolt abundance of each species, say at Bonneville Dam?...*

As the ISAB alludes, a metric characterizing passage abundance of juvenile salmon at Bonneville Dam could be used to enhance understanding of varying population characteristics, elucidate mechanisms that may constrain or promote salmonid survival and inform management decisions in the Columbia Basin. Toward addressing these recommendations, and in keeping with a history of CSS scientists proposing novel metrics to examine unexplored questions, in the 2018 CSS Annual Report[2], we presented initial steps toward developing methods to estimate smolt abundance at Bonneville Dam. Specifically, our objectives were to:

(1) adapt existing methods to estimate daily detection probability of spring migrant juvenile yearling Chinook salmon at Bonneville dam,
(2) examine the importance of select environmental and operational covariates in explaining variation in detection probability,
(3) assess the ability of a model to predict detection probability
(4) present preliminary estimates of total passage at Bonneville Dam to characterize range of values that might be expected from our approach across time.

Building on the analysis from the 2018 report, in 2019 we evaluated (a) refinements to the initial model developed (objective 4) to predict detection probability based on a suite of covariates primarily related to operation of Bonneville Dam and (b) whether these refinements might improve predictive performance.

Methods

Detection data

[2] We identified a coding error in data sets related to the corner collector variable used to fit the predictive model in the 2018 analysis. In the current report, we have remedied that error and results/discussion have been updated accordingly.

To begin exploring the feasibility of estimating detection probabilities, and ultimately total passage, at Bonneville dam, we restricted our population of interest to wild and hatchery spring-migrant yearling Chinook salmon. Daily records of fish detected at both the powerhouse 2 bypass at Bonneville Dam and the downstream trawl (see Morris et al. 2018) or the downstream trawl only, were assembled for the period between 1 March and 31 July, 2000–2017. Because we were interested in passage at Bonneville Dam, detections of transported fish occurring only at the trawl, were excluded.

Detection probability

Daily detection probabilities at Bonneville Dam were estimated following procedures and applicable assumptions outlined in Sanford and Smith (2002) and adapted from Schaefer (1951). For consistency, we use here a notation similar to that adopted by Sanford and Smith (2002). Given the subset of yearling Chinook salmon detected at both locations, for each detection day j at the trawl, there is a frequency distribution of prior detections at Bonneville Dam across multiple days i. We leveraged these distributions to reconstruct passage timing at Bonneville Dam for those fish detected only at the downstream trawl. First, the proportion of fish that were detected at Bonneville Dam on day i and subsequently at the trawl on day j (n_{ij}) was calculated as $n_{ij}/n_{.j}$, where $n_{.j}$ is the number of fish detected at both sites summed across all days i, corresponding to a given day j. This proportion was then multiplied by the number of fish that passed Bonneville undetected but were detected at the trawl on day j (u_j) to arrive at the number of fish detected only at the trawl on day j that passed Bonneville on day i. Repeating this for all n_{ij}, the estimated number of previously undetected fish that passed Bonneville Dam on day i is the sum of those apportionments. That is,

$$\hat{u}_{i.} = \sum_{j=1}^{t} u_j \cdot \frac{n_{ij}}{n_{.j}}. \qquad [1]$$

Detection probability at Bonneville Dam on day i was then estimated as,

$$\hat{P}_i = \frac{n_{i.}}{n_{i.} + \hat{u}_{i.}}, \qquad [2]$$

where $n_{i.}$ is derived from the subset of fish detected at both locations and represents the number of fish detected at Bonneville Dam on day i summed across all days j. Like Sanford and Smith (2002), when $n_{.j}$ was equal to zero, we apportioned u_j to passage dates at Bonneville Dam based on the distribution of fish travel times from Bonneville to the downstream trawl for the entire (year-specific) data set.

To characterize variability around daily detection probabilities, we estimated approximate 95% confidence intervals using a resampling approach (e.g., Efron 1979). Specifically, for each year, empirical distributions were resampled randomly with replacement until the resultant data set was the same size as the original. Daily detection probabilities were then estimated as above. This was repeated until daily distributions of 3,000 estimates were generated. Approximate 95% confidence intervals where then calculated for each estimate of daily detection probability as the 2.5th and 97.5th percentiles of the simulated distributions.

Linear modeling

Candidate predictor variables

We selected an initial set of seven predictor variables to include in regression analyses based on their putative ability to explain variation in detection probability at Bonneville Dam. Variables included: daily inflow (kcfs), mean daily spill proportion, mean daily forebay temperature (°C), corner collector (0 = not in operation [2000–2003], 1 = in operation [2004–2017]), the ratio of mean daily powerhouse 1 flow to mean daily powerhouse 2 flow, screens (the number of screens in place in powerhouse 2 units; 1–8) and day of year. Daily values for predictor variables were paired with detection probability estimates for days where suitable detection probability could be estimated.

Variable assessment

To assess the importance of the candidate variables in explaining variation in detection probability, in the 2018 CSS Annual Report, we fit a full model relating detection probability, transformed to a logistic function, to all seven candidate predictor variables. The full model was of the form:

$$\log_e\left(\frac{\hat{P}_{i,j}}{1-\hat{P}_{i,j}}\right) = \beta_0 + \beta_1 \cdot X_{1,i,j} + _{\dots} \beta_7 \cdot X_{7,i,j} + \varepsilon_{i,j}, \qquad [3]$$

where β_0, β_1,…, β_7 are regression parameters, $X_{1,i,j}$,…, $X_{7,ij}$ are values for predictor variables indexed by day i in year j and $\varepsilon_{i,j} \sim N(0, \sigma_\varepsilon^2)$. Diagnostic plots for the full model where then reviewed to ensure adherence to parametric assumptions and variance inflation factors (VIF) were calculated to assess multicolinearity. To isolate important variables, we then applied a foreword selection procedure based on Akaike information criterion (AIC). First, a null (intercept-only) model was fit to the data and AIC was calculated. Univariate models were then fit with each candidate variable from the full model as individual predictors and AIC was calculated for each model. The null and all univariate models were ranked according to AIC and the best univariate model was selected. Bivariate models were then fit by adding remaining candidate variables independently to the most highly supported univariate model. The bivariate model with the lowest AIC was selected. Accordingly, models with three terms were then fit by adding remaining candidate variables, one at a time, to the best bivariate model, and the best three-term model (i.e., lowest AIC) was selected. This procedure was repeated until the addition of further variables provided no more support relative to the best model from the prior step (i.e., AIC stabilized).

Predictive properties

To gauge the ability of the reduced equation formulated in 2018 to predict samples not used to fit the model (i.e, out-of-sample observations), we applied a routine in which the reduced model was fit to all data excluding one year. Predictions were then made for the year that was not included in the fitting routine. This was repeated so that each year (2000–2017) was left out once. Predicted and estimated/observed values were then plotted to visualize correspondence. Further, to formally evaluate the ability of the reduced model to predict out-of-sample detection probabilities, we calculated an index of agreement (d_r; Willmott et al. 2011) as,

$$d_{r=} \begin{cases} 1 - \frac{\sum_{i=1}^{n} |P_i - O_i|}{2 \sum_{i=1}^{n} |O_i - \bar{O}|}, \text{when} \\ \sum_{i=1}^{n} |P_i - O_i| \leq c \sum_{i=1}^{n} |O_i - \bar{O}| \\ \frac{c \sum_{i=1}^{n} |O_i - \bar{O}|}{\sum_{i=1}^{n} |P_i - O_i|} - 1, \text{when} \\ \sum_{i=1}^{n} |P_i - O_i| > c \sum_{i=1}^{n} |O_i - \bar{O}| \end{cases}, \quad [4]$$

where P_i are predicted values, O_i are estimated/observed values and d_r can take on any value from -1 to 1 where values approaching +1 indicate better model (predictive) performance.

Passage estimation

Estimates daily passage at Bonneville Dam were calculated by dividing daily collections (i.e., sample count/sample rate) of tagged and un-tagged fish in the juvenile bypass system–enumerated by the Smolt Monitoring Program–by the corresponding estimate of detection probability,

$$\hat{N}_i = \frac{n_{coll_i}}{\hat{P}_i} . \quad [5]$$

We then summed estimates across the spring migration season in a given year to arrive at a total passage estimate for that period,

$$\hat{N}_. = \sum_{i=1}^{s} \hat{N}_i . \quad [6]$$

Owing to a paucity of detections (e.g., where $n_{i.}$ = 0) on some days throughout annual time series used to estimate detection probability, some gaps in the daily passage series exist. We compared two approaches to dealing with these situations. First, we applied the reduced linear model developed in our assessment of variable importance to predict detection probabilities when they could not be estimated directly. These times series, combining direct and model-predicted estimates, were then used to calculate daily and season-wide passage, as above. We compared this to a second approach in which passage estimates were calculated based solely on model-predicted detection probabilities. For each method, bootstrap (bias-corrected accelerated; Efron and Tibshirana 1993) 90% confidence intervals (R = 10,000) around annual passage estimates were estimated. Because the sum of daily passage estimates is observed, these confidence intervals represent the range of potential outcomes if a number of independent (daily) estimates were generated in a similar manner.

Examining model refinement

Commenting on the 2018 CSS Annual Report, the ISAB suggested (ISAB 2018) that a plot of the correspondence between detection probabilities estimated directly versus those predicted from the best-supported linear model (Figure 8.6; see Methods: Linear modeling) indicated a non-linear model might be more appropriate. With this in mind, in the current report we assessed the benefit of accounting for potential non-linearity in our prediction model. We also explored the influence of serial dependence on predictions by modeling two error structures in conjunction with a linear predictor and models allowing for non-linear terms. The foundation for the suite of models developed to explore refinement was the simple linear model presented in the 2018 CSS Annual Report, where logit detection probability was related to spill proportion, a variable indicated whether the corner collector was in operation, the ratio of powerhouse 1 flow to powerhouse 2 flow, a variable indicated the number of screens in-place in the powerhouse 2 units and day of year. All analyses were conducted in the R computing environment (R Core Team 2019).

Non-linearity

To assess the ability to constrain prediction error by accounting for potential non-linearity, we fit a suite of generalized additive models (GAM; Hastie and Tibshirani, 1986), where smooth functions were applied to continuous covariates individually or in combination (Table 8.1). For this exercise, we defined smooth terms using thin plate splines with shrinkage. To select the dimension of the basis used to represent smooth terms (k; maximum degrees of freedom allowed), we examined plots of restricted maximum likelihood values (-REML) versus k, where the optimal basis dimension for a given model was the value at which -REML stabilized (e.g., Figure 8.1). Models were then fit to the data, and a simulation-based check was conducted to assess the adequacy of the selected basis dimensions. Model fitting and basis dimension checks were conducted using the gam and gam.check functions respectively in the mgcv package (Wood 2017). Diagnostic plots also were examined to ensure adherence to parametric assumptions. All smooth terms were found to be significant at $\alpha = 0.05$.

Error structure

Given our data effectively represent annual time series, we examined autocorrelation (ACF) and partial autocorrelation (PACF) functions of residuals from the simple linear model presented in the 2018 CSS Annual Report to assess the presence of serial dependence and to identify potential correlation structures. Plots of ACF and PACF indicated the presence of autocorrolated errors and suggested residual structure may best be modeled as a second-order autoregressive function (AR(2); Figure 8.2). We then fit a linear model where serial correlation was represented as an AR(2) process within years. To account for irregular spacing within time series, we included day of year as a covariate when specifying the error structure (i.e., form = ~doy|year). We also fit for comparison a second model where residual error was represented as a first-order autoregressive process (AR(1); Table 8.1). Model fitting was conducted using the gls function in the nlme package (Pinheiro et al. 2019). Diagnostic plots also were examined to ensure adherence to parametric assumptions.

Predictive performance of refined models

To assess the predictive performance of the models described above, we applied the same validation routine conducted previously (see Methods: Predictive properties). However, in addition to calculating d_r to formally assess correspondence among estimated and predicted detection probability, we compared models using the relative performance metric median symmetric accuracy (MSA; Morley et al. 2018), with MSA calculated as:

$$MSA = e^{median\,(|\log(\frac{P_i}{O_i})|)-1} \cdot 100, \qquad [7]$$

where P_i are predicted values, O_i are estimated/observed values.

Combined models

The suite of models developed during our exploration of the influence of non-linearity and serial dependence on predictive properties were compared in two ways: (1) by visualizing plots of correspondence among out-of-sample estimated and model predicted detection probabilities (Figure 8.8) and (2) by considering performance metrics (i.e., d_r and MSA; Table 8.1). Based on this review, we fit two additional models combining elements of the best performing prior models. Specifically, we evaluated formulations where smooth terms were applied to the spill proportion and day of year covariates and residual error was modeled as either an AR(2) or AR(1) process (again, serial dependence was considered within years, indexed by day of year; Table 8.1). These final models represented generalized additive mixed models (GAMM) and were fit using the gamm function in the mgcv package (Wood 2017). We conducted the same validation routine as above to both visualize and assess more formally correspondence between estimated and predicted detection probabilities. Further, diagnostic plots were examined to ensure adherence to parametric assumptions. As before, all smooth terms were found to be significant at $\alpha = 0.05$.

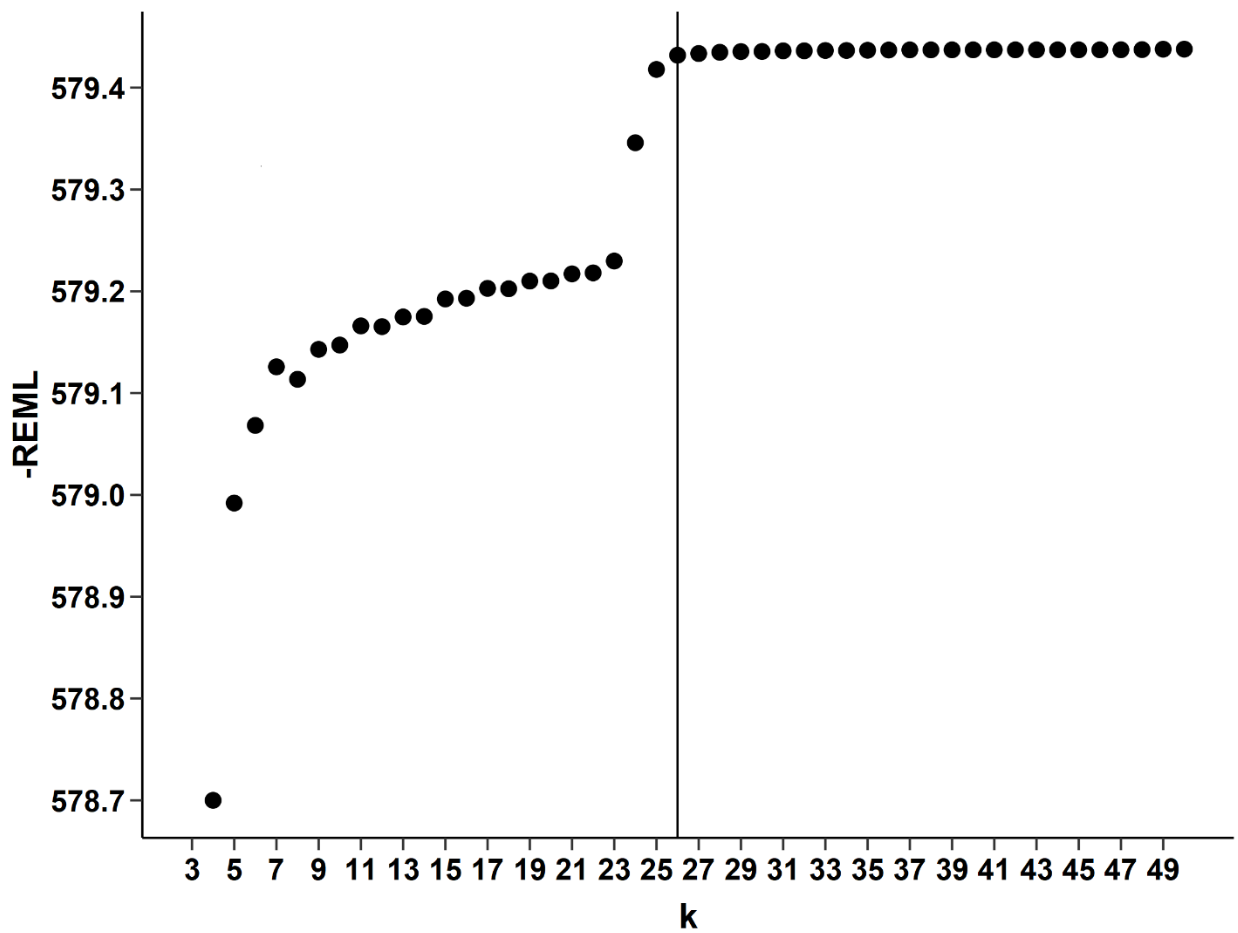


Figure 8.1. Example plot of -REML (restricted maximum likelihood) versus k used to select basis dimensions (k; maximum allowable degrees of freedom) for generalized additive models included in the assessment of model refinement. The solid vertical line indicates the value of k at which -REML appears to stabilize.

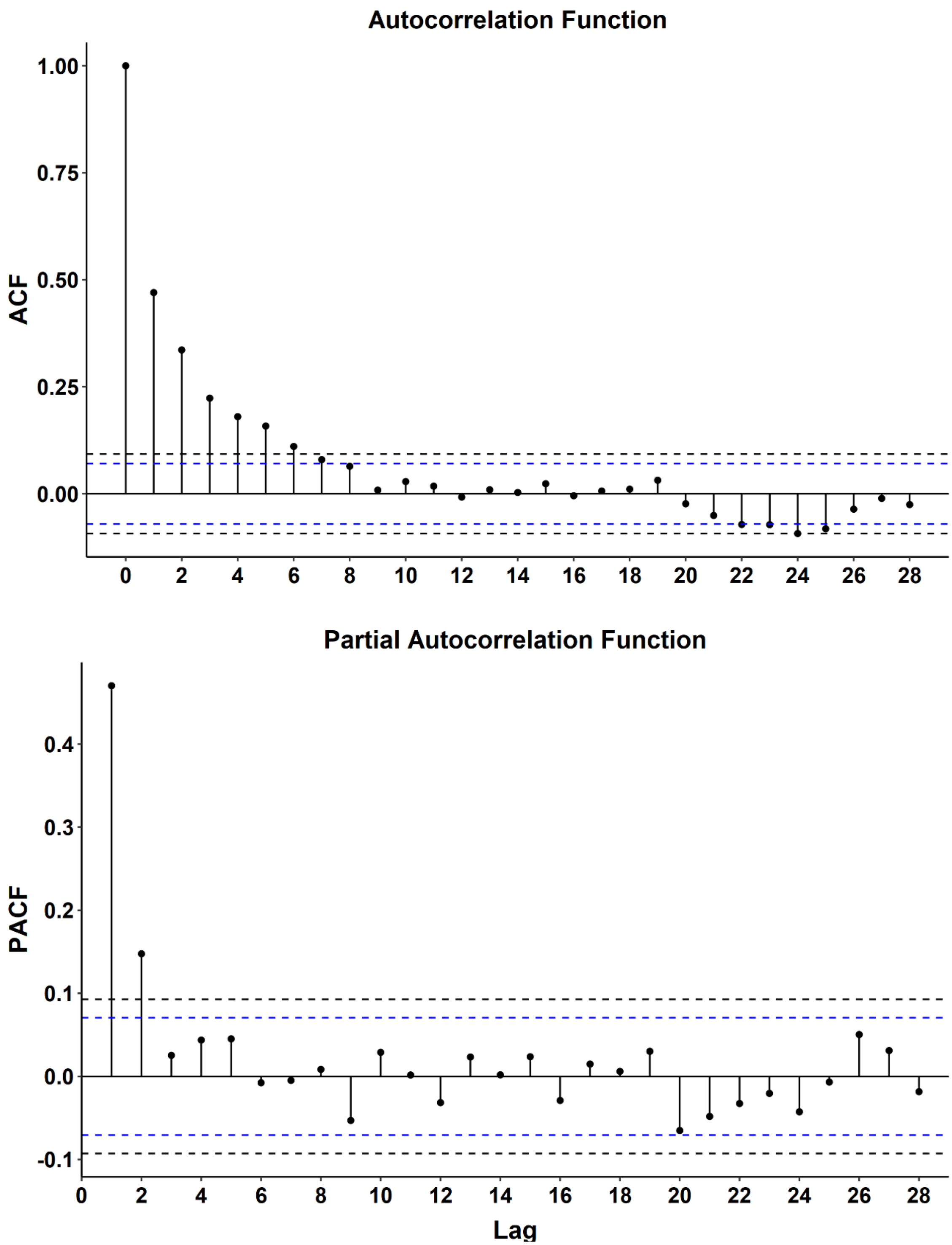


Figure 8.2. Autocorrelation and partial autocorrelation functions used to assess the presence of serial dependence and the order of autoregressive and moving average terms in potential models. Functions were fit to residuals from the reduced model identified in the 2018 CSS Annual Report (see Methods: Linear modeling). The black (dashed) horizontal line represents 99% confidence intervals. The blue (dashed) horizontal line represents 95% confidence intervals.

Results

Detection probability

Estimates of detection probability at Bonneville Dam varied both among and within years. Approximate 95% confidence intervals generally were broader at the beginning and end (i.e., the tails) of annual time series than in the middle. The most apparent exception to this occurred in 2001, where estimated confidence intervals were relatively broad throughout the time series (Figure 8.3). On average, the largest estimates occurred in 2001 (mean = 0.28 ± 0.09 s.d.) and the smallest during 2011 (mean = 0.05 ± 0.03 s.d.) and 2017 (mean = 0.05 ± 0.02 s.d.). The largest estimated detection probabilities corresponded to a year (2001) during which spill was curtailed substantially relative to the other years we considered. Further, inter-annual variation in mean detection probability from 2000 through 2006 was considerably greater (coefficient of variation = 44%) than the period between 2007 and 2017 (coefficient of variation = 17%; Figure 8.4).

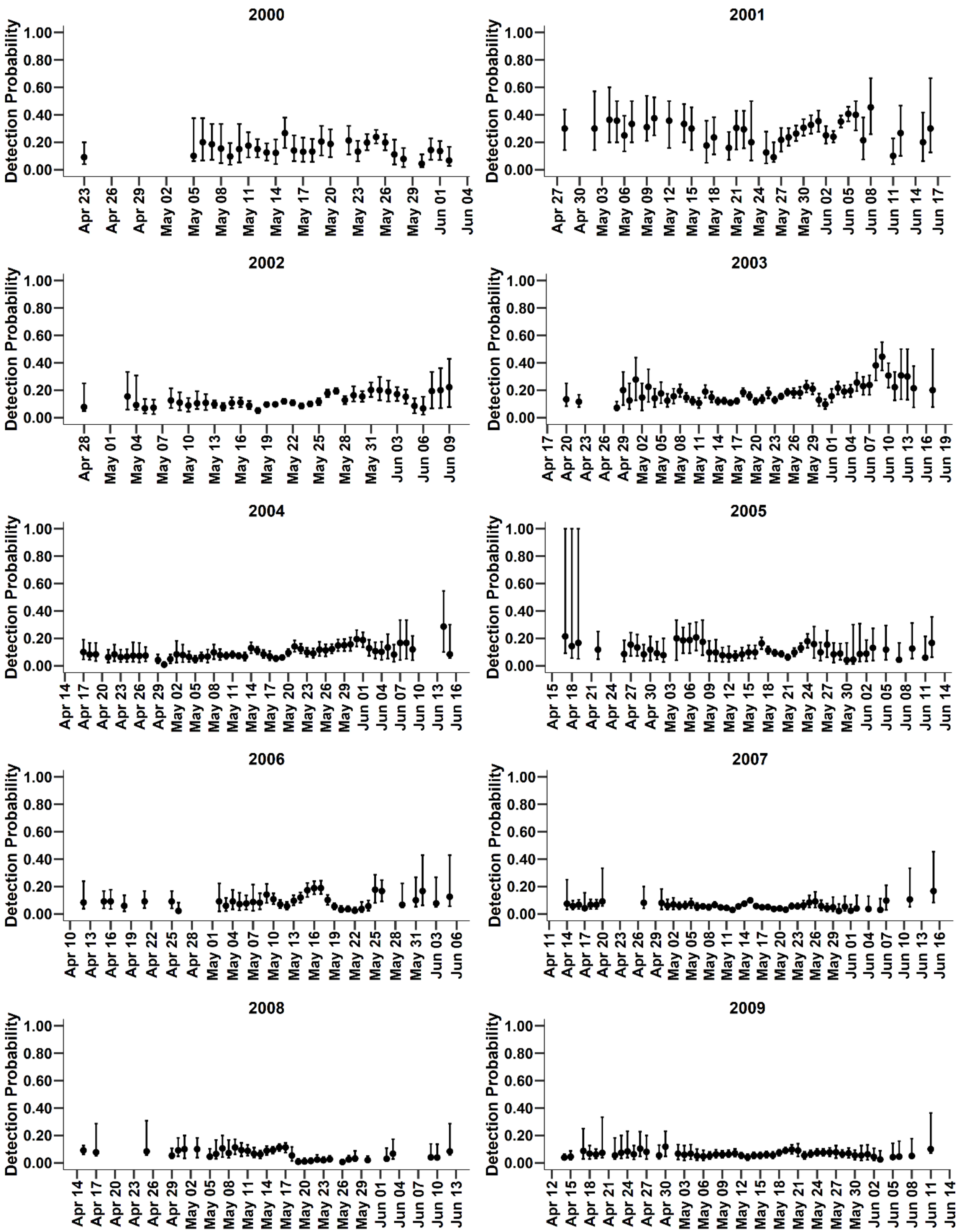


Figure 8.3. Time series of detection probabilities estimated for spring migrant yearling Chinook salmon passing Bonneville Dam, 2000–2017. Missing values correspond to days in which detections were insufficient to calculate detection probabilities. Error bars represent bootstrap approximate (quantile) 95% confidence

intervals.

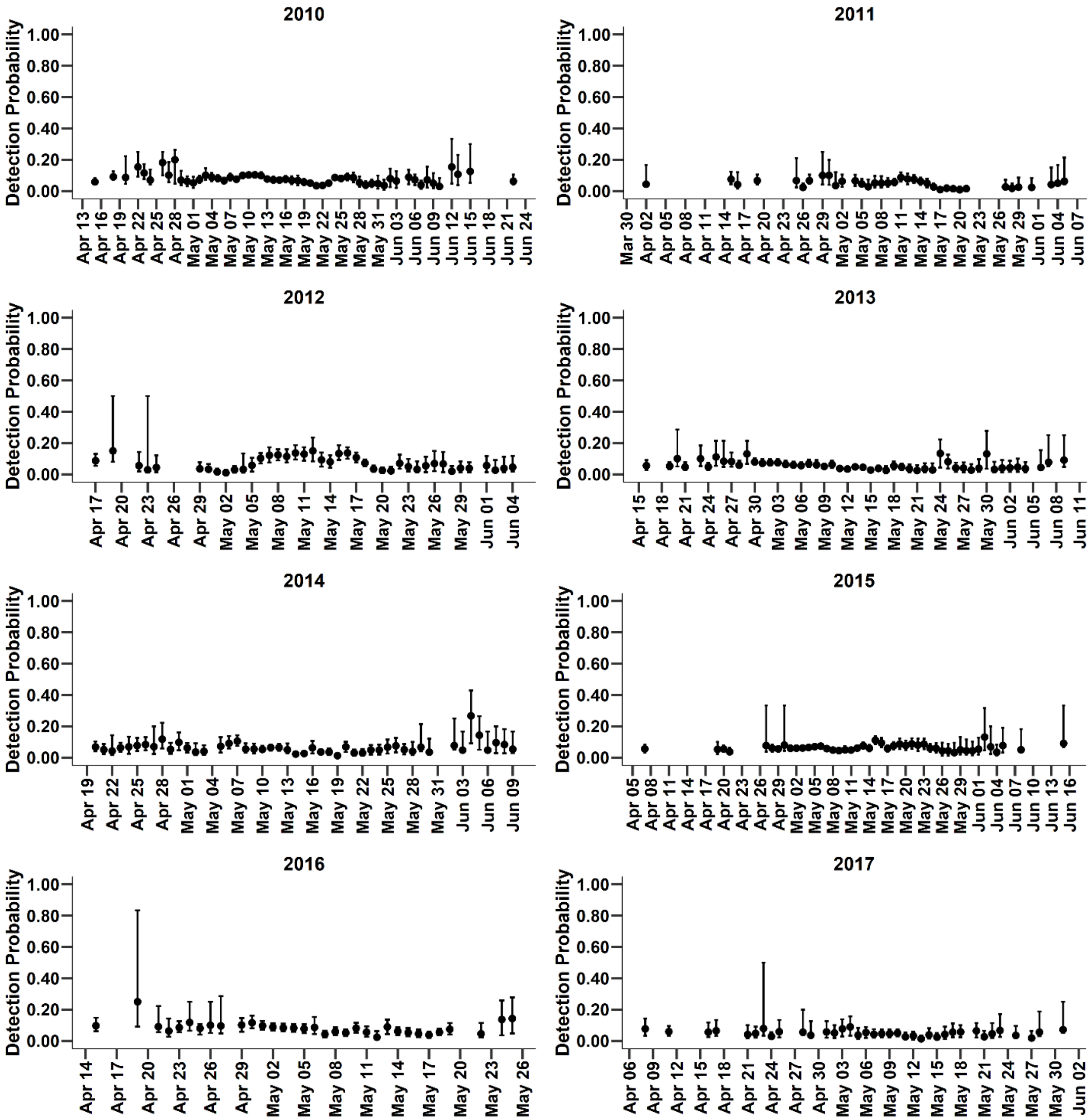


Figure 8.3 (cont.). Time series of detection probabilities estimated for spring migrant yearling Chinook salmon passing Bonneville Dam, 2000–2017. Missing values correspond to days in which detections were insufficient to calculate detection probabilities. Error bars represent bootstrap approximate (quantile) 95% confidence intervals.

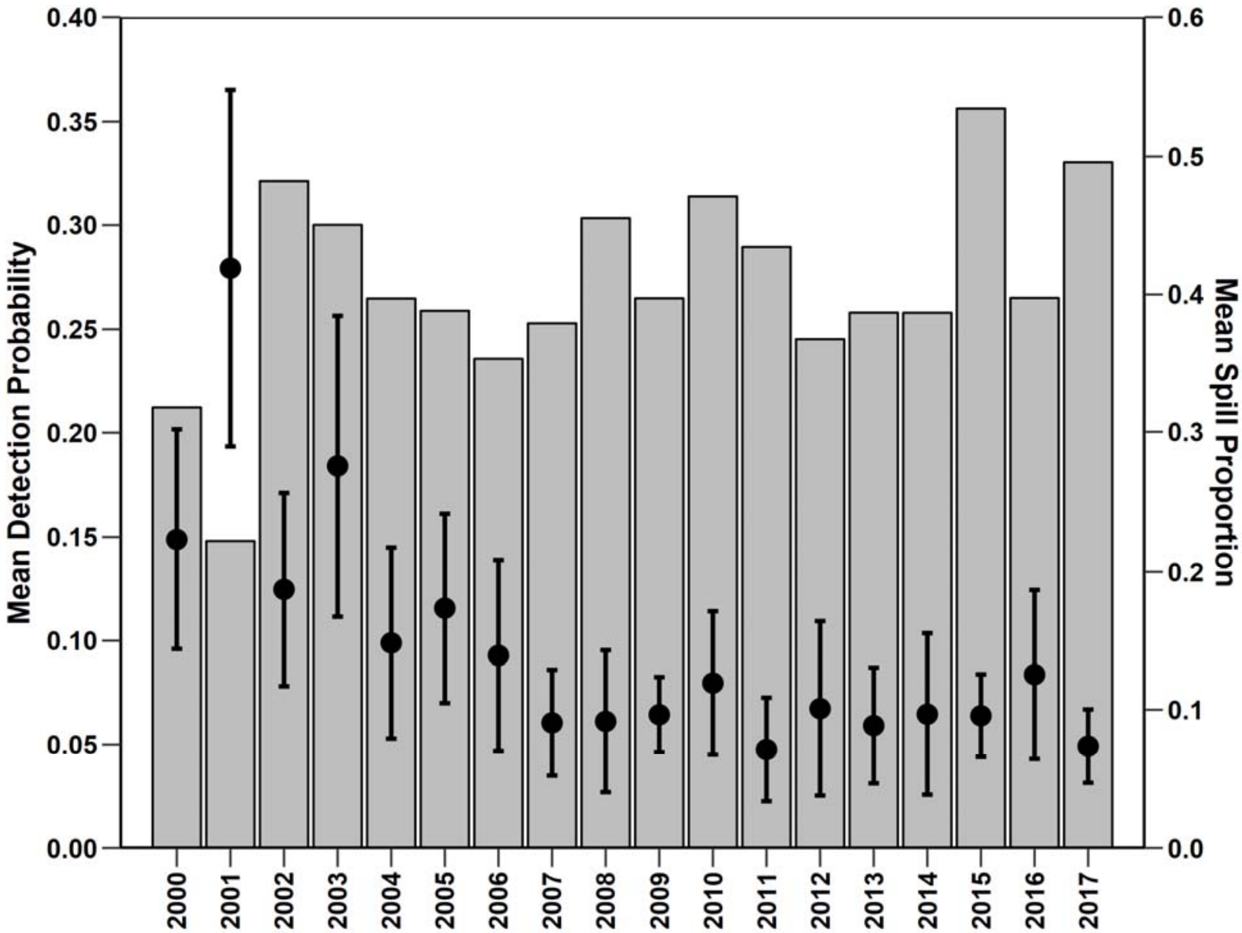


Figure 8.4. Mean estimated detection probability (black circles) and mean spill proportion (grey bars) at Bonneville Dam, 2000–2017. Detection probability values are the mean of daily values in Figure 1 for a given year; spill proportion represents the mean of values corresponding to daily detection probabilities. Error bars represent ± 1 standard deviation.

Linear modeling

Assessment of diagnostic plots indicated that primary parametric assumptions were not violated. Variance inflation factors showed temperature may contribute to collinearity; thus, that variable was not considered in the global model. The most highly supported model from our selection procedure included as predictor variables: spill proportion, corner collector, the ratio of powerhouse 1 flow to powerhouse 2 flow, screens and day of year. This reduced model explained approximately 50% of the variation in logit detection probability. The signs of parameter estimates for variables included in the reduced mode indicated logit detection probability at powerhouse 2 increased with decreasing spill proportion, increased as the ratio of powerhouse 1 flow to powerhouse 2 flow decreased and, on average, was greater when the corner collector was not in operation (i.e., prior to 2004). Conversely, logit detection probability increased with a greater number of screens in-place in the powerhouse 2 units and as day of year increased (i.e., on average, logit detection probability was greater at periods later in the outmigration; Figure 8.5).

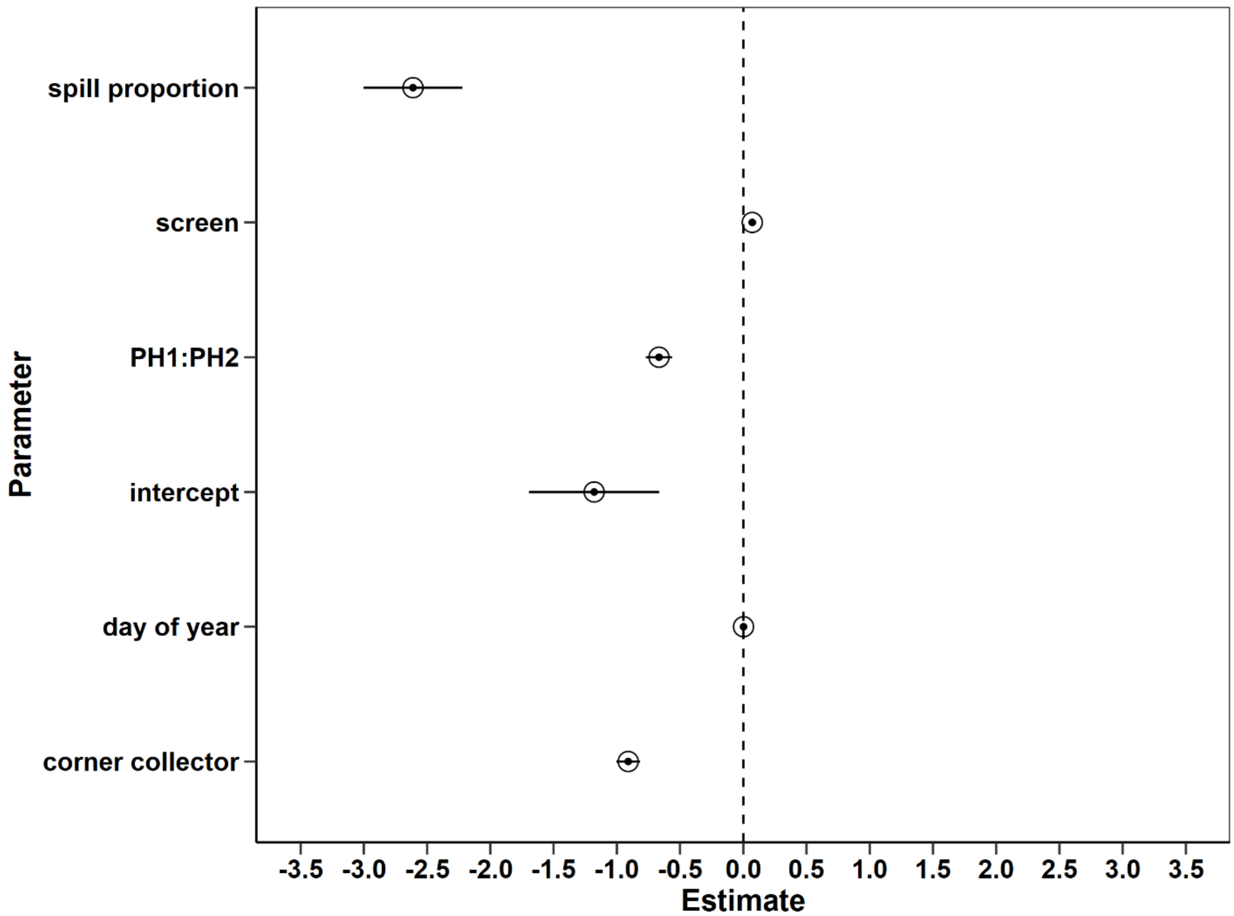


Figure 8.5. Parameter estimates (black circle) and 95% confidence intervals (horizontal lines) for the effects of predictor variables included in the reduced model.

Predictive properties

The best fitting model in many instances appeared to predict out-of-sample estimates reasonably well. This was substantiated by the index of agreement, where the calculated value (0.614) approached one, with an index value of one essentially indicating perfect agreement between predicted and observed/estimated values. This correspondence was particularly true for predictions made at the lower range of estimated values (e.g., ~ 0.0–0.15); where most direct estimates of detection probability fell. As might be expected, model predictions appeared more tenuous as direct estimates moved away from the mean (Figure 8.6).

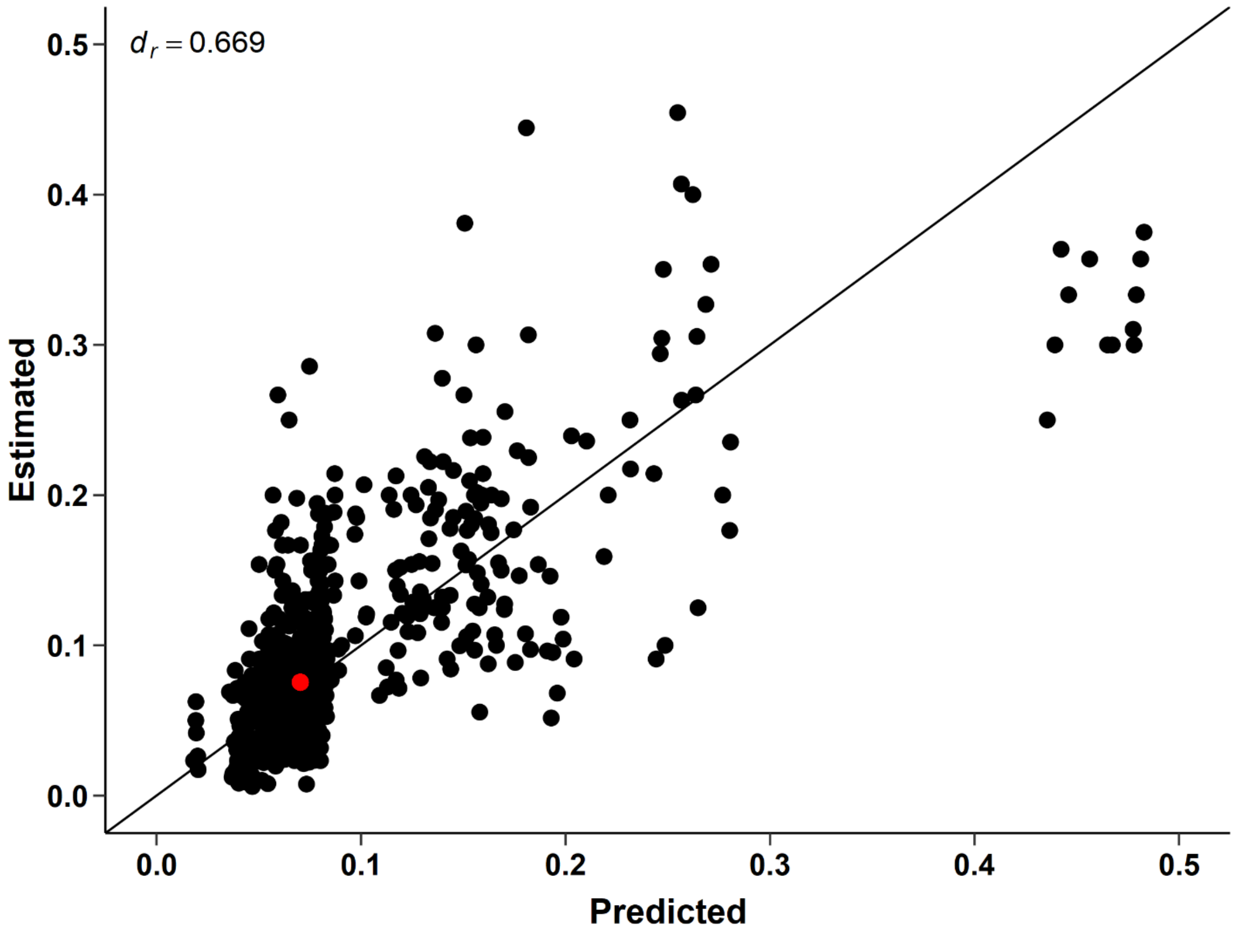


Figure 8.6. Correspondence between estimated detection probabilities and out-of-sample predictions. The solid line denotes perfect correspondence (i.e., 1:1) and dr is an index of agreement (Willmott et al. 2011), where values closer to 1.0 indicate better predictive performance. The red point indicates correspondence between the median estimated and median predicted values across the time series.

Preliminary passage estimates

We applied two different methods to arrive at the time series of detection probabilities underlying daily, and ultimately annual, estimates of passage at Bonneville Dam (see Methods). Across years, these approaches produced generally similar results (r = 0.69) and, at times, passage estimates were essentially equivalent (e.g., 2001, 2005, 2006). Yet, some pairwise comparisons of passage estimates showed relatively broad contrast (e.g., 2003). The direction of discrepancies was inconsistent among years. For example, in 2003, the estimate generated by applying an approach whereby the entire time series of detection probabilities was predicted using the linear model was much greater than the estimate where a combination of direct and predicted detection probabilities were used to expand collection counts; in 2008, the opposite was true. Across years, bootstrap intervals were generally wide, indicating the approach used to estimate annual passage can result in a broad range of values (Figure 8.7).

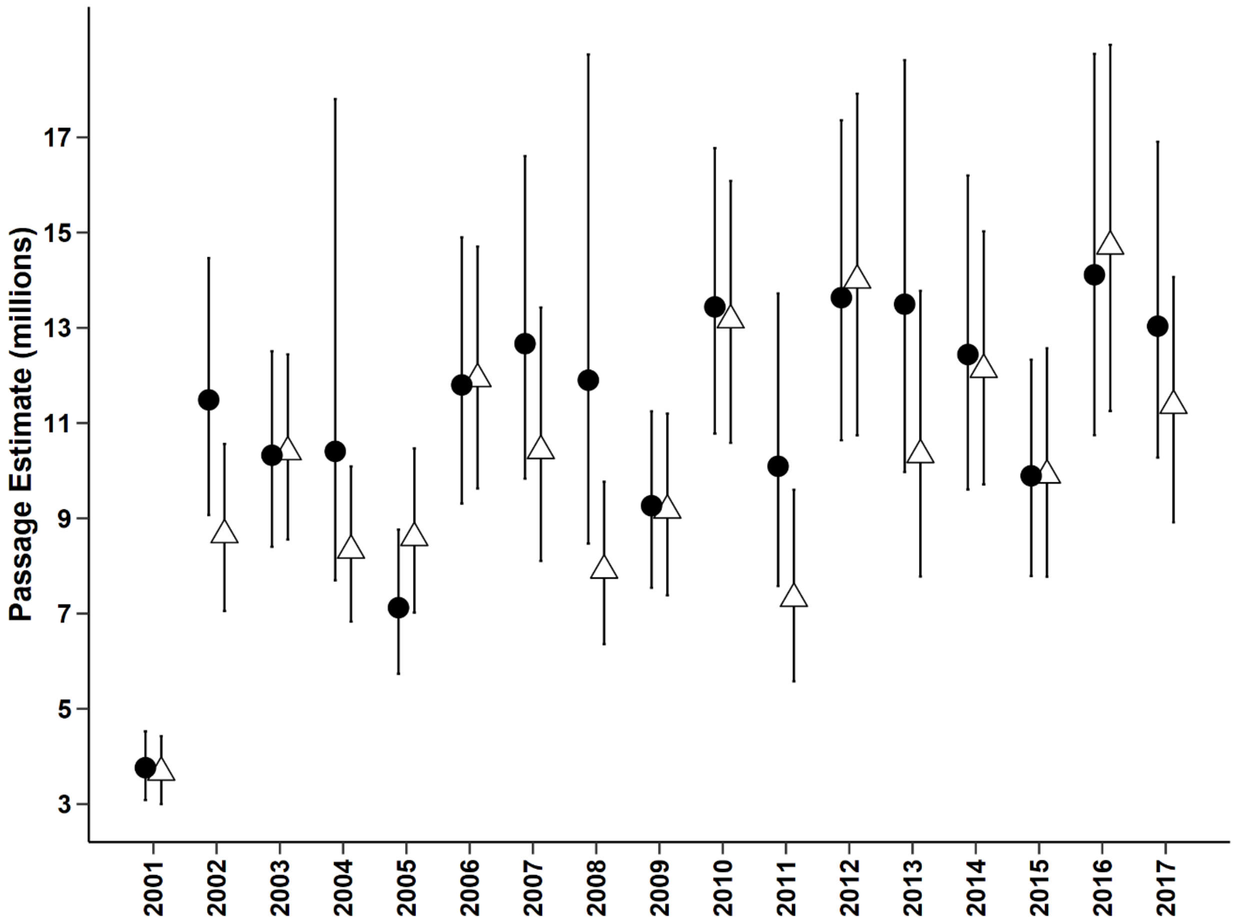


Figure 8.7. Estimated total passage of yearling Chinook salmon during the spring outmigration, 2001–2017. Values represented by black circles were estimated using the linear model to predict detection probabilities during those periods where probability could not be estimated directly. Values represented by triangles were estimated using a linear model to predict detection probabilities for entire time series. Error bars represent 90% bootstrap (bias-corrected accelerated) confidence intervals.

Examining model refinement

All refined models performed better than the base model presented in the 2018 CSS Annual report, yet among the refined models, improvements–in terms of performance metrics–appeared to be marginal. Of the refined models that accounted for non-linearity, the best performing included smooth terms on spill proportion and day of year. Linear models that accounted only for serial dependence were comparable, nonetheless ranked among the highest performing of the entire suite (Table 8.1; Figure 8.8) Models accounting for serial correlation (i.e., models 9–12; Figure 8.8) seemed to assuage at least some of the overestimation at extreme predicted values alluded to by the ISAB (ISAB 2018). Yet, the best performing model included smooth functions on spill proportion and day of year with the correlation structure modeled as an AR(1) process (Table 8.1).

Table 8.1. Properties of models developed to assess relative predictive performance and model-specific estimates of metrics to characterize correspondence between estimated and predicted detection probabilities.

Model No.	Model Class	Response	Family (link function)	Smooth Term (var(s), class, basis dimension [k])	Correlation Structure (form)	d_r [2]	MSA[3]
1	*gls*	logit($\hat{P}_i$)	Gaussian			0.6693	49.0684
2	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop.|PH1:PH2|day of year, ts[1], 25		0.6879	48.7795
3	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop.|PH1:PH2, ts[1], 26		0.6704	49.0593
4	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop.|day of year, ts[1], 26		0.6894	48.5850
5	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	PH1:PH2|day of year, ts[1], 19		0.6734	48.7482
6	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop., ts[1], 26		0.6728	49.0475
7	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	PH1:PH2r, ts[1], 21		0.6679	49.0621
8	*gam*	logit($\hat{P}_i$)	Gaussian (identity)	day of year, ts[1], 19		0.6757	48.8264
9	*gls*	logit($\hat{P}_i$)	Gaussian		AR2 (day of year|year)	0.6844	48.4568
10	*gls*	logit($\hat{P}_i$)	Gaussian		AR1 (day of year|year)	0.6845	48.4452
11	*gamm*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop.|day of year, ts[1], 26	AR2 (day of year|year)	0.6806	49.0097
12	*gamm*	logit($\hat{P}_i$)	Gaussian (identity)	spill prop.|day of year, ts[1], 26	AR1 (day of year|year)	0.6900	48.5231

Note:
[1]ts = thin plate spline with shrinkage
[2]IOA = Index of Agreement (see Results: Predictive properties)
[3]MSA = Median Symmetric Accuracy (see Methods: Examining model refinement)

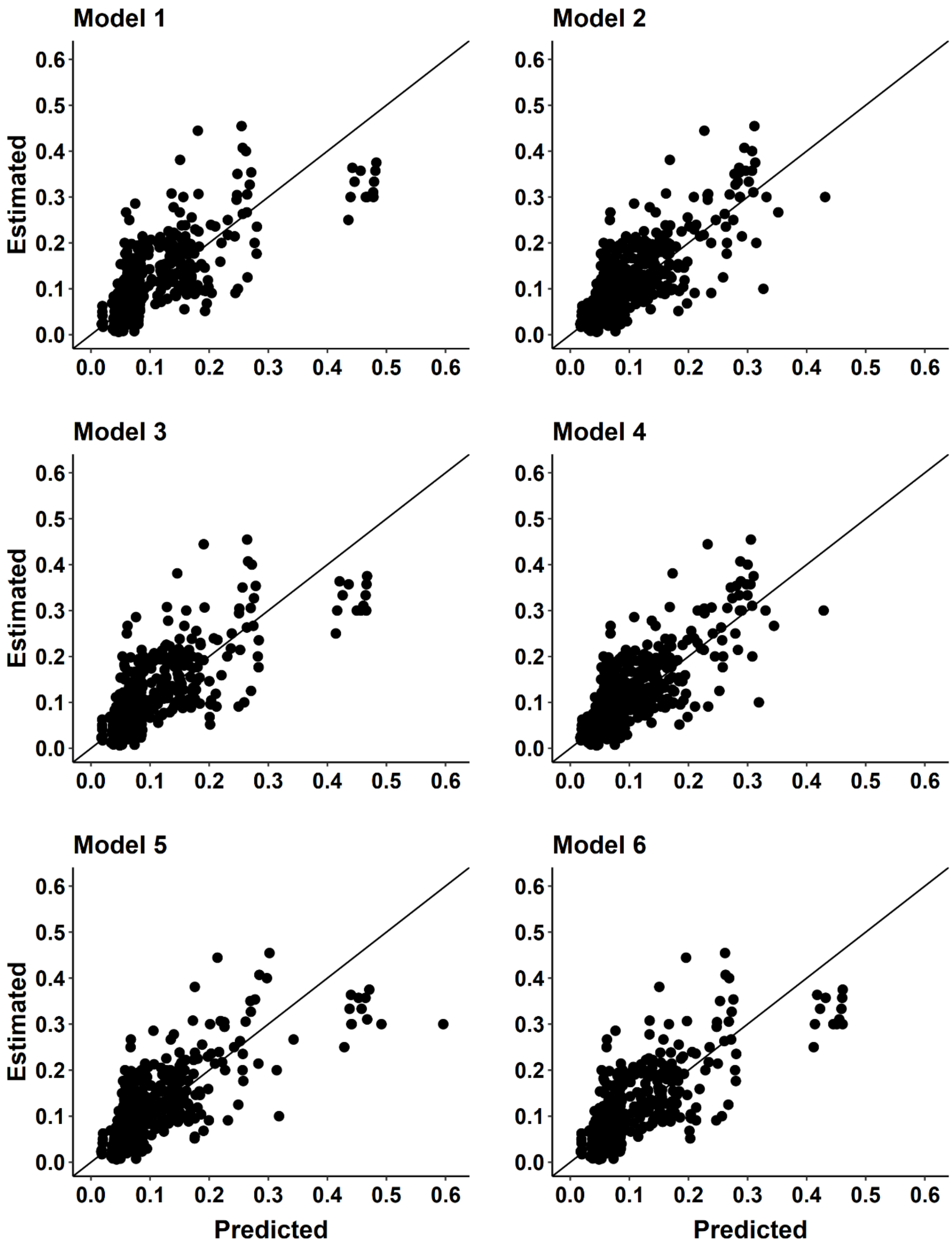


Figure 8.8. Correspondence between estimated detection probabilities and out-of-sample predictions for the suite of models fit to examine refinement of the linear model developed in the 2018 CSS Annual Report (Model 1 above). The solid line denotes perfect correspondence (i.e., 1:1). Model properties and performance metrics are shown in table 1.

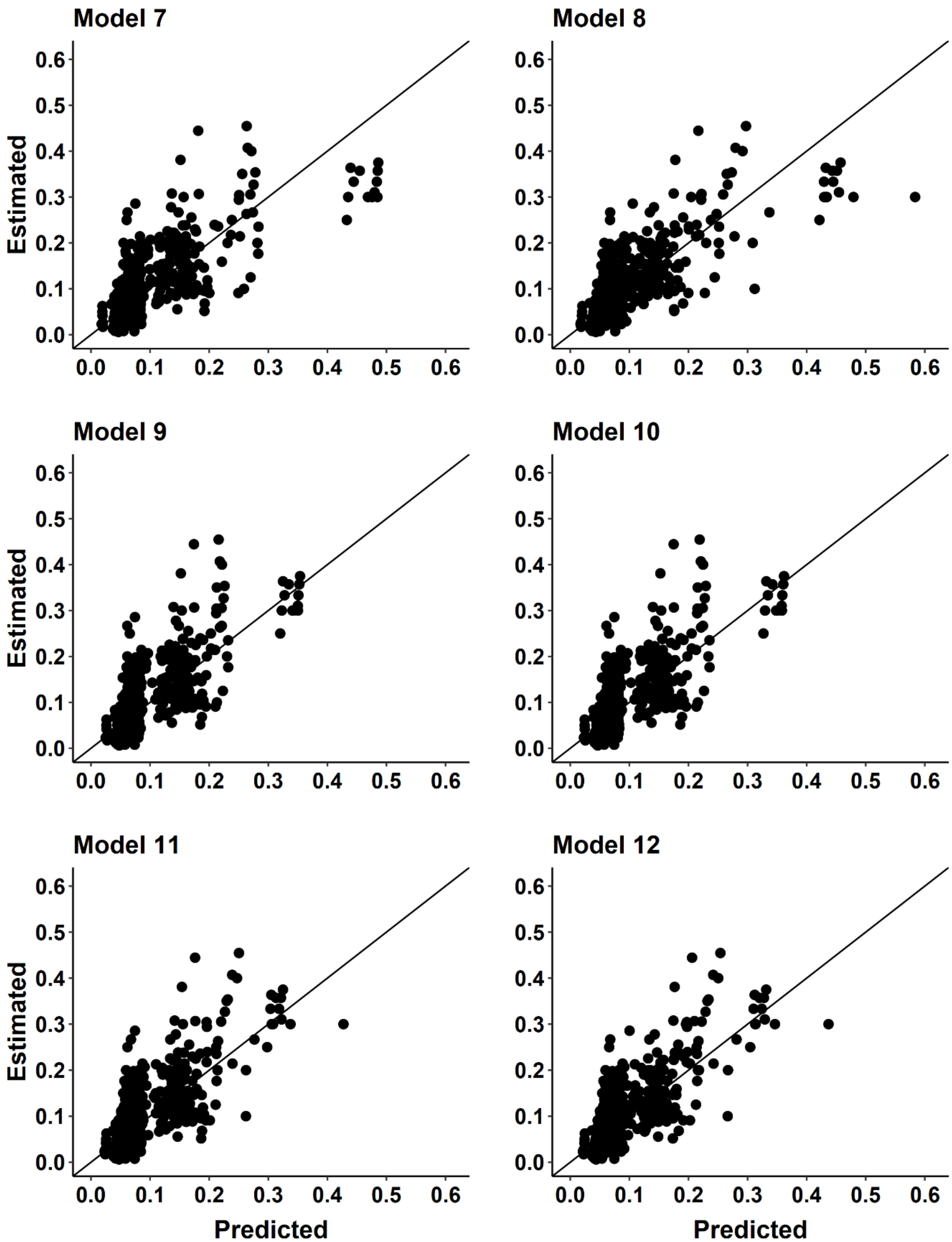


Figure 8.8 (cont.). Correspondence between estimated detection probabilities and out-of-sample predictions for the suite of models fit to examine refinement of the linear model developed in the 2018 CSS Annual Report (Model 1 above). The solid line denotes perfect correspondence (i.e., 1:1). Model properties and performance metrics are shown in table 1.

Discussion

The approach we presented in the 2018 CSS Annual Report to characterize detection probabilities at Bonneville Dam provided relatively continuous time series of direct estimates and appeared sensitive to large contrasts in hydrosystem operations. As in our analysis, other studies have highlighted associations between spill proportion and detection probability (e.g., Connor et al. 2009; Faulkner et al. 2017). One would expect higher detection probabilities during periods where little or no spill was provided. Among the years we considered, the greatest detection probability occurred in 2001, coinciding with the lowest mean spill proportion. There are of course other factors that explain variation in our estimates of detection probability (discussed below), but the contrast between 2001 and other years, indicate values resulting from this approach can reflect large operational changes one would expect to affect detection probability. Similarly, we found inter-annual variation in detection probabilities was considerably greater during the period from 2000–2006 compared to the years following. This may at least partially reflect operational changes occurring during those periods. For example, with implementation of the 2007 Operations Agreement and release of the 2008 Biological Opinion, operations throughout the FCRPS, including at Bonneville Dam, became more consistent relative to the prior periods (e.g., 2000–2006; FPC 2012, Memo 46-12). Reliable estimates of detection probability derived using the approach we applied are dependent on sufficient detections at Bonneville Dam or the downstream trawl. The effect of scarce detections is apparent in the broadening of confidence intervals toward the beginning and end of time series in most years, or in some cases, relatively wide confidence intervals throughout the time series; for example in 2001, where very little spill was provided–including at Bonneville Dam–and a majority of fish were transported at collector projects. In addition, survival of fish that remained in-river was very low.

The impetus for developing a simple linear model relating estimated detection probabilities to select environmental covariates was two-fold: (1) to provide an initial assessment of factors that may be important in explaining variation in detection probability at Bonneville Dam and (2) to develop and evaluate a tool for use in generating predictions across an entire period or on days where estimates cannot be obtained directly (e.g., when detections are insufficient). To the former, our 2018 analysis provided some insight into variables that influence estimates of detection probability at Bonneville Dam. Daily detection probability at dams depends in part on the efficiency of screens to divert fish entering the powerhouse toward the juvenile bypass system (Connor et al. 2009). Thus, if screens are removed for any reason, detection probability can decrease greatly. The sign of the fitted parameter corresponding to our screen variable was consistent with this logic; we found detection probability increased as the number of screens in-place increased. A negative relationship between spill or spill proportion and detection probability has been documented previously at Lower Granite Dam (e.g., Connor et al. 2009). Our results show likewise a significant negative relation between detection probability and spill proportion at Bonneville Dam. Bonneville dam is unique in its arrangement of two powerhouses separated by a spillway. With this in mind, diversion of flow away from the second powerhouse towards the first would presumably result in lower detection probability, where estimates are based on detections at the juvenile bypass. This was the rationale for including a variable characterizing the ratio of powerhouse 1 to powerhouse 2 flow, and as anticipated, our results indicated that as more flow is diverted to powerhouse 1 estimated detection probabilities decrease. We found, on average, estimates of detection probability were higher prior to the beginning of operation of the corner collector (i.e., 2004). This also is likely an artifact of the diversion of flow, and consequently juvenile fish, away from the powerhouse 2 bypass. Despite having been included in our model as a result of the selection procedure, the magnitude of the parameter estimate for day of year was extremely close to zero. This may indicate there is only a weak seasonal component to our data or seasonality in logit detection probability would be better characterize as a nonlinear function. Regardless, the magnitude of the parameter estimates seems to bring into question the utility of including day of year in a model meant for the purpose of prediction. Our best-fitting model explained approximately half of the variation in estimated detection probabilities. As presented below (Examining model refinement), work to better account for this variation will continue.

In 2018, we explored the utility of our best-fit linear model as a predictive tool to supplement direct estimates of detection probability or to provide an efficient means of predicting detection probabilities across a period without relying on direct estimation. Towards these purposes, out-of-sample predictions in some instances corresponded relatively well with direct estimates. As might be expected, this was particularly true at the lower range of detection probabilities, where a vast majority of values occurred. As direct estimates became more sparse, predictive performance appeared to suffer. In light of this point this point, and given the ISAB's comment to the 2018 report that "There appears to be overestimation happening for larger predicted values…" (ISAB 2018), in the current report, we examined refinements to the model developed to predict detection probabilities to isolate factors that may contribute to prediction error. Considering metrics of predictive performance (i.e., d_r and MSA), all updated models appeared to perform better than the base model presented in the 2018 CSS Annual report. Nonetheless, the magnitude of improvement–when contrasting performance metrics for updated models and the base model and when drawing comparisons among the refined models– generally were marginal. That is, more highly parameterized models showed no marked benefit when entire sets of predictions were considered together. Nonetheless, returning to the ISAB's comment, models accounting for non-linearity and serial dependence seemed to assuage some of this overestimation at larger predicted values; this was particularly evident in plots of estimated versus predicted detection probability values (Figure 8.8). From this standpoint, it appears greater parameterization was able to limit error at extreme predictions and the model allowing for non-linearity while accounting for serial dependence was the most successful. In this exercise, we effectively sought to account for prediction error by testing alternative parameterizations of our simple linear model. Yet, no new covariates were evaluated (i.e., we applied functions to existing covariates or alternative error structure were modeled). It remains possible that some of the error inherent in our predictions is an artifact of omitted-variable bias (OMB) or sources yet to be identified. Future work will explore this potential and seek to isolate other sources of error throughout the entire estimation framework.

The overall goal of this work is to generate passage estimates at Bonneville Dam that can be used to assess population dynamics across time and inform management decisions, or can be applied in broader contexts to elucidate factors (e.g., density dependence) that may affect survival. With this in mind, in the 2018 CSS Annual Report, we presented preliminary estimates of annual passage for yearling Chinook salmon during the spring migration period to show the range of values that might be expected from our overall approach. Future analyses will assess the accuracy of the estimates to aid in further development of the approach. As mentioned above, we calculated passage estimates in two ways: one where collection counts were expanded based on direct estimates of detection probability supplemented with model predictions, and a second where times series used for expansion were generated only from predicted detection probabilities. Comparisons of estimate from these approaches were mixed; during some years, estimates corresponded closely yet in others, discrepancies existed. The discrepancies reflect the sometimes-large prediction error uncovered in our assessment of model performance. Refinements to our predictive model presented in this chapter may assuage some of this discrepancy, but further refinements will undoubtedly be necessary.

The work presented here represents a continuation in development of a framework to estimate total passage at Bonneville Dam. Preliminarily, we focused on yearling Chinook salmon as a "test" group to assess various methods and template for further development. Further development of this approach will incorporate groups of fish beyond yearling Chinook and seek to address the many complications associated with estimating passage abundance at Bonneville Dam; some of which have been discussed above and others that will inevitably arise. Nonetheless, we view previous and these additional results as a promising basis upon which to further expand. We agree with the ISAB that a metric characterizing total passage dynamics Bonneville Dam will be useful in elucidating unexplored questions.

CHAPTER 9

A MULTISTATE MODEL TO ESTIMATE UPPER COLUMBIA RIVER SPRING CHINOOK LIFE CYCLE SURVIVAL FROM PASSIVE INTEGRATED TRANSPONDER TAGGING AND DETECTION

Introduction

The Upper Columbia River spring Chinook Evolutionary Significant Unit (ESU) is comprised of spring Chinook Salmon populations in the Wenatchee, Entiat, and Methow rivers. This ESU was listed for protection under the US Endangered Species Act in 1999 and a recovery plan was developed to rebuild the spring Chinook Salmon in the ESU (UCSRB 2007). The recovery plan supported actions to reduce life cycle mortality due to harvest, hatchery practices, hydro-electric operations, and degraded habitat. Despite over 15 years of efforts, in the last status review NOAA Fisheries concluded this ESU remained at a high extinction risk (NOAA Fisheries 2016). In 2017, the Independent Science Advisory Board (ISAB) was asked to review the recovery and research efforts for these spring Chinook Salmon populations (ISAB 2018-1). One ISAB recommendation was to integrate the results of different approaches, including life cycle models "to identify limiting factors to guide future revision of the Biological Strategy of the UCSRB's Regional Technical Team and the Recovery Plan for spring Chinook salmon" (ISAB-2018-1, page 2).

The Comparative Survival Study (CSS) has developed survival metrics using smolt and adult detections of PIT-tagged salmon and steelhead populations as they migrate past Snake and Columbia River dams with PIT tag detection capability. These metrics include time series estimates of smolt-to adult-return (SAR), smolt out-migration timing, juvenile migration rates and travel times, juvenile reach survivals, and using multiple linear regression to evaluate environmental covariates and the link these metrics to survival (Haeseker et al. 2012). These metrics are useful for informing management and recovery decisions related to the monitored populations. In 2013, the CSS began developing life cycle models (LCM) to explore their potential for assessing tributary smolt production, mainstem passage survival, ocean survival, and adult return rates. This approach partitions survival into freshwater and ocean components and provides a detailed analysis of spatial and temporal variability in SAR estimates across Snake River spring Chinook Salmon populations. Tributary productivity is modeled as a density-dependent Ricker spawner-to-smolt recruitment model; survival from smolt emigration to spawning, including ocean residence, is assumed to be density independent. This modeling approach was recently been expanded to the Entiat, Methow and Wenatchee spring Chinook Salmon populations in the Upper Columbia River (McCann et al. 2018).

A complementary approach to LCM is to use the Cormack-Jolly-Seber (CJS) model to estimate the probability of capture and survival of tagged animals between multiple sampling events (Cormack 1964, Jolly 1965, Seber 1965). In the Columbia River, the CJS model is most often used to estimate the survival of juvenile salmonids tagged with PIT tags (Prentice et al. 1990) between dams (Burnham et al. 1987, Skalski et al. 1998), and to assess changes in survival due to modification of dam infrastructure and hydrosystem operations (Haeseker et al. 2012). Buchanan and Skalski (2007) developed a modified CJS life cycle model for Columbia River spring Chinook Salmon that follows a group of PIT tagged fish from their release as smolts to their return as adults; referred to as river-ocean survival and transportation effects routine (ROSTER) model (Buchanan et al. 2007). However, ROSTER does not allow for multi-level or hierarchical modeling, or modeling multiple populations or years simultaneously. Recently, there has been an increased recent emphasis on the PIT tagging of juvenile salmon and steelhead parr in the prior to their outmigration as smolts to better understand migration patterns and overwinter survival (Buchanan et al. 2015), and to characterize adult survival from the last dam to the entry into the natal stream (Richins and Skalski 2018).

In this paper we developed a Bayesian multistate age-structured spring Chinook Salmon modified CJS model to estimate the probability of capture and survival for PIT tagged parr and smolts released from screw traps operated at multiple locations in the Methow, Entitat, and Wenatchee Rivers as they emigrate to the ocean and return as age 3, 4, and 5-year old fish to their natal stream. This modeling is the first unified framework to estimate survival over the entire tagging life cycle of spring Chinook salmon. This approach was developed as an example to more fully utilize the extensive PIT tagging and detection system in the mainstem Columbia River and its tributaries to address parr-to-smolt survival, juvenile survival through the hydro-system, SARs, adult survival from Bonneville Dam to the uppermost dam, and survival from the uppermost dam to their natal streams. This extension provides important quantitative information for salmon recovery and management, and provides additional information for these at risk populations (ISAB 2018-1). In addition, the parameter estimates from this approach can be incorporated into the Methow and Wenatchee spring Chinook Salmon LCM (McCann et al. 2018).

Methods

Study Site/Species

The Methow, Entitat, and Wenatchee Rivers support separate populations of spring Chinook salmon (Figure 1). Adult Spring Chinook Salmon enter the mainstem Columbia River in the spring, migrating upstream to their natal rivers, and holdover during the summer prior to spawning (Mullan et. 1993). Spawning occurs in the middle to upper reaches and tributaries of these rivers. After emergence in the spring, juveniles may complete freshwater rearing near spawning sites but some fish emigrate to the lower portions of these rivers or the Columbia River mainstem to complete rearing (Buchannan et al. 2015). Juveniles smolt after one year and emigrate down the Columbia River reaching the estuary in the spring. Precocial male Chinook Salmon (i.e., jacks) may return after approximately one year in the ocean, while adults return after two or more years in the ocean (Johnson et al. 2012).

Data Collection and Summarization

Emigrating juvenile Chinook Salmon were captured in rotary screw traps in the Methow River (rkm 30) and one of its primary tributaries, the Twisp River (rkm 2), in the Entitat River (rkm 2), and in the upper Wenatchee River (rkm 81), lower Wenatchee River (rkm 13), and tributaries of the Wenatchee River including Nason Creek (rkm 1) and the Chiwawa River (rkm 3). Traps were operated from late February through early December since 2003. Most PIT tagging occurred from February through May for smolts and from June to December for parr. Parr tagging dates varied by location and year, but generally most tagging occurred in the fall. Juveniles in good condition were PIT tagged in the peritoneal cavity and followed standard Columbia Basin protocols (CBFWA 1999). After tagging juvenile PIT tagged data was uploaded to PTAGIS. Data was further filtered using CSS protocols to eliminate precocial males, shed tags detected at instream arrays, and fish exhibiting juvenile or adult summer Chinook salmon life history patterns. These tag lists were used in PTAGIS to develop Tag Detail and Interrogation Detail queries, which were downloaded into an Access database to obtain individual PIT tag capture histories. A total of 55 releases from brood years 2009 to 2013 were analyzed. This resulted in 5 parr and 5 smolt releases from the Twisp trap (TWITRP), 5 parr and 4 smolt releases from the Methow trap (METHTR), 5 parr and 5 smolt releases from the Entiat Trap (ENTRPR), 5 parr and 5 smolt releases from the Nason trap (NASONC), 5 parr and smolt releases from the Chiwawa trap (CHIWAT), 3 smolt releases from the upper Wenatchee smolt trap (WENAT3) for brood years 2009-11, and 3 smolt releases from the lower Wenatchee smolt trap (WENAT4) for brood years 2011-13 (Figure 1).

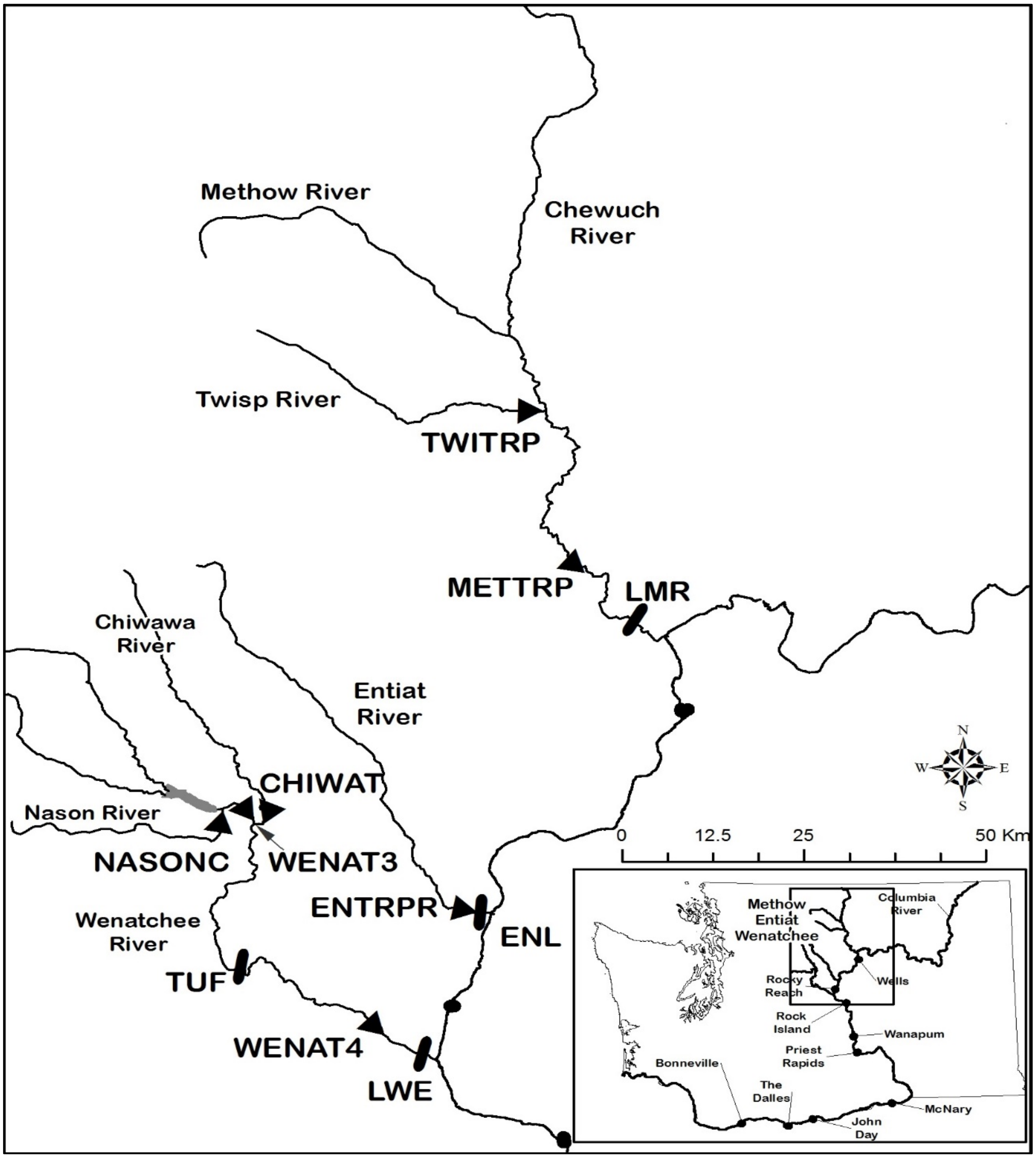


Figure9.1. Upper Columbia spring Chinook salmon populations. Fish were captured in screw traps (▲), PIT tagged and released. PIT tag were detected instream Passive Integrated Transponder sites [IPTDS; (▬)] as the adults returned to spawn in their natal stream. At mainstem dams juvenile detections occurred at Rocky Reach, McNary, John Day, and Bonneville, and adult detections occurred at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams.

Data Analysis

The Cormack-Jolly-Seber (CJS) model was used to estimate reach scale survival through the life cycle of PIT tagged juveniles. The CJS model is an open population capture-mark-recapture (CMR) model that is used to estimate the probability of capture and survival of tagged animals between multiple sampling events (Burnham et al. 1987). The sampling design for the CJS model consists of a random sample of animals from the first event that are individually tagged and immediately returned to the population. This sampling of animals is repeated at multiple times and/or locations depending on the study objectives and is commonly used to estimate animal survival within a season or annually (Williams et al. 2002). In the Columbia River, the CJS model is often used to estimate reach scale survival of juvenile salmonids tagged associated with dam infrastructure and hydrosystem operations (Burnham et al. 1987, Skalski et al. 1998). The CJS model assumes that all animals migrate at the same time, have a common probability of detection and survival over a given reach (Burnham et al. 1987). However, this assumption is violated when Chinook Salmon spend one, two, or three years in the ocean. In this case, heterogeneity is addressed by allowing spring Chinook Salmon in the ocean to have different probability of maturation and survival, where the different ocean ages are considered states in a multistate model context (Buchanan and Skalski 2007).

Individual capture histories were aggregated into group capture histories for each release group (Williams et al. 2002) and the likelihood can be expressed as:

$$ch_{ij} \sim Multinomial(\pi_{ij}, N_j) \qquad (1)$$

where ch_{ij} is the count of unique capture histories i for group j, N_j is the total number of PIT tagged fish released from each group j, π_{ij} is the proportion of unique capture histories i for release group j. The probability for each unique capture history is composed of 0's and 1's, where 1 indicates the fish was detected and 0 indicates the fish was not detected. The probability of each unique capture history is based on the probability of capture (ρ), the probability of survival (ϕ), and the probability that an animal is released at a site is not observed (χ; Williams et al. 2002). The smolt-to-adult survival of juveniles from Bonneville Dam to adults at Bonneville Dam is the sum the transition probabilities (Figure 2). In addition, we estimated overwintering survival from tagged parr to the survival of tagged smolts. The overwinter survival of parr release groups was estimated by:

$$OW\_\phi_j = pa\_\phi_j / sm\_\phi_j \qquad (2)$$

where OW_ϕ_j is the estimate of parr overwinter survival, pa_ϕ_j is the estimate of parr survival, and sm_ϕ_j is the estimate of smolt survival. The cumulative survival is the product of reach survival and can used to estimate juvenile or adult survival through the hydrosystem or smolt-to-adult returns (SAR) from different locations (Haeseker et al. 2012). The upper Columbia spring Chinook salmon multistate survival model is illustrated below in **Figure** 2.

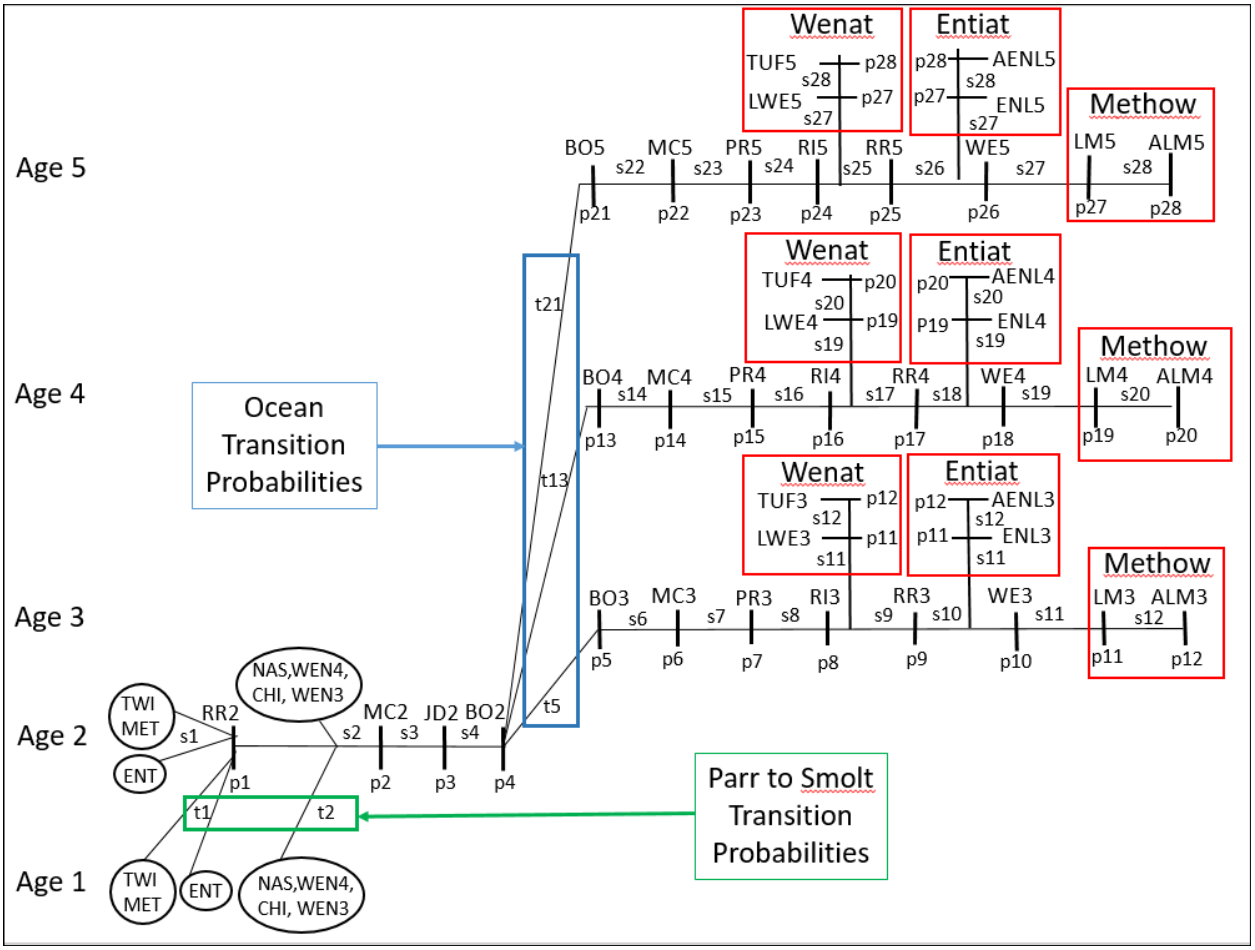


Figure 9.2. Graphical depiction of the Upper Columbia modified multistate Cormack-Jolly-Seber model. PIT tag releases occur as fall parr (age 1) and spring smolts (age 2) at tributary screw traps in the Methow (Twisp=TWI, Methow=MET), Entiat (ENT), and Wenatchee (Nason=NAS, Chiwawa=CHI, Upper Wenatchee=Wen3, and Lower Wenatchee=WEN4) watersheds (black circles). Smolts emigrate at age 2 (RR2), and adults return to their natal stream as age 3 (LM3), age 4 (LM4), and age 5 (LM5) for Methow spring Chinook Salmon. Adults by age are the sum of all detections above the lowest ISPDA (e.g. ALME4 for age 4 fish in the Methow). The probability of capture (p), apparent survival (s), and parr to smolt and ocean transition probabilities (t) are the statistics from tagging to adult return. Survival is estimated form the time of tagging to age 3 to age 5 returns to their natal streams (red squares).

We used a Bayesian framework for the CJS models (Brooks et al. 2000, Kery and Schaub 2012, King et al. 2009, Link and Barker 2010). The Bayesian analysis was conducted using Markov Chain Monte Carlo (MCMC) methods to sample the posterior probability density function in the JAGS software (Gilks et al.1996, Plummer 2003). JAGS was called from the statistical package R (R Development Core Team 2017) using R2jags (Su and Yajima 2015). After reaching equilibrium, the target for the number of independent samples, as measured by effective sample size (ESS), was 4,000. This provides 95% credible intervals (CI) that have posterior probabilities between 0.94 and 0.96 (Lunn et al. 2013). All of the modeling results described in this paper have been assessed for chain convergence and uncertainty in the parameter estimates due to Markov Chain variability. Multiple chains were used starting at divergent initial values and the chains were monitored until they reached equilibrium. Convergence was assessed by visually inspecting the MCMC chains and using the Brooks-Gelman-Rubin (BGR) statistic (Lunn et al. 2013). BGR values less than 1.1 are considered to have converged (Gelman et al. 2004). Based on this approach, it was assumed that the reported posterior distributions were accurate and represented the underlying stationary distributions of the estimated parameters.

For CJS model selection, we used the Deviance Information Criteria (DIC), which is a Bayesian analog of AIC that assesses model fit and complexity (Spiegelhalter et al. 2002, Burnham and Anderson 2002). Models with a ΔDIC of less than 2 have considerable support, ΔDIC of 3-7 have less support, and models with ΔDIC > 10 have negligible support. We estimated model support using the equation DIC = Dev(θm) + pV, where Dev(θm) is the posterior mean deviance for the model and pV = Var(D(θ|Y))/2 and is a measure of the number of effective terms in the model (Gelman et al. 2004). Models were ranked based on ΔDIC. Posterior predictive model checks were used compare of the posterior predictive distribution of replicated data from the model with the data analyzed by the model for a goodness of fit (GOF) test (Brooks et al. 2000). The Bayesian *p*-value is the proportion of the iterations that the replicated data is more extreme than the observed data and we considered lack of fit if Bayesian *p*-values were less than 0.025 or greater than 0.975. For the CJS model we used the Freeman-Tukey statistic since our count data consisted of many zero counts and this test statistic allows zeroes and does not require the pooling of cells to meet a minimum value (Brooks et al. 2000, King et al. 2010).

Given the many possible models to explore, we started with the simplest model and added complexity in areas that were supported by the migratory and survival patterns of UC spring Chinook Salmon populations using Bayesian p-values and DIC. We were mindful of extrinsic and intrinsic parameter identifiability in CJS model (Kery and Schaub 2012). Intrinsic identifiability occurs when the last estimates capture and survival probabilities are confounded (Lebreton et al. 1992). Therefore, we estimated survival to the instream Passive Integrated Transponder detection sites (IPTDS) at the mouth of the Methow and Entiat rivers. For the Wenatchee population, all of the spring Chinook Salmon adults are believed to use the Tumwater Falls (TUF) ladder where PIT tag detection is believed to approach 100%. Assuming all fish used the ladder we fixed detection probability at the ladder to one. This allowed us to estimate survival to the fish ladder. Extrinsic non-identifiability occurs when the posterior distribution is dominated by the prior due to sparse data (Kery and Schaub 2012). Gimenez et al. (2009) proposed to test for extrinsic non-identifiability in CMR models by comparing the overlap between a flat prior and the resulting posterior distribution. They proposed that parameters are considered weakly identifiable, thus sensitive to the prior, if the overlap between the prior and posterior is greater than 35%, which we used in this analysis.

We assumed independent ϕ and ρ by release group for our first model. We primarily used used this model to evaluate extrinsic non-identifiability in the simplest model. Our second model included an independent ϕ by release group and ρ consisted of pooled release groups along with independent and hierarchical models. First, we assumed constant p for each juvenile outmigration group (parr and smolts combined) from all combined populations (Methow, Entiat, and Wenatchee). We assumed that ρ for each combined outmigration group was exchangeable, that is posterior distribution of each group is from a common distribution of ρ for each detection site which is often referred to as hierarchical or multi-level modeling (Gelman et al. 2004). We estimated ocean age 3 (jacks) and ocean age 4 and 5 (adult) ρ separately and assumed a constant ρ for jacks and adults at each dam based on previous evidence of differing detection probabilities by life stage at mainstem dams (Buchannan and Skalski 2007). The adult ρ's at TUF were fixed to one as described above. For all jacks and adults returning from a brood year we hierarchically modeled ρ at each IPTDS for each population (Methow, Entiat, and Wenatchee).

For the third model, we assumed used the same detection model as described for model 2. We assumed constant p for each juvenile outmigration group (parr and smolts combined) from all combined populations for each year and we hierarchically modeled ρ for each year, which resulted in five groups for each detection site. We assumed a constant ρ for jacks at each dam, constant ρ for adults at each dam, adult ρ's were at TUF was fixed to one, and hierarchically modeled ρ for adults and jacks combined at each IPTDS for each population. For ϕ to the first detection site, we assumed a constant ϕ for the combined parr outmigration from each population for each year, a constant ϕ for the combined smolt outmigration from each population for each year, and hierarchically modeled each juvenile outmigrant life stage from each population. After the first detection site, we modeled pooled all outmigrants from all populations and modeled them hierarchically across the years. Crosier et al. (2016) identified that Entiat and Methow natural origin adult migration timing was similar but Wenatchee timing was approximately two weeks later, which may lead to different survival rates due to marine mammal predation or fishing mortality. Therefore, we modeled adult estimates of ϕ separately for the Methow/Entiat and the Wenatchee population. Columbia basin spring Chinook Salmon smolt-to-adult survival (SAS) has been highly variable for the brood years we examined (McCann et al. 2018). Using a hierarchical modeling, we would expect that the SAS estimates would shrink to the grand mean, and not capture the annual SAS variability. Therefore, we assumed the ocean transition probabilities (t5, t13, and t21) were independent for each of the three ocean ages and the two groups (Methow/Entiat and Wenatchee). We assumed hierarchical ϕ for each year (5) for the Methow/Entiat group and hierarchical ϕ for the Methow/Entiat group between the dams. For the last two stages of ϕ, we hierarchically modeled ϕ for adults and jacks combined at each IPTDS for each population.

For the fourth model was the same as the third model except for the following change. In the third model, we assumed a constant ρ for jacks at each dam and constant ρ for adults at each dam. In the fourth model, we assumed a constant ρ for jacks in each return year and hierarchically modeled ρ across the years, and assumed a constant ρ for adults from each brood year and hierarchically modeled ρ across the years.

Priors

We used uniform priors [Beta(1,1)] for ρ and ϕ to identify extrinsic identifiability in model 1. However, for the other models we used various vague priors. When ρ and ϕ were independent or constant across groups we used a Jeffreys prior [Beta (0.5, 0.5)] to reflect our desire to use a reference prior that has minimal influence on the posterior (Bernardo 1979). For hierarchical models, we used a bounded gamma distribution for the hypermeters ρ and ϕ (Zou and Normand 2001, Congdon 2005). The distributions are truncated to be greater than 1 to ensure the posterior distribution is concave and the gamma distribution was censored at the upper end to ensure convergence. This prior may expressed as:

$$\phi_j \sim \text{Beta}(a,b) \quad (3)$$
$$\rho_j \sim \text{Beta}(a,b) \quad (4)$$
$$a \sim \text{Gamma}(0.01,0.01)\text{T}(1,10) \quad (5)$$
$$b \sim \text{Gamma}(0.01,0.01)\text{T}(1,10) \quad (6)$$

where j is the year, and a and b are vague shape priors that control the posterior distribution of ρ and ϕ. To test the sensitivity of our priors we varied the upper bound on the Gamma distribution and also explore and bounded uniform distribution. Results indicate our posteriors were not sensitive to the prior (not shown).

Results

A total of 36, 78, and 61 unique capture histories were observed for brood years 2009-13 for the Methow, Entiat, and Wenatchee spring Chinook Salmon populations, respectively. During 2010-2015 8,255 PIT tags were applied in the Methow River, 23,308 in the Entiat, and 62,091 in the Wenatchee. We ran four chains with 21,000 samples per chain. We retained 2,000 samples per chain after a burn-in period of 1,000 samples and a thinning rate of 10. A total of 8,000 samples per parameter were summarized for inference.

The first two models had little support and the majority of the estimates in model 1 were weakly identifiable suggesting the posterior was sensitive to the prior. Model 4 was the same as model 3 except that the adult ρ and jack ρ were modeled hierarchically by brood year returns compared to model 3 where adult ρ and jack ρ were assumed to be constant across years and groups. Based on ΔDIC of 59, Model 3 is the most parsimonious model and there was model support for constant adult ρ at dams For 31 of 55 release groups, Bayesian p-values were consistent with the data. However, there is lack of fit in 44% of the release groups and in all populations. This needs to be further explored in future analyses.

Table 9.1. Results for CJS model selection and GOF tests for Upper Columbia spring Chinook Salmon tagged from brood year 2009 to 2013.

Model	Deviance	pV	DIC	ΔDIC	Methow*	Entiat*	Wenatchee*
1	5160.9	1334	6494.9	1843.8	0.13 (11/19)	0.04 (3/10)	0.09 (10/26)
2	4792.5	853.3	5645.8	994.7	0.11 (14/19)	0.03 (3/10)	0.09 (12/26)
3	4485.5	165.6	4651.1	0	0.21 (14/19)	0.08 (4/10)	0.22 (14/26)
4	4504.5	205.9	4710.4	59.3	0.20 (14/19)	0.06 (4/10)	0.20 (14/26)

* The first value is the mean Bayesian *p*-value for each release group by population and the second value is the number of Bayesian p-values that were between 0.025 and 0.975.

The life stage and reach estimates of salmon survival are provided in Tables 2-4. As expected, annual life stage estimates of smolt survival from tagging to Rocky Reach dam were greater for Entiat smolts than Methow smolts due to shorter travel time and because Entiat fish do not emigrate past any dams while Methow fish experience addition mortality when passing Wells Dam. In addition, parr survivals to the first dam were less than smolt survivals due to overwintering mortality. The Entiat overwinter parr survivals were much less (mean = 0.17) than the overwinter parr survival for the other two population, and overwinter parr survival was low for brood year 2013 (Tables 2-4). Smolt survival was lower in the John Day to Bonneville reach compared to the McNary to John Day reach (Tables 2-4).

Since the reach survival estimates from the CJS model are multiplicative, we summaries the smolt survival to Bonneville Dam and adult survival from Bonneville Dam to the tributaries. CJS smolt survivals estimates are near 20% except were lower for outmigration year 2015 (Figure 3, left panel). Adult survival from Bonneville Dam to these tributaries was near 70% for Wenatchee and Entiat fish. Adult survival estimates the Methow were lower (~ 50%) and more uncertain due to the low detection probability at the IPTDS in the Lower Methow River. These adult and juvenile survival estimates include mortality from dam operations, predation, along with natural and other sources of mortality.

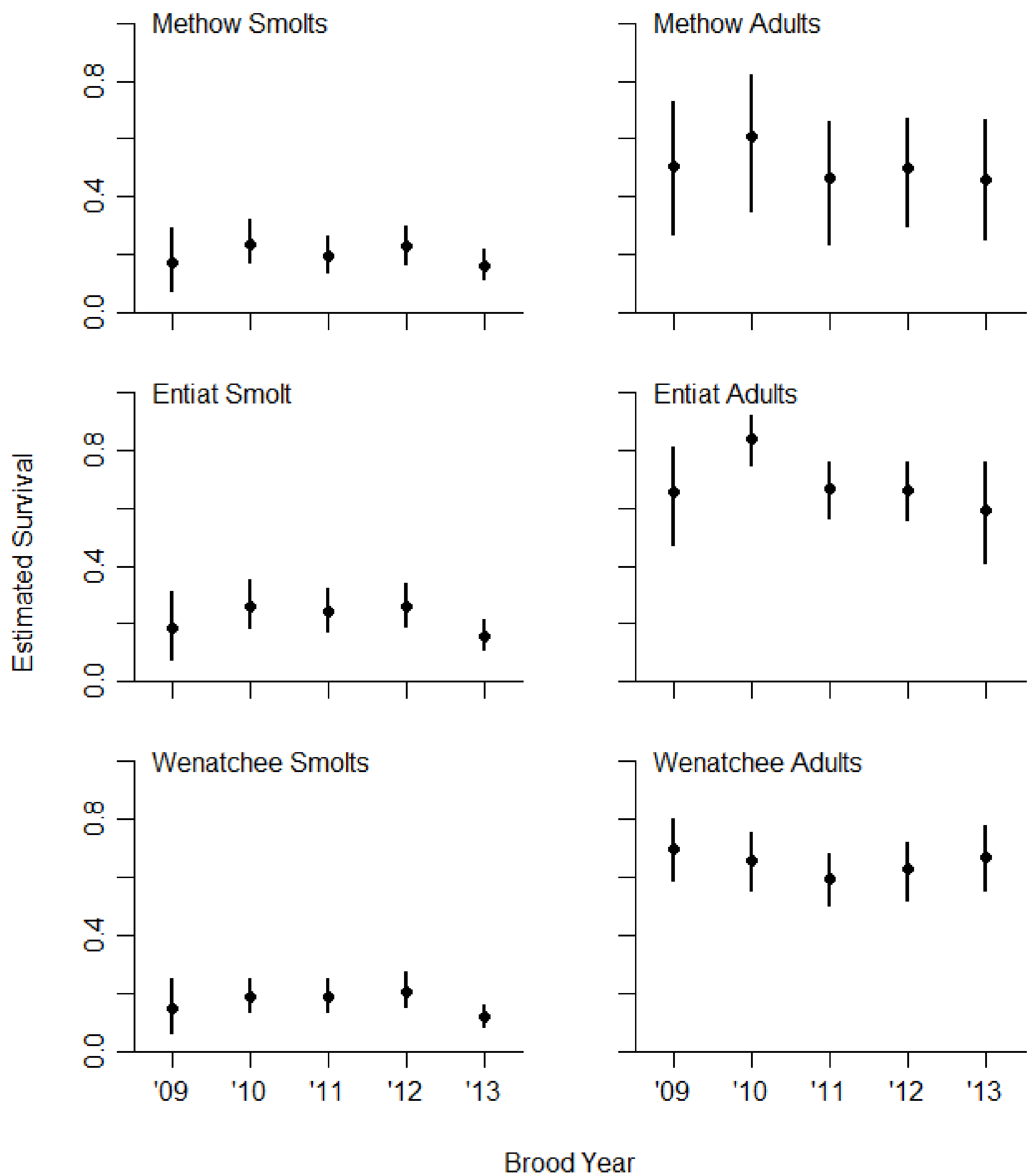


Figure 9.3. Survival estimate of smolts to Bonneville Dam (left panel) and survival estimates of adults from Bonneville Dam to the IPTDS mouth of Methow, Entiat, and Wenatchee river (right panel).

Bonneville to Bonneville SAR mean estimates without jacks for all populations ranged from 1.7% to 4.5% and were below the NPCC goal of 4% for 13 of 15 estimates. When SARs were estimated using juvenile PIT tag detection at the first dam to adults detected at BON, SAR with and without jacks were well below the 4% goal. SAR estimates for smolts tagged in the stream to adults returning to their natal stream were less than 1%.

Table 9.2. The mean (90% CI) for life stage and reach survival estimates for Methow River spring Chinook salmon by brood year.

Survival to:	LifeStage	2009		2010		2011		2012		2013	
RockyReach	Fall parr	0.360	(0.27-0.45)	0.230	(0.17-0.30)	0.430	(0.37-0.49)	0.340	(0.27-0.42)	0.300	(0.24-0.36)
RockyReach	Spring Smolt	0.730	(0.63-0.84)	0.760	(0.67-0.85)	0.630	(0.53-0.74)	0.750	(0.67-0.83)	0.790	(0.68-0.90)
McNary	Spring Smolt	0.640	(0.55-0.75)	0.610	(0.54-0.69)	0.610	(0.54-0.69)	0.580	(0.52-0.64)	0.470	(0.39-0.56)
John Day	Spring Smolt	0.910	(0.81-0.99)	0.860	(0.76-0.95)	0.910	(0.82-0.99)	0.880	(0.79-0.96)	0.760	(0.60-0.92)
Bonneville	Spring Smolt	0.400	(0.17-0.68)	0.600	(0.42-0.80)	0.560	(0.40-0.75)	0.600	(0.44-0.80)	0.570	(0.40-0.79)
SAR w/jacks	Age 3,4 & 5	0.026	(0.010-0.056)	0.036	(0.023-0.052)	0.056	(0.038-0.079)	0.039	(0.026-0.05	0.039	(0.020-0.064)
SAR wo/jacks	Age 4 & 5	0.017	(0.006-0.039)	0.025	(0.015-0.037)	0.045	(0.029-0.063)	0.036	(0.024-0.05	0.023	(0.010-0.041)
McNary	Adult	0.870	(0.72-0.98)	0.930	(0.85-0.98)	0.760	(0.67-0.85)	0.770	(0.67-0.86)	0.750	(0.56-0.89)
Priest Rapids	Adult	0.980	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.95-1.00)	0.980	(0.94-1.00)	0.960	(0.87-1.00)
Rock Island	Adult	0.950	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.94-1.00)	0.970	(0.91-1.00)	0.950	(0.87-1.00)
Rocky Reach	Adult	0.910	(0.79-0.98)	0.970	(0.93-1.00)	0.960	(0.91-0.99)	0.950	(0.89-0.99)	0.950	(0.85-1.00)
Wells	Adult	0.910	(0.75-0.99)	0.930	(0.82-0.99)	0.910	(0.78-0.99)	0.920	(0.80-0.99)	0.930	(0.80-0.99)
Lo. Methow	Adult	0.770	(0.44-0.98)	0.760	(0.45-0.97)	0.720	(0.37-0.97)	0.780	(0.48-0.99)	0.770	(0.48-0.97)
OverWinter	Parr to smolt	0.490	(0.37-0.62)	0.310	(0.23-0.40)	0.680	(0.58-0.81)	0.460	(0.36-0.56)	0.370	(0.31-0.44)

Table 9.3. The mean (90% CI) for life stage and reach survival estimates for Entiat River spring Chinook salmon by brood year.

Survival to:	LifeStage	2009		2010		2011		2012		2013	
RockyReach	Fall parr	0.180	(0.15-0.21)	0.150	(0.13-0.18)	0.160	(0.14-0.18)	0.120	(0.10-0.13)	0.070	(0.05-0.08)
RockyReach	Spring Smolt	0.780	(0.68-0.89)	0.840	(0.75-0.93)	0.790	(0.70-0.88)	0.850	(0.78-0.93)	0.770	(0.65-0.89)
McNary	Spring Smolt	0.640	(0.55-0.75)	0.610	(0.54-0.69)	0.610	(0.54-0.69)	0.580	(0.52-0.64)	0.470	(0.39-0.56)
John Day	Spring Smolt	0.910	(0.81-0.99)	0.860	(0.76-0.95)	0.910	(0.82-0.99)	0.880	(0.79-0.96)	0.760	(0.60-0.92)
Bonneville	Spring Smolt	0.400	(0.17-0.68)	0.600	(0.42-0.80)	0.560	(0.40-0.75)	0.600	(0.44-0.80)	0.570	(0.40-0.79)
SAR w/jacks	Age 3,4 & 5	0.026	(0.010-0.056)	0.036	(0.023-0.052)	0.056	(0.038-0.079)	0.039	(0.026-0.05	0.039	(0.020-0.064)
SAR wo/jacks	Age 4 & 5	0.017	(0.006-0.039)	0.025	(0.015-0.037)	0.045	(0.029-0.063)	0.036	(0.024-0.05	0.023	(0.010-0.041)
McNary	Adult	0.870	(0.72-0.98)	0.930	(0.85-0.98)	0.760	(0.67-0.85)	0.770	(0.67-0.86)	0.750	(0.56-0.89)
Priest Rapids	Adult	0.980	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.95-1.00)	0.980	(0.94-1.00)	0.960	(0.87-1.00)
Rock Island	Adult	0.950	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.94-1.00)	0.970	(0.91-1.00)	0.950	(0.87-1.00)
Rocky Reach	Adult	0.910	(0.79-0.98)	0.970	(0.93-1.00)	0.960	(0.91-0.99)	0.950	(0.89-0.99)	0.950	(0.85-1.00)
Lo. Entiat	Adult	0.900	(0.76-0.99)	0.970	(0.92-1.00)	0.940	(0.87-0.99)	0.960	(0.89-1.00)	0.920	(0.79-0.99)
OverWinter	Parr to smolt	0.230	(0.20-0.27)	0.180	(0.16-0.20)	0.200	(0.18-0.22)	0.140	(0.12-0.15)	0.090	(0.07-0.11)

Table 9.4. The mean (90% CI) for life stage and reach survival estimates for Wenatchee River spring Chinook salmon by brood year.

Survival to:	LifeStage	2009		2010		2011		2012		2013	
McNary	Fall parr	0.160	(0.14-0.18)	0.170	(0.15-0.19)	0.140	(0.12-0.15)	0.140	(0.13-0.15)	0.050	(0.04-0.06)
McNary	Spring Smolt	0.400	(0.37-0.45)	0.360	(0.34-0.39)	0.370	(0.34-0.40)	0.390	(0.36-0.42)	0.270	(0.24-0.30)
John Day	Spring Smolt	0.910	(0.81-0.99)	0.860	(0.76-0.95)	0.910	(0.82-0.99)	0.880	(0.79-0.96)	0.760	(0.60-0.92)
Bonneville	Spring Smolt	0.400	(0.17-0.68)	0.600	(0.42-0.80)	0.560	(0.40-0.75)	0.600	(0.44-0.80)	0.570	(0.40-0.79)
SAR w/jacks	Age 3,4 & 5	0.035	(0.016-0.071)	0.021	(0.014-0.031)	0.041	(0.028-0.058)	0.020	(0.013-0.02	0.210	(0.013-0.032)
SAR wo/jacks	Age 4 & 5	0.032	(0.014-0.065)	0.018	(0.012-0.027)	0.039	(0.026-0.055)	0.017	(0.011-0.02	0.019	(0.011-0.028)
McNary	Adult	0.870	(0.72-0.98)	0.930	(0.85-0.98)	0.760	(0.67-0.85)	0.770	(0.67-0.86)	0.750	(0.56-0.89)
Priest Rapids	Adult	0.980	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.95-1.00)	0.980	(0.94-1.00)	0.960	(0.87-1.00)
Rock Island	Adult	0.950	(0.87-1.00)	0.980	(0.94-1.00)	0.980	(0.94-1.00)	0.970	(0.91-1.00)	0.950	(0.87-1.00)
Lo. Wenachee	Adult	0.930	(0.85-0.99)	0.970	(0.91-1.00)	0.930	(0.85-0.99)	0.950	(0.88-0.99)	0.960	(0.89-1.00)
TUF Wenatchee	Adult	0.950	(0.88-1.00)	0.970	(0.92-1.00)	0.960	(0.90-1.00)	0.960	(0.91-1.00)	0.970	(0.90-1.00)
OverWinter	Parr to smolt	0.390	(0.35-0.44)	0.470	(0.42-0.51)	0.370	(0.34-0.41)	0.360	(0.33-0.39)	0.180	(0.15-0.20)

Discussion

This is the first attempt within the Columbia Basin to extend PIT tag work across the life cycle of spring Chinook salmon over multiple years. Although the multistate modified CJS model requires more effort, the benefit is that survival can be estimated from the individual reach scale, to combined reach scales such as juvenile or adult survival through the hydro-system, or different measures of SARs. The observed Rocky Reach to Bonneville and McNary to Bonneville SARs that we estimated are consistent with those previously reported (McCann et al. 2018). Our estimates of juvenile survival from Rocky Reach to McNary were consistent with CSS estimates, but were less variable due the hierarchical model used in this analysis. This is not surprising because hierarchical models tend to pull individual parameter estimates toward the mean (shrinkage effect), and the amount of shrinkage depends on the variance of the parameters (Royle and Link 2002). This analysis addresses the recommendation for more life cycle information for Upper Columbia River spring Chinook Salmon to assist with salmon recovery planning (ISAB 2018-1).

CJS Assumptions

The CJS model makes the following assumptions (e.g., Williams et al. 2002): A1) marks are neither lost nor overlooked, and are recorded correctly; A2) sampling periods are instantaneous and recaptured animals are immediately released; A3) every marked animal present in the population at sampling period i has the same probability of being recaptured or detected at period *i*; A4) every marked animal present in the population immediately following sampling period i has the same probability of survival until the next sampling period i +1; and A5) the fate of each animal with respect to capture and survival probability is independent of the fate of any other animal.

To meet the marking assumption (A1), we used standard Columbia Basin protocols for PIT tagging parr and smolts (CBFWA 1999), used experience and trained taggers, and only released fish that were in good condition. Juvenile PIT tag loss is often low for overwintering salmonids (< 3%) when using the standardized tagging protocols (Prentice et al. 1990a, Brakensiek and Hankin 2007, and Knudsen et al. 2009). Early PIT tag studies conducted by Prentice et al. (1990) indicated minimal tagging effect and more recent work by Brakensiek and Hankin (2007) indicated survival was positively correlated with the size at the time of PIT tagging. Two Columbia Basin studies found negligible and significant tagging effects, respectively, on survival (Knudsen et al. 2009, McCann et al. 2018). To the extent that there is a tagging effect on survival our estimates of survival may be negatively biased. The instantaneous sampling assumption (A2) was met because all fish were released immediately after recovery from tagging and detection. Since our model is a spatial model, the instantaneous assumption may be considered as being met because detection occurs over a negligible distance relative to the reach lengths after initial tagging (Buchanan and Skalski 2007).

The equal capture (A3), equal survival (A4), and independent fates assumption (A5) are sometimes violated in mark-recapture studies (Williams et al. 2002). GOF test based on discrepancy measure from the posterior predictive distribution showed lack of fit in 44% of the populations (Table 1), which indicate likely assumption violations for this analysis. Overdispersion is often assumed to be the cause of for lack of fit, but assumption violations usually lead to unbiased estimates, although the variance may be underestimated (Burnham et al 1987, Abadi et al. 2013). A frequentist approach to address lack of fit is to calculate a variance inflation factor and adjust variance based on overdispersion, which is not possible using a Bayesian approach. Assuming that heterogeneity is leading to the lack of fit in our models, we may be able to improve GOF test by: 1) splitting the 150 day parr release period into smaller more homogeneous groups (e.g., summer and fall), 2) allow for individual parr and smolt releases groups rather than pool the parr and smolt groups as we did in this initial analysis. Our capture histories for any given year were composed of mostly zero due to small release sizes for each tag group. We used a default omnibus CJS GOF test based on the Freeman-Tukey statistic (Brooks et al. 2000, Kery and Schaub 2012). However, this and other GOF test are sensitive to to many zero values. Other approaches for GOF test should be considered in future analysis.

Based on this analysis, there are a number of future directions that could be pursued. First, when spring and summer Chinook Salmon juveniles showed spatial and temporal overlap during emigration, the entire periods of juvenile releases were not included in our model. However, some of these juvenile spring Chinook Salmon survived and returned as adults, and we could include these adults detected at Bonneville Dam to increase the precision of our adult survival estimates. Second, the current model estimates survival of fish destined for their native stream. This model could be extended to account for straying by modifying the approach developed by Pope et al. (2016) and extended by Richins and Skalski (2018). Third, this multistate model can be extended to include additional parr releases to estimate survivals of different life history trajectories using the approach developed by Buchanan et al. (2015), where age 1 parr captured by electrofishing in tributaries and detected at PIT tag arrays at the mouth of these tributaries (e.g., Chiwawa) were used in survival analyses. Fourth, environmental covariates can be directly modeled in the multistate CJS model to identify environmental factors associated with survival at the reach or life stage scales (Haeseker 2012). Fifth, we used the capture history in our multistate modeling; this approach could be extended to individual covariate models (Gimenez et al. 2007, Kery and Schaub 2012). This is one possible approach that may address the lack of fit we observed in our GOF tests and possibly better incorporate covariates. However, given the high autocorrelation, it is likely that MCMC will have convergence problems for the 93,000 fish used in an individual covariate analysis. Currently the use of Hamiltonian MC (e.g. STAN) appears to be the only possible option available for individual covariate model with large datasets. Finally, this approach could be extended to other species in the upper Columbia River ESU and to other regions with the Columbia basin. If any of

these approaches are pursued, streamlining data processing and summarization, and the development of more flexible code are also recommended.
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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

APPENDIX B

ANNUAL OVERALL SARS
(SUPPORTING TABLES TO CHAPTERS 4)

All other appendices will be included in the Final Draft

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

APPENDIX A

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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 (1994–2018), hatchery spring/summer Chinook (1997–2018), wild steelhead (1997-2018), hatchery steelhead (1997–2018), hatchery sockeye (2009–2018), and wild and hatchery subyearling fall Chinook (2006-2012 and 2015-2018). Annual SARs, TIR, and *D* values are estimated for PIT-tagged wild spring/summer Chinook (1994–2017), hatchery spring/summer Chinook (1997–2017), wild and hatchery steelhead (1997–2016), hatchery sockeye (2009–2017), and wild and hatchery subyearling fall Chinook (2006-2016). 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 estimates of 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 SAR data for T_0 (or T_X), C_0, and C_1 by juvenile year and release.

b. “Overall Annual SARs for Zones in the Snake or 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 of 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 reach 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). Additionally, detections at estuary bird colonies of mortalities as well as adult returns to BON are used to supplement downstream detections at the TWX.

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. Prior to 2006 estimates of individual reach survival (e.g., LGR-to-LGS) were allowed to exceed

100% by implementing an identity link in survival estimation; however, this is often associated with an underestimate of survival in preceding or subsequent reaches. Therefore, when computing a multi-reach survival estimate, we allowed 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%. In 2019, we implemented a new estimation methodology. We applied this method to migration years after 2005. Under the new method, the estimates of individual reach survivals (e.g., LGR-to-LGS) were constrained to not exceed 100% using a logit link in the estimation process (White and Anderson 1989). The CJS survivals were estimated in program Mark, and implemented in R using packages 'RMark' and 'marked'. When computing a multi-reach survival estimate, we multiplied individual reach survival estimates to calculate the full reach estimate (for all groups in the years 2006 and later).

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. The methodology described above, of extrapolating to estimate S_R when fewer than six independent reach survival estimates were available, was used for all migration years through 2005. Beginning with migration year 2006, we applied a new methodology of using PIT-tag recoveries (i.e., mortalities) on bird colonies in the Columbia River estuary and adult detections at BON to augment the NOAA Trawl detections below BON. As stated previously, estimates of S_R using this new methodology, combined with the use of the logit link in survival estimation (migration year 2006 and later) are not extrapolated and, instead, are the product of the survival estimates from all six individual reaches between LGR and BON. For all groups and migration years, 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

Symbols for Primary Statistics

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

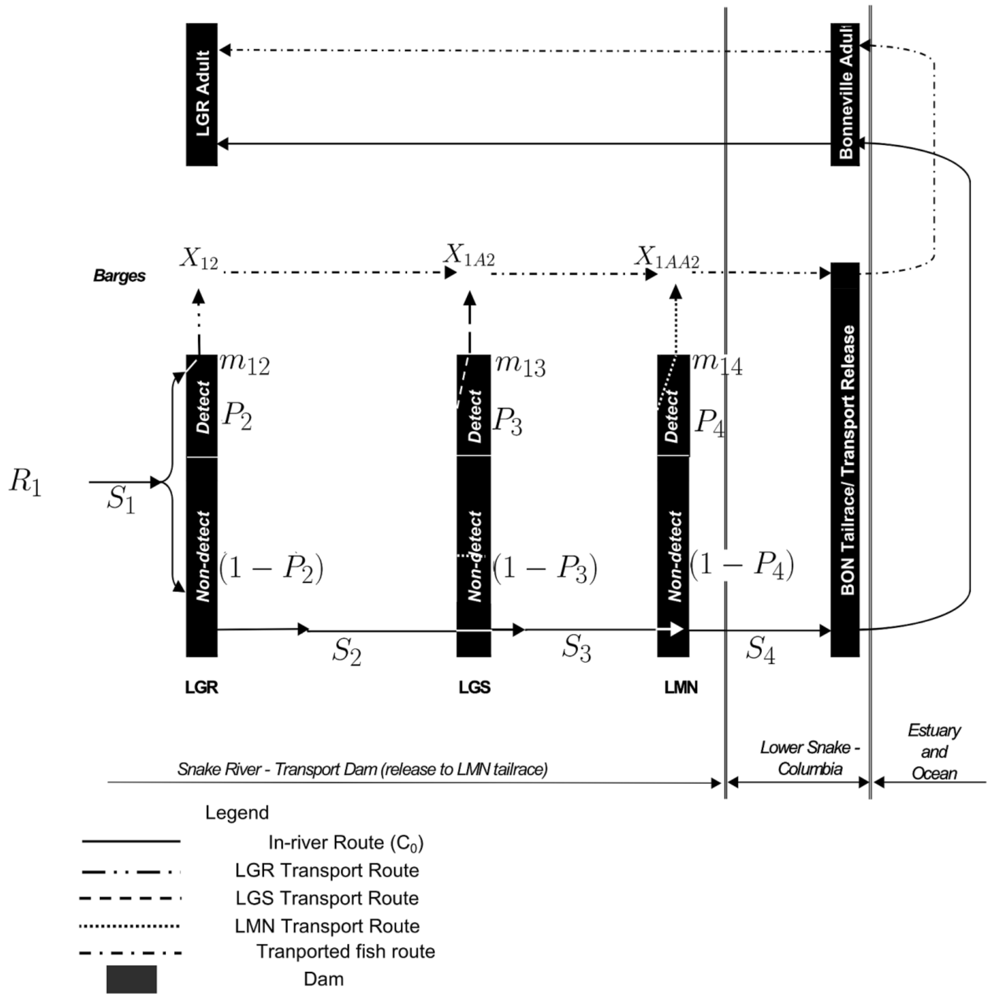

Figure A.1. Schematic of the Lower Snake and Columbia River system with focus on the three transport sites and estimation methods after migration year 2006. Locations for some primary statistics and parameters are shown.

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.

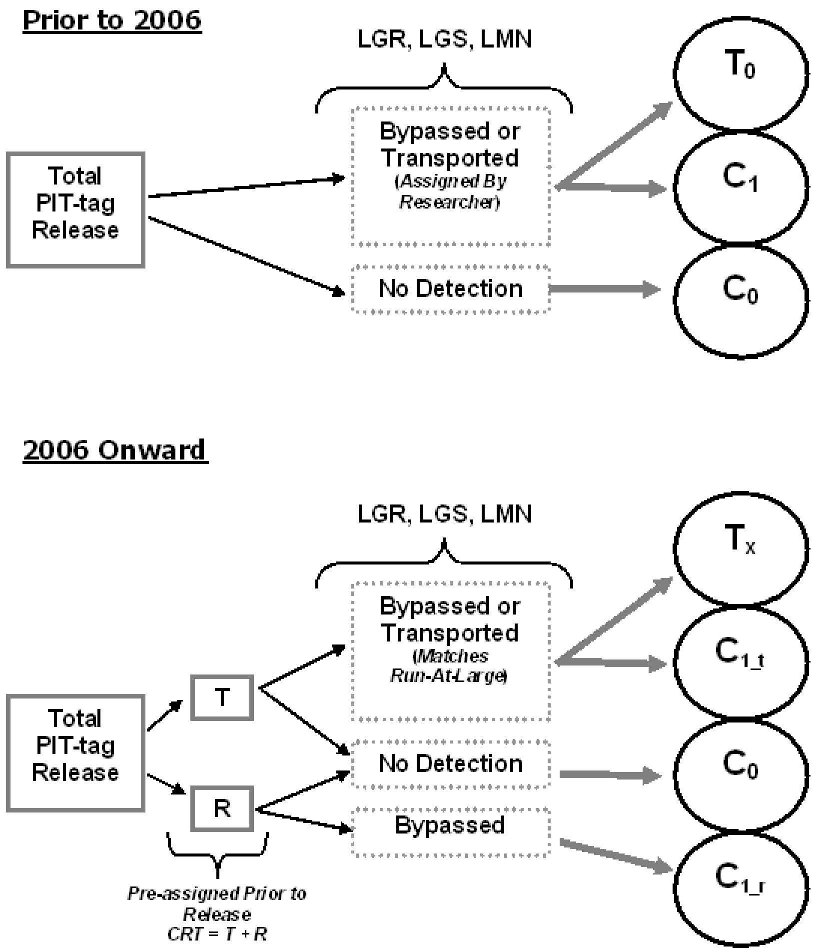

Figure A.2. Schematic depicting how the differently marked cohorts are used to translate into SARs for all years of the CSS relative to the passage of PIT-tagged smolts at the three Snake River collection/ transportation dams (LGR, LGS, and LMN). The upper flow chart covers years prior to pre-assignments 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:

$$T_{X\_t} = X_{12} + \frac{X_{1a2}}{S_2} + \frac{X_{1aa2}}{S_2 * S_3} \quad [A.4]$$

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:

$$C_{0\_crt} = "see \; Equation \; A.2"$$

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.

$$E[C_0] = R_1 * S_1 * (1 - P_2) * (1 - P_3) * (1 - P_4) - d_{C0} \quad [A.5]$$

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:

$$E[C_1] = R_1 * S_1 * [P_2 + (1 - P_2) * P_3 + (1 - P_2) * (1 - P_3) * P_4] - \left[d_2 + \frac{d_3}{S_2} + \frac{d_4}{S_2 * S_3} + d_{C1}\right] \quad \text{[A.6]}$$

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:

$$SAR(T_0) = \frac{\{AT_{LGR} + AT_{LGS} + AT_{LMN}\}}{T_0} \quad [A.7]$$

where

$$AT_{LGR} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LGR$$

$$AT_{LGS} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LGS$$

$$AT_{LMN} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LMN$$

$$SAR(C_0) = \frac{\{AC_0\}}{C_0} \quad [A.8]$$

where

$$AC_0 = adults\ at\ LGR\ with\ C_0\ smolt\ outmigration\ history$$

$$SAR(C_1) = \frac{\{AC_1\}}{C_1} \quad [A.9]$$

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:

$$SAR(T_{X\_t}) = \frac{\{AT_{LGR\_t} + AT_{LGS\_t} + AT_{LMN\_t}\}}{T_{X\_t}} \quad [A.10]$$

Using the total release, the formula for $SAR(C_0\_crt)$ is:

$$SAR\left(C_{0\_crt}\right) = \frac{\{AC_{0\_crt}\}}{C_{0\_crt}} \qquad [A.11]$$

Using the pre-assigned fish in Group T, the equations for $SAR[EC_1\_t]$ is:

$$SAR\left[EC_{1\_t}\right] = \frac{\{AC_{1\_t}\}}{E\left[C_{1\_t}\right]} \qquad [A.12]$$

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 ≠ 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:

$$D = \frac{SAR_{BON-LGR}(T_0)}{SAR_{BON-LGR}(C_0)} \qquad [A.14]$$

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:

$$D = \frac{\left(\frac{SAR(T_0)}{S_T}\right)}{\left(\frac{SAR(C_0)}{S_R}\right)} \qquad [A.15]$$

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 Juvenile In-river 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. In general, estimates of S_R for migration years through 2005 use the methodology of implementing an identity link and, when applicable, extrapolating survival per mile to estimate survival for the entire reach. Estimates of SR for migration years 2006 and later use a different methodology of implementing an logit link (which caps individual reach survivals at 1.0) and using recoveries at bird colonies below BON and adult detections to augment the NOAA Trawl detections below BON. For more details on these methodologies, see the Methods (Estimation of juvenile in-river survival (SR)) section above.

Wild and Hatchery Spring/Summer Chinook

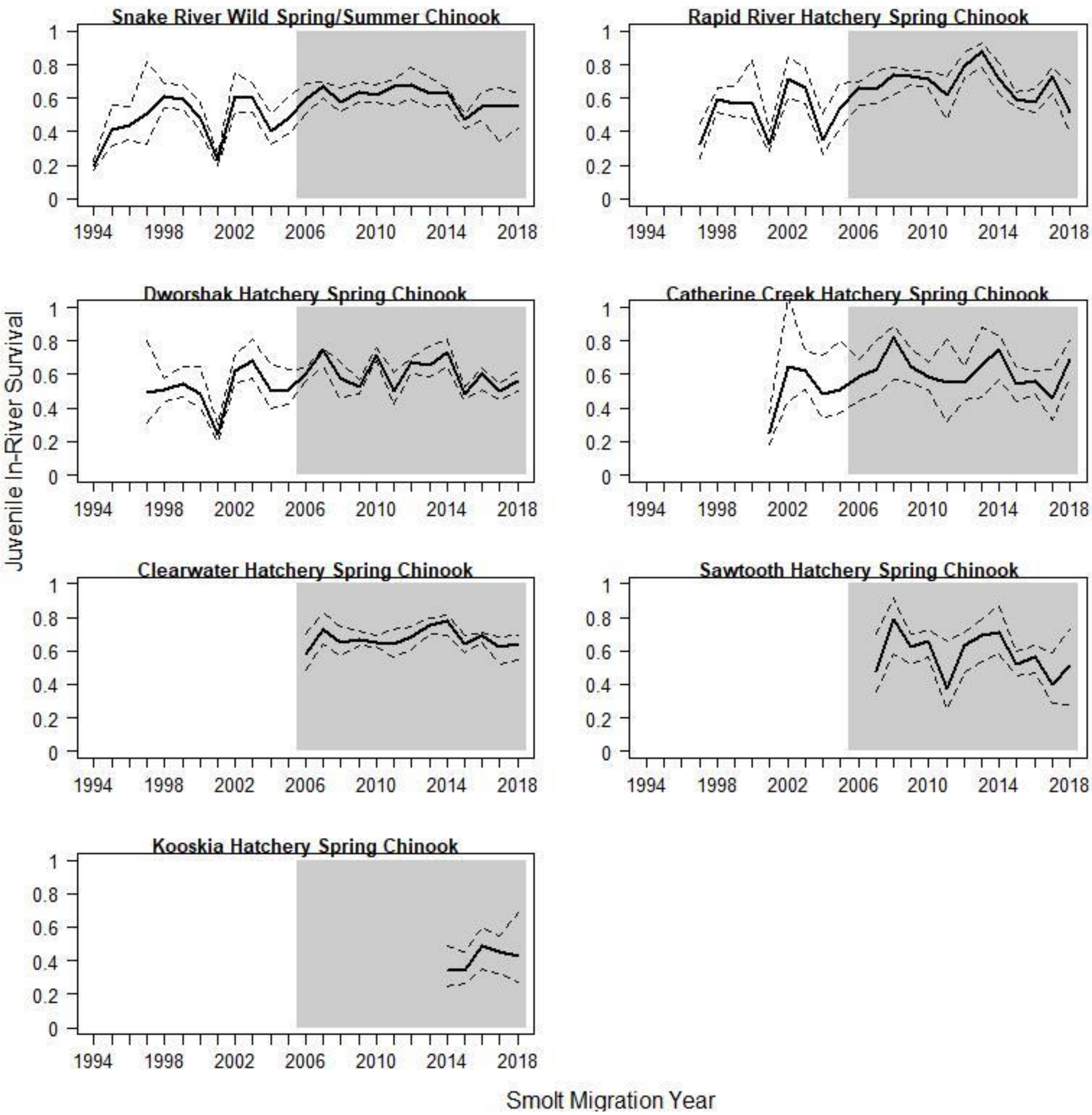

Figure A.3. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild spring/summer Chinook (1994-2018) and hatchery spring Chinook (1994-2018) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data are 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 (1994-2018) and hatchery spring Chinook from Rapid River Hatchery and Dworshak NFH (1997-2018) and Catherine Creek AP (2002-2018) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year[A]	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	0.59 (0.51 - 0.69)	0.66 (0.56 - 0.70)	0.60 (0.56 - 0.64)	0.59 (0.44 - 0.69)
2007	0.67 (0.60 - 0.70)	0.65 (0.57 - 0.77)	0.74 (0.65 - 0.76)	0.63 (0.48 - 0.80)
2008	0.58 (0.52 - 0.66)	0.74 (0.62 - 0.78)	0.58 (0.46 - 0.67)	0.82 (0.57 - 0.89)
2009	0.64 (0.58 - 0.70)	0.73 (0.68 - 0.77)	0.53 (0.48 - 0.57)	0.65 (0.55 - 0.76)
2010	0.62 (0.58 - 0.68)	0.71 (0.66 - 0.76)	0.72 (0.68 - 0.76)	0.59 (0.51 - 0.67)
2011	0.67 (0.56 - 0.71)	0.62 (0.47 - 0.73)	0.50 (0.42 - 0.61)	0.55 (0.32 - 0.81)
2012	0.68 (0.59 - 0.78)	0.79 (0.72 - 0.87)	0.67 (0.60 - 0.70)	0.55 (0.45 - 0.65)
2013	0.63 (0.55 - 0.72)	0.88 (0.78 - 0.93)	0.66 (0.59 - 0.77)	0.66 (0.47 - 0.88)
2014	0.64 (0.56 - 0.66)	0.71 (0.63 - 0.81)	0.73 (0.65 - 0.81)	0.75 (0.57 - 0.84)
2015	0.47 (0.42 - 0.51)	0.59 (0.54 - 0.64)	0.48 (0.45 - 0.53)	0.54 (0.44 - 0.65)
2016[B]	0.55 (0.46 - 0.64)	0.58 (0.52 - 0.65)	0.60 (0.51 - 0.64)	0.56 (0.48 - 0.62)
2017[B]	0.55 (0.34 - 0.66)	0.73 (0.63 - 0.78)	0.50 (0.45 - 0.54)	0.46 (0.33 - 0.63)
2018[B]	0.55 (0.42 - 0.63)	0.52 (0.40 - 0.69)	0.56 (0.50 - 0.62)	0.69 (0.57 - 0.80)
Geomean	**0.53**	**0.62**	**0.57**	**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] CJS estimation of S_R for migration years 2006 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] Estimate of S_R may change as groups are 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 (1994-2018) and hatchery spring Chinook from Clearwater Hatchery (2006-2018), Sawtooth Hatchery (2007-2018), and Kooskia Hatchery (2014-2018) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year[A]	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	0.59 (0.51 - 0.69)	0.58 (0.49 - 0.70)		
2007	0.67 (0.60 - 0.70)	0.73 (0.64 - 0.83)	0.48 (0.36 - 0.70)	
2008	0.58 (0.52 - 0.66)	0.65 (0.57 - 0.74)	0.79 (0.58 - 0.92)	
2009	0.64 (0.58 - 0.70)	0.67 (0.63 - 0.72)	0.62 (0.52 - 0.70)	
2010	0.62 (0.58 - 0.68)	0.65 (0.62 - 0.69)	0.66 (0.56 - 0.73)	
2011	0.67 (0.56 - 0.71)	0.64 (0.56 - 0.73)	0.37 (0.25 - 0.66)	
2012	0.68 (0.59 - 0.78)	0.68 (0.61 - 0.74)	0.63 (0.47 - 0.71)	
2013	0.63 (0.55 - 0.72)	0.75 (0.70 - 0.80)	0.69 (0.54 - 0.79)	
2014	0.64 (0.56 - 0.66)	0.78 (0.69 - 0.81)	0.71 (0.58 - 0.87)	0.34 (0.25 - 0.49)
2015	0.47 (0.42 - 0.51)	0.64 (0.59 - 0.69)	0.52 (0.45 - 0.60)	0.34 (0.26 - 0.45)
2016[B]	0.55 (0.46 - 0.64)	0.69 (0.65 - 0.71)	0.56 (0.47 - 0.63)	0.49 (0.35 - 0.60)
2017[B]	0.55 (0.34 - 0.66)	0.62 (0.52 - 0.68)	0.40 (0.29 - 0.59)	0.45 (0.32 - 0.55)
2018[B]	0.55 (0.42 - 0.63)	0.64 (0.55 - 0.69)	0.51 (0.28 - 0.73)	0.43 (0.27 - 0.69)
Geomean	**0.53**	**0.67**	**0.56**	**0.41**
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] CJS estimation of S_R for migration years 2006and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] Estimate of S_R may change as groups are finalized for estimation of SARs.

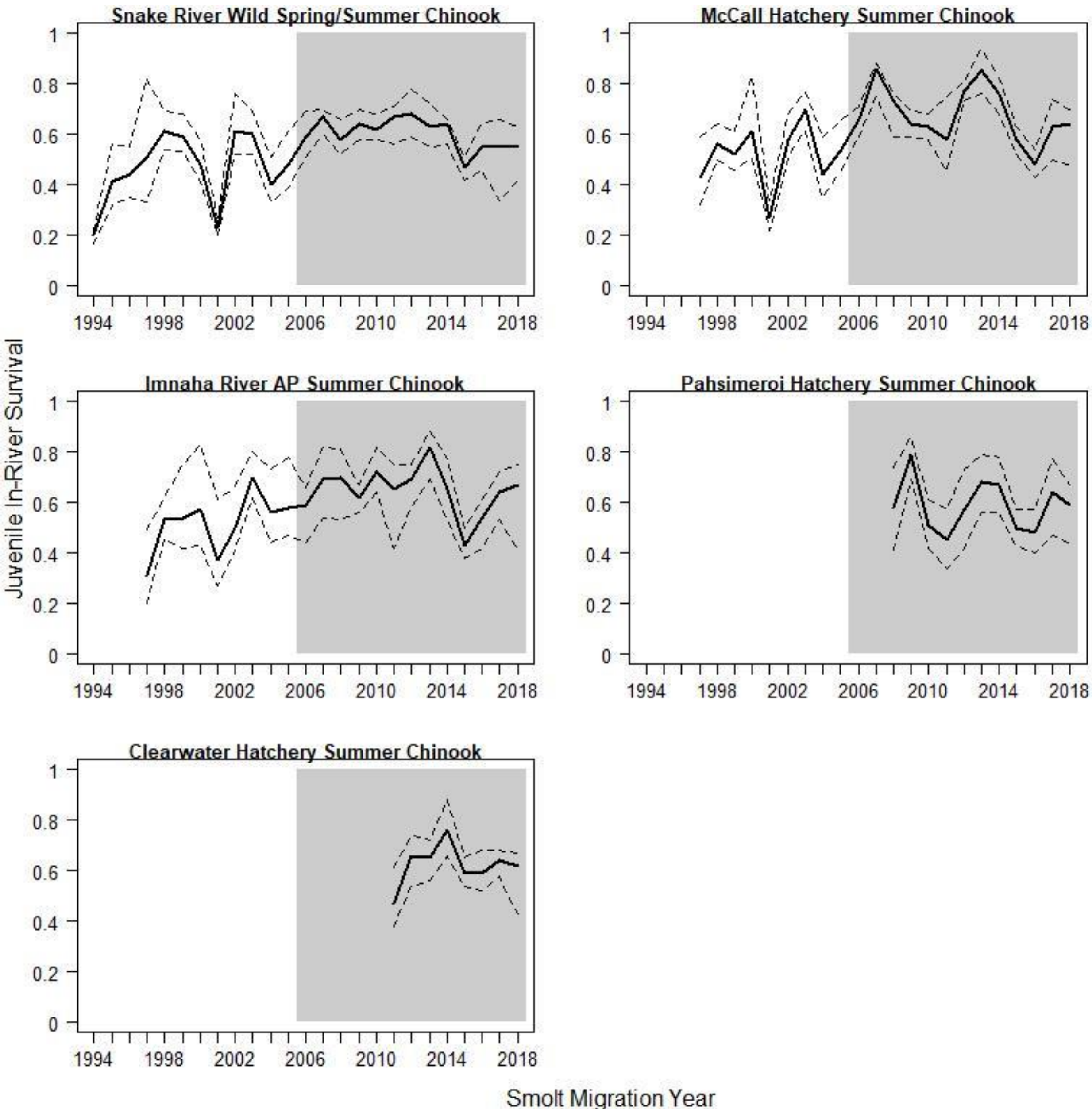

Figure A.4. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild spring/summer Chinook (1994-2018) and hatchery summer Chinook (1994 to 2018) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data 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 and Imnaha AP (1997-2018), Pahsimeroi Hatchery (2008-2019), and Clearwater Hatchery (2011-2018) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year[A]	McCall Hatchery	Imnaha Acclimation Pond	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	0.66 (0.59 - 0.71)	0.59 (0.44 - 0.66)		
2007	0.86 (0.75 - 0.88)	0.69 (0.54 - 0.82)		
2008	0.73 (0.59 - 0.76)	0.70 (0.53 - 0.81)	0.58 (0.41 - 0.74)	
2009	0.64 (0.59 - 0.69)	0.62 (0.56 - 0.67)	0.79 (0.69 - 0.86)	
2010	0.63 (0.58 - 0.68)	0.72 (0.64 - 0.82)	0.51 (0.42 - 0.61)	
2011	0.58 (0.45 - 0.75)	0.65 (0.42 - 0.75)	0.45 (0.34 - 0.57)	0.47 (0.38 - 0.61)
2012	0.77 (0.73 - 0.81)	0.69 (0.58 - 0.75)	0.57 (0.42 - 0.73)	0.66 (0.54 - 0.74)
2013	0.85 (0.76 - 0.94)	0.82 (0.69 - 0.88)	0.68 (0.56 - 0.79)	0.65 (0.56 - 0.72)
2014	0.76 (0.68 - 0.83)	0.65 (0.53 - 0.77)	0.67 (0.56 - 0.78)	0.76 (0.66 - 0.88)
2015	0.58 (0.52 - 0.63)	0.43 (0.38 - 0.50)	0.50 (0.43 - 0.57)	0.59 (0.54 - 0.65)
2016[B]	0.48 (0.43 - 0.54)	0.54 (0.42 - 0.61)	0.48 (0.40 - 0.57)	0.59 (0.52 - 0.68)
2017[B]	0.63 (0.50 - 0.74)	0.64 (0.53 - 0.72)	0.64 (0.47 - 0.77)	0.64 (0.58 - 0.68)
2018[B]	0.64 (0.48 - 0.70)	0.67 (0.41 - 0.75)	0.59 (0.44 - 0.67)	0.62 (0.43 - 0.67)
Geomean	**0.62**	**0.59**	**0.58**	**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).

[A] CJS estimation of S_R for migration years 2006 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] Estimate of S_R may change as groups are finalized for estimation of SARs.

Wild and Hatchery Steelhead

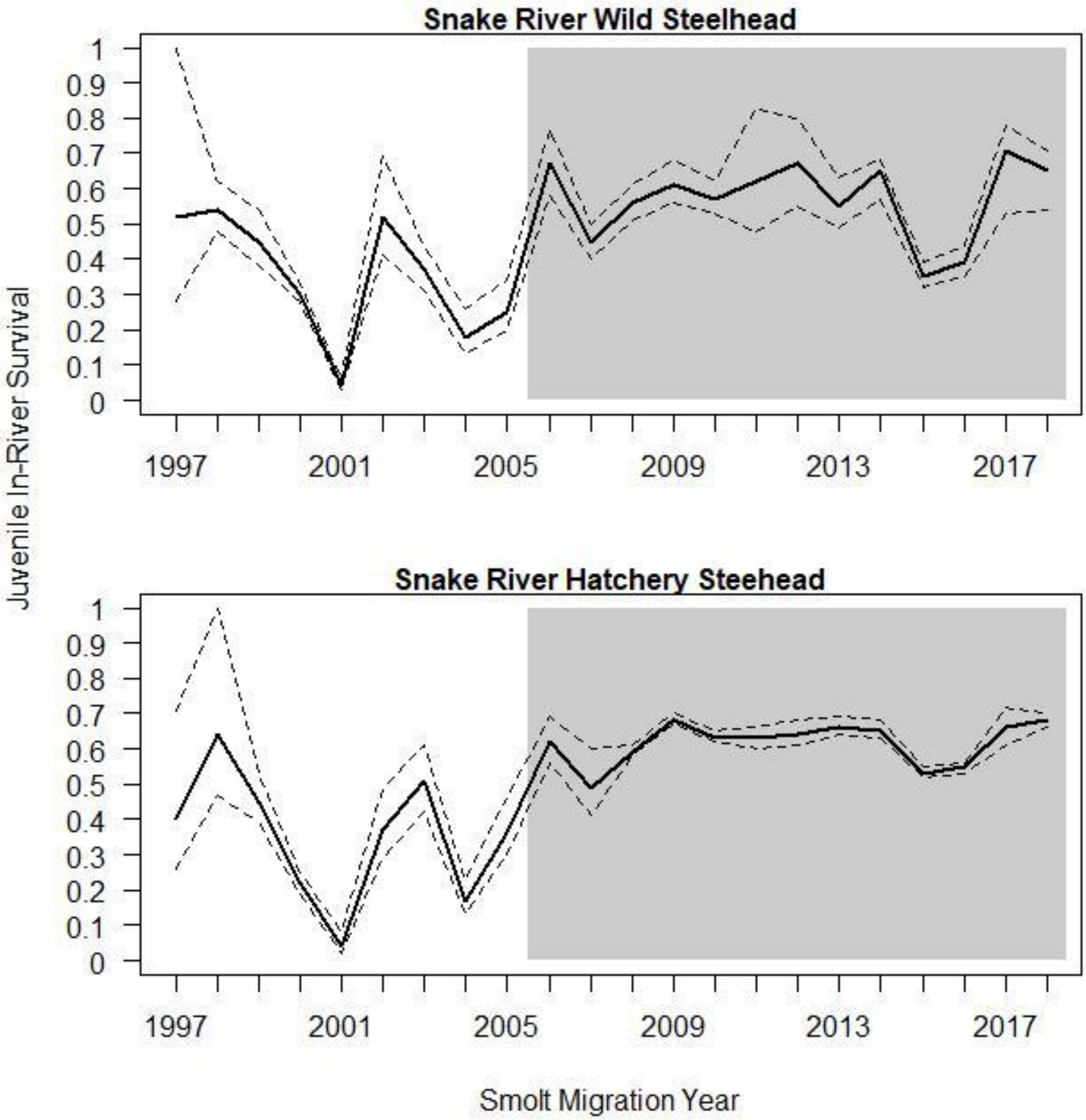

Figure A.5. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River aggregate wild (1997-2018) and aggregate hatchery (1997-2018) steelhead (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.4.

Table A.4. Estimated in-river survival LGR to BON (S_R) of PIT-tagged aggregate wild and aggregate hatchery steelhead (1997-2018) (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[A]	Aggregate Hatchery Steelhead[B]
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	0.67 (0.58 - 0.77)	0.62[1] (0.56 - 0.69)
2007	0.45 (0.40 - 0.50)	0.49 (0.41 - 0.60)
2008	0.56 (0.51 - 0.61)	0.59 (0.58 - 0.61)
2009	0.61 (0.56 - 0.68)	0.68 (0.67 - 0.70)
2010	0.57 (0.53 - 0.62)	0.63 (0.62 - 0.65)
2011	0.62 (0.48 - 0.83)	0.63 (0.60 - 0.66)
2012	0.67 (0.55 - 0.80)	0.64 (0.61 - 0.68)
2013	0.55 (0.49 - 0.63)	0.66 (0.64 - 0.69)
2014	0.65 (0.57 - 0.68)	0.65 (0.63 - 0.68)
2015	0.35 (0.32 - 0.39)	0.53 (0.52 - 0.54)
2016[C]	0.39 (0.35 - 0.44)	0.55 (0.53 - 0.56)
2017[C]	0.71 (0.53 - 0.78)	0.66 (0.61 - 0.72)
2018[C]	0.65 (0.54 - 0.71)	0.68 (0.66 - 0.70)
Geomean	**0.48**	**0.50**
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] CJS estimation of S_R for migration years 2006 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] CJS estimation of S_R for migration years 2008 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[C] Estimate of S_R may change as groups are finalized for estimation of SARs.

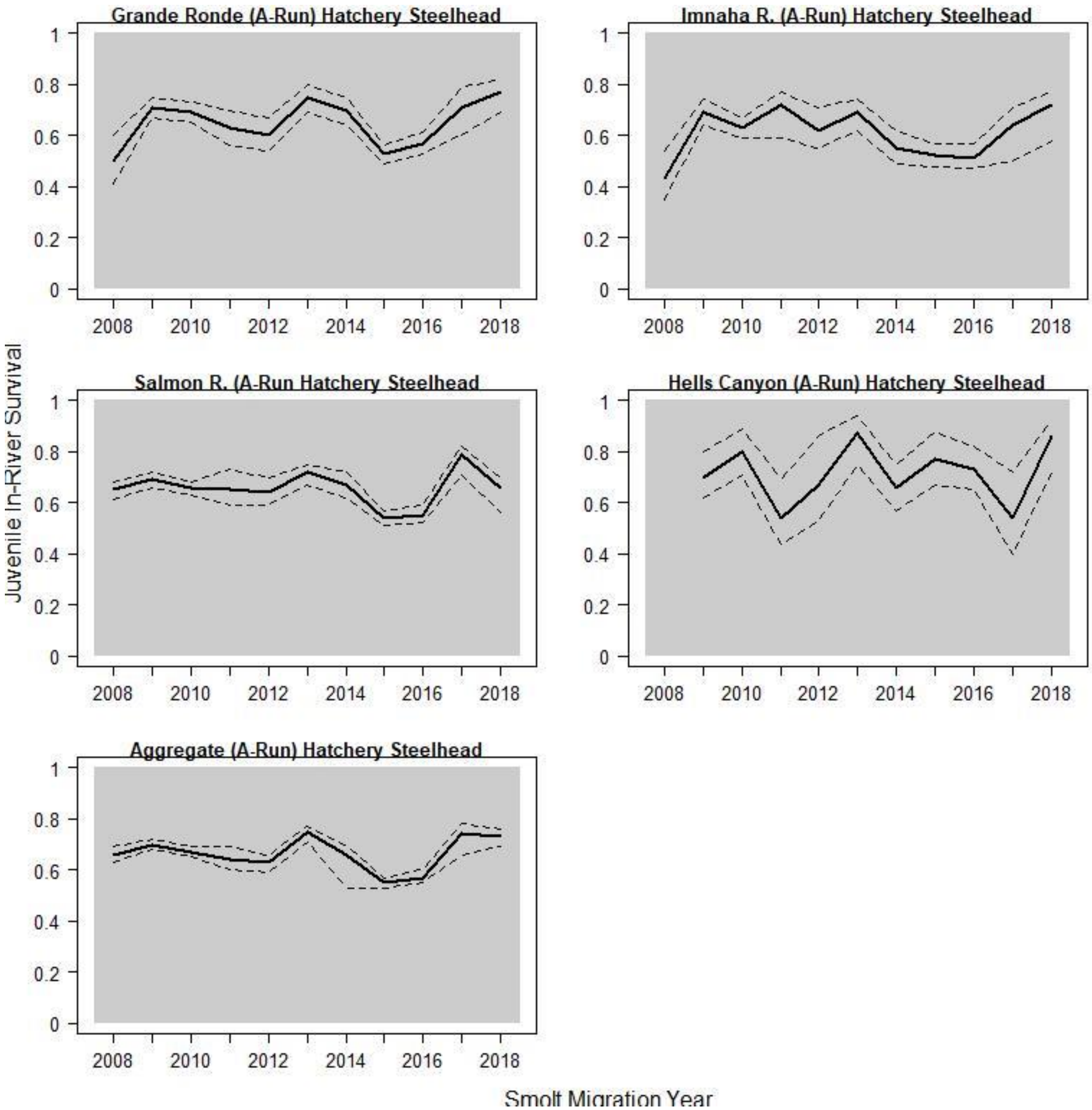

Figure A.6. Trend in juvenile in-river survival LGR to BON (S_R) for various groups of PIT-tagged Snake River A-Run hatchery steelhead (2008-2018) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from 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 2018 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Grande Ronde R. A-run (Wallowa)[A]	Imnaha R. A-run[A]	Salmon R. A-run[B]	Mainstem below HCD A-run[A]	Aggregate A-run[B]
2008	0.50[2] (0.41 - 0.60)	0.43[2] (0.35 - 0.54)	0.65 (0.61 - 0.68)		0.66 (0.63 - 0.69)
2009	0.71 (0.67 - 0.75)	0.69 (0.64 - 0.74)	0.69 (0.66 - 0.72)	0.70 (0.62 - 0.80)	0.70 (0.68 - 0.72)
2010	0.69 (0.65 - 0.73)	0.63 (0.59 - 0.67)	0.66 (0.63 - 0.68)	0.80 (0.71 - 0.89)	0.67 (0.65 - 0.69)
2011	0.63 (0.56 - 0.70)	0.72 (0.59 - 0.77)	0.65 (0.59 - 0.73)	0.54 (0.44 - 0.69)	0.64 (0.60 - 0.69)
2012	0.60 (0.54 - 0.67)	0.62 (0.55 - 0.71)	0.64 (0.59 - 0.70)	0.67 (0.53 - 0.86)	0.63 (0.59 - 0.66)
2013	0.75 (0.69 - 0.80)	0.69 (0.62 - 0.74)	0.72 (0.67 - 0.75)	0.87 (0.75 - 0.94)	0.75 (0.71 - 0.77)
2014	0.70 (0.64 - 0.75)	0.55 (0.49 - 0.62)	0.67 (0.62 - 0.72)	0.66 (0.57 - 0.75)	0.66 (0.53 - 0.70)
2015	0.53 (0.49 - 0.56)	0.52 (0.48 - 0.57)	0.54 (0.51 - 0.57)	0.77 (0.67 - 0.88)	0.55 (0.53 - 0.57)
2016[C]	0.57 (0.53 - 0.61)	0.51 (0.47 - 0.57)	0.55 (0.52 - 0.59)	0.73 (0.65 - 0.82)	0.57 (0.55 - 0.60)
2017[C]	0.71 (0.60 - 0.79)	0.64 (0.50 - 0.71)	0.79 (0.71 - 0.82)	0.54 (0.40 - 0.72)	0.74 (0.66 - 0.78)
2018[C]	0.77 (0.69 - 0.82)	0.72 (0.58 - 0.77)	0.66 (0.56 - 0.70)	0.86 (0.72 - 0.92)	0.73 (0.69 - 0.76)
Geomean	**0.64**	**0.60**	**0.65**	**0.71**	**0.66**

[A] CJS estimation of S_R for migration years 2009 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[B] CJS estimation of S_R for migration years 2008 and later uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Estimate of S_R may change as groups are finalized for estimation of SARs.

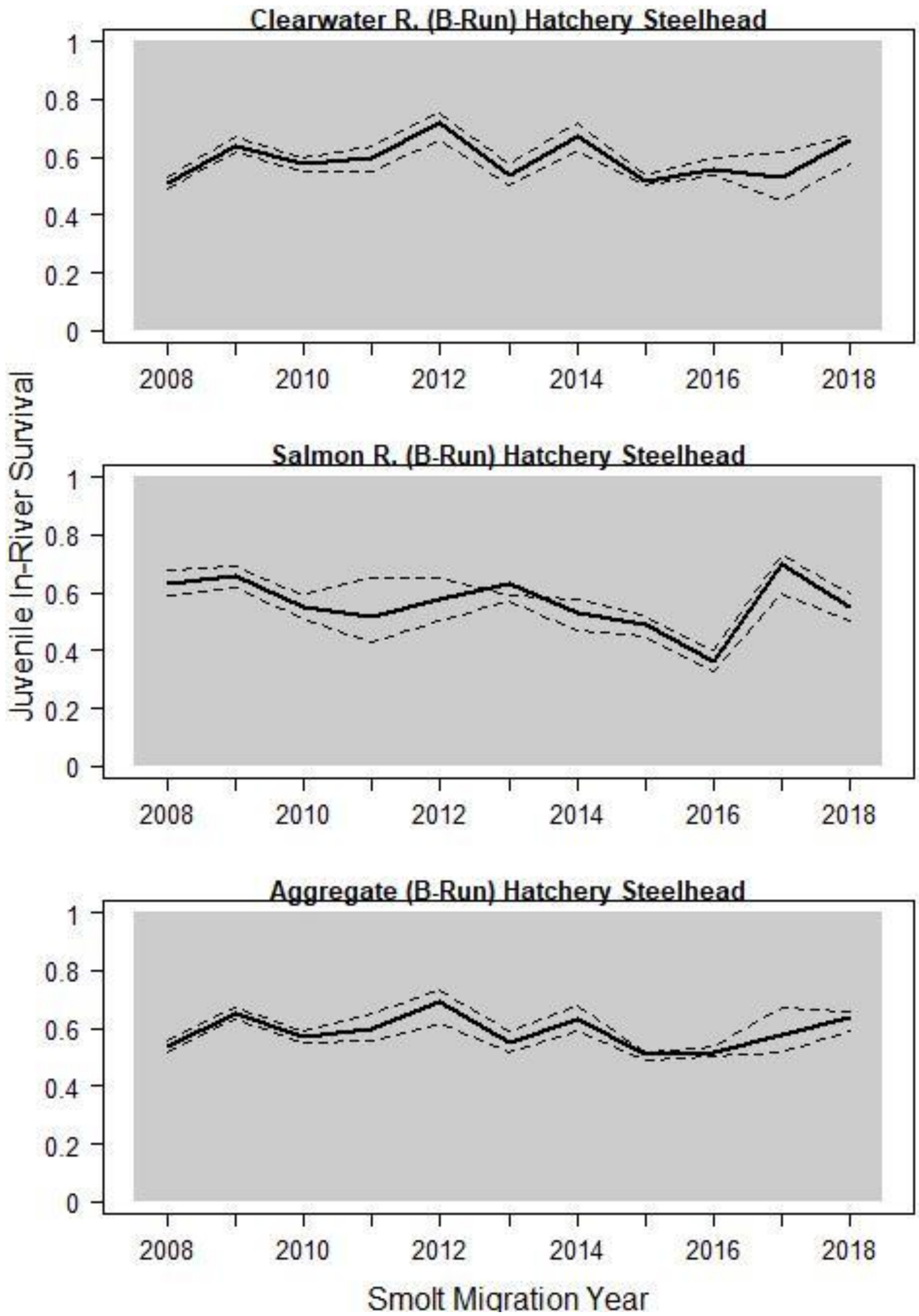

Figure A.7. Trend in juvenile in-river survival LGR to BON (S_R) for various groups of PIT-tagged Snake River B-Run hatchery steelhead (2008-2018) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from 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 2018 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year[A]	Clearwater R. B-run	Salmon R. B-run	Aggregate B-run
2008	0.51 (0.49 - 0.53)	0.63 (0.59 - 0.68)	0.54 (0.52 - 0.56)
2009	0.64 (0.62 - 0.67)	0.66 (0.62 - 0.69)	0.65 (0.63 - 0.67)
2010	0.58 (0.55 - 0.60)	0.55 (0.51 - 0.59)	0.57 (0.55 - 0.59)
2011	0.60 (0.55 - 0.64)	0.52 (0.43 - 0.65)	0.60 (0.56 - 0.65)
2012	0.72 (0.66 - 0.75)	0.58 (0.50 - 0.65)	0.69 (0.62 - 0.73)
2013	0.54 (0.50 - 0.58)	0.63 (0.57 - 0.59)	0.55 (0.52 - 0.59)
2014	0.67 (0.62 - 0.72)	0.53 (0.47 - 0.58)	0.63 (0.59 - 0.68)
2015	0.52 (0.50 - 0.54)	0.49 (0.45 - 0.52)	0.51 (0.49 - 0.52)
2016[B]	0.56 (0.54 - 0.60)	0.36 (0.33 - 0.40)	0.52 (0.50 - 0.54)
2017[B]	0.53 (0.45 - 0.62)	0.70 (0.60 - 0.73)	0.58 (0.52 - 0.67)
2018[B]	0.66 (0.58 - 0.68)	0.55 (0.50 - 0.60)	0.64 (0.59 - 0.66)
Geomean	**0.59**	**0.56**	**0.59**

[A] CJS estimation of SR uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] Estimates of S_R may change as groups are finalized for estimation of SARs.

Hatchery Sockeye

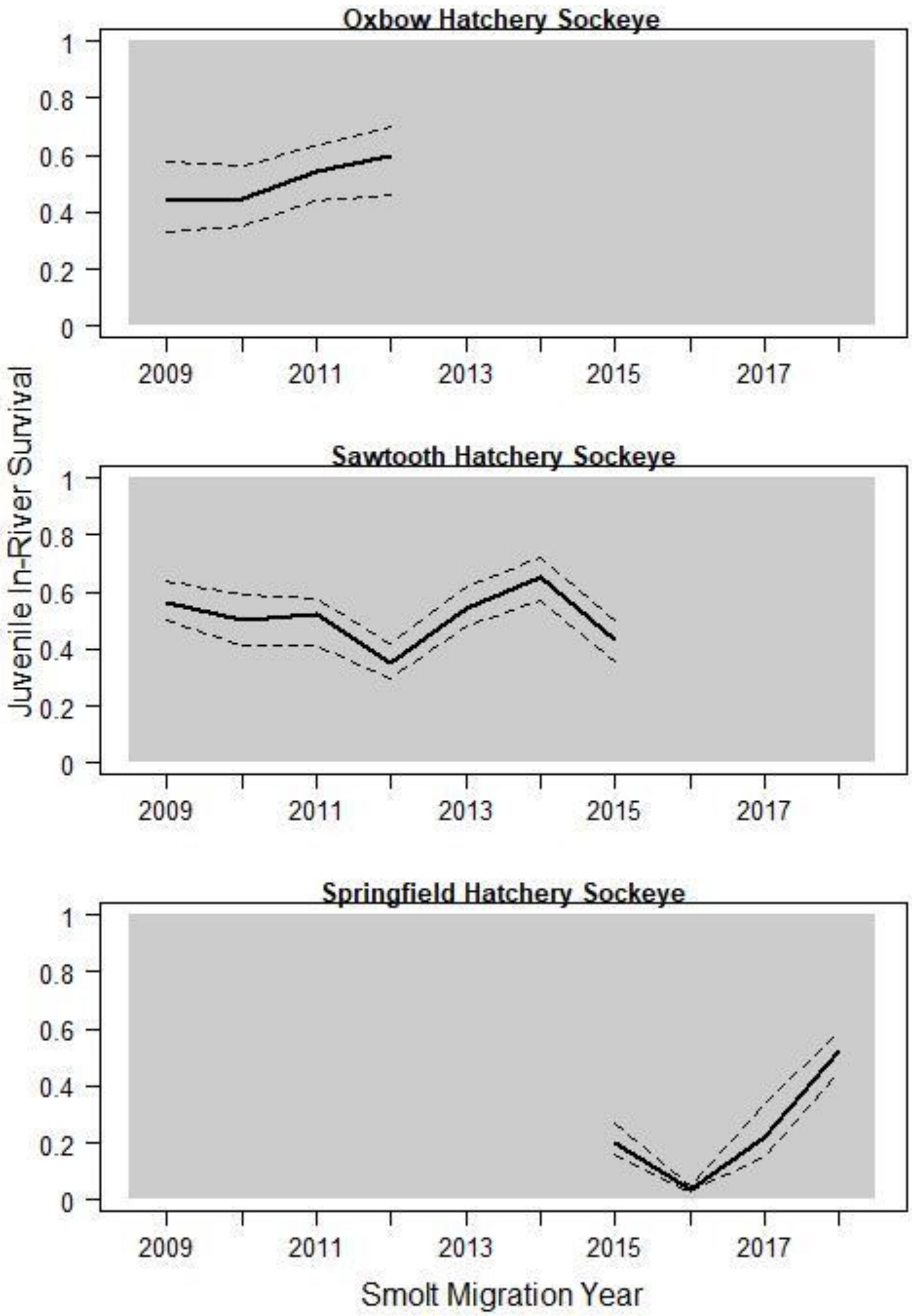

Figure A.8. Trend in in-river survival LGR to BON (S_R) of PIT-tagged Snake River hatchery sockeye from Oxbow (2009-2012), Sawtooth (2009-2015) and Springfield (2015-2017) hatcheries (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.7.

Table A.7. Estimated in-river survival LGR to BON (S_R) of PIT-tagged Snake River hatchery sockeye from Sawtooth (2009-2015), Oxbow (2009-2012), and Springfield (2015-2018) hatcheries (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year[A]	Sawtooth Hatchery	Oxbow Hatchery	Springfield Hatchery
2009	0.56 (0.50 - 0.64)	0.44 (0.33 - 0.58)	---
2010	0.50 (0.41 - 0.59)	0.45 (0.35 - 0.56)	---
2011	0.52 (0.41 - 0.58)	0.54 (0.44 - 0.63)	---
2012	0.35 (0.30 - 0.42)	0.60 (0.46 - 0.70)	---
2013	0.54 (0.48 - 0.62)	---	---
2014	0.65 (0.57 - 0.72)	---	---
2015	0.43 (0.36 - 0.50)	---	0.20 (0.16 - 0.27)
2016[B]	---	---	0.04 (0.03 - 0.05)
2017[B]	---	---	0.22 (0.15 - 0.34)
2018[B]			0.52 (0.45 - 0.59)
Geomean	**0.50**	**0.50**	**0.17**

[A] CJS estimation of SR uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

[B] Estimates of S_R may change as groups are finalized for estimation of SARs.

Wild and Hatchery Subyearling Fall Chinook

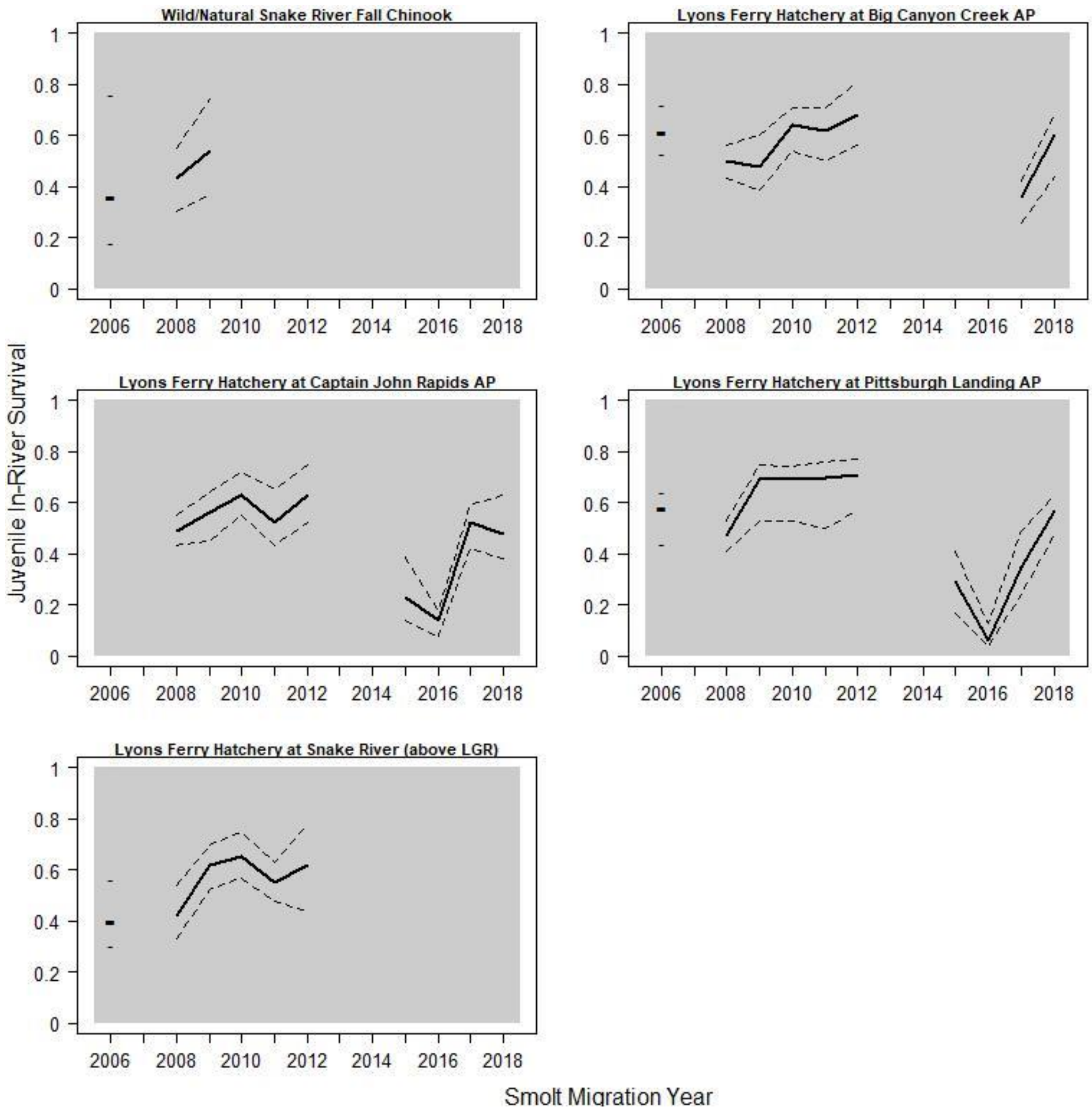

Figure A.9. Trend in in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild/natural subyearling fall Chinook and Lyons Ferry Hatchery subyearling fall Chinook (2006-2018) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data for wild/natural and Lyons Ferry Hatchery fall Chinook are from Table A.8.

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 2015-2018 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year[A]	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	0.36 (0.18 - 0.76)	0.61 (0.53 - 0.72)	---	0.58 (0.44 - 0.64)	0.40 (0.30 - 0.56)
2007[B]	---	---	---	---	---
2008	0.43 (0.30 - 0.55)	0.50 (0.43 - 0.56)	0.49 (0.43 - 0.55)	0.47 (0.41 - 0.53)	0.42 (0.33 - 0.54)
2009	0.54 (0.37 - 0.74)	0.48 (0.39 - 0.60)	0.56 (0.45 - 0.64)	0.69 (0.53 - 0.75)	0.62 (0.52 - 0.70)
2010	---	0.64 (0.54 - 0.71)	0.63 (0.55 - 0.72)	0.69 (0.53 - 0.74)	0.65 (0.57 - 0.75)
2011	---	0.62 (0.50 - 0.71)	0.52 (0.43 - 0.65)	0.70 (0.50 - 0.76)	0.55 (0.48 - 0.63)
2012	---	0.68 (0.56 - 0.81)	0.63 (0.52 - 0.75)	0.71 (0.57 - 0.77)	0.62 (0.44 - 0.78)
2015	---		0.23 (0.14 - 0.39)	0.29 (0.17 - 0.41)	---
2016[C]	---		0.14 (0.08 - 0.18)	0.06 (0.04 - 0.13)	---
2017[C]	---	0.36 (0.26 - 0.42)	0.52 (0.42 - 0.59)	0.35 (0.24 - 0.49)	---
2018[C]		0.60 (0.44 - 0.68)	0.48 (0.38 - 0.63)	0.57 (0.47 - 0.63)	
Geomean	**0.44**	**0.55**	**0.43**	**0.43**	**0.53**

[A] CJS estimation of S_R for migration years 2008-2017 uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[B] S_R not reported for 2007 due to small sample sizes and lack of pre-assignments in that year.
[C] Estimates of S_R may change as groups are finalized for estimation of SARs.

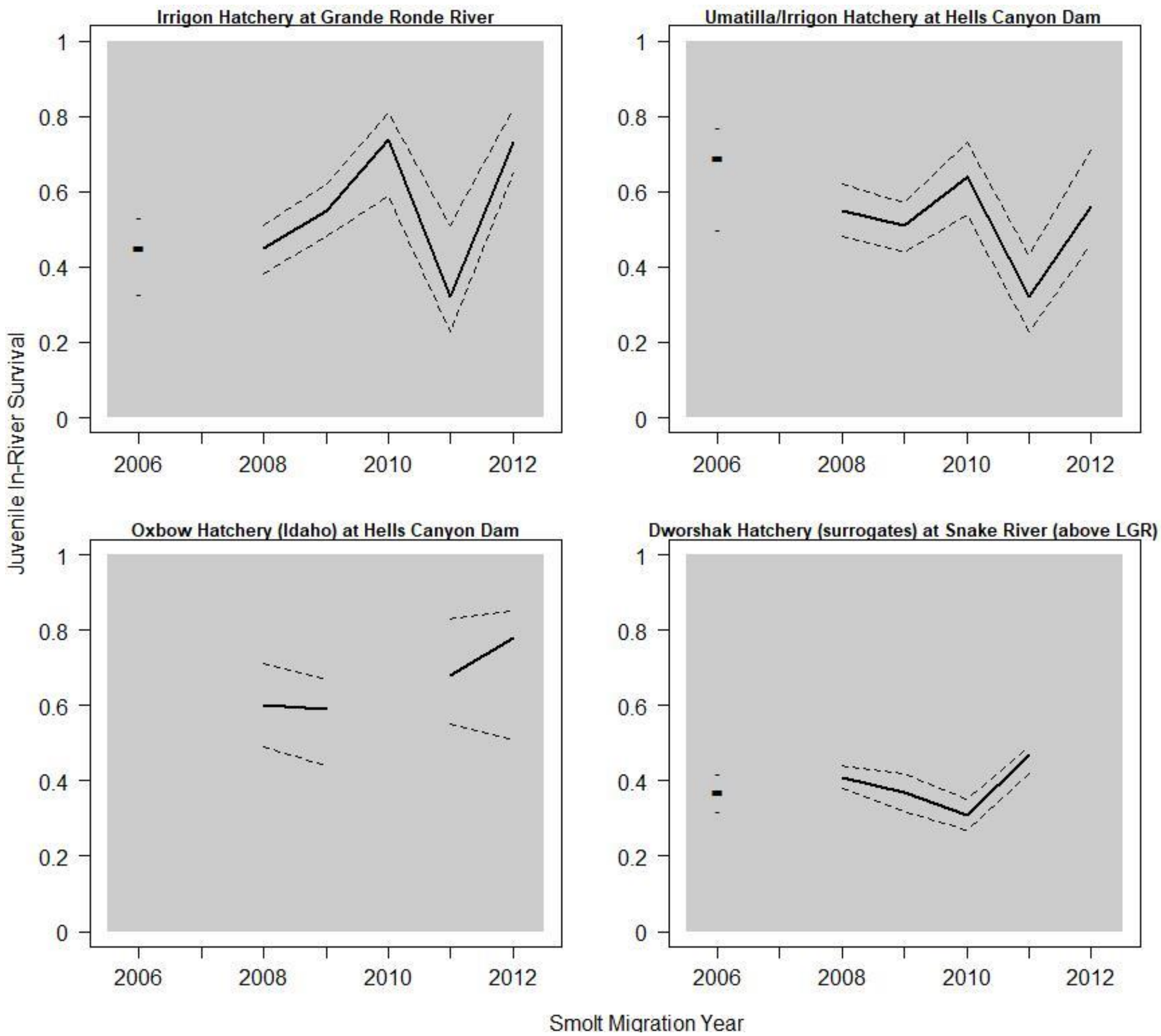

Figure A.10. Trend in in-river survival LGR to BON (S_R) for PIT-tagged hatchery subyearling fall Chinook (various hatcheries and release sites) in migration years 2006 to 2012 (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery fall Chinook are from Table A.9.

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[A]	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 (0.33 - 0.53)	0.69 (0.50 - 0.77)	---	0.37 (0.32 - 0.42)
2007[C]	---	---	---	---
2008	0.45 (0.38 - 0.51)	0.55 (0.48 - 0.62)	0.60 (0.49 - 0.71)	0.41 (0.38 - 0.44)
2009	0.55 (0.48 - 0.62)	0.51 (0.44 - 0.57)	0.59 (0.44 - 0.67)	0.37 (0.32 - 0.42)
2010	0.74 (0.59 - 0.81)	0.64 (0.54 - 0.73)	---	0.31 (0.27 - 0.35)
2011	0.32 (0.23 - 0.51)	0.32 (0.23 - 0.43)	0.68 (0.55 - 0.83)	0.47 (0.42 - 0.49)
2012	0.73 (0.65 - 0.82)	0.56 (0.46 - 0.71)	0.78 (0.51 - 0.85)	---[E]
Geomean	**0.52**	**0.53**	**0.66**	**0.38**

[A] CJS estimation of S_R for migration years 2008-2017 uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[B] 2006 release into Grande Ronde River were reared at Lyons Ferry Hatchery
[C] S_R not reported for 2007 due to small sample sizes and lack of pre-assignments in that year.
[D] No PIT-tags were released for this group in 2010.
[E] S_R not reported due to high estimates of holdover rates.

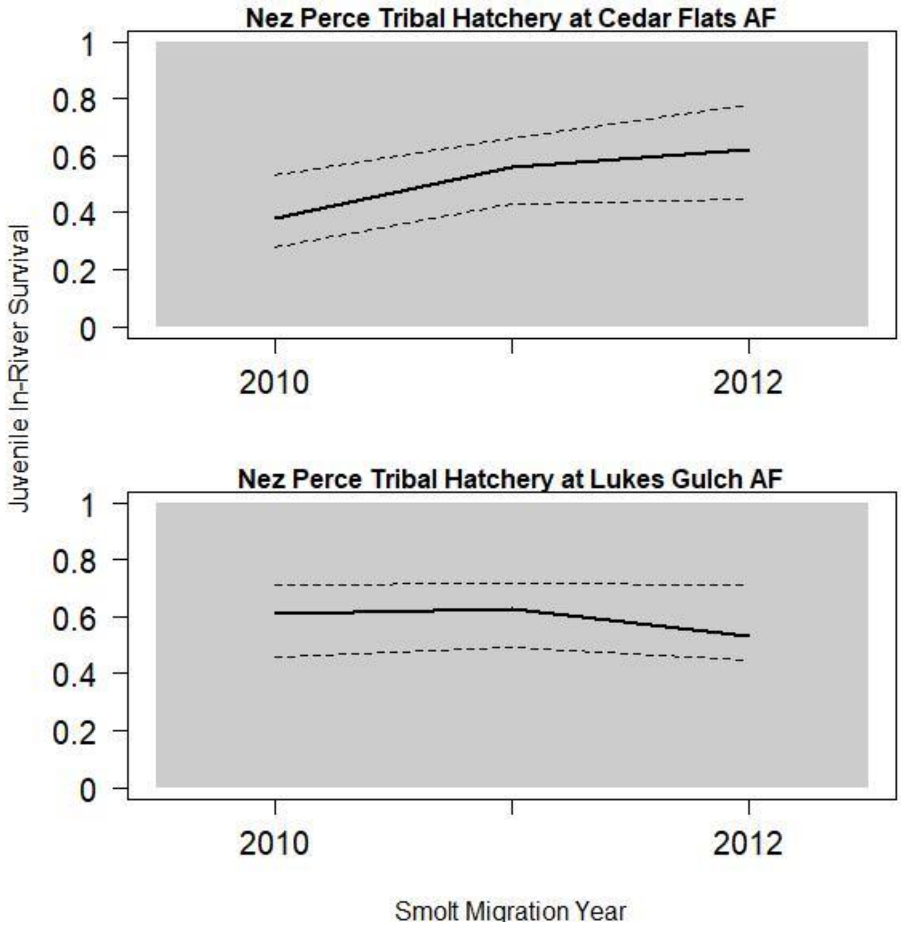

Figure A.11. Trend in in-river survival LGR to BON (S_R) for PIT-tagged hatchery subyearling fall Chinook from the Nez Perce Tribal Hatchery released at Cedar Flats and Lukes Gulch acclimation facilities in migration years 2010 to 2012 (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data are from Table A.10.

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[A]	Cedar Flats Acclimation Facility	Lukes Gulch Acclimation Facility
2010	0.38 (0.28 - 0.53)	0.61 (0.46 - 0.71)
2011	0.56 (0.43 - 0.66)	0.63 (0.49 - 0.72)
2012	0.62 (0.45 - 0.78)	0.53 (0.45 - 0.71)
Geomean	**0.51**	**0.59**

[A] CJS estimation of S_R for migration years 2008-2017 uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

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

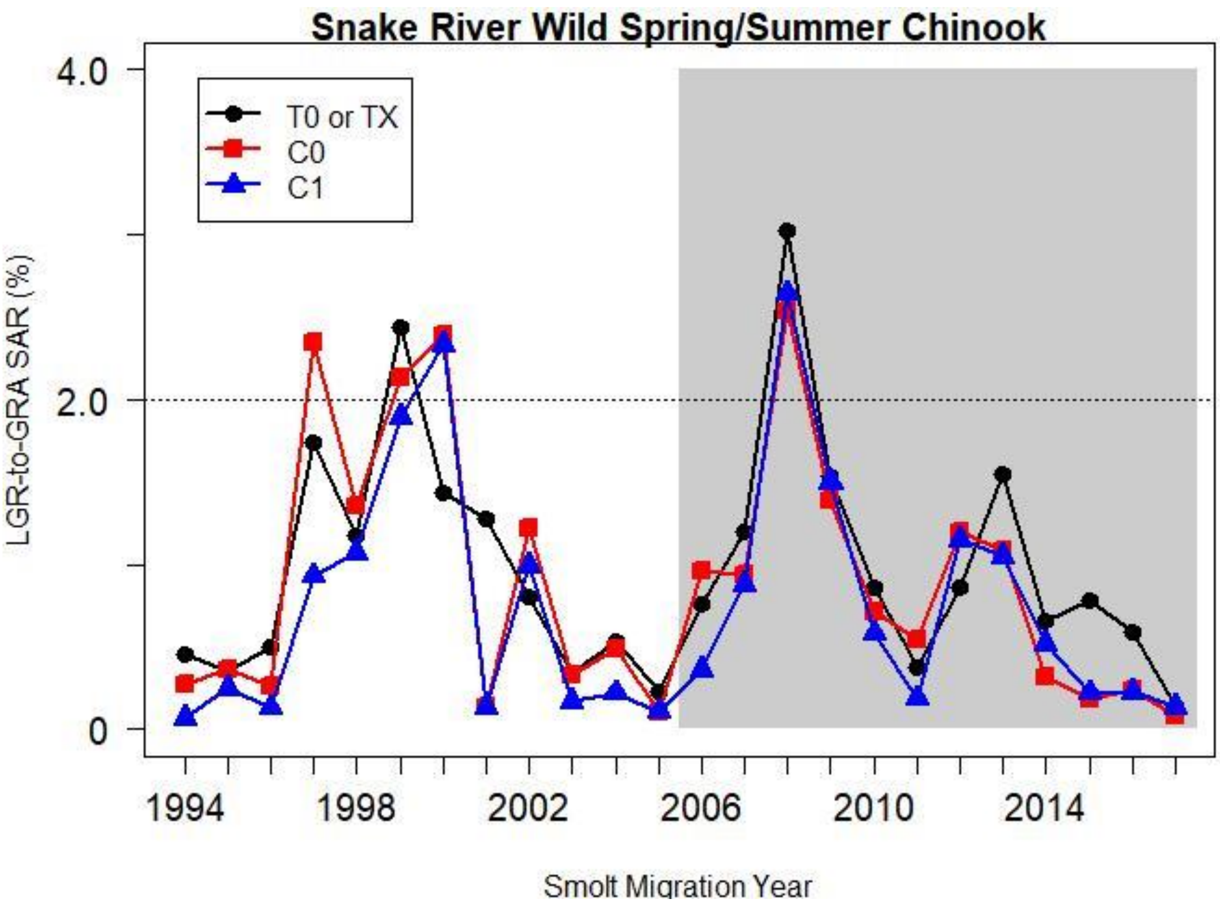

Figure A.12. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged wild spring/summer Chinook aggregate in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1994 to 2017 (incomplete adult returns for 2017). Shaded area highlights the period of Court 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 2017 (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 (0.61 - 0.89)	0.96 (0.70 - 1.22)	0.36 (0.18 - 0.55)
2007	1.20 (0.87 - 1.54)	0.94 (0.78 - 1.08)	0.88 (0.67 - 1.10)
2008	3.02 (2.71 - 3.33)	2.54 (2.25 - 2.85)	2.64 (2.27 - 3.06)
2009	1.54 (1.31 - 1.76)	1.39 (1.14 - 1.66)	1.50 (1.27 - 1.76)
2010	0.86 (0.72 - 1.00)	0.71 (0.61 - 0.80)	0.58 (0.30 - 0.93)
2011	0.38 (0.27 - 0.49)	0.55 (0.41 - 0.70)	0.19 (0.13 - 0.27)
2012	0.86 (0.63 - 1.12)	1.20 (1.01 - 1.43)	1.15 (0.99 - 1.31)
2013	1.55 (1.31 - 1.82)	1.09 (0.95 - 1.23)	1.05 (0.79 - 1.35)
2014	0.66 (0.50 - 0.82)	0.32 (0.22 - 0.44)	0.52 (0.40 - 0.65)
2015	0.78 (0.47 - 1.12)	0.18 (0.12 - 0.24)	0.22 (0.09 - 0.40)
2016	0.59 (0.40 - 0.79)	0.24 (0.12 - 0.36)	0.23 (0.15 - 0.32)
2017[C]	0.14 (0.00 - 0.41)	0.08 (0.00 - 0.16)	0.14 (0.05 - 0.23)
24-yr avg.	**0.98 (0.73 – 1.23)**	**0.9 (0.62 – 1.18)**	**0.74 (0.48 – 1)**

[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 June 28, 2019.

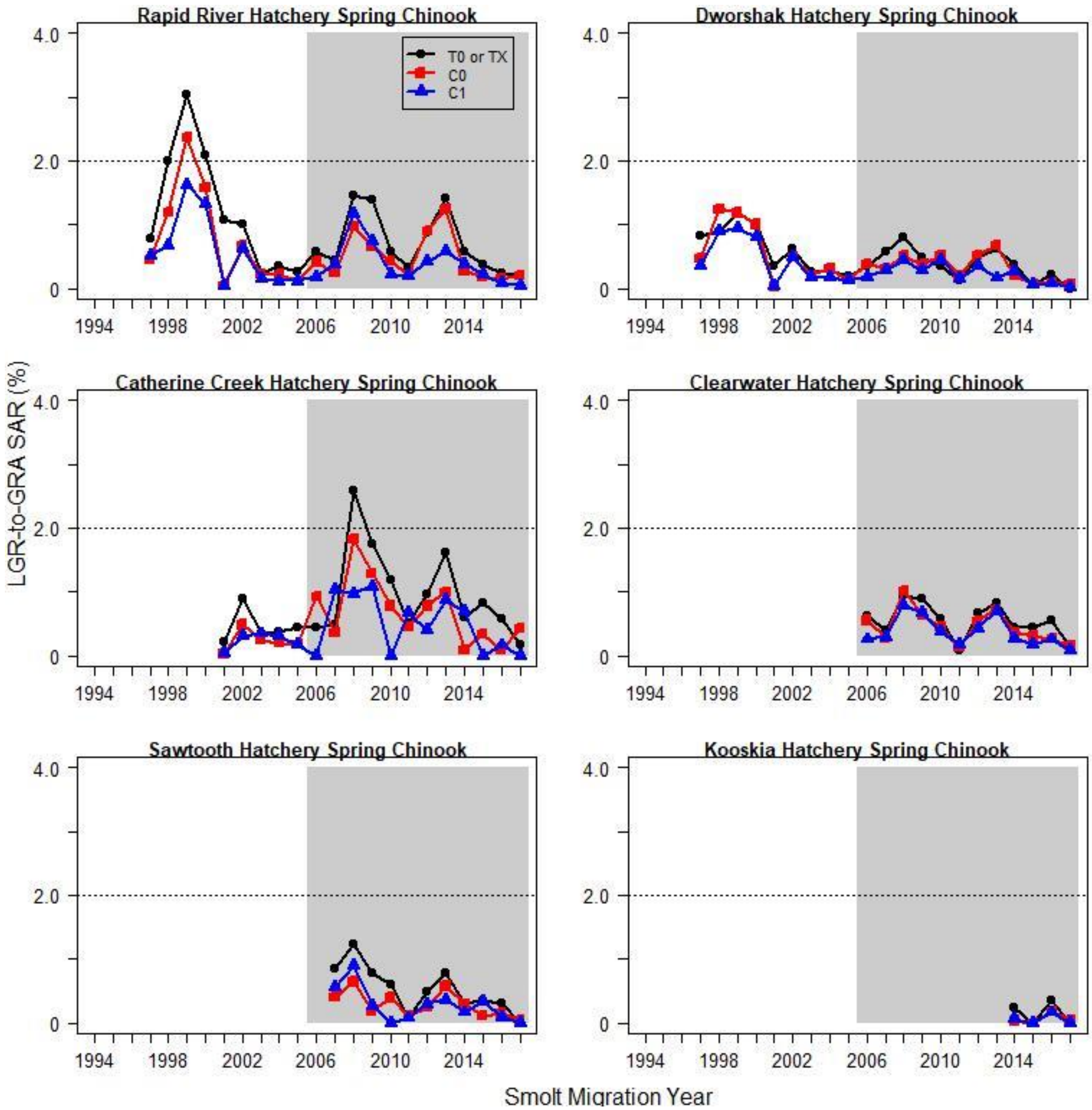

Figure A.13. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass Hatchery), Clearwater, Sawtooth, and Kooskia hatcheries in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1997 to 2017 (incomplete adult returns for 2017). 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 2017 (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	(0.47 - 0.65)	0.42	(0.31 - 0.54)	0.19	(0.05 - 0.35)
2007	0.45	(0.34 - 0.57)	0.25	(0.19 - 0.31)	0.38	(0.21 - 0.56)
2008	1.47	(1.33 - 1.63)	0.97	(0.81 - 1.12)	1.18	(0.90 - 1.48)
2009	1.40	(1.22 - 1.58)	0.67	(0.57 - 0.78)	0.74	(0.53 - 0.95)
2010	0.57	(0.42 - 0.73)	0.43	(0.36 - 0.49)	0.23	(0.00 - 0.67)
2011	0.33	(0.25 - 0.43)	0.23	(0.16 - 0.30)	0.20	(0.11 - 0.31)
2012	0.87	(0.73 - 1.01)	0.91	(0.79 - 1.04)	0.43	(0.29 - 0.60)
2013	1.41	(1.22 - 1.61)	1.24	(1.11 - 1.36)	0.58	(0.24 - 0.96)
2014	0.57	(0.47 - 0.69)	0.28	(0.21 - 0.34)	0.39	(0.17 - 0.63)
2015	0.37	(0.24 - 0.50)	0.18	(0.15 - 0.22)	0.23	(0.00 - 0.53)
2016	0.25	(0.16 - 0.34)	0.16	(0.10 - 0.22)	0.09	(0.05 - 0.14)
2017[C]	0.21	(0.12 - 0.31)	0.21	(0.15 - 0.26)	0.05	(0.00 - 0.10)
21-yr avg.	**0.92**	**(0.63 – 1.21)**	**0.61**	**(0.38 – 0.84)**	**0.47**	**(0.3 – 0.64)**

[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 June 28, 2019.

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 2017 (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	(0.28 - 0.45)	0.39	(0.30 - 0.48)	0.19	(0.10 - 0.31)
2007	0.59	(0.34 - 0.86)	0.32	(0.27 - 0.37)	0.29	(0.19 - 0.40)
2008	0.80	(0.65 - 0.96)	0.52	(0.43 - 0.61)	0.45	(0.30 - 0.62)
2009	0.49	(0.37 - 0.62)	0.38	(0.30 - 0.46)	0.29	(0.16 - 0.44)
2010	0.36	(0.24 - 0.49)	0.52	(0.45 - 0.58)	0.46	(0.26 - 0.67)
2011	0.13	(0.08 - 0.20)	0.21	(0.15 - 0.27)	0.15	(0.09 - 0.23)
2012	0.50	(0.35 - 0.66)	0.53	(0.44 - 0.62)	0.36	(0.27 - 0.46)
2013	0.62	(0.48 - 0.79)	0.68	(0.69 - 0.76)	0.17	(0.07 - 0.29)
2014	0.38	(0.29 - 0.48)	0.20	(0.15 - 0.26)	0.28	(0.13 - 0.44)
2015	0.06	(0.00 - 0.18)	0.08	(0.05 - 0.11)	0.06	(0.00 - 0.14)
2016	0.22	(0.06 - 0.41)	0.10	(0.05 - 0.15)	0.08	(0.04 - 0.12)
2017[C,D]	0.00	(0.00 - 0.16)	0.07	(0.04 - 0.11)	0.03	(0.00 - 0.05)
21-yr avg.	**0.48**	**(0.36 – 0.6)**	**0.43**	**(0.29 – 0.57)**	**0.33**	**(0.23 – 0.43)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete, 2-salt returns through June 28, 2019.

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 2017 (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]	0.44	(0.25 - 0.65)	0.93	(0.56 - 1.37)	0.00	(0.00 - 0.07)
2007	0.50	(0.26 - 0.77)	0.37	(0.20 - 0.55)	1.03	(0.00 - 2.15)
2008	2.58	(2.17 - 3.00)	1.83	(1.40 - 2.30)	0.98	(0.42 - 1.65)
2009	1.76	(1.36 - 2.17)	1.29	(0.95 - 1.66)	1.09	(0.40 - 1.97)
2010[C]	1.18	(0.77 - 1.64)	0.78	(0.60 - 0.99)	0.00	(0.00 - 4.79)
2011	0.52	(0.30 - 0.78)	0.45	(0.21 - 0.71)	0.67	(0.17 - 1.27)
2012	0.96	(0.64 - 1.31)	0.78	(0.52 - 1.08)	0.40	(0.10 - 0.74)
2013	1.62	(1.14 - 2.14)	1.00	(0.65 - 1.38)	0.88	(0.00 - 2.09)
2014	0.60	(0.34 - 0.89)	0.10	(0.00 - 0.24)	0.70	(0.00 - 1.41)
2015[C]	0.83	(0.30 - 1.41)	0.34	(0.18 - 0.48)	0.00	(0.00 - 1.16)
2016	0.59	(0.27 - 0.94)	0.09	(0.00 - 0.22)	0.17	(0.04 - 0.30)
2017[C,D]	0.18	(0.04 - 0.33)	0.44	(0.28 - 0.60)	0.00	(0.00 - 0.65)
17-yr avg.	**0.83**	**(0.55 – 1.11)**	**0.56**	**(0.35 – 0.77)**	**0.42**	**(0.25 – 0.59)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[D] Incomplete, 2-salt returns through September 15, 2018.

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 2017 (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)	0.56 (0.43 - 0.71)	0.26 (0.10 - 0.46)
2007	0.41 (0.24 - 0.57)	0.28 (0.22 - 0.34)	0.30 (0.19 - 0.43)
2008	0.93 (0.76 - 1.11)	1.02 (0.85 - 1.22)	0.80 (0.53 - 1.09)
2009	0.89 (0.71 - 1.07)	0.65 (0.56 - 0.75)	0.67 (0.53 - 0.84)
2010	0.59 (0.43 - 0.78)	0.45 (0.39 - 0.51)	0.38 (0.18 - 0.60)
2011	0.09 (0.04 - 0.15)	0.14 (0.09 - 0.20)	0.18 (0.11 - 0.24)
2012	0.67 (0.48 - 0.84)	0.55 (0.46 - 0.64)	0.44 (0.36 - 0.54)
2013	0.82 (0.60 - 1.04)	0.73 (0.64 - 0.81)	0.71 (0.51 - 0.90)
2014	0.45 (0.32 - 0.59)	0.37 (0.29 - 0.44)	0.28 (0.18 - 0.38)
2015	0.44 (0.00 - 1.00)	0.31 (0.24 - 0.39)	0.18 (0.09 - 0.27)
2016	0.55 (0.34 - 0.77)	0.27 (0.20 - 0.34)	0.26 (0.20 - 0.32)
2017[B]	0.12 (0.05 - 0.21)	0.16 (0.12 - 0.21)	0.09 (0.05 - 0.13)
12-yr avg.	**0.55 (0.4 – 0.7)**	**0.46 (0.32 – 0.6)**	**0.38 (0.26 – 0.5)**

[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, 2-salt returns through June 28, 2019.

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 2017 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %
2007	0.85 (0.61 - 1.11)	0.41 (0.24 - 0.59)	0.56 (0.14 - 1.08)
2008	1.23 (0.86 - 1.62)	0.65 (0.33 - 1.00)	0.90 (0.22 - 1.62)
2009	0.79 (0.48 - 1.11)	0.19 (0.06 - 0.33)	0.28 (0.00 - 0.64)
2010[B]	0.61 (0.36 - 0.88)	0.40 (0.27 - 0.53)	0.00 (0.00 - 2.98)
2011	0.09 (0.02 - 0.18)	0.11 (0.00 - 0.22)	0.08 (0.00 - 0.25)
2012	0.49 (0.30 - 0.71)	0.25 (0.11 - 0.41)	0.30 (0.08 - 0.54)
2013	0.78 (0.57 - 1.01)	0.58 (0.41 - 0.74)	0.37 (0.00 - 1.11)
2014	0.30 (0.16 - 0.45)	0.30 (0.18 - 0.44)	0.17 (0.00 - 0.41)
2015	0.36 (0.15 - 0.57)	0.11 (0.06 - 0.16)	0.33 (0.00 - 0.99)
2016	0.30 (0.14 - 0.49)	0.15 (0.05 - 0.26)	0.10 (0.02 - 0.19)
2017[B,C]	0.00 (0.00 - 0.16)	0.05 (0.00 - 0.11)	0.00 (0.00 - 0.10)
11-yr avg.	**0.53 (0.32 – 0.74)**	**0.29 (0.18 – 0.4)**	**0.28 (0.13 – 0.43)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through June 28, 2019.

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 2017 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2014	0.24 (0.06 - 0.45)	0.04 (0.00 - 0.11)	0.07 (0.00 - 0.20)
2015[B]	0.00 (0.00 - 2.04)	0.00 (0.00 - 0.10)	0.00 (0.00 - 0.41)
2016	0.36 (0.00 - 1.11)	0.18 (0.00 - 0.37)	0.17 (0.04 - 0.30)
2017[B,C]	0.00 (0.00 - 0.57)	0.05 (0.00 - 0.15)	0.00 (0.00 - 0.34)
3-yr avg.	**0.15 (0.00[D] – 0.39)**	**0.07 (0.00[D] – 0.18)**	**0.06 (0.00[D] – 0.17)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[C] Incomplete, 2-salt returns through September 15, 2018.

[D] 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.

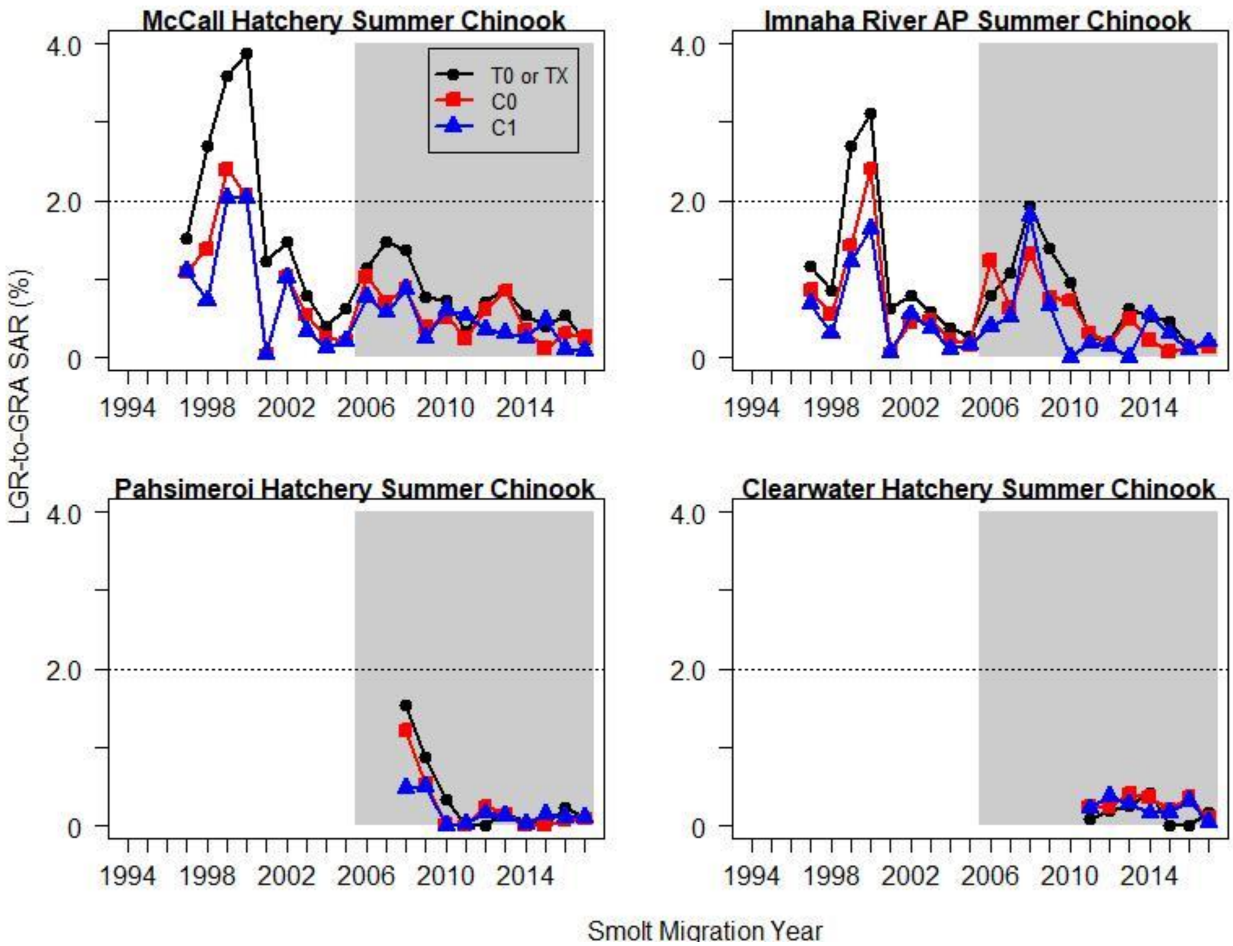

Figure A.14. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged summer Chinook from McCall, Imnaha (Lookingglass Hatchery), Pahsimeroi, and Clearwater hatcheries in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1994 to 2017 (incomplete adult returns for 2017). 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 2017 (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)	1.03	(0.86 - 1.21)	0.77	(0.45 - 1.15)
2007	1.48	(1.20 - 1.76)	0.70	(0.60 - 0.81)	0.57	(0.32 - 0.87)
2008	1.36	(1.17 - 1.55)	0.88	(0.74 - 1.03)	0.87	(0.56 - 1.17)
2009	0.76	(0.60 - 0.92)	0.38	(0.29 - 0.48)	0.25	(0.08 - 0.43)
2010	0.72	(0.54 - 0.90)	0.51	(0.43 - 0.59)	0.60	(0.00 - 1.33)
2011	0.33	(0.25 - 0.44)	0.24	(0.17 - 0.31)	0.53	(0.35 - 0.73)
2012	0.70	(0.53 - 0.87)	0.61	(0.50 - 0.73)	0.36	(0.24 - 0.50)
2013	0.87	(0.70 - 1.05)	0.85	(0.75 - 0.96)	0.32	(0.09 - 0.67)
2014	0.55	(0.44 - 0.66)	0.34	(0.27 - 0.42)	0.24	(0.06 - 0.44)
2015	0.40	(0.26 - 0.54)	0.11	(0.08 - 0.14)	0.48	(0.00 - 1.47)
2016	0.53	(0.42 - 0.64)	0.31	(0.24 - 0.39)	0.10	(0.03 - 0.19)
2017[C]	0.20	(0.12 - 0.28)	0.26	(0.20 - 0.32)	0.09	(0.00 - 0.22)
21-yr avg.	**1.20**	**(0.81 – 1.59)**	**0.72**	**(0.48 – 0.96)**	**0.61**	**(0.39 – 0.83)**

[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 July 31, 2019.

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 2017 (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	0.78 (0.59 - 0.96)	1.24 (0.89 - 1.60)	0.40 (0.10 - 0.74)
2007	1.07 (0.70 - 1.42)	0.63 (0.49 - 0.77)	0.52 (0.28 - 0.78)
2008	1.92 (1.61 - 2.25)	1.32 (1.03 - 1.62)	1.80 (1.28 - 2.31)
2009	1.39 (1.12 - 1.65)	0.76 (0.58 - 0.97)	0.67 (0.33 - 1.10)
2010[C]	0.95 (0.65 - 1.26)	0.73 (0.58 - 0.88)	0.00 (0.00 - 2.15)
2011	0.26 (0.13 - 0.38)	0.31 (0.17 - 0.46)	0.18 (0.00 - 0.38)
2012	0.20 (0.07 - 0.33)	0.18 (0.08 - 0.29)	0.14 (0.06 - 0.25)
2013[C]	0.63 (0.41 - 0.88)	0.49 (0.37 - 0.61)	0.00 (0.00 - 0.59)
2014	0.51 (0.35 - 0.68)	0.22 (0.13 - 0.33)	0.55 (0.14 - 1.08)
2015	0.45 (0.26 - 0.68)	0.07 (0.03 - 0.12)	0.30 (0.00 - 0.89)
2016	0.14 (0.06 - 0.25)	0.12 (0.05 - 0.22)	0.10 (0.03 - 0.20)
2017[D]	0.13 (0.03 - 0.24)	0.13 (0.06 - 0.21)	0.20 (0.00 - 0.44)
21-yr avg.	**0.90 (0.59 – 1.21)**	**0.61 (0.38 – 0.84)**	**0.47 (0.28 – 0.66)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete, 2-salt returns through July 31, 2019.

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 2017 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %
2008	1.54 (1.18 - 1.92)	1.21 (0.84 - 1.63)	0.48 (0.12 - 0.90)
2009	0.87 (0.33 - 1.60)	0.54 (0.34 - 0.73)	0.50 (0.33 - 0.72)
2010[B]	0.34 (0.08 - 0.62)	0.02 (0.00 - 0.05)	0.00 (0.00 - 0.57)
2011	0.00 (0.00 - 0.20)	0.00 (0.00 - 0.12)	0.02 (0.00 - 0.07)
2012[B]	0.00 (0.00 - 1.47)	0.24 (0.12 - 0.39)	0.16 (0.08 - 0.26)
2013	0.17 (0.00 - 0.36)	0.14 (0.09 - 0.21)	0.12 (0.00 - 0.24)
2014	0.04 (0.00 - 0.12)	0.00 (0.00 - 0.04)	0.02 (0.00 - 0.07)
2015[B]	0.00 (0.00 - 0.44)	0.01 (0.00 - 0.02)	0.14 (0.00 - 0.31)
2016	0.22 (0.13 - 0.32)	0.06 (0.00 - 0.12)	0.10 (0.00 - 0.30)
2017[C]	0.11 (0.00 - 0.22)	0.08 (0.03 - 0.13)	0.11 (0.03 - 0.21)
10-yr avg.	**0.33 (0.02 – 0.64)**	**0.23 (0.00 – 0.46)**	**0.17 (0.06 – 0.28)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through July 31, 2019.

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 2017 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %
2011	0.08 (0.03 - 0.17)	0.25 (0.14 - 0.38)	0.22 (0.07 - 0.36)
2012	0.19 (0.00 - 0.38)	0.23 (0.12 - 0.34)	0.38 (0.25 - 0.51)
2013	0.26 (0.09 - 0.44)	0.41 (0.31 - 0.53)	0.28 (0.07 - 0.50)
2014	0.42 (0.26 - 0.61)	0.36 (0.26 - 0.46)	0.16 (0.06 - 0.30)
2015[B]	0.00 (0.00 - 1.31)	0.20 (0.15 - 0.26)	0.17 (0.04 - 0.32)
2016[B]	0.00 (0.00 - 0.90)	0.36 (0.23 - 0.50)	0.31 (0.22 - 0.43)
2017[C]	0.17 (0.00 - 0.40)	0.09 (0.03 - 0.15)	0.04 (0.00 - 0.08)
7-yr avg.	**0.16 (0.04 – 0.28)**	**0.27 (0.18 – 0.36)**	**0.22 (0.13 – 0.31)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through July 31, 2019.

Wild and Hatchery Steelhead

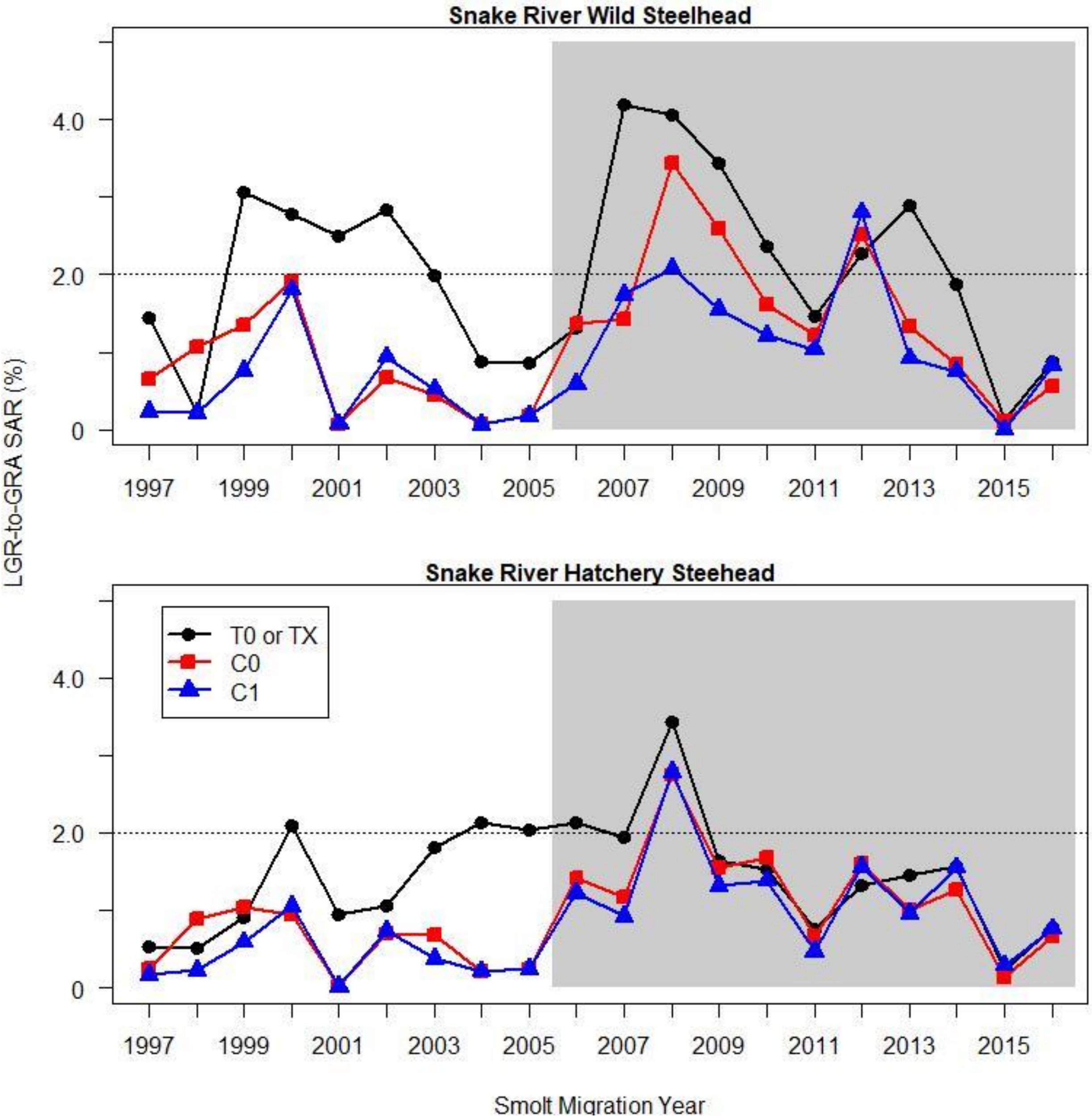

Figure A.15. Estimated LGR-to-GRA SAR for PIT-tagged wild and hatchery steelhead aggregate in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 1997 to 2016. Shaded area highlights the period of Court Order spill and later start of transportation. The 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 (2006-2016) and hatchery steelhead aggregate (2008-2016) 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 2016 (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	1.32	(1.00 - 1.66)	1.37	(0.63 - 2.17)	0.59	(0.32 - 0.94)
2007	4.20	(3.62 - 4.79)	1.43	(1.12 - 1.78)	1.74	(1.19 - 2.30)
2008	4.06	(3.41 - 4.81)	3.45	(2.93 - 4.00)	2.08	(1.47 - 2.75)
2009	3.45	(2.88 - 4.02)	2.60	(2.01 - 3.17)	1.55	(1.12 - 2.04)
2010	2.37	(1.93 - 2.84)	1.62	(1.36 - 1.87)	1.21	(0.58 - 1.83)
2011	1.47	(1.05 - 1.91)	1.21	(0.82 - 1.66)	1.03	(0.59 - 1.46)
2012	2.28	(1.65 - 2.93)	2.51	(2.05 - 3.02)	2.81	(2.34 - 3.26)
2013	2.90	(2.47 - 3.35)	1.33	(1.10 - 1.59)	0.92	(0.45 - 1.45)
2014	1.87	(1.54 - 2.21)	0.84	(0.62 - 1.05)	0.75	(0.41 - 1.10)
2015[C]	0.12	(0.00 - 0.28)	0.11	(0.05 - 0.16)	0.00	(0.00 - 0.67)
2016[D]	0.87	(0.57 - 1.19)	0.55	(0.35 - 0.76)	0.83	(0.56 - 1.09)
20-yr avg.	**2.07**	**(1.60 – 2.54)**	**1.17**	**(0.81 – 1.53)**	**0.91**	**(0.61 – 1.21)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019 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 2016 (with 90% confidence intervals).

Migration Year	$SAR(T_0)$ %		$SAR(C_0)$ %		$SAR(C_1)$ %	
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]	3.43	(3.27 - 3.58)	2.76	(2.62 - 2.90)	2.79	(2.59 - 2.98)
2009	1.65	(1.55 - 1.76)	1.54	(1.43 - 1.65)	1.32	(1.22 - 1.42)
2010	1.52	(1.41 - 1.62)	1.68	(1.60 - 1.75)	1.38	(1.18 - 1.58)
2011	0.76	(0.69 - 0.83)	0.66	(0.60 - 0.73)	0.47	(0.41 - 0.52)
2012	1.33	(1.22 - 1.44)	1.60	(1.49 - 1.72)	1.56	(1.46 - 1.67)
2013	1.45	(1.34 - 1.56)	1.00	(0.94 - 1.07)	0.96	(0.82 - 1.11)
2014	1.56	(1.45 - 1.67)	1.27	(1.20 - 1.35)	1.55	(1.40 - 1.71)
2015	0.22	(0.16 - 0.30)	0.14	(0.12 - 0.16)	0.29	(0.20 - 0.40)
2016[E]	0.78	(0.70 - 0.88)	0.67	(0.60 - 0.74)	0.76	(0.68 - 0.84)
20-yr avg.	**1.44**	**(1.14 – 1.74)**	**0.94**	**(0.68 – 1.2)**	**0.84**	**(0.57 – 1.11)**

[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 June 28, 2019 at GRA.

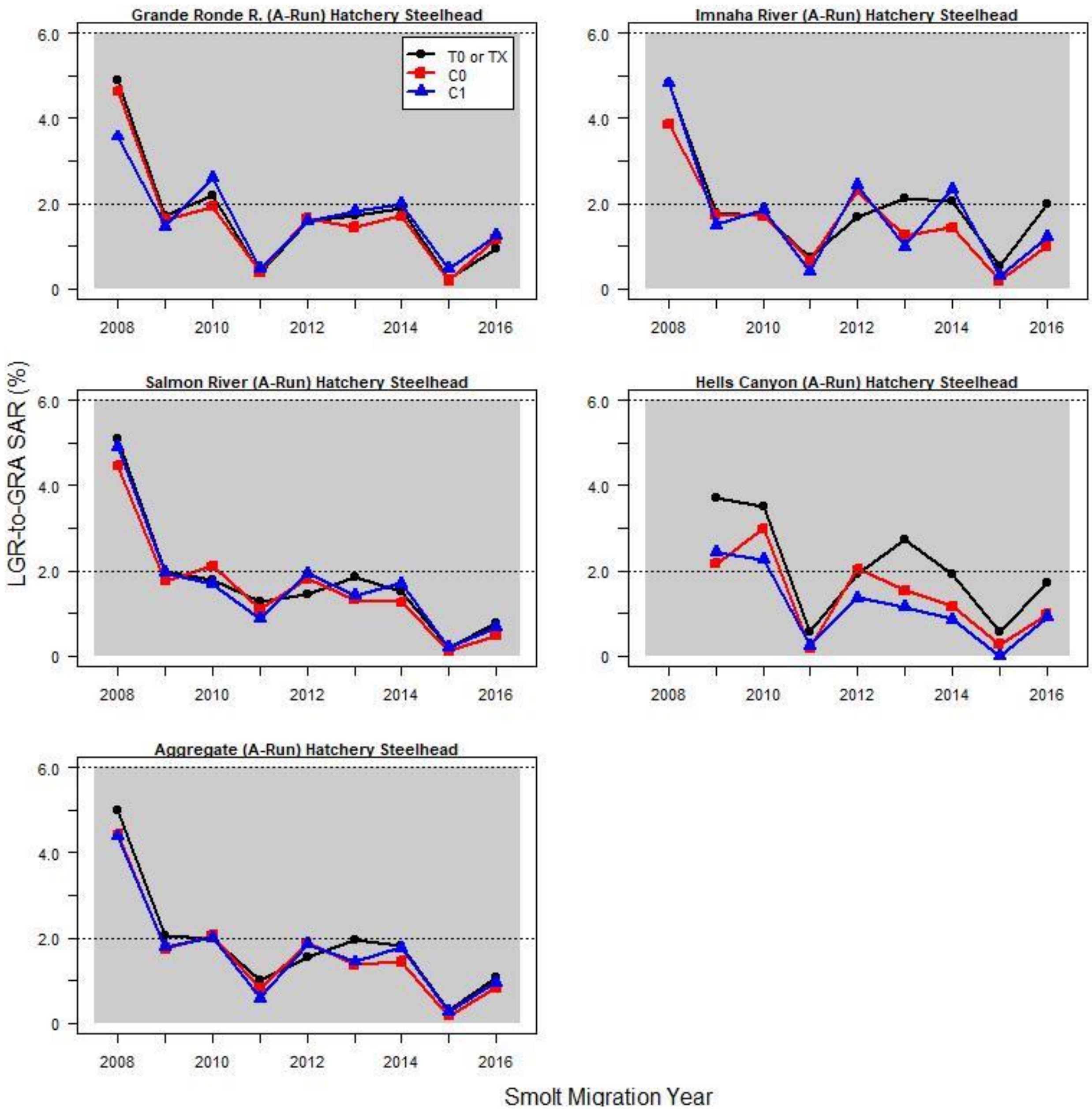

Figure A.16. Estimated LGR-to-GRA SAR (%) for individual groups of PIT-tagged A-run hatchery steelhead in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 2008 to 2016. Shaded area highlights the period of Court Order spill and later start of transportation. 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 2016 (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	(1.48 - 1.98)	1.63	(1.35 - 1.91)	1.47	(1.15 - 1.80)
2010	2.20	(1.86 - 2.54)	1.93	(1.72 - 2.13)	2.59	(1.77 - 3.35)
2011	0.36	(0.23 - 0.52)	0.40	(0.27 - 0.53)	0.46	(0.32 - 0.61)
2012	1.59	(1.28 - 1.92)	1.65	(1.41 - 1.90)	1.59	(1.34 - 1.84)
2013	1.72	(1.41 - 2.00)	1.44	(1.25 - 1.61)	1.82	(1.31 - 2.35)
2014	1.88	(1.56 - 2.17)	1.71	(1.50 - 1.93)	2.00	(1.58 - 2.45)
2015	0.22	(0.08 - 0.38)	0.19	(0.14 - 0.24)	0.48	(0.18 - 0.86)
2016[C]	0.94	(0.60 - 1.29)	1.17	(0.95 - 1.39)	1.24	(0.98 - 1.51)
9-yr avg.	**1.72**	**(0.82 – 2.62)**	**1.64**	**(0.80 – 2.48)**	**1.69**	**(1.05 – 2.33)**

[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 June 28, 2019, 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 2016 (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	1.77	(1.48 - 2.07)	1.74	(1.40 - 2.09)	1.50	(1.14 - 1.87)
2010	1.72	(1.43 - 2.02)	1.70	(1.48 - 1.92)	1.86	(1.11 - 2.77)
2011	0.75	(0.55 - 0.96)	0.66	(0.47 - 0.86)	0.39	(0.19 - 0.63)
2012	1.67	(1.34 - 1.99)	2.30	(1.94 - 2.67)	2.44	(1.99 - 2.87)
2013	2.11	(1.77 - 2.42)	1.24	(1.02 - 1.47)	0.99	(0.45 - 1.60)
2014	2.04	(1.75 - 2.32)	1.43	(1.19 - 1.69)	2.35	(1.60 - 3.13)
2015	0.53	(0.23 - 0.85)	0.18	(0.12 - 0.26)	0.31	(0.00 - 0.94)
2016[C]	1.99	(1.51 - 2.49)	1.00	(0.73 - 1.25)	1.21	(0.83 - 1.64)
9-yr avg.	**1.94**	**(1.13 – 2.75)**	**1.57**	**(0.87 – 2.27)**	**1.76**	**(0.86 – 2.66)**

[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 June 28, 2019, 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 2016 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	5.11	(4.71 - 5.49)	4.46	(4.10 - 4.82)	4.92	(4.24 - 5.60)
2009	2.00	(1.82 - 2.20)	1.76	(1.55 - 2.00)	1.95	(1.71 - 2.19)
2010	1.77	(1.58 - 1.96)	2.11	(1.96 - 2.27)	1.68	(1.20 - 2.20)
2011	1.29	(1.14 - 1.45)	1.09	(0.95 - 1.23)	0.88	(0.70 - 1.08)
2012	1.46	(1.26 - 1.65)	1.80	(1.62 - 1.99)	1.94	(1.74 - 2.15)
2013	1.84	(1.63 - 2.03)	1.32	(1.19 - 1.45)	1.41	(1.05 - 1.81)
2014	1.52	(1.30 - 1.74)	1.26	(1.10 - 1.41)	1.70	(1.36 - 2.05)
2015	0.20	(0.07 - 0.34)	0.12	(0.09 - 0.16)	0.20	(0.06 - 0.41)
2016[B]	0.77	(0.60 - 0.93)	0.47	(0.36 - 0.59)	0.67	(0.50 - 0.85)
9-yr avg.	**1.77**	**(0.87 – 2.67)**	**1.60**	**(0.78 – 2.42)**	**1.71**	**(0.82 – 2.60)**

[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 June 28, 2019, 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 2016 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2009	3.70	(3.10 - 4.32)	2.17	(1.53 - 2.88)	2.44	(1.65 - 3.33)
2010	3.52	(2.84 - 4.19)	2.99	(2.54 - 3.40)	2.27	(0.58 - 4.67)
2011	0.56	(0.24 - 0.95)	0.18	(0.00 - 0.39)	0.25	(0.10 - 0.45)
2012	1.93	(1.21 - 2.75)	2.04	(1.40 - 2.76)	1.37	(0.97 - 1.80)
2013	2.72	(2.05 - 3.41)	1.54	(1.19 - 1.90)	1.14	(0.43 - 2.05)
2014	1.92	(1.35 - 2.46)	1.16	(0.80 - 1.54)	0.86	(0.44 - 1.36)
2015[B]	0.57	(0.14 - 1.12)	0.27	(0.16 - 0.39)	0.00	(0.00 - 0.83)
2016[C]	1.73	(1.15 - 2.37)	0.98	(0.68 - 1.30)	0.91	(0.51 - 1.34)
8-yr avg.	**2.08**	**(1.23 – 2.93)**	**1.42**	**(0.73 – 2.11)**	**1.16**	**(0.54 – 1.78)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, 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 2016 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	5.01	(4.78 - 5.26)	4.44	(4.20 - 4.70)	4.38	(4.03 - 4.73)
2009	2.05	(1.91 - 2.18)	1.75	(1.60 - 1.90)	1.79	(1.61 - 1.96)
2010	1.99	(1.83 - 2.13)	2.06	(1.97 - 2.16)	2.01	(1.63 - 2.40)
2011	0.99	(0.89 - 1.09)	0.80	(0.71 - 0.88)	0.59	(0.50 - 0.70)
2012	1.55	(1.41 - 1.70)	1.87	(1.74 - 2.01)	1.86	(1.72 - 2.00)
2013	1.94	(1.79 - 2.08)	1.37	(1.28 - 1.47)	1.44	(1.19 - 1.70)
2014	1.80	(1.65 - 1.95)	1.44	(1.34 - 1.55)	1.77	(1.55 - 2.01)
2015	0.30	(0.20 - 0.42)	0.17	(0.14 - 0.19)	0.27	(0.15 - 0.43)
2016[B]	1.08	(0.93 - 1.23)	0.82	(0.72 - 0.92)	0.96	(0.83 - 1.10)
9-yr avg.	**1.86**	**(0.99 – 2.73)**	**1.64**	**(0.84 – 2.44)**	**1.67**	**(0.89 – 2.45)**

[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 June 28, 2019, at GRA.

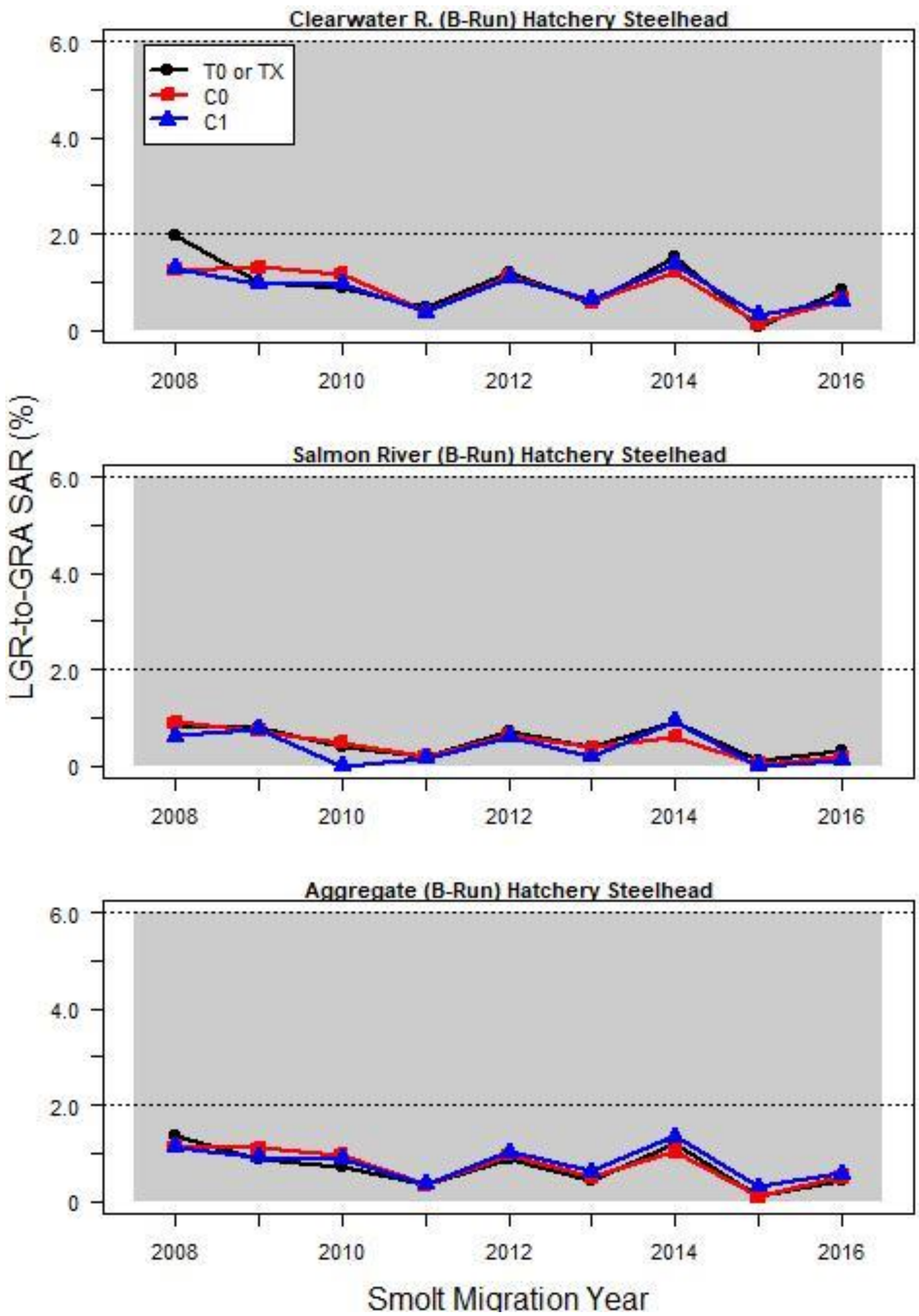

Figure A.17. Estimated LGR-to-GRA SAR (%) for individual groups of PIT-tagged B-run hatchery steelhead in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 2008 to 2016. Shaded area highlights the period of Court Order spill and later start of transportation. 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 2016 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %		$SAR(C_0)$_crt %		$SAR(EC_1)$_t %	
2008	1.97	(1.72 - 2.23)	1.26	(1.10 - 1.43)	1.29	(1.07 - 1.50)
2009	0.99	(0.80 - 1.20)	1.32	(1.09 - 1.54)	0.98	(0.86 - 1.11)
2010	0.90	(0.74 - 1.06)	1.17	(1.05 - 1.29)	0.97	(0.75 - 1.21)
2011	0.48	(0.36 - 0.59)	0.39	(0.29 - 0.50)	0.39	(0.32 - 0.46)
2012	1.21	(0.89 - 1.56)	1.13	(0.93 - 1.33)	1.09	(0.94 - 1.25)
2013	0.55	(0.37 - 0.74)	0.59	(0.50 - 0.67)	0.65	(0.50 - 0.80)
2014	1.52	(1.29 - 1.76)	1.22	(1.08 - 1.36)	1.37	(1.17 - 1.58)
2015	0.09	(0.00 - 0.23)	0.15	(0.11 - 0.19)	0.32	(0.18 - 0.47)
2016[B]	0.83	(0.55 - 1.13)	0.66	(0.55 - 0.77)	0.62	(0.52 - 0.72)
9-yr avg.	**0.95**	**(0.58 – 1.32)**	**0.88**	**(0.59 – 1.17)**	**0.85**	**(0.60 – 1.10)**

[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 June 28, 2019, 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 2016 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %		$SAR(C_0)$_crt %		$SAR(EC_1)$_t %	
2008	0.84	(0.70 - 1.01)	0.91	(0.74 - 1.09)	0.63	(0.38 - 0.94)
2009	0.79	(0.63 - 0.96)	0.74	(0.54 - 0.95)	0.77	(0.54 - 1.00)
2010[B]	0.38	(0.25 - 0.53)	0.49	(0.37 - 0.61)	0.00	(0.00 - 0.67)
2011	0.18	(0.10 - 0.28)	0.20	(0.09 - 0.31)	0.16	(0.00 - 0.32)
2012	0.72	(0.56 - 0.89)	0.64	(0.45 - 0.89)	0.60	(0.30 - 0.94)
2013	0.40	(0.27 - 0.53)	0.39	(0.29 - 0.50)	0.19	(0.00 - 0.57)
2014	0.94	(0.79 - 1.12)	0.61	(0.47 - 0.76)	0.94	(0.33 - 1.68)
2015[B]	0.11	(0.00 - 0.22)	0.03	(0.01 - 0.06)	0.00	(0.00 - 1.38)
2016[C]	0.30	(0.21 - 0.42)	0.19	(0.11 - 0.27)	0.13	(0.00 - 0.38)
9-yr avg.	**0.52**	**(0.32 – 0.72)**	**0.47**	**(0.28 – 0.66)**	**0.38**	**(0.15 – 0.61)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, 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 2016 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %
2008	1.35 (1.19 - 1.49)	1.13 (1.01 - 1.25)	1.14 (0.95 - 1.32)
2009	0.87 (0.75 - 1.00)	1.11 (0.95 - 1.27)	0.94 (0.83 - 1.05)
2010	0.72 (0.62 - 0.84)	0.98 (0.89 - 1.08)	0.88 (0.68 - 1.09)
2011	0.36 (0.28 - 0.44)	0.34 (0.26 - 0.42)	0.37 (0.31 - 0.45)
2012	0.87 (0.73 - 1.04)	0.98 (0.84 - 1.13)	1.03 (0.89 - 1.18)
2013	0.45 (0.35 - 0.55)	0.52 (0.45 - 0.59)	0.63 (0.49 - 0.78)
2014	1.22 (1.07 - 1.35)	1.04 (0.92 - 1.15)	1.35 (1.15 - 1.55)
2015	0.10 (0.04 - 0.18)	0.11 (0.08 - 0.14)	0.31 (0.18 - 0.45)
2016[B]	0.42 (0.32 - 0.53)	0.52 (0.44 - 0.60)	0.59 (0.49 - 0.69)
9-yr avg.	**0.71 (0.44 – 0.98)**	**0.75 (0.50 – 1.00)**	**0.80 (0.57 – 1.03)**

[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, 2018, at GRA.

Hatchery Sockeye

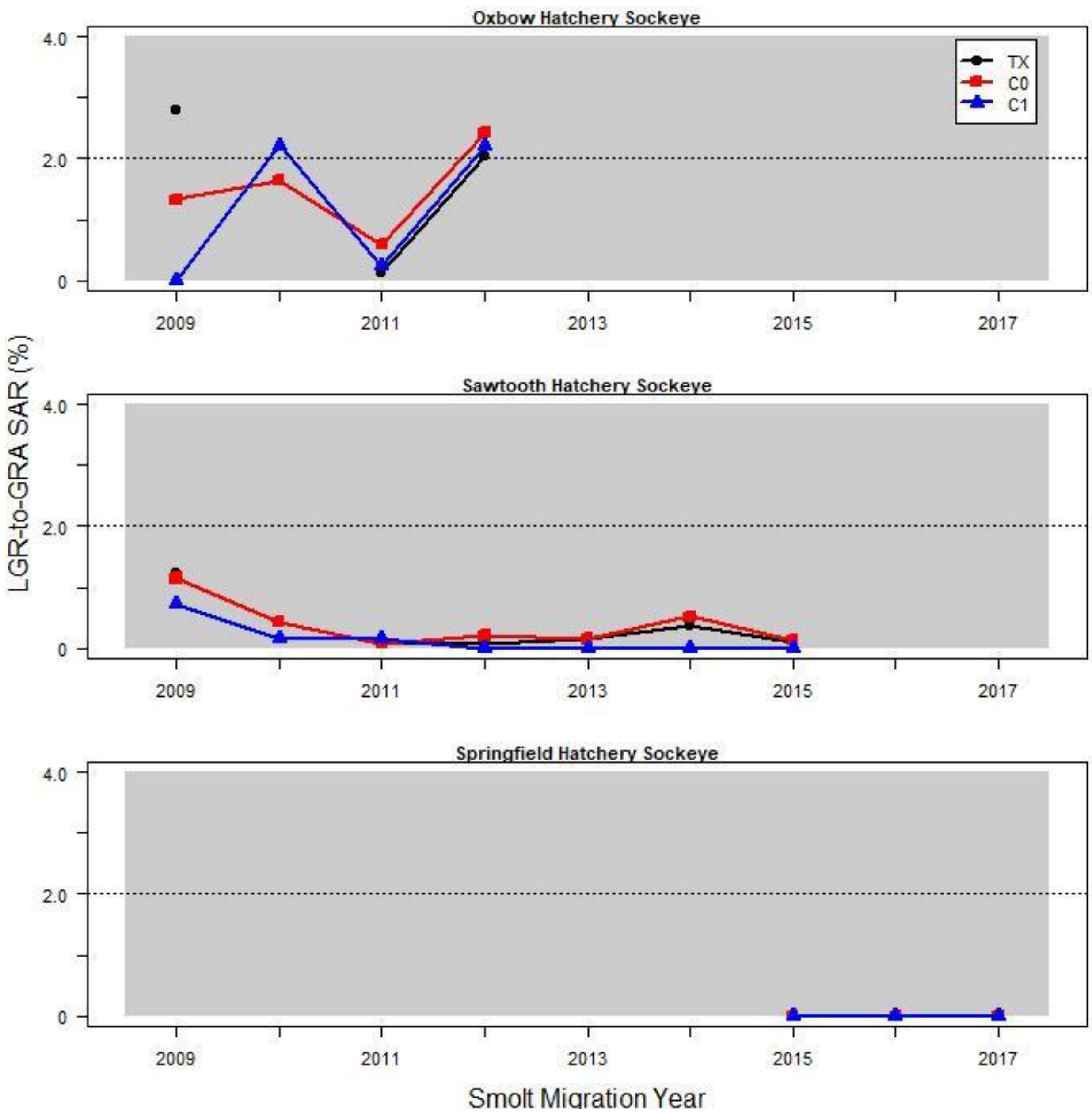

Figure A.18. Estimated LGR-to-GRA SAR for PIT-tagged sockeye from Oxbow (2009-2012), Sawtooth (2009-2015), and Springfield (2015-2017) hatcheries in transport (T_X) and in-river (C_0 and C_1) study categories. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. Data for individual hatchery sockeye groups are from Tables A.32-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]	2.79 (1.92 - 3.75)	1.33 (0.87 - 1.77)	0.00 (0.00 - 4.13)
2010[C]	---	1.65 (1.12 - 2.20)	2.22 (1.04 - 3.52)
2011	0.14 (0.00 - 0.28)	0.60 (0.38 - 0.81)	0.25 (0.06 - 0.44)
2012	2.04 (1.40 - 2.76)	2.43 (1.91 - 2.93)	2.20 (0.00 - 5.62)
4-yr avg.	**1.67 (0.00 – 4.53)[D]**	**1.50 (0.48 – 2.52)**	**1.55 (0.00 – 3.86)[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Due to very few juveniles being transported, transport SAR not estimable.
[D] 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	1.22 (1.04 - 1.39)	1.15 (0.97 - 1.37)	0.72 (0.34 - 1.10)
2010[B]	---	0.44 (0.30 - 0.61)	0.16 (0.05 - 0.33)
2011	0.07 (0.03 - 0.13)	0.09 (0.05 - 0.13)	0.16 (0.09 - 0.23)
2012[C]	0.08 (0.04 - 0.11)	0.21 (0.14 - 0.29)	0.00 (0.00 - 0.28)
2013[C]	0.16 (0.10 - 0.23)	0.16 (0.11 - 0.23)	0.00 (0.00 - 0.24)
2014[C]	0.37 (0.24 - 0.50)	0.53 (0.43 - 0.63)	0.00 (0.00 - 1.24)
2015[C]	0.10 (0.00 - 0.21)	0.14 (0.09 - 0.18)	0.00 (0.00 - 7.98)
6-yr avg.	**0.33 (0.00[D] – 0.73)**	**0.39 (0.09 – 0.69)**	**0.21 (0.00[D] – 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] Due to very few juveniles being transported, transport SAR not estimable.
[C] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[D] 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 2015-2017 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %
2015[B]	0.00 (0.00 - 0.11)	0.00 (0.00 - 0.03)	0.00 (0.00 - 6.58)
2016[B]	0.00 (0.00 - 0.08)	0.00 (0.00 - 0.03)	0.00 (0.00 - 3.72)
2017[B,C]	0.00 (0.00 - 0.15)	0.00 (0.00 - 0.06)	0.00 (0.00 - 2.16)

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through July 31, 2019.

Wild and Hatchery Subyearling Fall Chinook

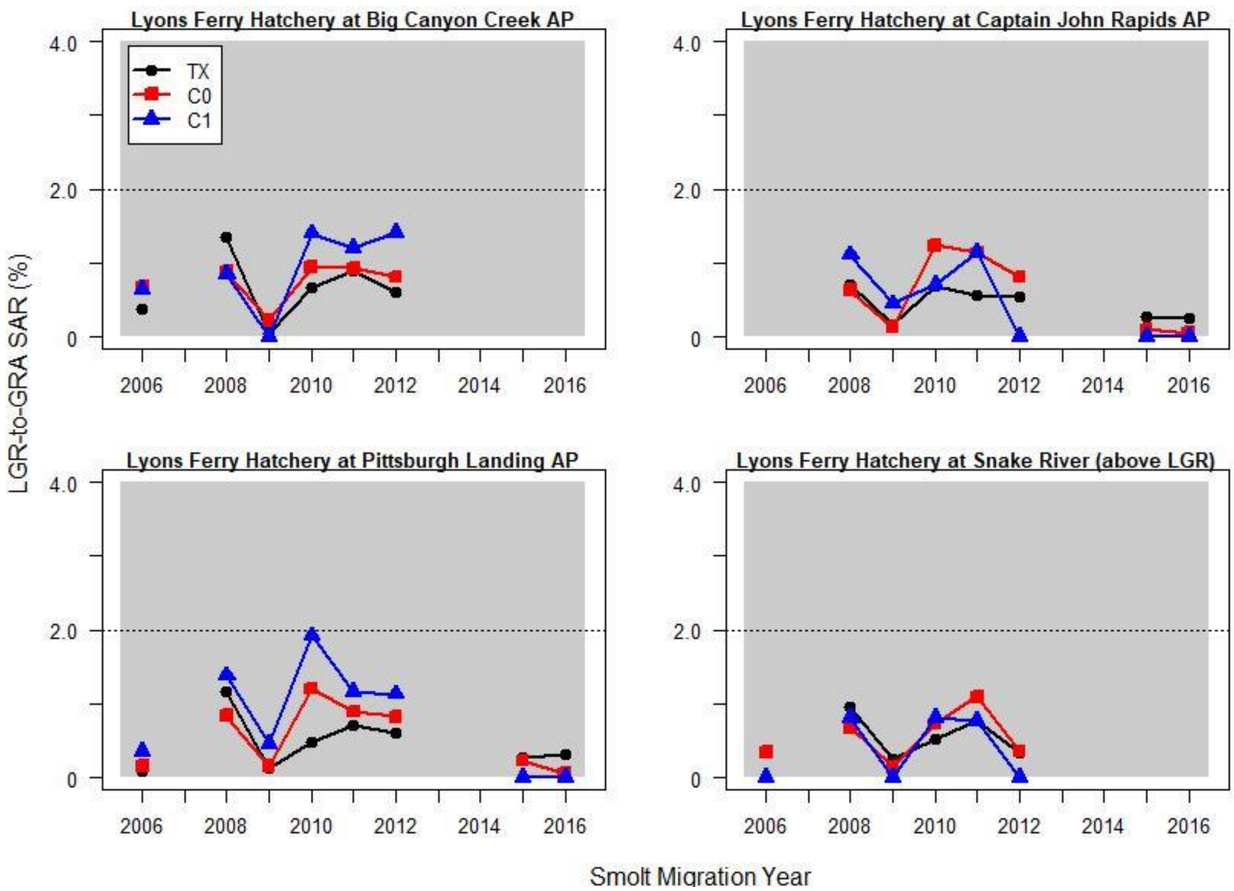

Figure A.19. Estimated LGR-to-GRA SAR for PIT-tagged Lyons Ferry hatchery subyearling fall Chinook in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2006 to 2016. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. Data for above figures are from Tables A.36 through A.39. Data for Snake River wild/natural subyearling fall Chinook not displayed due to so few years 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 (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	$SAR(T_X)$_t %	$SAR(C_0)$_crt %	$SAR(EC_1)$_t %[A]
2006[B]	0.57 (0.00 – 1.50)	0.91 (0.32 – 1.54)	---
2007[C]	---	---	---
2008[B,D]	0.00 (0.00 - 2.30)	1.42 (0.99 - 1.87)	---
2009	1.38 (0.38 - 2.77)	0.42 (0.18 - 0.69)	---
2010[E]	---	---	---
2011[F]	---	---	---
3-yr avg[G].	**0.65 (0.00-2.08)**	**0.92 (0.00-1.95)**	

[A] Due to small and unreliable estimates of juvenile population and zero adults returning, could not estimate C_1 SAR

[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] Could not estimate SARs due to small sample size of PIT-tags released.

[D] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[E] Could not estimate SARs due to high holdover probability in 2010

[F] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.

[G] 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.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)	0.68 (0.59 - 0.77)	0.64 (0.22 - 1.18)
2007[B]	---	---	---
2008	1.34 (1.07 - 1.63)	0.88 (0.76 - 1.01)	0.85 (0.23 - 1.75)
2009[C]	0.04 (0.00 - 0.12)	0.22 (0.12 - 0.33)	0.00 (0.00 - 1.24)
2010	0.67 (0.52 - 0.83)	0.94 (0.80 - 1.08)	1.40 (0.79 - 2.05)
2011	0.90 (0.71 - 1.11)	0.93 (0.81 - 1.06)	1.21 (0.66 - 1.91)
2012	0.60 (0.44 - 0.78)	0.81 (0.71 - 0.92)	1.41 (0.00 - 4.40)
6-yr avg.	**0.65 (0.25 – 1.05)**	**0.74 (0.49 – 0.99)**	**0.92 (0.43 – 1.41)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

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 and 2015 to 2016 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %		$SAR(C_0)$_crt %		$SAR(EC_1)$_t %	
2007[B]	---		---		---	
2008	0.70	(0.54 - 0.86)	0.63	(0.53 - 0.73)	1.11	(0.28 - 2.22)
2009	0.16	(0.06 - 0.30)	0.13	(0.04 - 0.21)	0.45	(0.00 - 1.40)
2010	0.69	(0.55 - 0.86)	1.24	(1.08 - 1.40)	0.70	(0.26 - 1.29)
2011	0.57	(0.40 - 0.75)	1.14	(1.01 - 1.26)	1.14	(0.68 - 1.64)
2012[C]	0.54	(0.40 - 0.68)	0.81	(0.70 - 0.93)	0.00	(0.00 - 1.77)
2015[C]	0.28	(0.15 - 0.42)	0.10	(0.06 - 0.15)	0.00	(0.00 - 1.89)
2016[C,D]	0.24	(0.15 - 0.36)	0.05	(0.02 - 0.09)	0.00	(0.00 - 5.12)
7-yr avg.	**0.45**	**(0.27 – 0.63)**	**0.59**	**(0.19 – 0.99)**	**0.49**	**(0.08 – 0.9)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete, 3-salt returns through July 31, 2019.

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 and 2015 to 2016 (with 90% confidence intervals).

Migration Year[A]	$SAR(T_X)$_t %		$SAR(C_0)$_crt %		$SAR(EC_1)$_t %	
2006	0.08	(0.03 - 0.13)	0.15	(0.09 - 0.23)	0.35	(0.00 - 0.80)
2007[B]	---		---		---	
2008	1.17	(0.94 - 1.39)	0.84	(0.70 - 0.98)	1.38	(0.32 - 2.73)
2009	0.12	(0.04 - 0.24)	0.15	(0.06 - 0.24)	0.46	(0.00 - 1.41)
2010	0.47	(0.33 - 0.62)	1.20	(1.02 - 1.39)	1.92	(1.02 - 2.99)
2011	0.70	(0.49 - 0.92)	0.89	(0.78 - 1.01)	1.16	(0.61 - 1.82)
2012	0.60	(0.44 - 0.75)	0.82	(0.70 - 0.96)	1.13	(0.00 - 3.23)
2015[C]	0.27	(0.14 - 0.41)	0.23	(0.14 - 0.33)	0.00	(0.00 - 2.39)
2016[C,D]	0.31	(0.19 - 0.45)	0.05	(0.00 - 0.10)	0.00	(0.00 - 2.84)
8-yr avg.	**0.47**	**(0.21 – 0.73)**	**0.54**	**(0.22 – 0.86)**	**0.8**	**(0.30 – 1.30)**

[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete, 2-salt returns through December 31, 2017.

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 - 0.54)	0.34 (0.25 - 0.45)	0.00 (0.00 - 2.37)
2007[C]	---	---	---
2008	0.96 (0.63 - 1.33)	0.68 (0.51 - 0.89)	0.81 (0.00 - 2.55)
2009[B]	0.26 (0.09 - 0.45)	0.14 (0.05 - 0.24)	0.00 (0.00 - 2.35)
2010	0.52 (0.30 - 0.77)	0.73 (0.51 - 0.97)	0.81 (0.00 - 1.92)
2011	0.77 (0.52 - 1.03)	1.09 (0.90 - 1.31)	0.77 (0.00 - 1.78)
2012[B]	0.34 (0.15 - 0.58)	0.35 (0.25 - 0.47)	0.00 (0.00 - 18.10)
6-yr avg.	**0.54 (0.29 – 0.79)**	**0.56 (0.25 – 0.87)**	**0.40 (0.01 – 0.79)**

[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 zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[C] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.

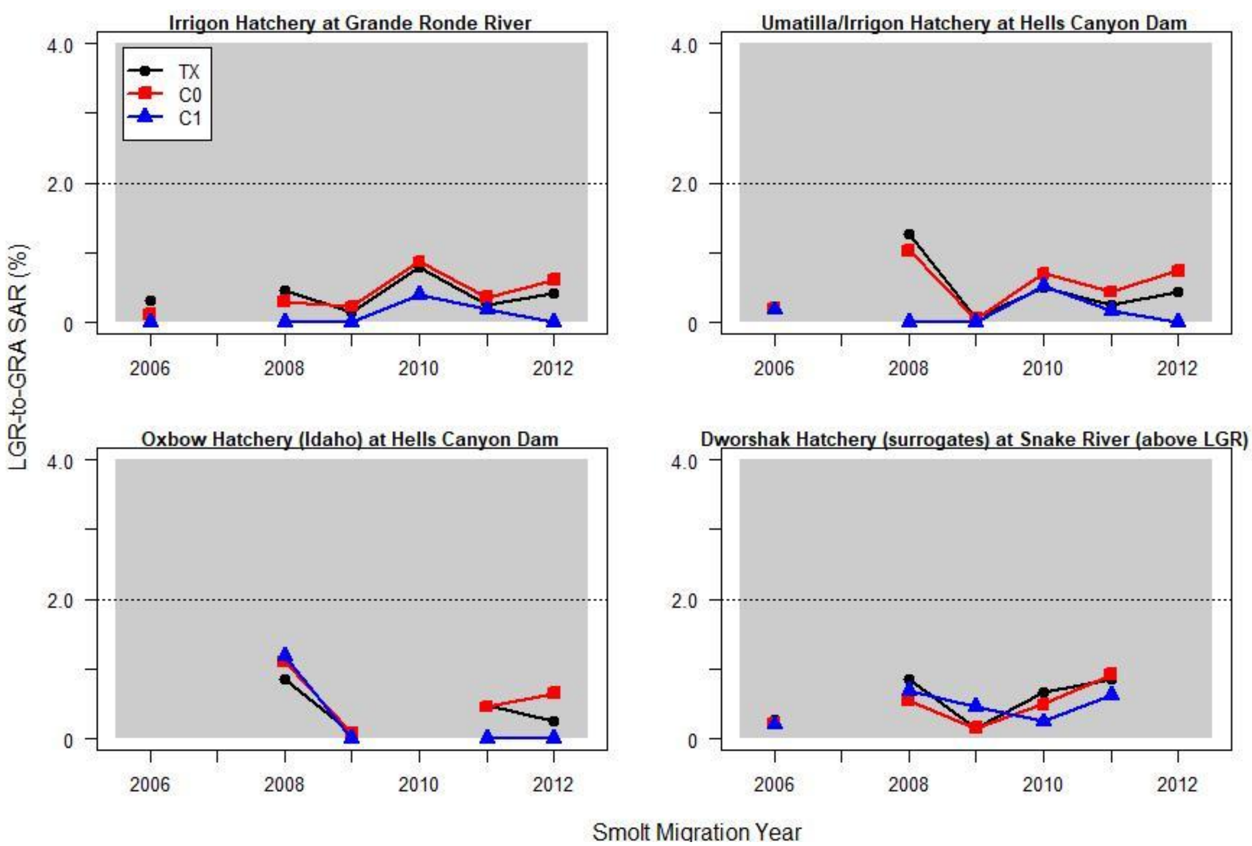

Figure A.20. Estimated LGR-to-GRA SAR for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2006 to 2012. Shaded area highlights the period of Court Order spill and later start of transportation. 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.43.

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	(0.18 - 0.47)	0.12	(0.06 - 0.17)	0.00	(0.00 - 2.69)
2007[D]	---		---		---	
2008[C]	0.46	(0.25 - 0.68)	0.30	(0.21 - 0.40)	0.00	(0.00 - 2.33)
2009[C]	0.15	(0.06 - 0.27)	0.23	(0.16 - 0.31)	0.00	(0.00 - 1.90)
2010	0.78	(0.60 - 0.97)	0.87	(0.72 - 1.02)	0.40	(0.00 - 0.96)
2011	0.26	(0.12 - 0.41)	0.36	(0.27 - 0.45)	0.18	(0.00 - 0.56)
2012[C]	0.41	(0.23 - 0.61)	0.61	(0.51 - 0.71)	0.00	(0.00 - 5.93)
6-yr avg.	**0.40**	**(0.20 – 0.60)**	**0.42**	**(0.17 – 0.67)**	**0.10**	**(0.00 – 0.25)**[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[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.

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 - 0.33)	0.20	(0.12 - 0.29)	0.18	(0.00 - 0.52)
2007[B]	---		---		---	
2008[C]	1.26	(1.02 - 1.49)	1.03	(0.90 - 1.17)	0.00	(0.00 - 0.83)
2009[C]	0.07	(0.03 - 0.12)	0.05	(0.03 - 0.08)	0.00	(0.00 - 0.38)
2010	0.49	(0.35 - 0.65)	0.70	(0.58 - 0.83)	0.52	(0.21 - 0.85)
2011	0.24	(0.12 - 0.38)	0.44	(0.34 - 0.54)	0.17	(0.00 - 0.49)
2012[C]	0.44	(0.30 - 0.60)	0.74	(0.63 - 0.87)	0.00	(0.00 - 2.92)
6-yr avg.	**0.45**	**(0.07 – 0.83)**	**0.53**	**(0.20 – 0.86)**	**0.15**	**(0.00 – 0.33)**[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[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	(0.59 - 1.16)	1.11	(0.87 - 1.36)	1.19	(0.28 - 2.27)
2009[C]	0.08	(0.00 - 0.17)	0.08	(0.02 - 0.16)	0.00	(0.00 - 1.20)
2010[D]	---		---		---	
2011[C]	0.47	(0.20 - 0.80)	0.46	(0.33 - 0.59)	0.00	(0.00 - 0.60)
2012[C]	0.25	(0.11 - 0.41)	0.65	(0.46 - 0.85)	0.00	(0.00 - 15.33)
4-yr avg.	**0.42**	**(0.00 – 0.88)[E]**	**0.58**	**(0.00 – 1.16)**	**0.30**	**(0.00 – 1.11)[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] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.

[C] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[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 - 0.33)	0.22	(0.19 - 0.25)	0.20	(0.06 - 0.43)
2007[B]	---		---		---	
2008	0.86	(0.76 - 0.96)	0.54	(0.49 - 0.58)	0.69	(0.35 - 1.08)
2009	0.15	(0.10 - 0.21)	0.15	(0.12 - 0.17)	0.46	(0.20 - 0.79)
2010	0.66	(0.55 - 0.78)	0.49	(0.44 - 0.54)	0.24	(0.06 - 0.45)
2011	0.85	(0.74 - 0.96)	0.92	(0.85 - 0.98)	0.62	(0.39 - 0.90)
2012[C]	---		---		---	
5-yr avg.	**0.56**	**(0.21 – 0.91)**	**0.46**	**(0.13 – 0.79)**	**0.44**	**(0.21 – 0.67)**

[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.

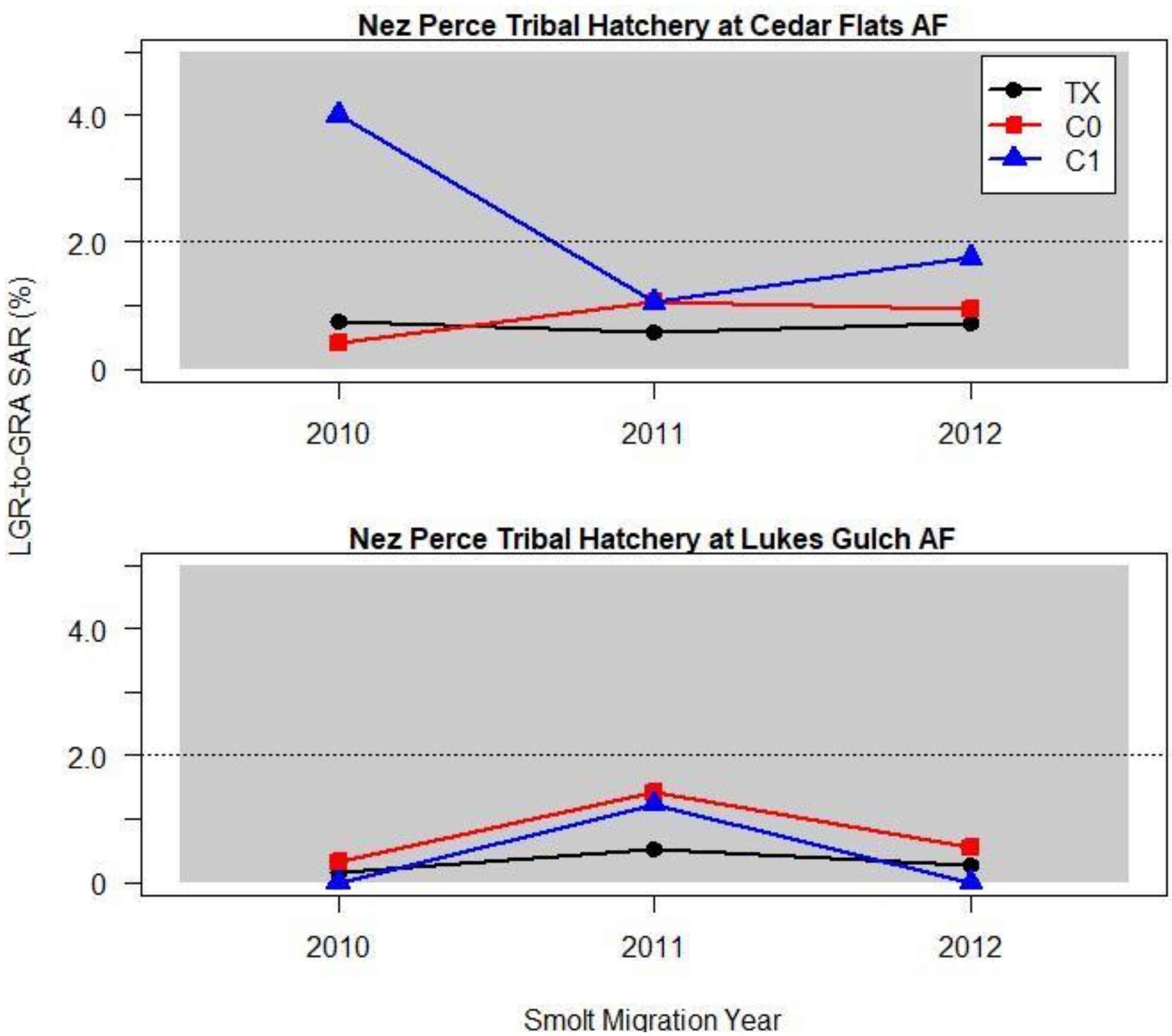

Figure A.21. Estimated LGR-to-GRA SAR for PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats and Lukes Gulch acclimation facilities in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2010 to 2012. Shaded area highlights the period of 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.44 and A.45.

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	0.75 (0.37 - 1.23)	0.42 (0.27 - 0.60)	4.00 (0.00 - 25.00)
2011	0.57 (0.36 - 0.78)	1.07 (0.85 - 1.28)	1.05 (0.28 - 2.26)
2012	0.73 (0.39 - 1.10)	0.94 (0.76 - 1.13)	1.75 (0.00 - 4.60)
3-yr avg.	**0.68 (0.48 – 0.88)**	**0.81 (0.10 – 1.52)**	**2.27 (0.00 – 5.45)[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 (0.00 - 0.32)	0.32 (0.21 - 0.43)	0.00 (0.00 - 2.89)
2011	0.51 (0.32 - 0.72)	1.43 (1.18 - 1.68)	1.23 (0.00 - 2.64)
2012[B]	0.28 (0.10 - 0.50)	0.56 (0.42 - 0.69)	0.00 (0.00 - 4.57)
3-yr avg.	**0.31 (0.00 – 0.69)[C]**	**0.77 (0.00 – 1.98)[C]**	**0.41 (0.00 – 1.88)[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] Due to zero adult returns, 90% confidence intervals for point estimates of 0.00 are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[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

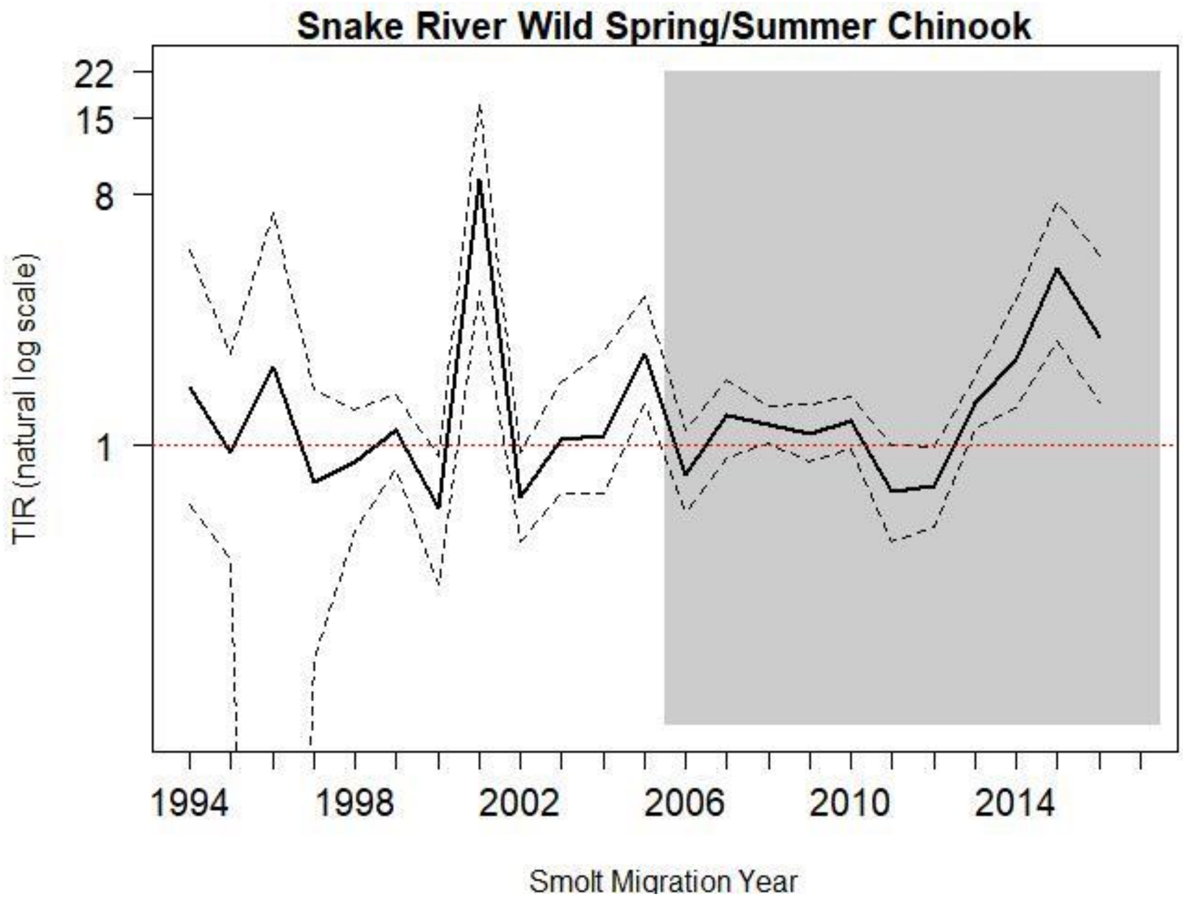

Figure A.22. Trend in TIR on the natural log scale for PIT-tagged Snake River wild spring/summer Chinook for migration years 1994 to 2017 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of 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.

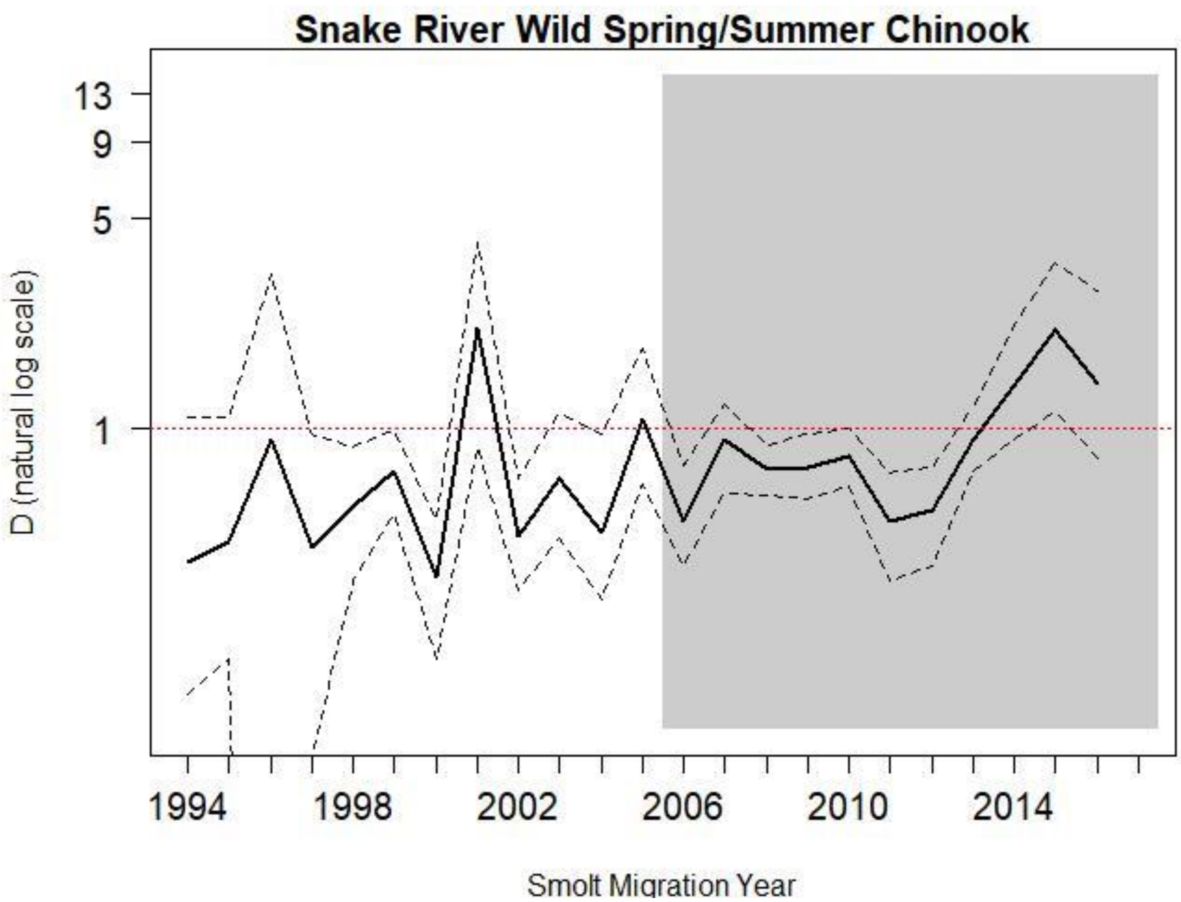

Figure A.23. Trend in *D* on the natural log scale for PIT-tagged Snake River wild spring/summer Chinook in migration years 1994–2017 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights 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 2017 (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,D]				
2006	0.79	(0.58 - 1.13)	0.49	(0.35 - ***0.75***)
2007	1.28	(0.90 - 1.73)	0.91	(0.61 - 1.20)
2008	1.19	(**1.02** - 1.39)	0.73	(0.60 - ***0.88***)
2009	1.11	(0.88 - 1.40)	0.74	(0.58 - ***0.96***)
2010	1.22	(0.98 - 1.49)	0.81	(0.64 - 1.00)
2011	0.69	(0.45 - 1.01)	0.49	(0.31 - ***0.71***)
2012	0.72	(0.51 - ***0.99***)	0.53	(0.35 - ***0.74***)
2013	1.43	(**1.15** - 1.77)	0.92	(0.72 - 1.19)
2014	2.05	(**1.37** - 3.31)	1.38	(0.91 - 2.17)
2015	4.28	(**2.38** - 7.44)	2.11	(**1.14** - 3.56)
2016	2.43	(**1.44** - 4.82)	1.41	(0.79 - 2.85)
2017[E,F]		---		---
Geomean	1.31	(**1.04** - 1.64)	0.71	(0.59 - ***0.86***)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[F] Incomplete, 2-salt returns through June 28, 2019.

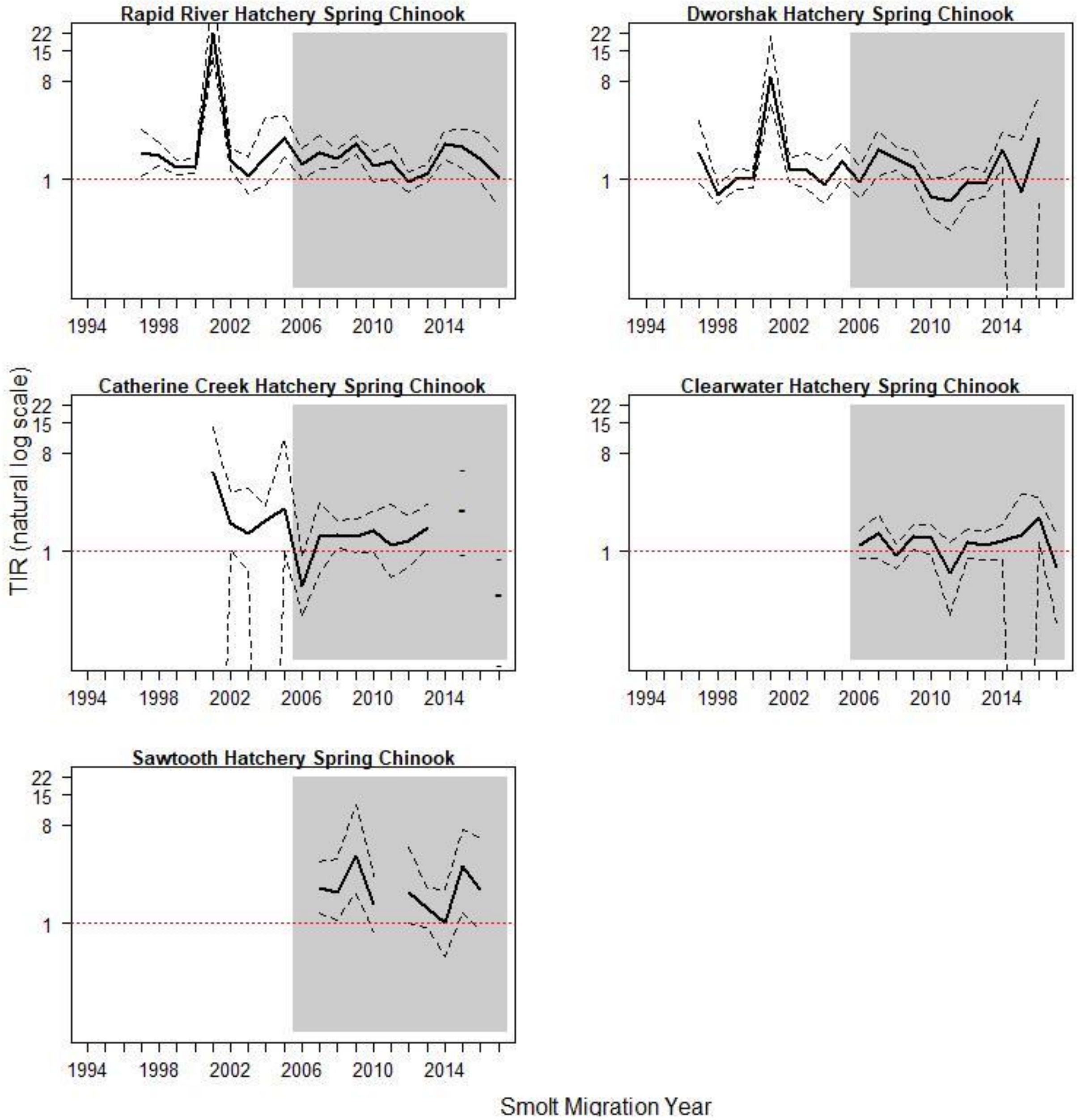

Figure A.24. Trend in TIR on the natural log scale for PIT-tagged Snake River spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass), Clearwater, and Sawtooth hatcheries for migration years 1994 to 2017 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value 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 in most years (Table A.52).

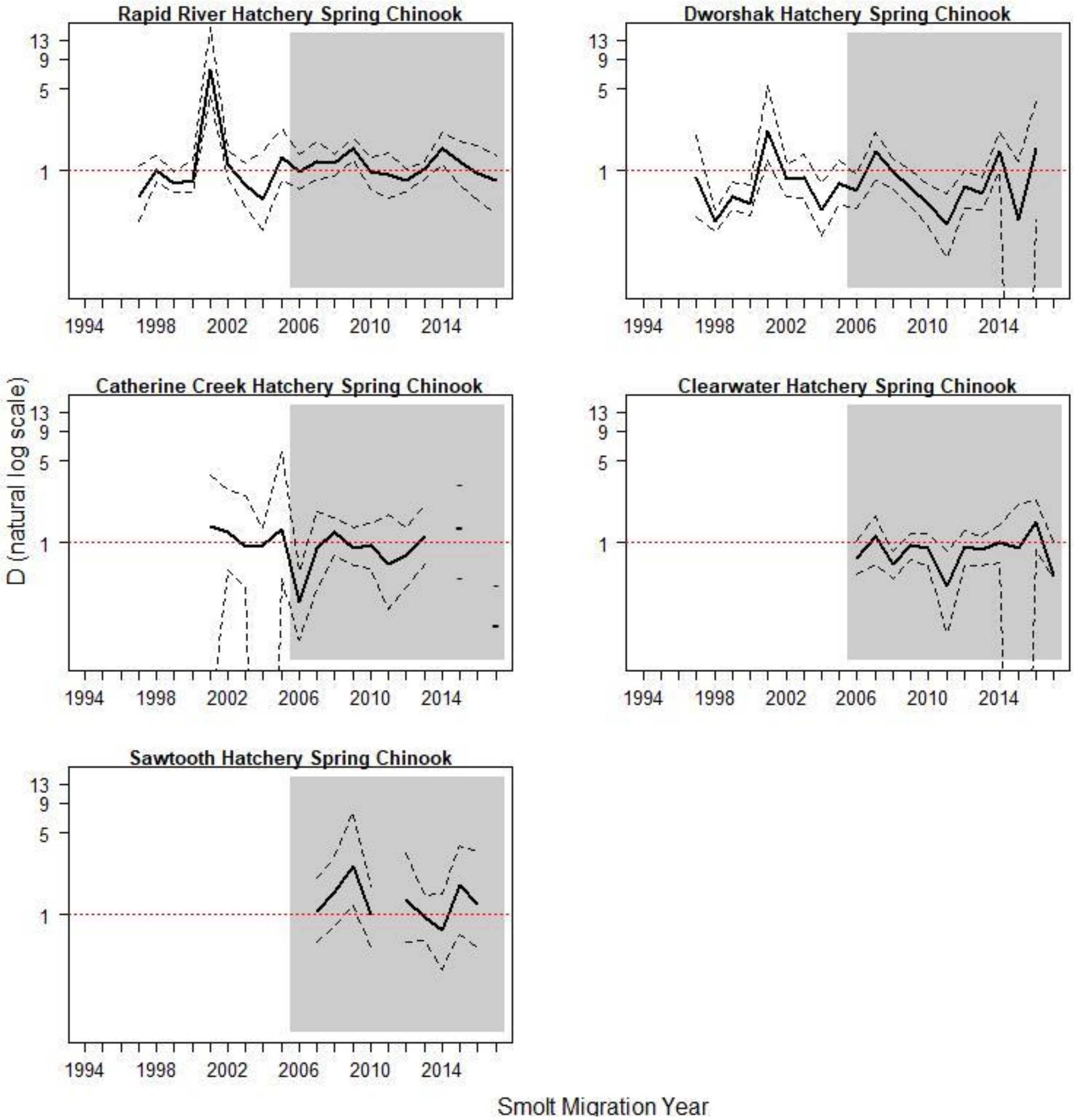

Figure A.25. Trend in *D* on the natural log scale for PIT-tagged Snake River spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass), Clearwater, and Sawtooth hatcheries in migration years 1994–2017 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value 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* in most years (Table A.52).

Table A.47. Estimated TIR and *D* of PIT-tagged Rapid River Hatchery spring Chinook for 1997 to 2017 (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,D]				
2006	1.36	(0.99 - 1.90)	0.99	(0.69 - 1.37)
2007	1.77	(**1.25** - 2.53)	1.21	(0.84 - 1.77)
2008	1.52	(**1.27** - 1.84)	1.16	(0.90 - 1.39)
2009	2.08	(**1.68** - 2.54)	1.54	(**1.24** - 1.90)
2010	1.33	(0.94 - 1.79)	0.98	(0.69 - 1.32)
2011	1.47	(0.99 - 2.18)	0.94	(0.59 - 1.44)
2012	0.95	(0.76 - 1.18)	0.83	(0.66 - 1.04)
2013	1.14	(0.95 - 1.35)	1.03	(0.84 - 1.21)
2014	2.07	(**1.54** - 2.81)	1.53	(**1.12** - 2.11)
2015	1.98	(**1.25** - 2.87)	1.21	(0.76 - 1.77)
2016	1.56	(0.94 - 2.68)	0.96	(0.57 - 1.62)
2017[E]	1.04	(0.55 - 1.72)	0.82	(0.43 - 1.34)
Geomean	1.70	(**1.34** - 2.15)	1.08	(0.89 - 1.30)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Incomplete, 2-salt returns through June 28, 2019.

Table A.48. Estimated TIR and *D* of PIT-tagged Dworshak Hatchery spring Chinook for 1997 to 2017 (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,D]				
2006	0.94	(0.68 - 1.31)	0.68	(0.48 - ***0.93***)
2007	1.85	(**1.07** - 2.79)	1.45	(0.83 - 2.11)
2008	1.54	(**1.19** - 1.95)	0.99	(0.70 - 1.28)
2009	1.29	(0.92 - 1.82)	0.71	(0.50 - 1.01)
2010	0.70	(0.46 - ***0.99***)	0.53	(0.34 - ***0.75***)
2011	0.64	(0.34 - 1.08)	0.35	(0.18 - ***0.63***)
2012	0.95	(0.64 - 1.34)	0.74	(0.48 - 1.02)
2013	0.91	(0.69 - 1.18)	0.63	(0.47 - ***0.87***)
2014	1.87	(**1.30** - 2.72)	1.45	(0.99 - 2.12)
2015	0.77	(0.00 - 2.27)	0.38	(0.00 - 1.19)
2016	2.35	(0.59 - 5.84)	1.55	(0.38 - 3.84)
2017[E,F]	---		---	
Geomean	1.25	(1.00 - 1.57)	0.75	(0.62 - ***0.91***)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[F] Incomplete, 2-salt returns through June 28, 2019.

Table A.49. Estimated TIR and *D* of PIT-tagged Catherine Creek AP spring Chinook for 2001 to 2017 (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,D]				
2006	0.48	(0.25 - ***0.88***)	0.31	(0.15 - ***0.57***)
2007	1.35	(0.64 - 2.78)	0.90	(0.40 - 1.84)
2008	1.41	(**1.07** - 1.92)	1.24	(0.78 - 1.63)
2009	1.36	(0.96 - 1.96)	0.91	(0.63 - 1.33)
2010	1.52	(0.96 - 2.31)	0.95	(0.60 - 1.47)
2011	1.15	(0.57 - 2.68)	0.66	(0.27 - 1.75)
2012	1.23	(0.72 - 2.08)	0.77	(0.42 - 1.34)
2013	1.62	(**1.06** - 2.69)	1.14	(0.66 - 2.13)
2014[E]		---		---
2015	2.44	(0.95 - 5.56)	1.36	(0.51 - 3.16)
2016[E]		---		---
2017[F]	0.40	(0.09 - ***0.85***)	0.20	(0.05 - ***0.44***)
Geomean	1.46	(1.10 - 1.93)	0.85	(0.67 - 1.10)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[F] Incomplete, 2-salt returns through June 28, 2019.

Table A.50. Estimated TIR and *D* of PIT-tagged Clearwater Hatchery spring Chinook for 2006 to 2017 (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,B]	TIR	*D*
2006	1.13 (0.85 - 1.52)	0.74 (0.54 - 1.04)
2007	1.47 (0.87 - 2.18)	1.13 (0.66 - 1.70)
2008	0.91 (0.70 - 1.16)	0.66 (0.49 - ***0.86***)
2009	1.37 (**1.04** - 1.73)	0.95 (0.72 - 1.21)
2010	1.33 (0.94 - 1.76)	0.89 (0.63 - 1.20)
2011	0.63 (0.26 - 1.19)	0.43 (0.17 - ***0.84***)
2012	1.22 (0.85 - 1.60)	0.93 (0.63 - 1.26)
2013	1.13 (0.82 - 1.48)	0.87 (0.63 - 1.14)
2014	1.23 (0.84 - 1.74)	1.01 (0.68 - 1.43)
2015	1.40 (0.00 - 3.32)	0.91 (0.00 - 2.15)
2016	2.03 (**1.20** - 3.15)	1.49 (0.88 - 2.29)
2017[C]	0.72 (0.22 - 1.39)	0.52 (0.50 - 1.00)
Geomean	1.16 (0.98 - 1.37)	0.84 (0.70 - ***0.99***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete, 2-salt returns through September 15, 2018.

Table A.51. Estimated TIR and *D* of PIT-tagged Sawtooth Hatchery spring Chinook for 2007 to 2017 (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,B]	TIR	*D*
2007	2.10 (**1.26** - 3.66)	1.06 (0.58 - 2.08)
2008	1.90 (**1.05** - 3.88)	1.53 (0.81 - 3.11)
2009	4.17 (**1.94** - 12.06)	2.63 (**1.20** - 7.46)
2010	1.51 (0.83 - 2.65)	1.01 (0.54 - 1.75)
2011[C]	---	---
2012	1.92 (0.99 - 4.99)	1.36 (0.59 - 3.34)
2013	1.36 (0.92 - 2.07)	0.96 (0.60 - 1.47)
2014	0.99 (0.49 - 2.02)	0.73 (0.34 - 1.49)
2015	3.30 (**1.26** - 7.28)	1.78 (0.67 - 3.83)
2016	2.05 (0.86 - 5.91)	1.24 (0.52 - 3.47)
2017[C,D]	---	---
Geomean	1.97 (**1.50** - 2.58)	1.28 (**1.01** - 1.62)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[D] Incomplete, 2-salt returns through June 28, 2019.

Table A.52. Estimated TIR and *D* of PIT-tagged Kooskia Hatchery spring Chinook for 2014 to 2017 (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,B]	TIR	*D*
2014[C]	---	---
2015[C]	---	---
2016	1.99 (0.00 - 16.86)	1.09 (0.00 - 8.58)
2017[C]	---	---

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[D] Incomplete, 2-salt returns through June 28, 2019.

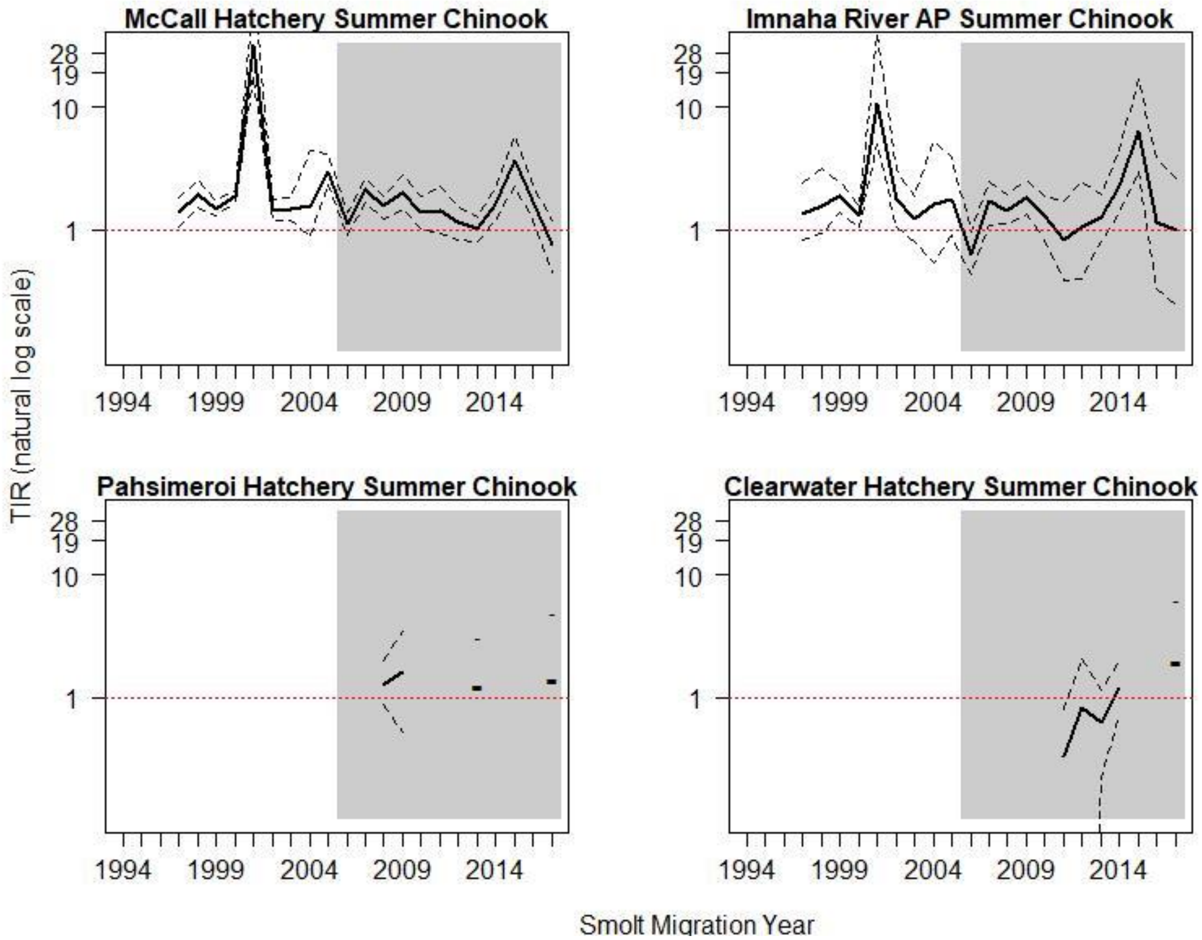

Figure A.26. Trend in TIR on the natural log scale for PIT-tagged Snake River summer Chinook from McCall, Imnaha (Lookingglass Hatchery), Pahsimeroi, and Clearwater hatcheries for migration years 1994 to 2017 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river 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.

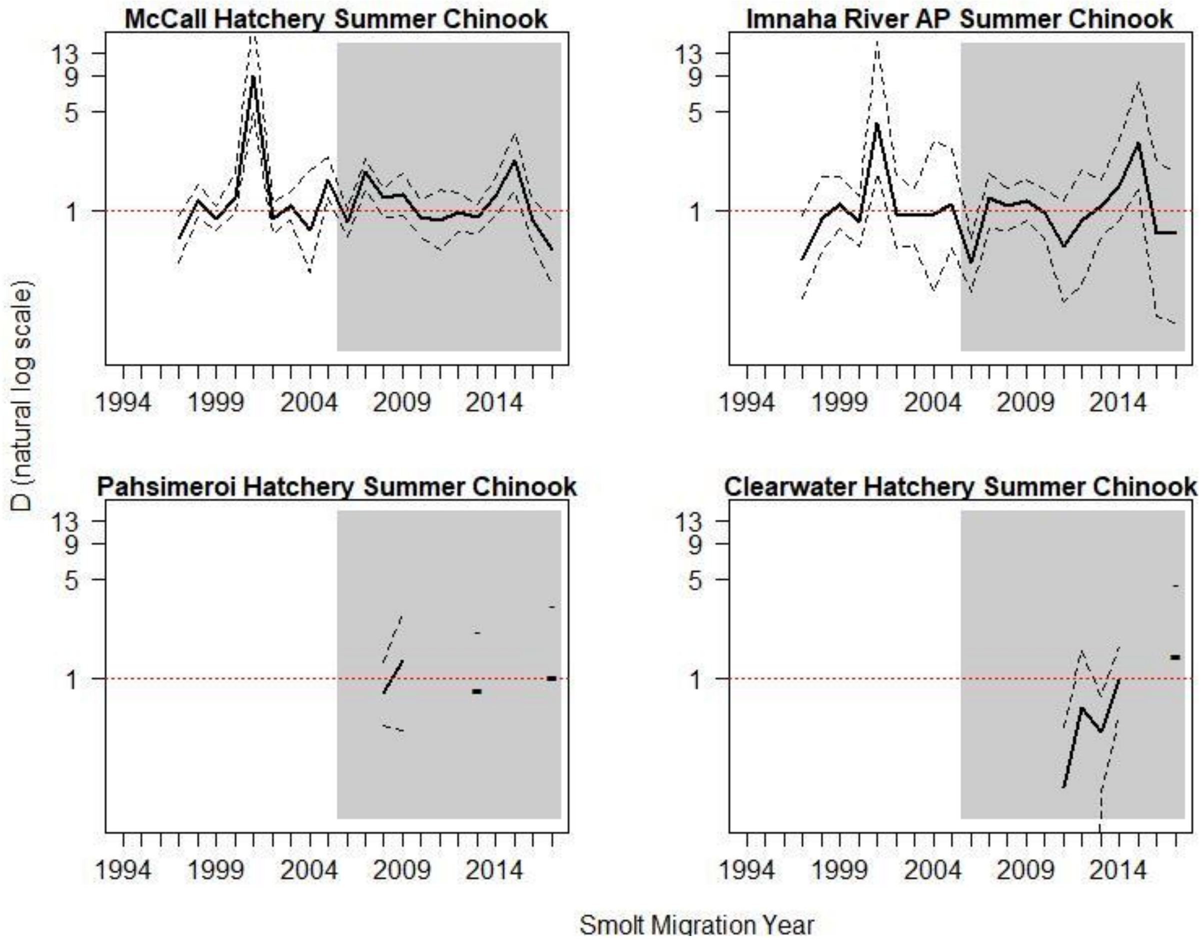

Figure A.27. Trend in *D* on the natural log scale for PIT-tagged Snake River summer Chinook from McCall, Imnaha (Lookingglass Hatchery), Pahsimeroi, and Clearwater hatcheries in migration years 1994–2017 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river 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 2017 (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,D]				
2006	1.12	(0.91 - 1.39)	0.82	(0.65 - 1.02)
2007	2.10	(**1.67** - 2.66)	1.86	(**1.42** - 2.32)
2008	1.55	(**1.23** - 1.91)	1.22	(0.89 - 1.46)
2009	1.98	(**1.46** - 2.78)	1.31	(0.93 - 1.85)
2010[D]	1.39	(**1.02** - 1.87)	0.89	(0.65 - 1.19)
2011	1.42	(0.94 - 2.27)	0.85	(0.53 - 1.42)
2012	1.14	(0.82 - 1.55)	0.96	(0.70 - 1.33)
2013	1.02	(0.81 - 1.28)	0.89	(0.69 - 1.12)
2014	1.61	(**1.18** - 2.18)	1.26	(0.91 - 1.69)
2015	3.74	(**2.25** - 5.79)	2.25	(**1.35** - 3.54)
2016[E]	1.70	(**1.22** - 2.36)	0.84	(0.59 - 1.21)
2017[E]	0.76	(0.45 - 1.19)	0.53	(0.30 - ***0.86***)
Geomean	1.83	(**1.38** - 2.42)	1.14	(0.92 - 1.42)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Incomplete, 2-salt returns through July 31, 2019.

Table A.54. Estimated TIR and *D* of PIT-tagged Imnaha AP summer Chinook for 1997 to 2017 (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,D]				
2006	0.62	(0.43 - ***0.95***)	0.43	(0.27 - ***0.63***)
2007	1.70	(**1.08** - 2.45)	1.23	(0.75 - 1.85)
2008	1.45	(**1.11** - 1.93)	1.07	(0.73 - 1.45)
2009	1.83	(**1.33** - 2.55)	1.18	(0.84 - 1.65)
2010	1.31	(0.86 - 1.87)	0.96	(0.63 - 1.41)
2011	0.83	(0.39 - 1.74)	0.56	(0.23 - 1.18)
2012	1.06	(0.40 - 2.51)	0.84	(0.30 - 1.93)
2013	1.28	(0.80 - 1.95)	1.08	(0.65 - 1.64)
2014	2.26	(**1.35** - 4.45)	1.50	(0.84 - 3.06)
2015	6.44	(**2.97** - 16.92)	2.99	(**1.41** - 7.95)
2016	1.17	(0.33 - 3.86)	0.69	(0.18 - 2.26)
2017[E]	1.00	(0.24 - 2.65)	0.68	(0.16 - 1.83)
Geomean	1.62	(**1.28** - 2.05)	1.00	(0.82 - 1.21)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Incomplete, 2-salt returns through July 31, 2019.

Table A.55. Estimated TIR and *D* of PIT-tagged Pahsimeroi Hatchery summer Chinook for 2008 to 2017 (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,,B]	TIR		*D*	
2008	1.27	(0.87 - 1.99)	0.79	(0.46 - 1.29)
2009	1.62	(0.52 - 3.44)	1.33	(0.43 - 2.89)
2010[C]		---		---
2011[C]		---		---
2012[C]		---		---
2013	1.21	(0.00 - 3.03)	0.83	(0.00 - 2.16)
2014[C]		---		---
2015[C]		---		---
2016[C]		---		---
2017[D]	1.40	(0.00 - 4.90)	1.02	(0.00 - 3.31)
Geomean	1.37	(**1.15** - 1.63)	0.97	(0.70 - 1.34)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few adults in Transport and/or C_0 study category to estimate TIR and *D*.
[D] Incomplete, 2-salt returns through July 31, 2019.

Table A.56. Estimated TIR and *D* of PIT-tagged Clearwater Hatchery summer Chinook for 2011 and 2017 (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,B]	TIR		*D*	
2011	0.33	(0.06 - ***0.81***)	0.17	(0.03 - ***0.45***)
2012	0.83	(0.00 - 2.09)	0.62	(0.00 - 1.56)
2013	0.63	(0.22 - 1.15)	0.42	(0.15 - ***0.75***)
2014	1.18	(0.69 - 1.95)	0.98	(0.55 - 1.64)
2015[C]		---		---
2016[C]		---		---
2017[D]	1.95	(0.00 - 6.13)	1.44	(0.00 - 4.60)
Geomean	0.83	(0.44 - 1.57)	0.57	(0.26 - 1.26)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few adults in Transport and/or C_0 study category to estimate TIR and *D*.
[D] Incomplete, 2-salt returns through July 31, 2019.

Wild and Hatchery Steelhead

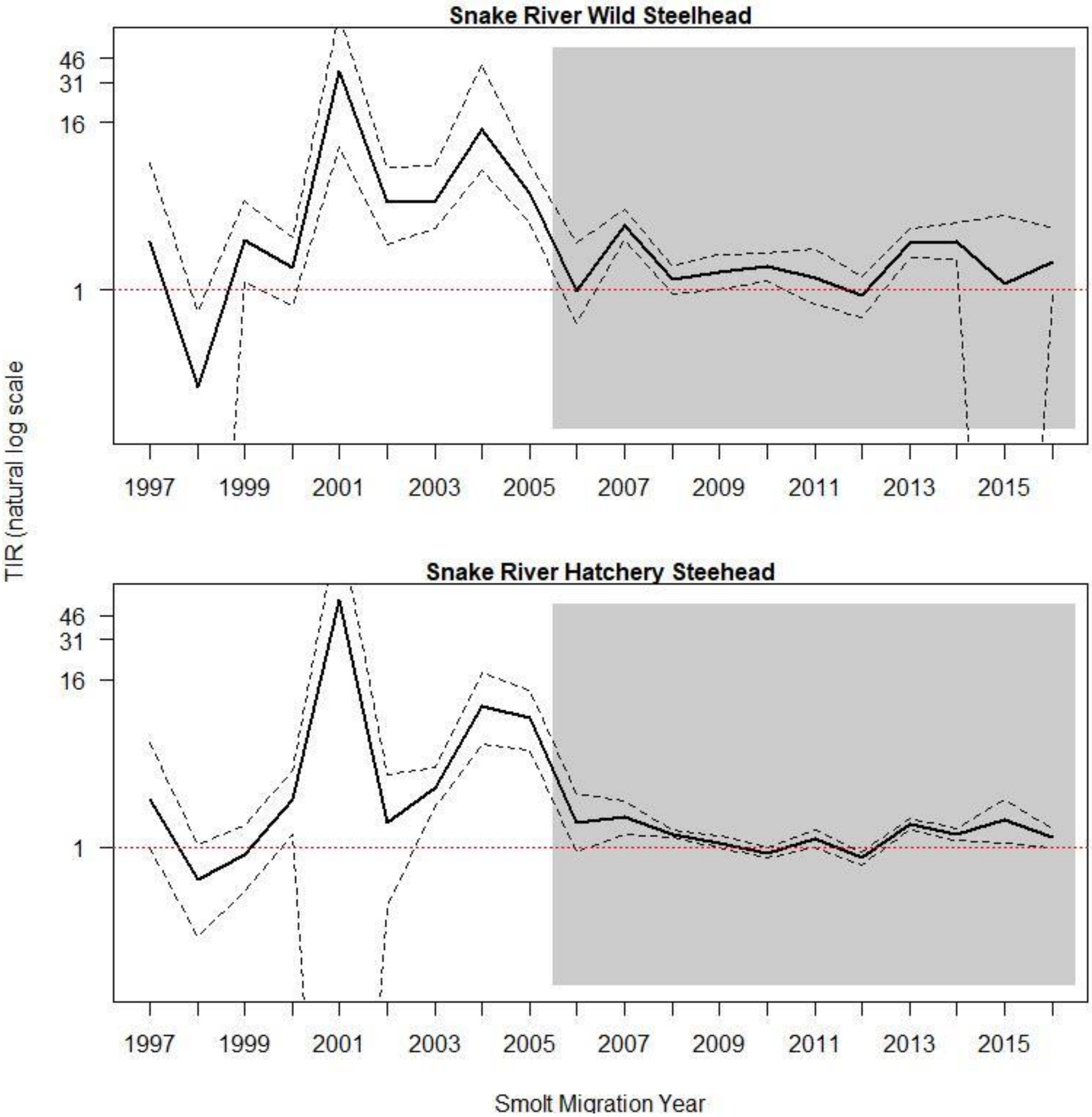

Figure A.28. Trend in TIR on the natural log scale for PIT-tagged Snake River wild (aggregate) and hatchery (aggregate) in migration years 1997 to 2016 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights 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.

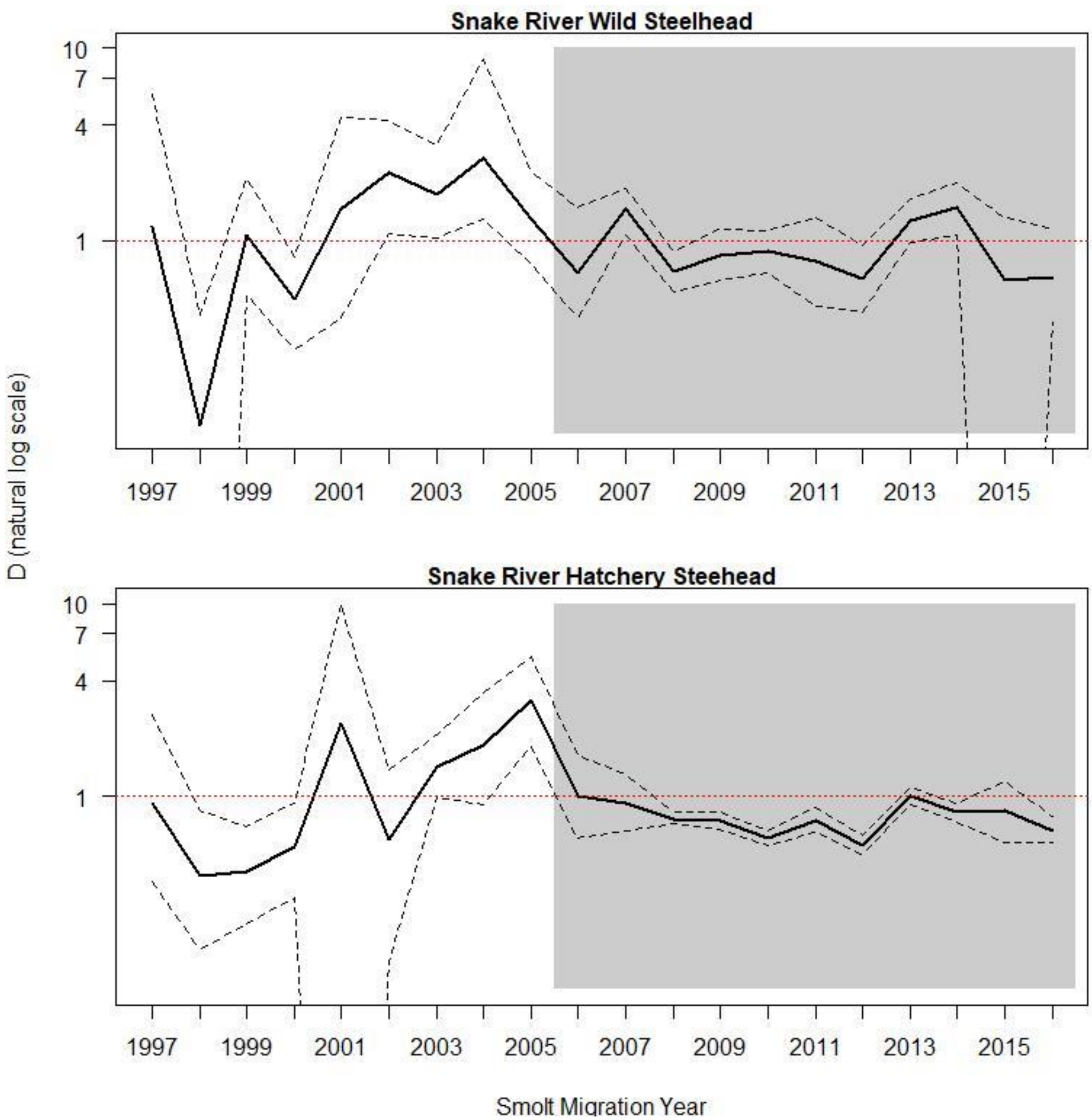

Figure A.29. Trend in *D* on the natural log scale for PIT-tagged Snake River wild (aggregate) and hatchery (aggregate) steelhead in migration years 1997–2016 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are 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 2016 (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,D]				
2006	0.97	(0.57 - 2.17)	0.68	(0.40 - 1.50)
2007	2.93	(**2.26** - 3.82)	1.47	(**1.08** - 1.86)
2008	1.18	(0.94 - 1.49)	0.69	(0.54 - ***0.88***)
2009	1.33	(**1.01** - 1.77)	0.84	(0.63 - 1.14)
2010	1.46	(**1.15** - 1.85)	0.88	(0.68 - 1.12)
2011	1.21	(0.79 - 1.95)	0.78	(0.46 - 1.31)
2012	0.91	(0.63 - 1.26)	0.64	(0.43 - ***0.95***)
2013	2.18	(**1.72** - 2.77)	1.27	(0.98 - 1.64)
2014	2.23	(**1.68** - 3.06)	1.49	(**1.07** - 2.01)
2015	1.10	(0.00 - 3.41)	0.63	(0.00 - 1.31)
2016[E]	1.57	(0.92 - 2.79)	0.65	(0.38 - 1.15)
Geomean	2.14	(**1.41** - 3.26)	0.94	(0.72 - 1.22)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[E] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

Table A.58. Estimated TIR, and *D* of PIT-tagged hatchery (aggregate) steelhead for migration years 1997 to 2016 (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,E]				
2008[F]	1.24	(**1.16** - 1.32)	0.77	(0.72 - ***0.83***)
2009	1.07	(0.98 - 1.19)	0.75	(0.68 - ***0.83***)
2010	0.90	(0.83 - ***0.98***)	0.61	(0.56 - ***0.66***)
2011	1.15	(**1.00** - 1.31)	0.75	(0.65 - ***0.87***)
2012	0.83	(0.74 - ***0.92***)	0.56	(0.50 - ***0.63***)
2013	1.44	(**1.31** - 1.59)	1.01	(0.91 - 1.11)
2014	1.22	(**1.12** - 1.35)	0.83	(0.74 - ***0.92***)
2015	1.57	(**1.07** - 2.18)	0.85	(0.58 - 1.19)
2016[G]	1.17	(1.00 - 1.37)	0.67	(0.58 - ***0.79***)
Geomean	1.92	(**1.27** - 2.91)	0.87	(0.71 - 1.08)

[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] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[F] 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).
[G] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

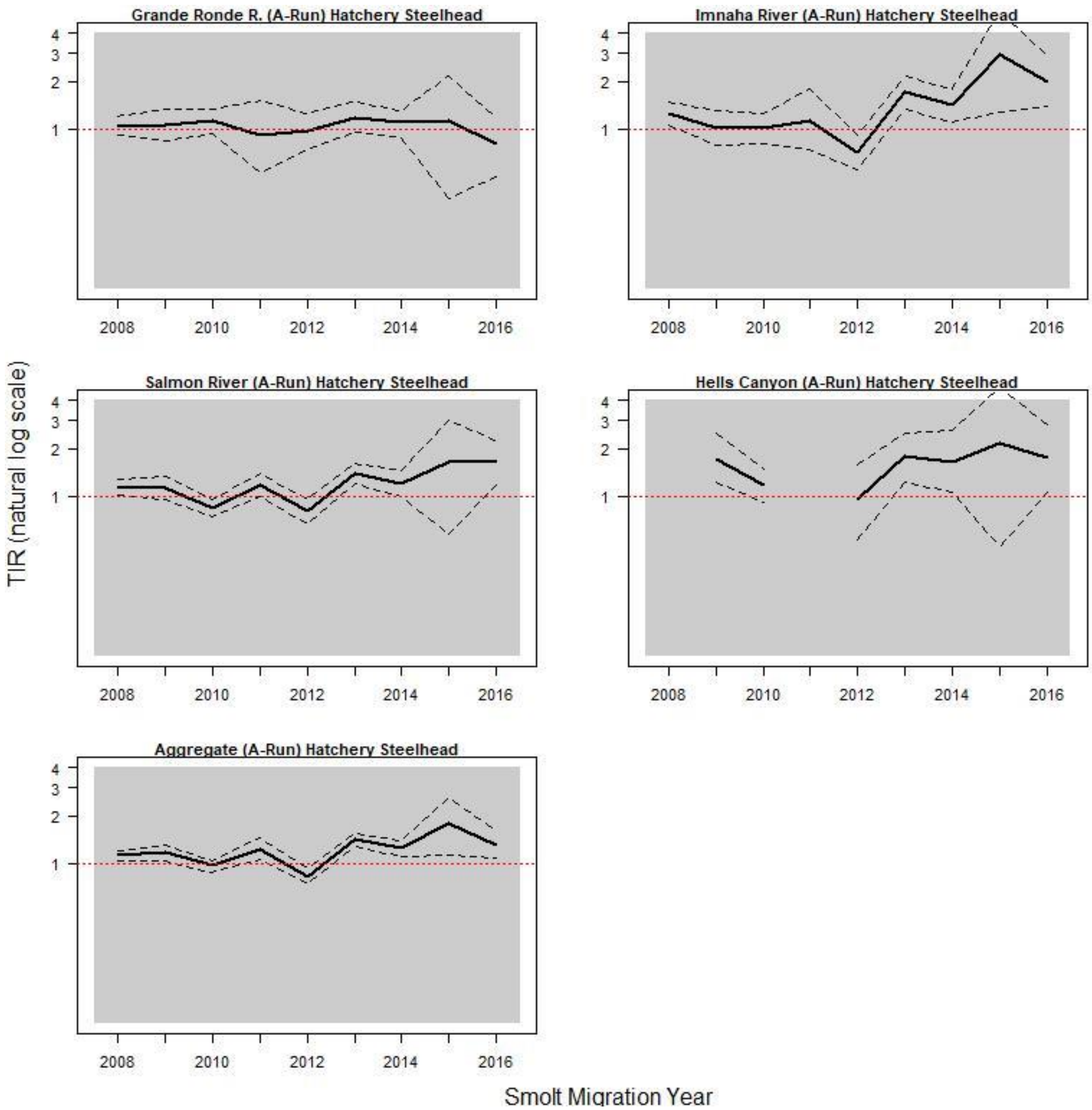

Figure A.30. Trend in TIR on the natural log scale for PIT-tagged Snake River A-run hatchery steelhead in migration years 2008 to 2016 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery A-run steelhead are from Tables A.59–A.63.

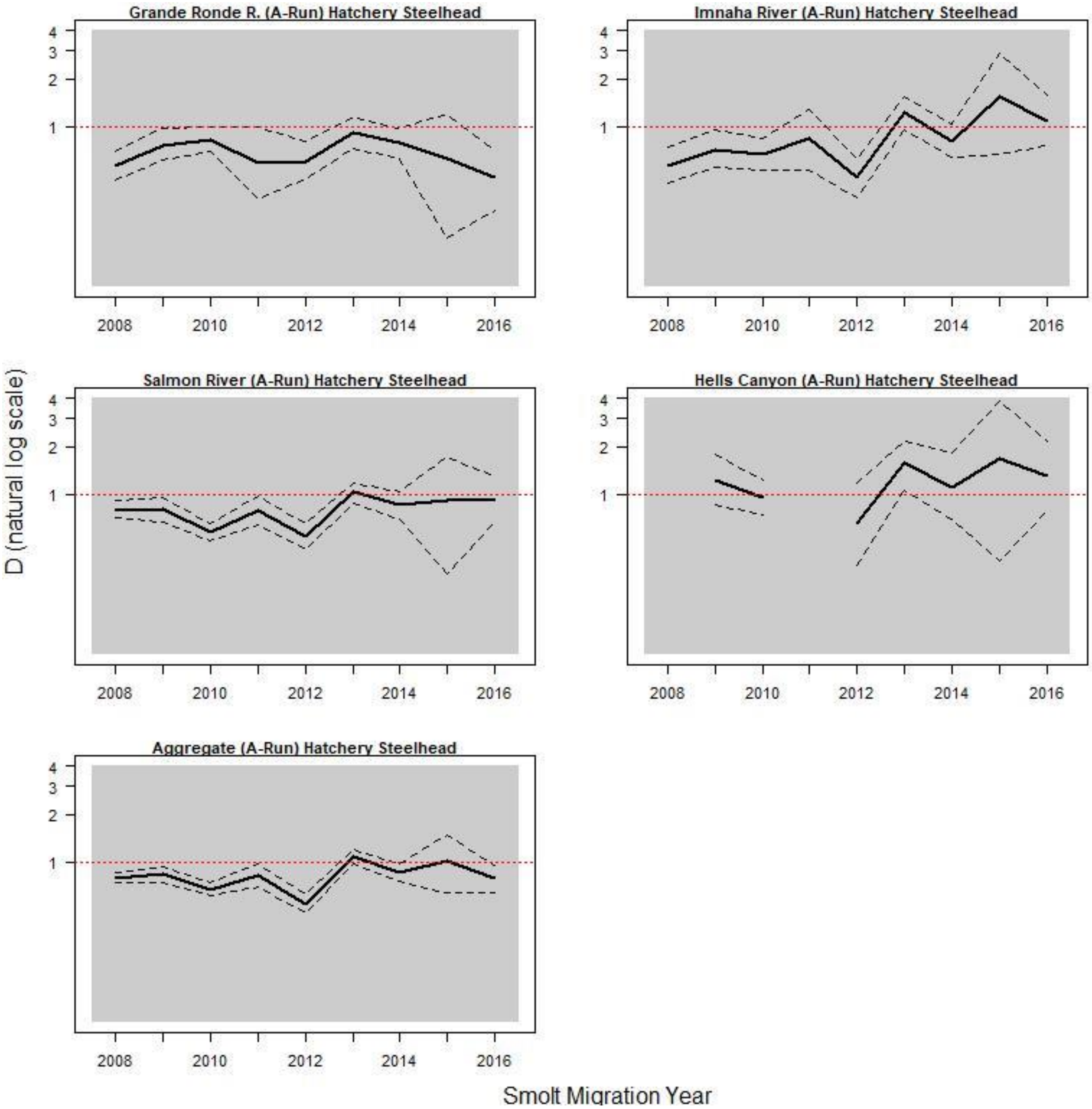

Figure A.31. Trend in *D* on the natural log scale for PIT-tagged Snake River A-run hatchery steelhead in migration years 2008 to 2016 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights 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 2016 (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,B]	TIR	*D*
2008[C]	1.05 (0.92 - 1.20)	0.57 (0.46 - ***0.70***)
2009	1.06 (0.85 - 1.35)	0.77 (0.62 - ***0.98***)
2010	1.14 (0.94 - 1.35)	0.83 (0.70 - ***0.99***)
2011	0.92 (0.54 - 1.51)	0.60 (0.35 - 1.00)
2012	0.97 (0.74 - 1.26)	0.61 (0.47 - ***0.82***)
2013	1.19 (0.95 - 1.48)	0.92 (0.73 - 1.15)
2014	1.10 (0.88 - 1.32)	0.79 (0.63 - ***0.97***)
2015	1.14 (0.37 - 2.16)	0.63 (0.20 - 1.20)
2016[D]	0.81 (0.50 - 1.18)	0.48 (0.30 - ***0.72***)
Geomean	1.04 (0.96 - 1.12)	0.68 (0.59 - ***0.77***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] 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).
[D] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

Table A.60. Estimated TIR, and *D* of PIT-tagged Imnaha River Basin (A-Run) hatchery steelhead for migration years 2008 to 2016 (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,B]	TIR	*D*
2008[C]	1.25 (**1.06** - 1.47)	0.57 (0.44 - ***0.75***)
2009	1.02 (0.79 - 1.31)	0.72 (0.56 - ***0.95***)
2010	1.01 (0.81 - 1.25)	0.68 (0.54 - ***0.84***)
2011	1.14 (0.74 - 1.77)	0.85 (0.53 - 1.28)
2012	0.72 (0.56 - ***0.92***)	0.48 (0.36 - ***0.63***)
2013	1.70 (**1.34** - 2.14)	1.24 (0.95 - 1.56)
2014	1.43 (**1.11** - 1.79)	0.81 (0.64 - 1.04)
2015	2.93 (**1.27** - 5.48)	1.56 (0.68 - 2.91)
2016[D]	2.00 (**1.40** - 2.86)	1.09 (0.76 - 1.58)
Geomean	1.35 (**1.04** - 1.75)	0.83 (0.66 - 1.05)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] 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).
[D] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

Table A.61. Estimated TIR, and *D* of PIT-tagged Salmon River Basin (A-Run) hatchery steelhead for migration years 2008 to 2016 (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,B]	TIR		*D*	
2008	1.15	(**1.03** - 1.28)	0.80	(0.72 - ***0.91***)
2009	1.14	(0.96 - 1.33)	0.81	(0.68 - ***0.95***)
2010	0.84	(0.74 - ***0.95***)	0.58	(0.51 - ***0.66***)
2011	1.18	(0.99 - 1.40)	0.80	(0.65 - ***0.97***)
2012	0.81	(0.68 - ***0.96***)	0.55	(0.45 - ***0.66***)
2013	1.39	(**1.20** - 1.60)	1.04	(0.88 - 1.19)
2014	1.21	(**1.00** - 1.45)	0.86	(0.70 - 1.04)
2015	1.63	(0.58 - 3.02)	0.91	(0.32 - 1.70)
2016[C]	1.63	(**1.18** - 2.24)	0.94	(0.68 - 1.30)
Geomean	1.19	(**1.02** - 1.39)	0.79	(0.70 - ***0.91***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019.

Table A.62. Estimated TIR, and *D* of PIT-tagged Hells Canyon Dam (A-Run) hatchery steelhead for migration years 2009 to 2016 (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,B]	TIR		*D*	
2009	1.70	(**1.23** - 2.47)	1.24	(0.87 - 1.80)
2010	1.18	(0.91 - 1.48)	0.96	(0.75 - 1.24)
2011[C]	---		---	
2012	0.95	(0.54 - 1.59)	0.66	(0.36 - 1.19)
2013	1.77	(**1.24** - 2.48)	1.57	(**1.06** - 2.17)
2014	1.65	(**1.06** - 2.59)	1.12	(0.70 - 1.83)
2015	2.14	(0.48 - 4.89)	1.69	(0.38 - 3.88)
2016[D]	1.76	(**1.06** - 2.82)	1.32	(0.79 - 2.15)
Geomean	1.54	(**1.26** - 1.89)	1.17	(0.93 - 1.48)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[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 June 28, 2019, at GRA.

Table A.63. Estimated TIR, and *D* of PIT-tagged hatchery steelhead (Aggregate A-Run) for migration years 2008 to 2016 (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,B]	**TIR**	***D***
2008	1.13 (**1.05** - 1.21)	0.79 (0.74 - ***0.86***)
2009	1.17 (**1.05** - 1.31)	0.84 (0.75 - ***0.94***)
2010	0.97 (0.88 - 1.05)	0.68 (0.62 - ***0.74***)
2011	1.24 (**1.07** - 1.45)	0.82 (0.70 - ***0.97***)
2012	0.83 (0.74 - ***0.93***)	0.55 (0.48 - ***0.63***)
2013	1.42 (**1.27** - 1.56)	1.09 (0.97 - 1.21)
2014	1.25 (**1.12** - 1.39)	0.86 (0.76 - ***0.98***)
2015	1.80 (**1.13** - 2.59)	1.02 (0.64 - 1.47)
2016[C]	1.32 (**1.09** - 1.60)	0.79 (0.65 - ***0.96***)
Geomean	1.21 (**1.06** - 1.39)	0.81 (0.72 - ***0.92***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

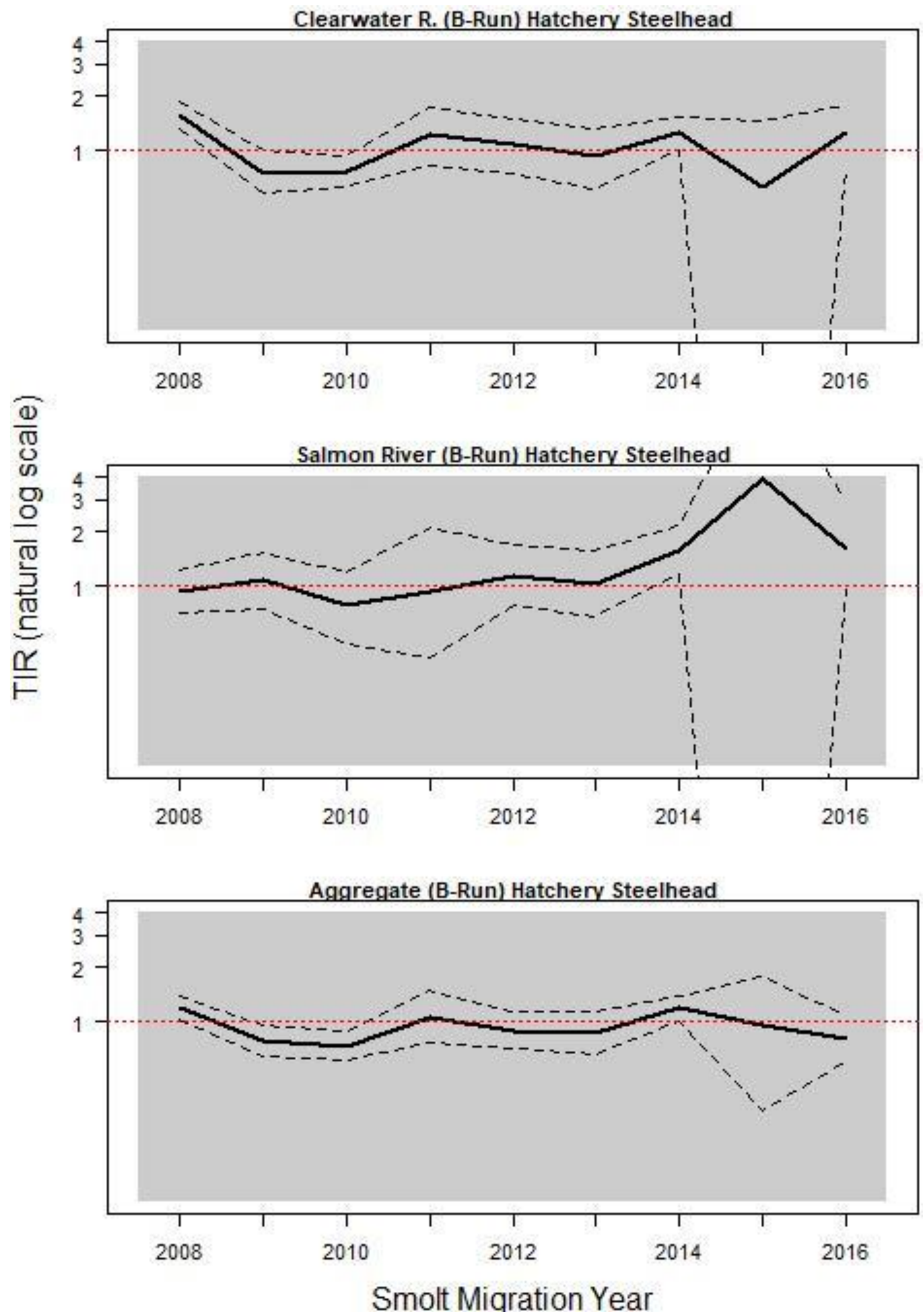

Figure A.32. Trend in TIR on the natural log scale for PIT-tagged Snake River B-run hatchery steelhead in migration years 2008 to 2016 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery B-run steelhead are from Tables A.64–A.66.

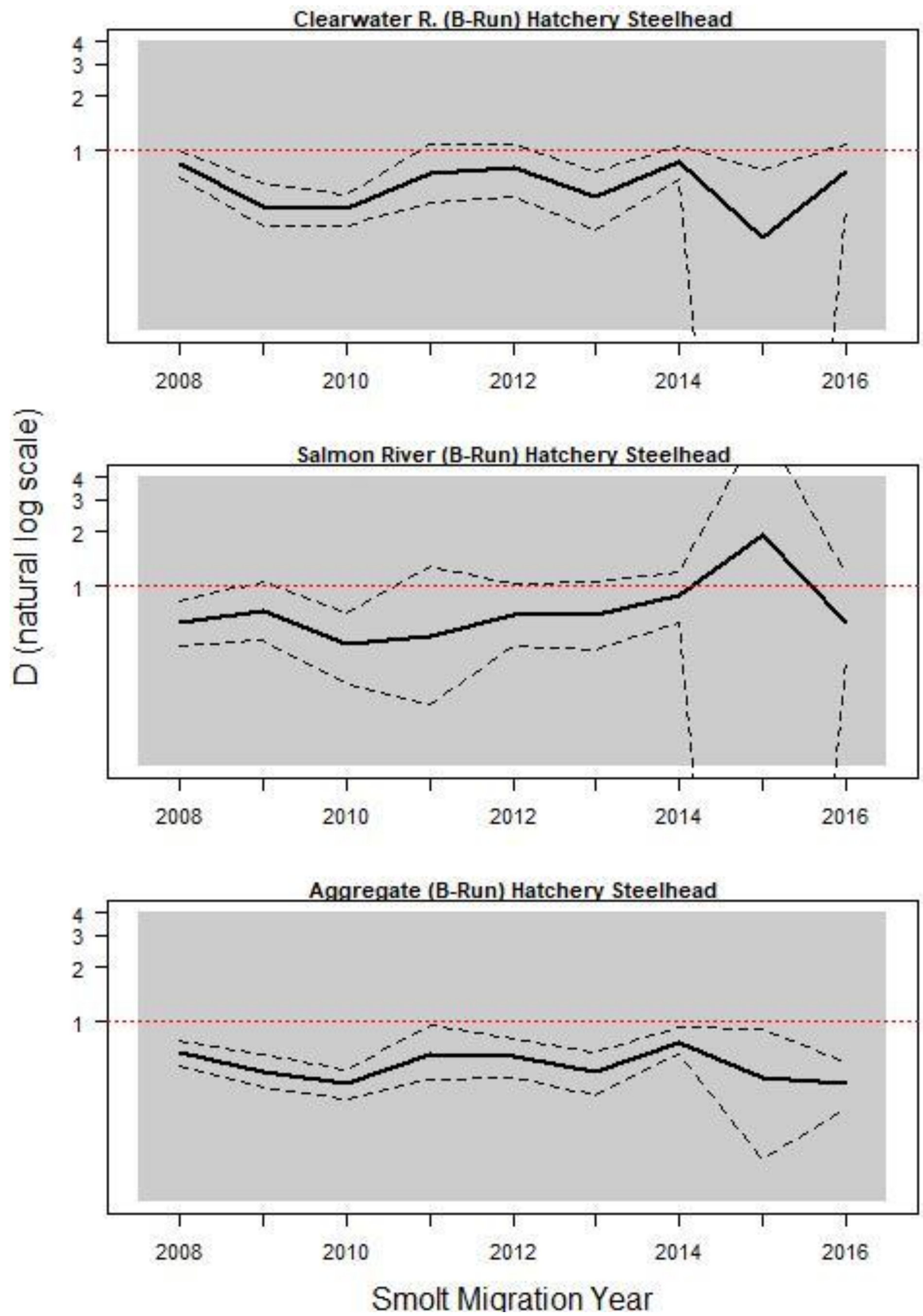

Figure A.33. Trend in *D* on the natural log scale for PIT-tagged Snake River B-run hatchery steelhead in migration years 2008 to 2016 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights 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 2016 (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,B]	TIR	*D*
2008	1.56 (**1.31** - 1.88)	0.84 (0.70 - 1.01)
2009	0.75 (0.58 - ***0.99***)	0.49 (0.38 - ***0.65***)
2010	0.77 (0.62 - ***0.93***)	0.47 (0.38 - ***0.57***)
2011	1.21 (0.82 - 1.72)	0.75 (0.51 - 1.08)
2012	1.07 (0.75 - 1.47)	0.81 (0.55 - 1.09)
2013	0.94 (0.61 - 1.30)	0.55 (0.36 - ***0.77***)
2014	1.25 (**1.01** - 1.52)	0.86 (0.69 - 1.05)
2015	0.62 (0.00 - 1.46)	0.33 (0.00 - ***0.78***)
2016[C]	1.26 (0.81 - 1.77)	0.77 (0.49 - 1.09)
Geomean	1.01 (0.84 - 1.21)	0.62 (0.51 - ***0.77***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019.

Table A.65. Estimated TIR, and *D* of PIT-tagged Salmon River Basin (B-Run) hatchery steelhead for migration years 2008 to 2016 (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,B]	TIR	*D*
2008	0.93 (0.70 - 1.23)	0.62 (0.46 - ***0.82***)
2009	1.08 (0.74 - 1.53)	0.73 (0.50 - 1.05)
2010	0.78 (0.47 - 1.19)	0.47 (0.29 - ***0.71***)
2011	0.92 (0.40 - 2.13)	0.52 (0.22 - 1.27)
2012	1.13 (0.78 - 1.68)	0.69 (0.46 - 1.02)
2013	1.03 (0.67 - 1.56)	0.69 (0.44 - 1.04)
2014	1.56 (**1.15** - 2.14)	0.88 (0.63 - 1.20)
2015	3.89 (0.00 - 15.89)	1.93 (0.00 - 8.09)
2016[C]	1.62 (0.95 - 2.97)	0.63 (0.37 - 1.15)
Geomean	1.26 (0.94 - 1.71)	0.73 (0.56 - ***0.94***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

Table A.66. Estimated TIR, and *D* of PIT-tagged hatchery steelhead (Aggregate B-Run) for migration years 2008 to 2016 (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,B]	TIR		***D***	
2008	1.19	(**1.02** - 1.39)	0.67	(0.57 - ***0.78***)
2009	0.79	(0.64 - ***0.96***)	0.53	(0.43 - ***0.65***)
2010	0.73	(0.61 - ***0.89***)	0.45	(0.37 - ***0.54***)
2011	1.05	(0.77 - 1.47)	0.66	(0.47 - ***0.96***)
2012	0.89	(0.70 - 1.12)	0.64	(0.49 - ***0.81***)
2013	0.87	(0.65 - 1.12)	0.52	(0.39 - ***0.68***)
2014	1.18	(1.00 - 1.38)	0.77	(0.65 - ***0.93***)
2015	0.95	(0.32 - 1.76)	0.49	(0.17 - ***0.91***)
2016[C]	0.81	(0.60 - 1.09)	0.45	(0.33 - ***0.60***)
Geomean	0.93	(0.83 - 1.03)	0.57	(0.50 - ***0.64***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after June 28, 2019, at GRA.

Hatchery Sockeye

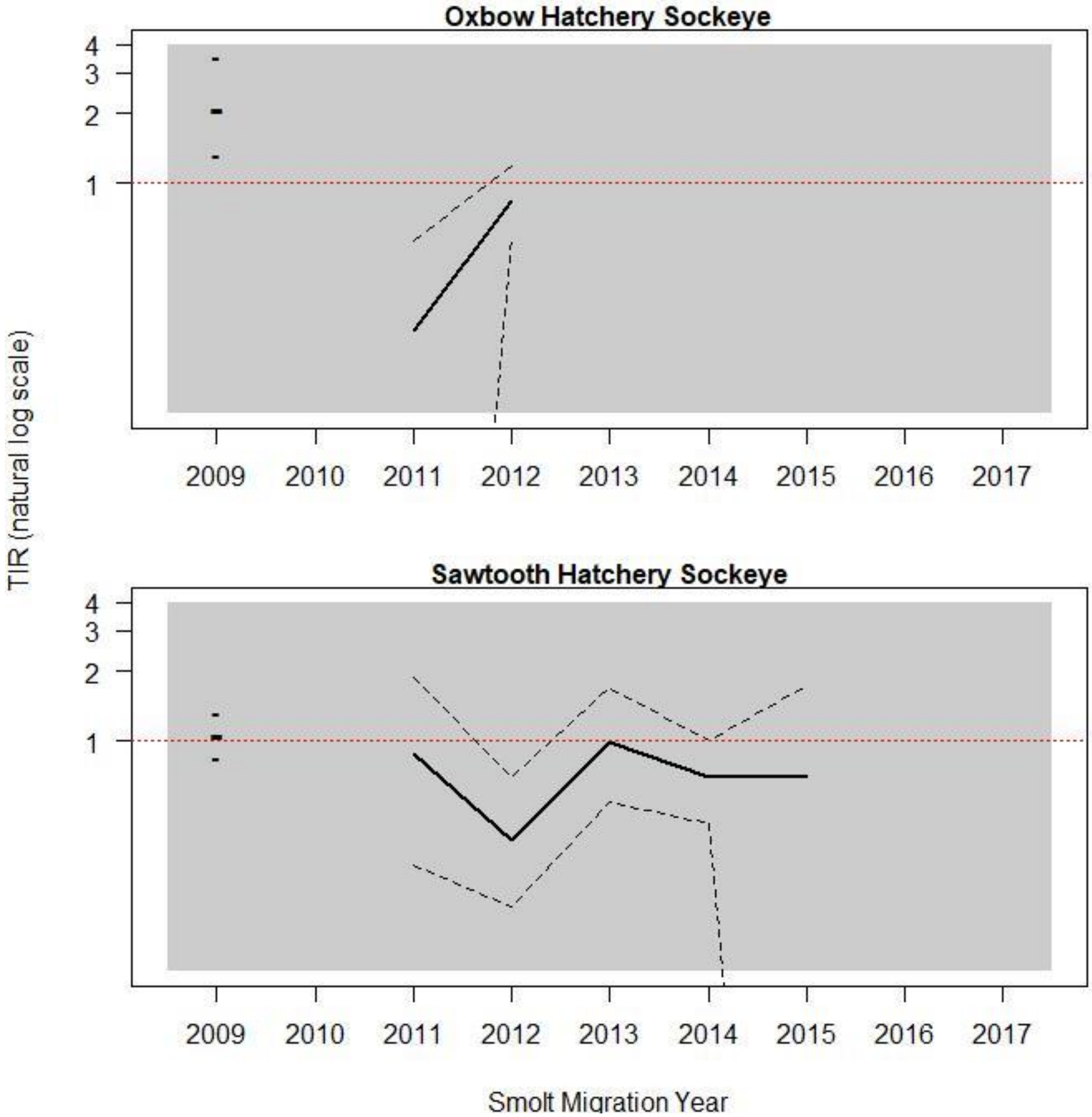

Figure A.34. Trend in TIR on the natural log scale for PIT-tagged Snake River hatchery sockeye in migration years 2009 to 2017 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order 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 2015-2017 (Table A.69).

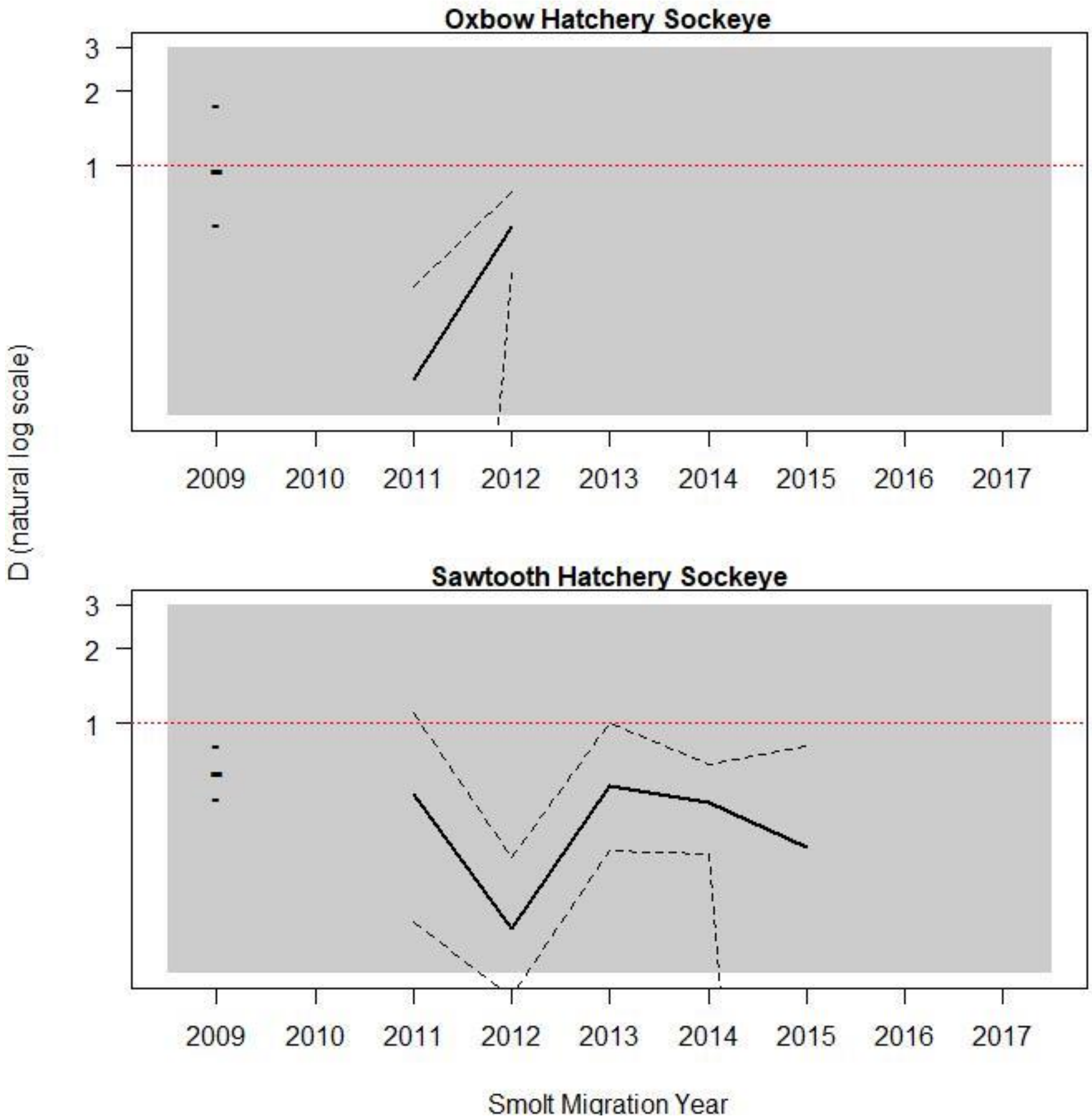

Figure A.35. Trend in *D* on the natural log scale for PIT-tagged Sawtooth Hatchery sockeye in migration years 2009-2017 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery sockeye are from Table A.65. Springfield hatchery sockeye are not displayed because of inability to estimate *D* for 2016-2017 (Table 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,B]	TIR		*D*	
2009	2.09	(**1.31** - 3.49)	0.96	(0.58 - 1.75)
2010[C]	---		---	
2011	0.23	(0.00 - ***0.56***)	0.14	(0.00 - ***0.33***)
2012	0.84	(0.58 - 1.19)	0.57	(0.37 - ***0.79***)
Geomean	0.74	(0.11 - 4.79)	0.42	(0.08 - 2.28)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few juveniles and no adults in Transport group to estimate TIR and *D*.

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,B]	TIR		*D*	
2009	1.06	(0.84 - 1.31)	0.64	(0.50 - ***0.82***)
2010[C]	---		---	
2011	0.87	(0.29 - 1.87)	0.52	(0.16 - 1.11)
2012	0.37	(0.19 - ***0.69***)	0.15	(0.08 - ***0.29***)
2013	0.98	(0.54 - 1.71)	0.56	(0.31 - 1.00)
2014	0.70	(0.44 - 1.01)	0.48	(0.30 - ***0.69***)
2015	0.70	(0.00 - 1.72)	0.32	(0.00 - ***0.81***)
Geomean	0.74	(0.54 - 1.01)	0.40	(0.26 - ***0.63***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Too few juveniles and no adults in Transport group to estimate TIR and *D*.

Table A.69. Estimated TIR and *D* of PIT-tagged hatchery sockeye reared at Springfield Hatchery for migration year 2015 and 2017 (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,B]	TIR	*D*
2015[C]	---	---
2016[C]	---	---
2017[D]	---	---

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] No returning PIT-tagged adults have been detected for this group. Therefore, cannot estimate TIR or *D*.
[D] Incomplete. 2-salt returns through July 31, 2019.

Wild and Hatchery Subyearling Fall Chinook

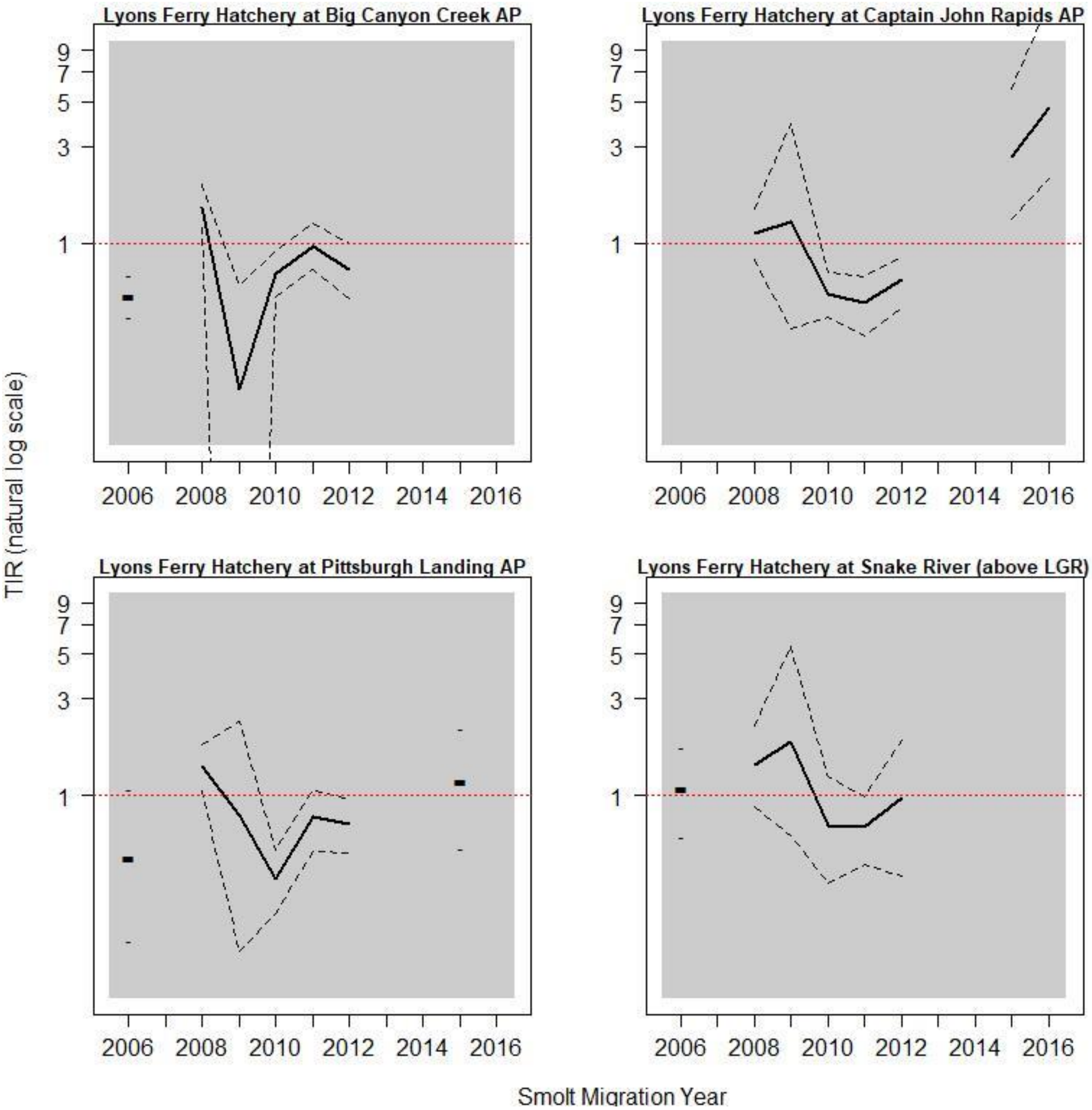

Figure A.36. Trend in TIR on the natural log scale for PIT-tagged Lyons Ferry hatchery subyearling fall Chinook in migration years 2006-2016 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for Lyons Ferry hatchery subyearling fall Chinook are from Tables A.71-A.74. Data for Snake River wild/natural subyearling fall Chinook not displayed due to few years of TIR data (Table A.70).

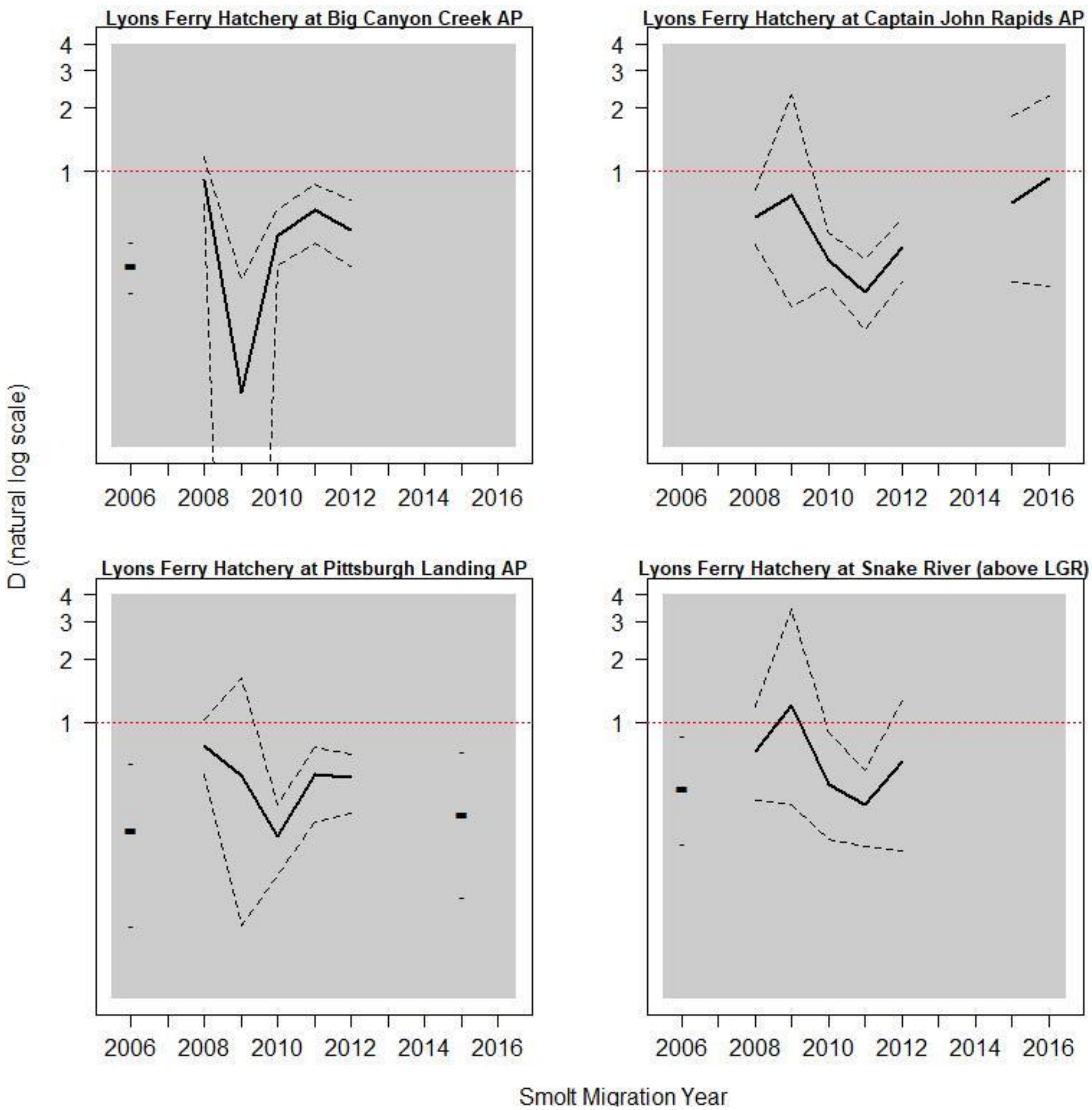

Figure A.37. Trend in *D* on the natural log scale for PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook in migration years 2006-2016 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for Lyons Ferry Hatchery subyearling fall Chinook are from Tables A.71-A.74. Data for Snake River wild/natural subyearling fall Chinook not displayed due to few years of *D* estimates (Table A.70).

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 and 2009 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year	TIR	*D*
2006[A]	0.62 (0.00 – 2.56)	0.27 (0.00 – 1.54)
2007[B]	---	---
2008[A,.C]	---	---
2009[A]	3.29 (0.56 – 10.87)	2.18 (0.34 – 7.64)
2010[B]	---	---
2011[D]	---	---
Geomean	0.81 (0.02 – 42.40)	0.48 (0.01 – 41.84)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] Cannot estimate TIR and D due to small sample size of PIT-tagged fish (2007) and high holdover rate (2010).
[C] Cannot estimate TIR and D due to no returning adults in the Tx group.
[D] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

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,B]	TIR	*D*
2006	0.55 (0.43 - ***0.70***)	0.36 (0.27 - ***0.47***)
2007[C]	---	---
2008	1.51 (**1.19** - 1.95)	0.91 (0.70 - 1.17)
2009	0.19 (0.00 - ***0.62***)	0.09 (0.00 - ***0.31***)
2010	0.71 (0.54 - ***0.92***)	0.50 (0.36 - ***0.66***)
2011	0.97 (0.74 - 1.25)	0.66 (0.46 - ***0.87***)
2012	0.74 (0.53 - ***0.99***)	0.53 (0.36 - ***0.74***)
Geomean	0.66 (0.37 – 1.17)	0.42 (0.21 – ***0.81***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] 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, and 2015 to 2016 (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,B]	TIR		*D*	
2007[C]	---		---	
2008	1.11	(0.83 - 1.47)	0.61	(0.45 - ***0.82***)
2009	1.28	(0.38 - 3.91)	0.77	(0.23 - 2.31)
2010	0.56	(0.43 - ***0.72***)	0.38	(0.29 - ***0.51***)
2011	0.51	(0.35 - ***0.68***)	0.27	(0.18 - ***0.39***)
2012	0.66	(0.48 - ***0.86***)	0.44	(0.30 - ***0.60***)
2015	2.66	(**1.31** - 5.76)	0.71	(0.30 - 1.83)
2016[D]	4.68	(**2.08** - 15.43)	0.93	(0.29 - 2.28)
Geomean	1.19	(0.64 - 2.19)	0.54	(0.39 - ***0.75***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.
[D] Incomplete, 3-salt returns through July 31, 2019.

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, and 2015 to 2016 (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,B]	TIR		*D*	
2006	0.49	(0.19 - 1.08)	0.31	(0.11 - ***0.64***)
2007[C]	---		---	
2008	1.39	(**1.06** - 1.80)	0.78	(0.57 - 1.03)
2009	0.80	(0.17 - 2.32)	0.56	(0.11 - 1.61)
2010	0.39	(0.26 - ***0.54***)	0.29	(0.19 - ***0.41***)
2011	0.78	(0.53 - 1.08)	0.57	(0.34 - ***0.76***)
2012	0.72	(0.52 - ***0.96***)	0.55	(0.37 - ***0.71***)
2015	1.17	(0.55 - 2.15)	0.37	(0.15 - ***0.73***)
2016[D,E]	---		---	
Geomean	0.75	(0.54 - 1.05)	0.46	(0.35 - ***0.61***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.
[D] Too few adults in Transport and/or C0 group to estimate TIR and *D*.
[E] Incomplete, 2-salt returns through December 31, 2017.

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,B]	TIR	*D*
2006	1.08 (0.62 - 1.74)	0.49 (0.27 - ***0.87***)
2007[C]	---	---
2008	1.41 (0.88 - 2.20)	0.73 (0.43 - 1.19)
2009	1.86 (0.64 - 5.43)	1.21 (0.41 - 3.43)
2010	0.71 (0.37 - 1.24)	0.51 (0.28 - ***0.90***)
2011	0.70 (0.46 - ***0.99***)	0.41 (0.26 - ***0.60***)
2012	0.97 (0.40 - 1.88)	0.65 (0.25 - 1.26)
Geomean	1.05 (0.77 - 1.44)	0.62 (0.45 - ***0.86***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

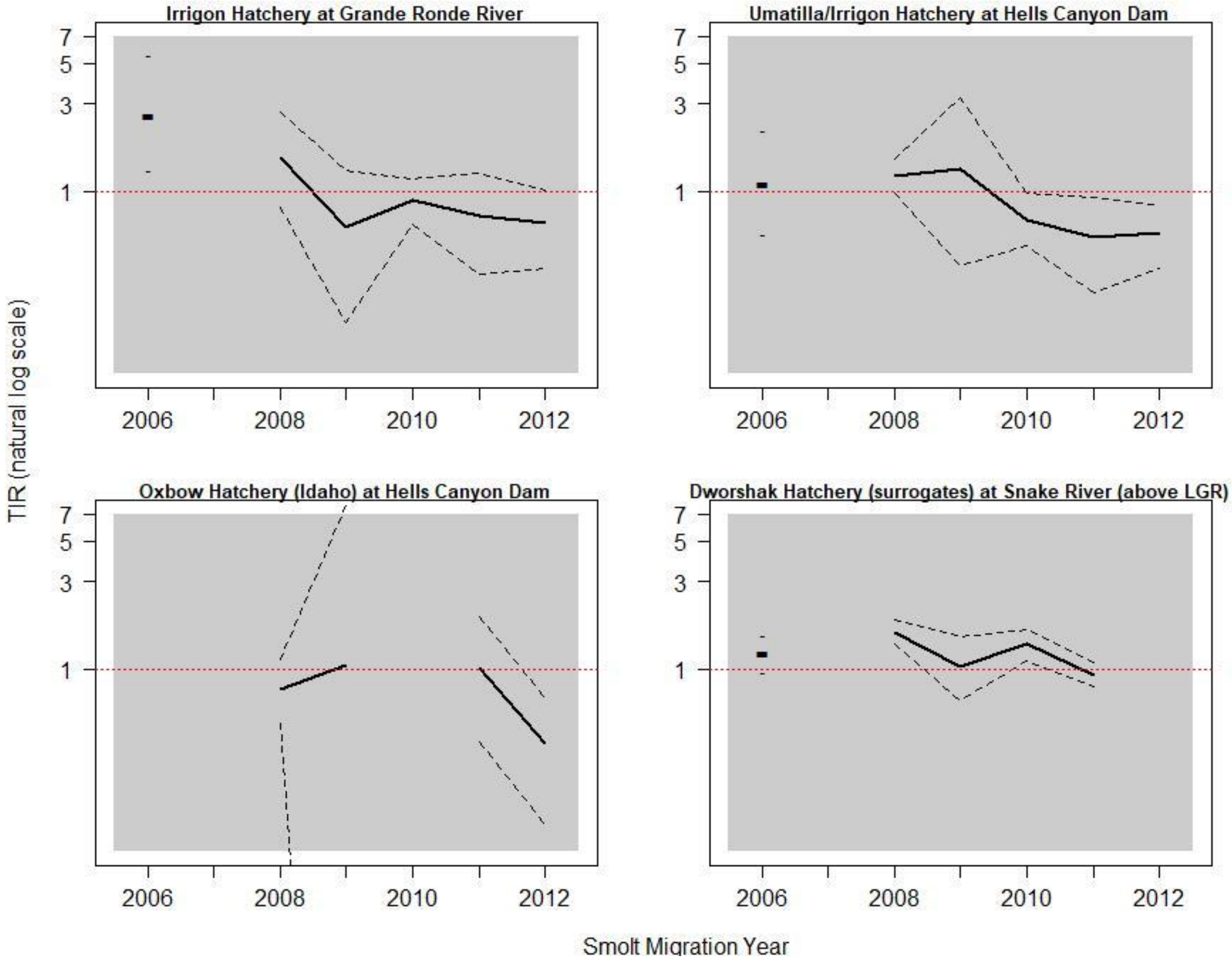

Figure A.38. Trend in TIR on the natural log scale for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for above figure are from Tables A.75-A.78.

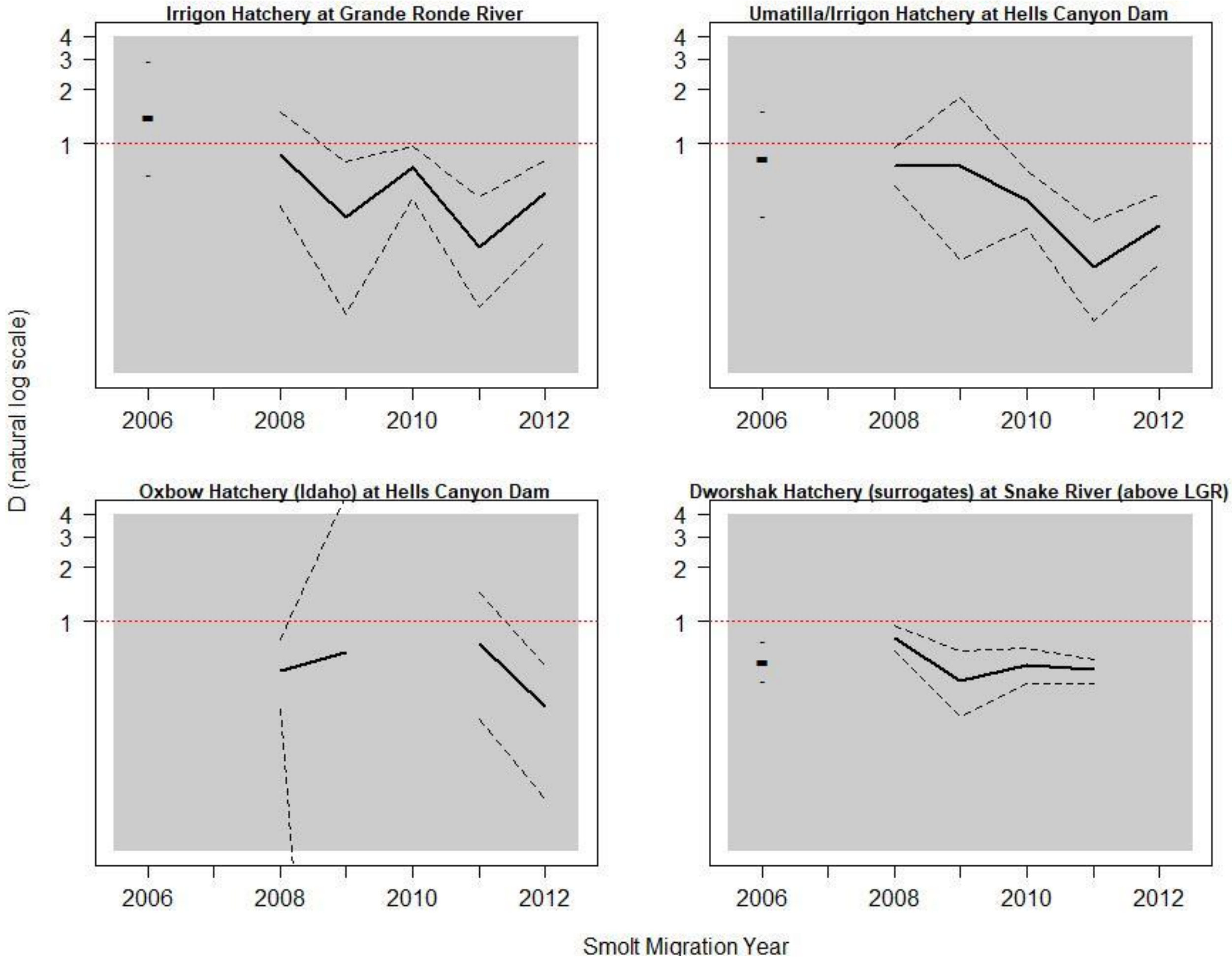

Figure A.39. Trend in *D* on the natural log scale for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for above figure are from Tables A.75-A.78.

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,B]	TIR		D	
2006[C]	2.58	(**1.30** - 5.54)	1.41	(0.67 - 2.91)
2007[D]		---		---
2008	1.54	(0.82 - 2.70)	0.86	(0.44 - 1.49)
2009	0.64	(0.19 - 1.29)	0.38	(0.11 - ***0.78***)
2010	0.90	(0.66 - 1.17)	0.73	(0.49 - ***0.97***)
2011	0.73	(0.35 - 1.25)	0.26	(0.12 - ***0.50***)
2012	0.67	(0.38 - 1.02)	0.52	(0.28 - ***0.80***)
Geomean	1.02	(0.64 - 1.61)	0.60	(0.36 - ***0.98***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] 2006 release was reared at Lyons Ferry Hatchery
[D] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

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,B]	TIR		D	
2006	1.09	(0.58 - 2.13)	0.82	(0.39 - 1.52)
2007[C]		---		---
2008	1.21	(0.97 - 1.50)	0.74	(0.57 - ***0.94***)
2009	1.32	(0.39 - 3.22)	0.74	(0.22 - 1.80)
2010	0.70	(0.50 - ***0.98***)	0.48	(0.33 - ***0.70***)
2011	0.56	(0.28 - ***0.92***)	0.20	(0.10 - ***0.36***)
2012	0.59	(0.38 - ***0.83***)	0.34	(0.21 - ***0.51***)
Geomean	0.86	(0.63 - 1.18)	0.49	(0.31 - ***0.78***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] 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,B]	TIR		***D***	
2007[C]	---		---	
2008	0.77	(0.50 - 1.13)	0.52	(0.32 - ***0.78***)
2009	1.04	(0.00 - 7.80)	0.67	(0.00 - 5.12)
2010[D]	---		---	
2011	1.01	(0.40 - 1.94)	0.74	(0.28 - 1.45)
2012	0.39	(0.14 - ***0.70***)	0.33	(0.10 - ***0.56***)
Geomean	0.75	(0.44 - 1.28)	0.54	(0.35 - ***0.83***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.
[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,B]	TIR		***D***	
2006	1.21	(0.96 - 1.52)	0.59	(0.46 - ***0.77***)
2007[C]	---		---	
2008	1.59	(**1.38** - 1.85)	0.80	(0.68 - ***0.94***)
2009	1.03	(0.67 - 1.49)	0.46	(0.29 - ***0.68***)
2010	1.36	(**1.11** - 1.64)	0.56	(0.44 - ***0.70***)
2011	0.93	(0.80 - 1.09)	0.53	(0.44 - ***0.61***)
2012[D]	---		---	
Geomean	1.20	(0.98 - 1.47)	0.58	(0.48 - ***0.70***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.
[C] Due to low broodstock, no PIT-tags were released for this group in 2007.
[D] TIR and D not estimable due to high estimated holdover rates.

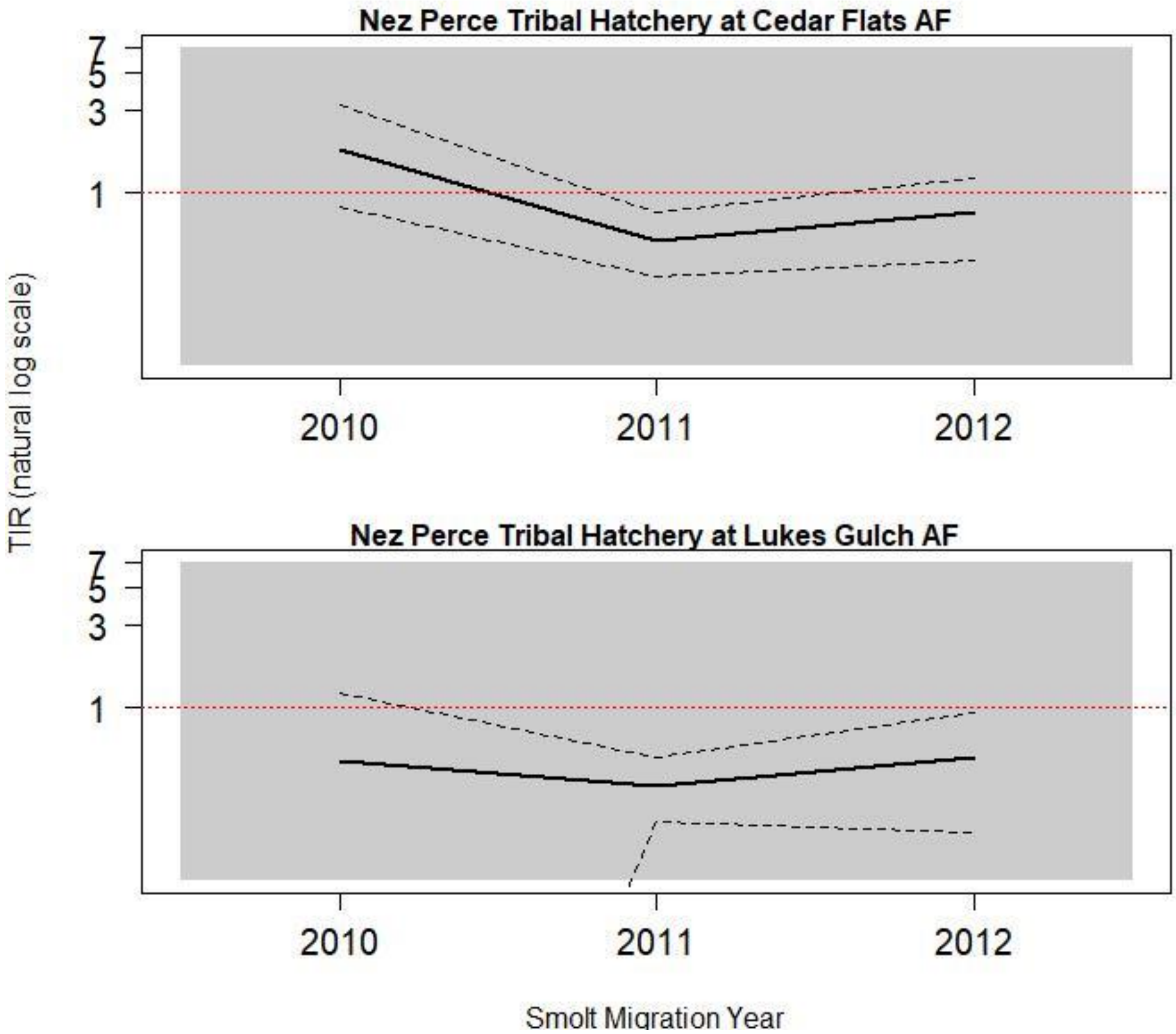

Figure A.40. Trend in TIR on the natural log scale for PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats and Lukes Gulch acclimation facilities in migration years 2010-2012 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river 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.79 and A.80.

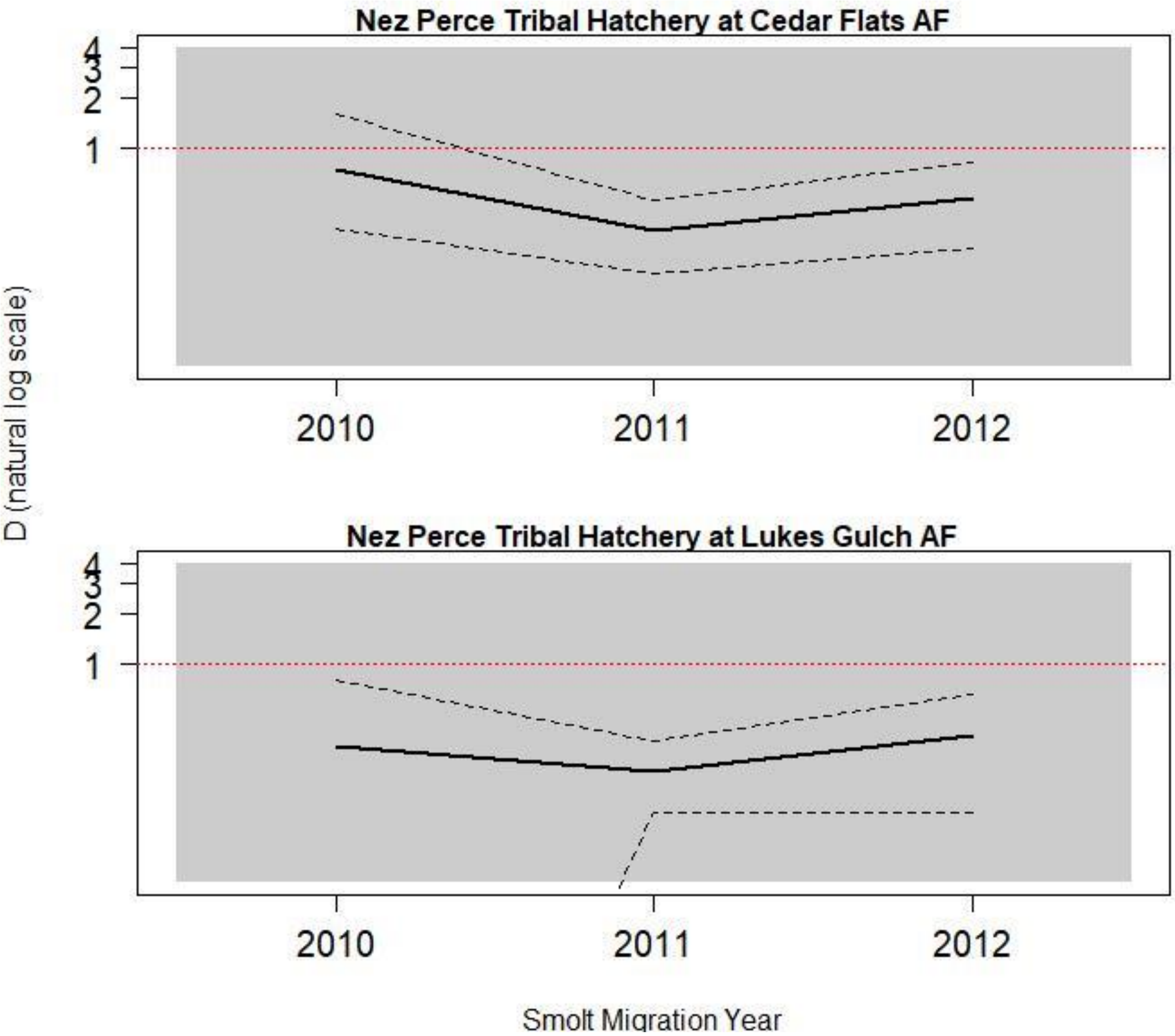

Figure A.41. Trend in *D* on the natural log scale for PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats and Lukes Gulch acclimation facilities in migration years 2010-2012 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value 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.79 and A.80.

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,B]	TIR	*D*
2010	1.78 (0.83 - 3.28)	0.75 (0.33 - 1.60)
2011	0.53 (0.33 - ***0.78***)	0.32 (0.18 - ***0.49***)
2012	0.77 (0.41 - 1.22)	0.50 (0.25 - 0.82)
Geomean	0.90 (0.32 - 2.56)	0.49 (0.24 - 1.01)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

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,B]	TIR	*D*
2010	0.49 (0.00 - 1.22)	0.32 (0.00 - ***0.80***)
2011	0.35 (0.22 - ***0.52***)	0.23 (0.13 - ***0.35***)
2012	0.51 (0.19 - ***0.94***)	0.37 (0.13 - ***0.66***)
Geomean	0.44 (0.31 - ***0.63***)	0.30 (0.20 - ***0.45***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] CJS estimation of S_R (which is used to estimate *D*) uses PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON and Logit link.

APPENDIX B

ANNUAL OVERALL SARS
(SUPPORTING TABLES TO CHAPTERS 4)

Snake River wild spring/summer Chinook

Table B.1. Overall LGR-to-GRA SARs for Snake River Basin (above LGR) Wild Chinook, 1994 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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
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	15,283	0.69	0.58	0.80	0.74	0.63	0.85
2007	14,953	0.98	0.84	1.11	1.09	0.95	1.23
2008	18,531	2.75	2.56	2.94	3.24	3.04	3.46
2009	18,775	1.45	1.30	1.60	1.61	1.45	1.76
2010	26,604	0.74	0.65	0.83	0.93	0.83	1.03
2011	23,327	0.33	0.27	0.40	0.36	0.30	0.43
2012	21,559	1.10	0.99	1.22	1.43	1.31	1.57
2013	19,033	1.20	1.07	1.34	1.36	1.22	1.51
2014	21,434	0.52	0.44	0.60	0.57	0.48	0.66
2015	12,352	0.23	0.17	0.31	0.29	0.21	0.37
2016	16,647	0.34	0.27	0.41	0.38	0.31	0.47
2017[B]	6,869	0.13	0.07	0.20	0.15	0.07	0.22
Arithmetic mean (incl. zeros)		0.92			1.01		
Geometric mean (excl. zeros)		0.68			0.76		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.2. Overall LGR-to-BOA SARs for Snake River Basin (above LGR) Wild Chinook, 2000 to 2017. 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	15,283	0.84	0.72	0.95	0.89	0.76	1.01
2007	14,953	1.16	1.01	1.29	1.27	1.11	1.41
2008	18,531	3.58	3.37	3.81	4.14	3.92	4.39
2009	18,775	1.93	1.76	2.10	2.09	1.92	2.26
2010	26,604	0.92	0.83	1.02	1.16	1.05	1.26
2011	23,327	0.42	0.35	0.49	0.45	0.38	0.53
2012	21,559	1.48	1.35	1.63	1.84	1.70	1.99
2013	19,033	1.54	1.40	1.70	1.70	1.56	1.87
2014	21,434	0.61	0.63	0.70	0.69	0.60	0.79
2015	12,352	0.28	0.20	0.36	0.35	0.26	0.43
2016	16,647	0.44	0.36	0.52	0.49	0.40	0.57
2017[B]	6,869	0.20	0.12	0.29	0.23	0.14	0.33
Arithmetic mean (incl. zeros)		1.13			1.26		
Geometric mean (excl. zeros)		0.83			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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.3. Overall LGR-to-GRA SARs for Clearwater River Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	1,787	0.28	0.11	0.50	0.34	0.11	0.57
2007	576	0.87	0.33	1.59	0.87	0.33	1.59
2008	1,136	1.41	0.87	2.08	1.58	1.02	2.29
2009	1,068	1.03	0.56	1.57	1.03	0.56	1.57
2010	5,725	0.75	0.57	0.95	0.75	0.57	0.95
2011	1,433	0.35	0.07	0.62	0.35	0.07	0.62
2012	1,303	0.69	0.32	1.12	0.69	0.32	1.12
2013	1,095	0.37	0.09	0.65	0.37	0.09	0.65
2014	825	0.24	0.00	0.57	0.24	0.00	0.57
2015	510	0.20	0.00	0.57	0.20	0.00	0.57
2016	774	0.13	0.00	0.39	0.13	0.00	0.39
2017[B]	210	0.48	0.00	1.30	0.48	0.00	1.30
Arithmetic mean (incl. zeros)		0.57			0.59		
Geometric mean (excl. zeros)		0.45			0.46		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.4. Overall LGR-to-BOA SARs for Clearwater River Wild Chinook, 2006–2017. 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	1,787	0.39	0.17	0.63	0.45	0.22	0.71
2007	576	1.04	0.36	1.83	1.04	0.36	1.83
2008	1,136	1.76	1.16	2.46	1.94	1.30	2.69
2009	1,068	1.41	0.83	0.20	1.41	0.83	2.00
2010	5,725	1.05	0.84	1.29	1.07	0.85	1.31
2011	1,433	0.49	0.20	0.78	0.49	0.20	0.78
2012	1,303	0.69	0.35	1.11	0.69	0.35	1.11
2013	1,095	0.73	0.33	1.16	0.73	0.33	1.16
2014	825	0.36	0.00	0.74	0.36	0.00	0.74
2015	510	0.20	0.00	0.57	0.20	0.00	0.57
2016	774	0.13	0.00	0.39	0.13	0.00	0.39
2017[B]	210	0.48	0.00	1.30	0.48	0.00	1.30
Arithmetic mean (incl. zeros)		0.73			0.75		
Geometric mean (excl. zeros)		0.57			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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.5. Overall LGR-to-GRA SARs for Grande Ronde Basin Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	3,466	0.87	0.61	1.11	0.92	0.68	1.18
2007	2,687	1.15	0.84	1.50	1.38	1.04	1.74
2008	2,393	2.92	2.31	3.50	3.26	2.64	3.87
2009	2,777	2.16	1.68	2.63	2.30	1.84	2.78
2010	3,723	0.54	0.34	0.73	0.64	0.43	0.84
2011	3,263	0.43	0.25	0.63	0.43	0.25	0.63
2012	3,092	1.46	1.13	1.85	1.65	1.30	2.06
2013	3,232	1.55	1.18	1.90	1.79	1.40	2.16
2014	3,391	1.30	0.98	1.64	1.36	1.04	1.70
2015	1,327	0.53	0.21	0.88	0.60	0.25	0.98
2016	2,595	0.62	0.38	0.86	0.62	0.38	0.86
2017[B]	808	0.12	0.00	0.36	0.12	0.00	0.36
Arithmetic mean (incl. zeros)		1.14			1.26		
Geometric mean (excl. zeros)		0.86			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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.6. Overall LGR-to-BOA SARs for Grande Ronde Basin Wild Chinook, 2006–2017. 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	3,466	1.04	0.77	1.31	1.10	0.83	1.38
2007	2,687	1.49	1.14	1.90	1.71	1.35	2.13
2008	2,393	3.80	3.12	4.45	4.14	3.43	4.83
2009	2,777	2.77	2.23	3.31	2.85	2.31	3.39
2010	3,723	0.81	0.58	1.05	0.94	0.68	1.18
2011	3,263	0.49	0.31	0.72	0.49	0.31	0.72
2012	3,092	2.00	1.59	2.44	2.20	1.78	2.65
2013	3,232	1.92	1.51	2.28	2.17	1.74	2.57
2014	3,391	1.50	1.18	1.89	1.59	1.25	1.98
2015	1,327	0.68	0.31	1.08	0.83	0.44	1.24
2016	2,595	0.69	0.43	0.94	0.69	0.43	0.94
2017[B]	808	0.25	0.00	0.53	0.37	0.12	0.75
Arithmetic mean (incl. zeros)		1.45			1.59		
Geometric mean (excl. zeros)		1.13			1.26		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.7. Overall LGR-to-GRA SARs for Imnaha River Basin Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	729	0.69	0.27	1.23	0.69	0.27	1.23
2007	4,112	0.63	0.43	0.83	0.78	0.55	1.00
2008	4,034	2.83	2.41	3.25	3.55	3.07	4.02
2009	3,161	1.68	1.30	2.06	1.90	1.51	2.30
2010	4,065	0.84	0.63	1.10	1.11	0.85	1.39
2011	5,411	0.33	0.16	0.53	0.37	0.17	0.59
2012	2,384	0.80	0.51	1.10	1.01	0.70	1.35
2013	3,012	1.20	0.88	1.54	1.43	1.08	1.79
2014	3,401	0.44	0.27	0.62	0.50	0.32	0.70
2015	3,156	0.41	0.24	0.62	0.48	0.29	0.69
2016	1,459	0.34	0.13	0.61	0.34	0.13	0.61
2017[B]	839	0.24	0.00	0.50	0.36	0.00	0.71
Arithmetic mean (incl. zeros)		0.87			1.04		
Geometric mean (excl. zeros)		0.67			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.8. Overall LGR-to-BOA SARs for Imnaha River Basin Wild Chinook, 2006–2017. 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	729	0.69	0.27	1.23	0.82	0.28	1.42
2007	4,112	0.71	0.50	0.93	0.88	0.63	1.11
2008	4,034	3.89	3.39	4.39	4.74	4.20	5.31
2009	3,161	2.44	2.00	2.90	2.66	2.20	3.12
2010	4,065	0.93	0.70	1.22	1.28	1.01	1.59
2011	2,411	0.41	0.21	0.63	0.50	0.29	0.74
2012	2,384	1.13	0.77	1.49	1.51	1.09	1.93
2013	3,012	1.46	1.11	1.81	1.69	1.30	2.07
2014	3,401	0.50	0.31	0.69	0.62	0.41	0.85
2015	3,156	0.48	0.29	0.69	0.54	0.34	0.77
2016	1,459	0.55	0.26	0.90	0.55	0.26	0.90
2017[B]	839	0.48	0.12	0.87	0.60	0.23	1.04
Arithmetic mean (incl. zeros)		1.14			1.37		
Geometric mean (excl. zeros)		0.87			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.9. Overall LGR-to-GRA SARs for South Fork Salmon River Basin Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	1,282	0.86	0.47	1.30	0.86	0.47	1.30
2007	2,121	1.41	1.01	1.86	1.46	1.04	1.93
2008	1,614	3.90	3.12	4.71	4.77	3.93	5.64
2009	1,895	1.37	0.97	1.83	1.53	1.10	2.00
2010	1,504	1.40	0.91	1.94	1.60	1.08	2.18
2011	1,103	0.27	0.09	0.57	0.27	0.09	0.57
2012	888	1.01	0.54	1.60	1.01	0.54	1.60
2013	608	0.99	0.33	1.69	0.99	0.33	1.69
2014	517	0.77	0.19	1.45	0.77	0.19	1.56
2015	422	0.24	0.00	0.71	0.24	0.00	0.71
2016	863	0.35	0.00	0.68	0.35	0.00	0.68
2017[B,C]	1,252	0.00	0.00	0.24	0.00	0.00	0.24
Arithmetic mean (incl. zeros)		1.05			1.15		
Geometric mean (excl. zeros)		0.85			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[C] Incomplete, 2-salt returns through July 31, 2019.

Table B.10. Overall LGR-to-BOA SARs for South Fork Salmon River Basin Wild Chinook, 2006–2017. 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	1,282	0.94	0.54	1.40	0.94	0.54	1.40
2007	2,121	1.60	1.14	2.06	1.65	1.18	2.12
2008	1,614	4.83	3.94	5.75	5.82	4.85	6.80
2009	1,895	1.85	1.36	2.37	2.01	1.50	2.55
2010	1,504	1.53	1.03	2.10	1.86	1.31	2.52
2011	1,103	0.27	0.09	0.57	0.27	0.09	0.57
2012	888	1.24	0.67	1.86	1.24	0.67	1.86
2013	608	1.48	0.70	2.28	1.48	0.70	2.28
2014	517	0.77	0.19	1.45	0.77	0.19	1.45
2015	422	0.47	0.00	1.05	0.47	0.00	1.05
2016	863	0.46	0.12	0.82	0.46	0.12	0.82
2017[B]	1,252	0.16	0.00	0.38	0.16	0.00	0.38
Arithmetic mean (incl. zeros)		1.30			1.43		
Geometric mean (excl. zeros)		0.90			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.11. Overall LGR-to-GRA SARs for Middle Fork Salmon River Basin Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	259	0.39	0.00	1.15	0.39	0.00	1.15
2007	342	0.59	0.00	1.25	0.59	0.00	1.25
2008	3,006	2.96	2.47	3.49	3.49	2.95	4.04
2009	2,629	1.14	0.80	1.47	1.56	1.17	1.95
2010	2,868	0.94	0.63	1.25	1.60	1.21	1.98
2011	3,186	0.35	0.19	0.52	0.44	0.25	0.63
2012	2,518	0.91	0.59	1.24	1.59	1.17	2.01
2013	2,333	1.46	1.04	1.88	1.54	1.11	1.98
2014	3,044	0.49	0.29	0.72	0.56	0.33	0.80
2015	2,432	0.08	0.00	0.18	0.21	0.08	0.36
2016	2,045	0.39	0.19	0.63	0.49	0.24	0.76
2017[B]	1,800	0.17	0.00	0.33	0.17	0.00	0.33
Arithmetic mean (incl. zeros)		0.82			1.05		
Geometric mean (excl. zeros)		0.56			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.12. Overall LGR-to-BOA SARs for Middle Fork Salmon River Basin Wild Chinook, 2006–2017. 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	259	0.39	0.00	1.15	0.39	0.00	1.15
2007	342	1.17	0.28	2.10	1.17	0.28	2.10
2008	3,006	3.53	2.96	4.11	4.12	3.53	4.74
2009	2,629	1.56	1.16	1.94	1.98	1.54	2.44
2010	2,868	1.12	0.80	1.43	1.85	1.44	2.26
2011	3,186	0.41	0.22	0.59	0.50	0.31	0.70
2012	2,518	1.35	0.98	1.73	2.03	1.56	2.49
2013	2,333	1.76	1.32	2.22	1.84	1.39	2.32
2014	3,044	0.56	0.34	0.79	0.66	0.40	0.92
2015	2,432	0.08	0.00	0.18	0.21	0.08	0.36
2016	2,045	0.49	0.24	0.76	0.59	0.34	0.88
2017[B]	1,800	0.17	0.00	0.33	0.17	0.00	0.33
Arithmetic mean (incl. zeros)		1.05			1.29		
Geometric mean (excl. zeros)		0.68			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.13. Overall LGR-to-GRA SARs for Upper Salmon River Basin Wild Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.3.

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	2,883	0.52	0.32	0.74	0.55	0.35	0.78
2007	1,977	0.96	0.61	1.34	0.96	0.61	1.34
2008	1,612	2.73	2.01	3.41	2.85	2.10	3.53
2009	2,110	1.56	1.12	2.02	1.61	1.17	2.08
2010	3,612	0.94	0.69	1.19	1.08	0.80	1.34
2011	4,805	0.35	0.23	0.50	0.35	0.23	0.50
2012	3,783	1.53	1.23	1.87	1.98	1.62	2.38
2013	3,527	1.22	0.92	1.54	1.28	0.99	1.60
2014	3,477	0.35	0.18	0.51	0.37	0.20	0.54
2015	2,287	0.09	0.00	0.19	0.13	0.00	0.26
2016	4,800	0.27	0.15	0.40	0.35	0.21	0.50
2017[B]	1,926	0.21	0.05	0.37	0.21	0.05	0.37
Arithmetic mean (incl. zeros)		0.89			0.98		
Geometric mean (excl. zeros)		0.60			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.14. Overall LGR-to-BOA SARs for Upper Salmon River Basin Wild Chinook, 2006–2017. 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	2,883	0.66	0.43	0.90	0.69	0.45	0.95
2007	1,977	1.01	0.65	1.39	1.01	0.65	1.39
2008	1,612	3.91	3.10	4.72	4.09	3.29	4.89
2009	2,110	1.94	1.49	2.48	1.99	1.52	2.52
2010	3,612	1.11	0.83	1.37	1.27	0.96	1.56
2011	4,805	0.46	0.31	0.62	0.46	0.31	0.62
2012	3,783	1.88	1.54	2.25	2.33	1.93	2.76
2013	3,527	1.64	1.31	2.02	1.70	1.37	2.09
2014	3,477	0.40	0.23	0.58	0.43	0.25	0.61
2015	2,287	0.13	0.00	0.27	0.17	0.04	0.33
2016	4,800	0.42	0.27	0.58	0.50	0.33	0.68
2017[B]	1,926	0.21	0.05	0.37	0.21	0.05	0.37
Arithmetic mean (incl. zeros)		1.15			1.24		
Geometric mean (excl. zeros)		0.76			0.83		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Snake River hatchery spring and summer Chinook

Table B.15. Overall LGR-to-GRA SARs for Dworshak hatchery spring Chinook, 1997–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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	29,421	0.35	0.30	0.42	0.46	0.40	0.52
2007	28,585	0.36	0.30	0.41	0.46	0.39	0.52
2008	25,681	0.57	0.50	0.65	0.84	0.75	0.95
2009	24,715	0.38	0.32	0.45	0.43	0.37	0.50
2010	32,584	0.46	0.40	0.52	0.79	0.72	0.87
2011	26,315	0.17	0.13	0.21	0.19	0.15	0.24
2012	26,760	0.47	0.41	0.54	0.67	0.58	0.75
2013	29,447	0.59	0.51	0.67	0.71	0.63	0.80
2014	29,759	0.26	0.22	0.31	0.29	0.24	0.34
2015	22,760	0.08	0.05	0.12	0.12	0.08	0.15
2016	20,472	0.10	0.06	0.14	0.10	0.07	0.14
2017[B]	19,660	0.06	0.03	0.09	0.06	0.03	0.09
Arithmetic mean (incl. zeros)		0.44			0.52		
Geometric mean (excl. zeros)		0.34			0.40		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.16. Overall LGR-to-BOA SARs for Dworshak hatchery spring Chinook, 2000–2017. 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	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	29,421	0.56	0.50	0.64	0.69	0.61	0.77
2007	28,585	0.48	0.41	0.55	0.59	0.51	0.66
2008	25,681	1.00	0.91	1.12	1.32	1.20	1.45
2009	24,715	0.53	0.45	0.61	0.59	0.51	0.67
2010	32,584	0.69	0.62	0.77	1.14	1.04	1.24
2011	26,315	0.24	0.19	0.29	0.25	0.21	0.31
2012	26,760	0.66	0.57	0.74	0.89	0.79	0.98
2013	29,447	0.84	0.75	0.93	1.00	0.91	1.09
2014	29,759	0.37	0.31	0.43	0.40	0.34	0.46
2015	22,760	0.14	0.10	0.19	0.18	0.13	0.22
2016	20,472	0.16	0.11	0.20	0.18	0.13	0.23
2017[B]	19,660	0.07	0.04	0.10	0.07	0.04	0.10
Arithmetic mean (incl. zeros)		0.53			0.63		
Geometric mean (excl. zeros)		0.42			0.49		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.17. Overall LGR-to-GRA SARs for Rapid River hatchery spring Chinook, 1997–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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	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	26,375	0.50	0.43	0.57	0.60	0.52	0.68
2007	25,766	0.34	0.28	0.40	0.47	0.40	0.54
2008	29,103	1.30	1.19	1.41	1.96	1.83	2.09
2009	26,336	1.02	0.92	1.12	1.16	1.07	1.26
2010	28,987	0.48	0.41	0.55	0.77	0.69	0.87
2011	27,798	0.28	0.24	0.34	0.31	0.26	0.37
2012	26,918	0.82	0.74	0.92	1.01	0.92	1.11
2013	27,854	1.25	1.13	1.36	1.48	1.35	1.60
2014	27,711	0.43	0.37	0.50	0.50	0.43	0.57
2015	30,560	0.22	0.17	0.26	0.29	0.24	0.34
2016	29,625	0.15	0.11	0.19	0.20	0.16	0.24
2017[B]	23,734	0.20	0.15	0.24	0.22	0.17	0.27
Arithmetic mean (incl. zeros)		0.82			0.94		
Geometric mean (excl. zeros)		0.58			0.69		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.18. Overall LGR-to-BOA SARs for Rapid River hatchery spring Chinook, 2000–2017. 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	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	26,375	0.73	0.64	0.82	0.84	0.75	0.94
2007	25,766	0.48	0.41	0.55	0.62	0.54	0.71
2008	29,103	1.82	1.69	1.95	2.54	2.41	2.70
2009	26,336	1.44	1.32	1.56	1.56	1.44	1.69
2010	28,987	0.73	0.65	0.82	1.11	1.00	1.22
2011	27,798	0.35	0.29	0.41	0.38	0.32	0.45
2012	26,918	1.13	1.02	1.24	1.33	1.21	1.45
2013	27,854	1.46	1.34	1.58	1.72	1.58	1.85
2014	27,711	0.55	0.48	0.62	0.62	0.55	0.70
2015	30,560	0.27	0.22	0.32	0.36	0.30	0.42
2016	29,625	0.24	0.20	0.29	0.30	0.25	0.36
2017[B]	23,734	0.29	0.23	0.35	0.30	0.24	0.36
Arithmetic mean (incl. zeros)		0.86			1.01		
Geometric mean (excl. zeros)		0.66			0.78		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.19. Overall LGR-to-GRA SARs for Catherine Creek hatchery spring Chinook, 2001–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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
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	4,314	0.49	0.33	0.67	0.60	0.41	0.81
2007	4,706	0.42	0.27	0.61	0.83	0.60	1.06
2008	6,602	2.14	1.83	2.43	2.95	2.57	3.31
2009	5,381	1.54	1.27	1.82	1.80	1.51	2.13
2010	6,324	0.89	0.69	1.10	1.55	1.29	1.84
2011	4,344	0.48	0.32	0.67	0.51	0.33	0.69
2012	4,966	0.85	0.64	1.05	1.19	0.95	1.46
2013	3,255	1.35	1.02	1.69	1.84	1.45	2.25
2014	3,858	0.44	0.28	0.62	0.62	0.43	0.83
2015	3,871	0.44	0.26	0.61	0.62	0.40	0.82
2016	5,453	0.26	0.15	0.37	0.40	0.26	0.54
2017[B]	6,277	0.25	0.15	0.36	0.29	0.18	0.40
Arithmetic mean (incl. zeros)		0.68			0.93		
Geometric mean (excl. zeros)		0.54			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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.20. Overall LGR-to-BOA SARs for Catherine Creek hatchery spring Chinook, 2001–2017. 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	4,314	0.79	0.58	1.05	0.90	0.67	1.18
2007	4,706	0.53	0.36	0.71	0.98	0.73	1.22
2008	6,602	2.73	2.38	3.06	3.70	3.28	4.11
2009	5,381	2.10	1.79	2.43	2.40	2.05	2.75
2010	6,324	1.20	0.97	1.46	1.96	1.66	2.29
2011	4,344	0.64	0.45	0.86	0.67	0.47	0.90
2012	4,966	1.05	0.83	1.29	1.45	1.18	1.74
2013	3,255	1.63	1.27	2.03	2.15	1.70	2.62
2014	3,858	0.60	0.42	0.81	0.83	0.61	1.06
2015	2,871	0.57	0.37	0.74	0.78	0.53	1.00
2016	5,453	0.37	0.24	0.50	0.53	0.38	0.69
2017[B]	6,277	0.32	0.20	0.44	0.67	0.24	0.49
Arithmetic mean (incl. zeros)		0.89			1.19		
Geometric mean (excl. zeros)		0.72			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 total tag release in years through 2005 and Group T tags beginning in 2006. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.21. Overall LGR-to-GRA SARs for McCall[A] hatchery summer Chinook, 1997–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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	21,819	1.06	0.96	1.18	1.26	1.14	1.38
2007	19,102	0.90	0.78	1.01	1.42	1.27	1.57
2008	21,081	1.13	1.01	1.26	2.36	2.18	2.54
2009	18,489	0.52	0.44	0.61	0.83	0.71	0.94
2010	20,744	0.58	0.49	0.66	1.05	0.92	1.16
2011	22,880	0.31	0.26	0.38	0.37	0.31	0.44
2012	20,598	0.59	0.51	0.68	1.13	1.01	1.26
2013	24,936	0.85	0.76	0.96	1.38	1.26	1.51
2014	25,960	0.42	0.35	0.48	0.70	0.61	0.78
2015	26,054	0.17	0.13	0.22	0.25	0.20	0.30
2016	23,827	0.37	0.31	0.44	0.64	0.56	0.73
2017[C]	25,304	0.21	0.16	0.25	0.29	0.24	0.35
Arithmetic mean (incl. zeros)		1.02			1.38		
Geometric mean (excl. zeros)		0.75			1.06		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[C] Incomplete, 2-salt returns through July 31, 2019.

Table B.22. Overall LGR-to-BOA SARs for McCall[A] hatchery summer Chinook, 2000–2017. 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 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 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	21,819	1.28	1.16	1.41	1.52	1.38	1.65
2007	19,102	1.09	0.97	1.22	1.67	1.51	1.82
2008	21,081	1.56	1.40	1.70	3.06	2.86	3.28
2009	18,489	0.94	0.82	1.06	1.25	1.11	1.38
2010	20,744	0.73	0.63	0.82	1.31	1.17	1.43
2011	22,880	0.41	0.34	0.48	0.48	0.41	0.55
2012	20,598	0.99	0.87	1.10	1.64	1.50	1.78
2013	24,936	1.62	1.49	1.77	2.25	2.09	2.41
2014	25,960	0.59	0.51	0.66	1.05	0.94	1.15
2015	26,054	0.26	0.20	0.31	0.33	0.27	0.40
2016	23,827	0.55	0.47	0.63	0.90	0.80	0.99
2017[C]	25,304	0.26	0.21	0.32	0.36	0.30	0.42
Arithmetic mean (incl. zeros)		1.05			1.44		
Geometric mean (excl. zeros)		0.85			1.17		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[C] Incomplete, 2-salt returns through July 31, 2019.

Table B.23. Overall LGR-to-GRA SARs for Imnaha hatchery summer Chinook, 1997–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.2.

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	8,731	0.79	0.63	0.94	1.11	0.92	1.30
2007	9,589	0.67	0.53	0.81	1.39	1.20	1.57
2008	10,153	1.74	1.53	1.98	4.45	4.12	4.83
2009	9,738	1.04	0.87	1.20	1.84	1.62	2.06
2010	10,100	0.76	0.61	0.90	1.43	1.23	1.63
2011	8,366	0.24	0.15	0.33	0.43	0.31	0.56
2012	10,042	0.18	0.11	0.25	0.59	0.46	0.71
2013	10,423	0.52	0.40	0.64	1.54	1.33	1.74
2014	9,934	0.41	0.31	0.52	0.68	0.56	0.83
2015	9,971	0.16	0.10	0.23	0.23	0.16	0.32
2016	10,300	0.13	0.07	0.18	0.17	0.10	0.23
2017[B]	8,619	0.13	0.07	0.19	0.13	0.07	0.19
Arithmetic mean (incl. zeros)		0.78			1.33		
Geometric mean (excl. zeros)		0.54			0.90		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.24. Overall LGR-to-BOA SARs for Imnaha hatchery summer Chinook, 2000–2017. 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	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	8,731	0.99	0.81	1.16	1.40	1.18	1.62
2007	9,589	0.86	0.70	1.01	1.64	1.43	1.84
2008	10,153	2.46	2.20	2.71	5.53	5.14	5.92
2009	9,738	1.66	1.45	1.87	2.58	2.32	2.85
2010	10,100	0.92	0.76	1.07	1.78	1.56	2.00
2011	8,366	0.38	0.27	0.49	0.62	0.48	0.76
2012	10,042	0.39	0.29	0.50	0.92	0.76	1.07
2013	10,423	1.19	1.01	1.36	2.42	2.15	2.67
2014	9,934	0.51	0.39	0.63	0.96	0.80	1.12
2015	9,971	0.25	0.18	0.34	0.34	0.25	0.44
2016	10,300	0.17	0.11	0.23	0.20	0.13	0.28
2017[B]	8,619	0.13	0.07	0.19	0.13	0.07	0.19
Arithmetic mean (incl. zeros)		0.92			1.54		
Geometric mean (excl. zeros)		0.66			1.02		

[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. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.25. Overall LGR-to-GRA SARs for Clearwater Hatchery spring Chinook, 2006–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.4.

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	26,011	0.57	0.50	0.65	0.66	0.59	0.75
2007	30,058	0.30	0.25	0.36	0.40	0.35	0.48
2008	19,440	0.96	0.84	1.08	1.29	1.16	1.43
2009	28,905	0.71	0.63	0.79	0.86	0.77	0.95
2010	37,617	0.48	0.42	0.55	0.70	0.63	0.78
2011	31,210	0.15	0.11	0.19	0.16	0.12	0.20
2012	33,284	0.51	0.44	0.57	0.69	0.62	0.77
2013	30,480	0.73	0.64	0.80	0.86	0.77	0.95
2014	25,067	0.36	0.29	0.42	0.44	0.37	0.51
2015	18,430	0.28	0.22	0.35	0.37	0.30	0.45
2016	32,883	0.29	0.24	0.34	0.39	0.33	0.44
2017[B]	29,724	0.14	0.11	0.18	0.21	0.17	0.25
Arithmetic mean (incl. zeros)		0.46			0.59		
Geometric mean (excl. zeros)		0.39			0.50		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.26. Overall LGR-to-BOA SARs for Clearwater Hatchery spring Chinook, 2006–2017. 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	26,011	0.88	0.78	0.98	0.99	0.90	1.10
2007	30,058	0.43	0.36	0.49	0.54	0.47	0.62
2008	19,440	1.33	1.20	1.48	1.73	1.57	1.89
2009	28,905	1.02	0.93	1.12	1.19	1.09	1.29
2010	37,617	0.65	0.58	0.73	0.93	0.85	1.01
2011	31,210	0.21	0.17	0.26	0.23	0.19	0.28
2012	33,284	0.69	0.61	0.76	0.90	0.81	0.98
2013	30,480	0.88	0.78	0.96	1.04	0.94	1.13
2014	25,067	0.49	0.42	0.56	0.59	0.52	0.67
2015	18,430	0.42	0.35	0.51	0.52	0.44	0.61
2016	32,883	0.41	0.35	0.47	0.51	0.45	0.58
2017[B]	29,724	0.21	0.17	0.25	0.27	0.22	0.32
Arithmetic mean (incl. zeros)		0.64			0.79		
Geometric mean (excl. zeros)		0.55			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.27. Overall LGR-to-GRA SARs for Sawtooth Hatchery spring Chinook, 2007–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.4.

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
2007	7,834	0.63	0.48	0.78	1.07	0.87	1.29
2008	4,514	1.00	0.73	1.23	1.77	1.44	2.08
2009	4,906	0.39	0.26	0.53	0.57	0.40	0.74
2010	6,563	0.46	0.32	0.60	0.79	0.61	0.96
2011	7,464	0.08	0.03	0.14	0.13	0.07	0.21
2012	6,302	0.40	0.28	0.53	0.57	0.42	0.74
2013	8,576	0.69	0.55	0.82	0.77	0.63	0.91
2014	8,779	0.33	0.23	0.43	0.72	0.57	0.87
2015	9,938	0.17	0.10	0.23	0.20	0.13	0.27
2016	10,030	0.17	0.10	0.24	0.30	0.21	0.40
2017[B]	8,819	0.03	0.00	0.07	0.03	0.00	0.07
Arithmetic mean (incl. zeros)		0.39			0.63		
Geometric mean (excl. zeros)		0.28			0.42		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.28. Overall LGR-to-BOA SARs for Sawtooth Hatchery spring Chinook, 2007–2017. 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	7,834	0.71	0.56	0.88	1.19	0.98	1.40
2008	4,514	1.20	0.90	1.45	2.15	1.78	2.51
2009	4,906	0.43	0.29	0.58	0.61	0.44	0.80
2010	6,563	0.55	0.40	0.72	1.02	0.82	1.23
2011	7,464	0.12	0.07	0.19	0.17	0.10	0.26
2012	6,302	0.54	0.40	0.70	0.76	0.59	0.95
2013	8,576	1.00	0.83	1.18	1.11	0.93	1.28
2014	8,779	0.42	0.31	0.54	0.93	0.76	1.10
2015	9,938	0.24	0.16	0.32	0.28	0.20	0.36
2016	10,030	0.27	0.19	0.36	0.41	0.30	0.53
2017[B]	8,819	0.09	0.04	0.15	0.10	0.05	0.16
Arithmetic mean (incl. zeros)		0.51			0.79		
Geometric mean (excl. zeros)		0.39			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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.29. Overall LGR-to-GRA SARs for Kooskia Hatchery spring Chinook, 2014–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.4.

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	5,101	0.12	0.04	0.20	0.16	0.08	0.25
2015[B]	3,063	0.00	0.00	0.10	0.00	0.00	0.10
2016	3,795	0.21	0.10	0.35	0.21	0.10	0.35
2017[C]	2,846	0.04	0.00	0.11	0.04	0.00	0.11
Arithmetic mean (incl. zeros)		0.09			0.10		
Geometric mean (excl. zeros)		0.10			0.11		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through June 28, 2019.

Table B.30. Overall LGR-to-BOA SARs for Kooskia Hatchery spring Chinook, 2014–2017. 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	5,101	0.20	0.10	0.30	0.27	0.16	0.40
2015	3,063	0.03	0.00	0.10	0.03	0.00	0.10
2016	3,795	0.32	0.16	0.47	0.32	0.16	0.47
2017[B]	2,846	0.11	0.03	0.22	0.11	0.03	0.22
Arithmetic mean (incl. zeros)		0.17			0.18		
Geometric mean (excl. zeros)		0.12			0.13		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.31. Overall LGR-to-GRA SARs for Pahsimeroi Hatchery summer Chinook, 2008–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.4.

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	6,001	1.27	1.04	1.51	2.12	1.83	2.43
2009	6,884	0.55	0.41	0.70	0.73	0.57	0.89
2010	5,677	0.09	0.03	0.16	0.19	0.11	0.30
2011	7,381	0.01	0.00	0.04	0.01	0.00	0.04
2012	8,681	0.16	0.09	0.24	0.26	0.17	0.37
2013	9,179	0.15	0.09	0.22	0.27	0.19	0.36
2014	11,913	0.02	0.00	0.03	0.02	0.00	0.03
2015	11,550	0.03	0.01	0.05	0.03	0.01	0.07
2016	11,572	0.16	0.10	0.22	0.26	0.18	0.34
2017[B]	11,072	0.09	0.04	0.14	0.10	0.05	0.15
Arithmetic mean (incl. zeros)		0.25			0.40		
Geometric mean (excl. zeros)		0.11			0.15		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.32. Overall LGR-to-BOA SARs for Pahsimeroi Hatchery summer Chinook, 2008–2017. 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
2008	6,001	1.65	1.39	1.92	2.68	2.35	3.04
2009	6,884	0.92	0.73	1.10	1.08	0.87	1.28
2010	5,677	0.11	0.04	0.18	0.23	0.13	0.34
2011	7,381	0.01	0.00	0.04	0.01	0.00	0.04
2012	8,381	0.22	0.14	0.31	0.37	0.26	0.48
2013	9,179	0.27	0.19	0.36	0.42	0.32	0.54
2014	11,913	0.03	0.01	0.05	0.03	0.01	0.05
2015	11,550	0.03	0.01	0.06	0.05	0.02	0.09
2016	11,572	0.22	0.15	0.30	0.35	0.26	0.43
2017[B]	11,072	0.11	0.05	0.17	0.11	0.05	0.17
Arithmetic mean (incl. zeros)		0.36			0.53		
Geometric mean (excl. zeros)		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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.33. Overall LGR-to-GRA SARs for Clearwater Hatchery summer Chinook, 2011–2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.4.

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	9,410	0.18	0.11	0.25	0.24	0.16	0.33
2012	10,233	0.30	0.22	0.39	0.55	0.42	0.66
2013	10,268	0.31	0.23	0.40	0.44	0.33	0.55
2014	13,183	0.32	0.24	0.40	0.45	0.35	0.54
2015	14,261	0.20	0.14	0.26	0.25	0.18	0.32
2016	12,217	0.29	0.21	0.37	0.51	0.40	0.61
2017[B]	11,096	0.08	0.04	0.13	0.12	0.06	0.17
Arithmetic mean (incl. zeros)		0.24			0.37		
Geometric mean (excl. zeros)		0.22			0.33		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.34. Overall LGR-to-BOA SARs for Clearwater Hatchery summer Chinook, 2011–2017. 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	9,410	0.23	0.15	0.32	0.30	0.20	0.39
2012	10,233	0.48	0.37	0.59	0.77	0.63	0.91
2013	10,268	0.80	0.66	0.94	0.99	0.84	1.15
2014	13,183	0.52	0.42	0.62	0.77	0.64	0.89
2015	14,261	0.28	0.21	0.35	0.33	0.25	0.41
2016	12,217	0.38	0.29	0.47	0.64	0.52	0.76
2017[B]	11,096	0.12	0.06	0.18	0.15	0.09	0.22
Arithmetic mean (incl. zeros)		0.40			0.56		
Geometric mean		0.35			0.48		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.
[B] Incomplete, 2-salt returns through July 31, 2019.

Snake River wild Steelhead

Table B.35. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild Steelhead, 1997–2016. SARs (LGR-GRA) provided in Figure 4.6.

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	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	5,441	1.14	0.90	1.38	1.89	1.59	2.21
2007	7,076	2.57	2.26	2.88	3.31	2.95	3.65
2008	5,733	3.21	2.82	3.60	4.36	3.91	4.82
2009	5,989	2.45	2.13	2.79	3.56	3.16	3.95
2010	8,215	1.73	1.48	1.98	2.40	2.12	2.69
2011	4,943	1.27	1.02	1.55	1.84	1.50	2.19
2012	6,902	2.54	2.23	2.86	3.39	3.04	3.76
2013	8,424	1.99	1.73	2.25	2.69	2.39	3.01
2014	9,662	1.34	1.15	1.62	2.01	1.77	2.24
2015	8,609	0.10	0.05	0.16	0.20	0.12	0.28
2016	7,806	0.78	0.62	0.93	1.00	0.80	1.18
Arithmetic mean (incl. zeros)		1.70			2.37		
Geometric mean (excl. zeros)		1.35			1.99		

[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 through 2005 and Group T tags beginning in 2006. Also beginning in 2006, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

Table B.36. Overall LGR-to-GRA and LGR-to-BOA SARs for Clearwater Basin Wild Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.7.

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
2006	2,748	0.80	0.53	1.10	1.24	0.89	1.60
2007	2,253	1.15	0.78	1.56	1.51	1.08	1.94
2008	3,524	2.81	2.36	3.25	3.97	3.41	4.50
2009	1,753	1.71	1.24	2.22	2.28	1.72	2.88
2010	3,608	1.44	1.11	1.75	1.88	1.52	2.24
2011	1,830	1.09	0.70	1.51	1.15	0.75	1.54
2012	2,969	2.73	2.23	3.26	3.37	2.82	3.93
2013	3,080	2.31	1.87	2.74	2.66	2.19	3.14
2014	1,943	1.39	0.99	1.84	1.85	1.36	2.37
2015	2,195	0.14	0.00	0.28	0.32	0.12	0.52
2016	1,820	0.77	0.44	1.13	0.93	0.59	1.33
Arithmetic mean (incl. zeros)		1.49			1.92		
Geometric mean (excl. zeros)		1.19			1.60		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

Table B.37. Overall LGR-to-GRA and LGR-to-BOA SARs for Grande Ronde Basin Wild Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.7.

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
2006	557	1.62	0.75	2.49	3.59	2.32	4.90
2007	423	4.49	2.87	6.15	4.96	3.20	6.67
2008	349	3.44	1.86	4.99	5.73	3.71	7.83
2009	345	2.32	1.10	3.76	4.34	2.65	6.32
2010	482	2.90	1.64	4.18	4.15	2.59	5.83
2011	654	1.83	0.94	2.75	3.21	2.09	4.42
2012	532	3.57	2.25	4.95	4.14	2.68	5.59
2013	657	2.43	1.47	3.48	3.80	2.57	5.05
2014	632	1.42	0.74	2.22	2.69	1.64	3.71
2015	1,147	0.35	0.09	0.68	0.44	0.16	0.81
2016	999	1.00	0.52	1.56	1.20	0.69	1.77
Arithmetic mean (incl. zeros)		2.31			3.48		
Geometric mean (excl. zeros)		1.92			2.92		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

Table B.38. Overall LGR-to-GRA and LGR-to-BOA SARs for Imnaha Basin Wild Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.7.

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	1,694	1.24	0.82	1.67	2.18	1.59	2.78
2007	3,588	3.09	2.61	3.58	4.13	3.56	4.71
2008[B]	2,064	5.17	1.79	9.16	5.57	2.14	9.59
2009	2,226	3.64	2.96	4.33	5.08	4.35	5.91
2010	2,221	1.89	1.42	2.41	2.66	2.09	3.28
2011	960	1.04	0.52	1.58	1.67	1.02	2.37
2012	1,577	2.35	1.73	2.96	3.80	3.01	4.58
2013	2,706	2.00	1.57	2.44	3.03	2.49	3.57
2014	3,156	1.87	1.49	2.27	2.82	2.34	3.32
2015	2,855	0.07	0.00	0.16	0.18	0.07	0.31
Arithmetic mean (incl. zeros)		2.13			2.96		
Geometric mean (excl. zeros)		1.51			2.31		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[B] Due to lack of pre-assignment, 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 for this year.

Table B.39. Overall LGR-to-GRA and LGR-to-BOA SARs for Salmon Basin Wild Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.7.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2006	637	1.57	0.77	2.36	1.88	1.04	2.73
2007	816	3.19	2.23	4.19	3.80	2.73	4.88
2008	1,400	5.14	4.15	6.18	6.36	5.25	7.48
2009	1,450	1.93	1.36	2.54	3.10	2.37	3.85
2010	1,829	1.86	1.29	2.41	2.73	2.05	3.46
2011	1,474	1.36	0.89	1.85	2.17	1.59	2.75
2012	1,366	2.71	2.00	3.45	3.59	2.80	4.41
2013	1,280	1.48	0.90	2.06	2.27	1.57	2.96
2014	1,100	1.27	0.76	1.90	1.73	1.10	2.41
2015[B]	1,122	0.00	0.00	0.27	0.00	0.00	0.27
2016	1,433	0.70	0.35	1.08	0.70	0.35	1.08
Arithmetic mean (incl. zeros)		1.93			2.58		
Geometric mean (excl. zeros)		1.84			2.46		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

Table B.40. Overall LGR-to-GRA and LGR-to-BOA SARs for Asotin Creek Wild Steelhead, 2014-2016.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2014	1,977	0.66	0.35	0.97	1.26	0.86	1.68
2015[B]	406	0.00	0.00	0.73	0.00	0.00	0.73
2016	1,025	0.39	0.10	0.72	0.78	0.31	1.23
Arithmetic mean (incl. zeros)		0.35			0.68		
Geometric mean (excl. zeros)		0.51			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

Table B.41. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild A-run Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.8.

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	2,378	1.43	1.03	1.84	2.61	2.04	3.14
2007	4,496	3.29	2.84	3.74	4.27	3.73	4.76
2008	1,643	2.56	1.90	3.21	3.71	2.93	4.52
2009	3,571	2.88	2.43	3.39	4.23	3.68	4.81
2010	4,661	2.06	1.71	2.43	2.92	2.49	3.36
2011	3,014	1.39	1.07	1.75	2.16	1.74	2.61
2012	3,210	2.74	2.26	3.23	3.80	3.19	4.35
2013	4,643	2.33	1.98	2.69	3.23	2.83	3.65
2014	6,605	1.38	1.14	1.63	2.18	1.88	2.49
2015	6,284	0.11	0.05	0.19	0.21	0.12	0.32
2016	5,528	0.83	0.64	1.05	1.09	0.85	1.35
Arithmetic mean (incl. zeros)		1.91			2.76		
Geometric mean (excl. zeros)		1.49			2.23		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.42. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild B-run Steelhead, 2006–2016. SARs (LGR-GRA) provided in Figure 4.8.

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
2006	3,056	0.92	0.65	1.24	1.34	1.00	1.71
2007	1,855	1.40	0.95	1.84	1.78	1.26	2.27
2008	3,539	3.56	3.07	4.10	4.72	4.16	5.34
2009	2,398	1.83	1.39	2.29	2.59	2.07	3.14
2010	2,713	1.29	0.94	1.64	1.73	1.29	2.13
2011	1,899	1.05	0.67	1.44	1.32	0.91	1.72
2012	3,323	2.44	2.02	2.88	3.13	2.68	3.66
2013	2,555	1.84	1.41	2.31	2.35	1.85	2.86
2014	2,177	1.38	0.98	1.79	1.88	1.40	2.34
2015	1,722	0.12	0.00	0.27	0.23	0.06	0.44
2016	1,936	0.67	0.37	0.99	0.83	0.50	1.19
Arithmetic mean (incl. zeros)		1.50			1.99		
Geometric mean (excl. zeros)		1.17			1.60		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

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), 1997–2016. SARs (LGR-GRA) provided in Figure 4.6.

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	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	89,670	3.10	3.00	3.20	4.47	4.35	4.59
2009	104,055	1.49	1.43	1.55	2.14	2.06	2.21
2010	109,621	1.60	1.53	1.66	2.29	2.21	2.37
2011	106,323	0.63	0.59	0.67	0.95	0.91	1.00
2012	92,058	1.52	1.45	1.58	2.20	2.12	2.29
2013	103,082	1.16	1.10	1.22	1.58	1.51	1.64
2014	95,938	1.43	1.36	1.49	1.97	1.89	2.04
2015	89,155	0.16	0.14	0.19	0.20	0.18	0.23
2016	86,850	0.74	0.69	0.79	0.93	0.88	0.98
Arithmetic mean (incl. zeros)		1.32			1.97		
Geometric mean (excl. zeros)		1.11			1.67		

[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 2007 and Group T tags beginning in 2008. Also beginning in 2008, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.44. Overall LGR-to-GRA and LGR-to-BOA SARs for Grande Ronde River Basin (A-Run) Hatchery Steelhead, 2008–2016. SARs (LGR-GRA) provided in Figure 4.9.

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	16,858	4.54	4.23	4.85	6.75	6.37	7.15
2009	15,273	1.62	1.45	1.79	2.45	2.26	2.66
2010	16,338	2.03	1.84	2.22	3.15	2.91	3.40
2011	15,292	0.43	0.34	0.52	0.71	0.60	0.83
2012	15,455	1.64	1.48	1.81	2.56	2.36	2.78
2013	15,062	1.56	1.38	1.72	2.31	2.09	2.50
2014	15,517	1.80	1.63	1.98	2.66	2.44	2.87
2015	15,467	0.24	0.18	0.30	0.28	0.22	0.35
2016	10,581	1.26	1.08	1.43	1.61	1.41	1.79
Arithmetic mean (incl. zeros)		1.68			2.50		
Geometric mean (excl. zeros)		1.28			1.86		

[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 tags released in 2008 and Group T tags beginning in 2009. Also beginning in 2009, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.45. Overall LGR-to-GRA and LGR-to-BOA SARs for Imnaha River Basin (A-Run) Hatchery Steelhead, 2008–2016. SARs (LGR-GRA) provided in Figure 4.9.

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	12,468	4.50	4.15	4.83	6.70	6.26	7.12
2009	11,350	1.71	1.51	1.91	2.62	2.38	2.89
2010	12,071	1.67	1.47	1.86	2.38	2.15	2.61
2011	10,536	0.64	0.51	0.76	0.94	0.78	1.10
2012	10,480	2.15	1.91	2.37	3.15	2.87	3.43
2013	11,117	1.70	1.50	1.90	2.51	2.26	2.76
2014	11,837	1.82	1.63	2.00	2.69	2.45	2.92
2015	7,006	0.23	0.14	0.33	0.34	0.23	0.46
2016	6,244	1.41	1.17	1.65	1.92	1.64	2.21
Arithmetic mean (incl. zeros)		1.76			2.58		
Geometric mean (excl. zeros)		1.38			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 tags released in 2008 and Group T tags beginning in 2009. Also beginning in 2009, CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.46. Overall LGR-to-GRA and LGR-to-BOA SARs for Hells Canyon Dam (A-Run) Hatchery Steelhead, 2009–2016. SARs (LGR-GRA) provided in Figure 4.9.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2009	4,509	3.06	2.63	3.48	4.79	4.26	5.32
2010	5,332	3.13	2.71	3.53	4.59	4.05	5.08
2011	4,019	0.35	0.20	0.50	0.55	0.35	0.76
2012	3,646	1.76	1.41	2.13	2.66	2.25	3.11
2013	4,103	1.97	1.61	2.33	2.49	2.10	2.88
2014	4,485	1.43	1.13	1.73	2.59	2.20	2.96
2015	4,870	0.21	0.10	0.32	0.25	0.13	0.37
2016	4,586	1.07	0.82	1.32	1.40	1.13	1.68
Arithmetic mean (incl. zeros)		1.62			2.42		
Geometric mean (excl. zeros)		1.18			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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.47. Overall LGR-to-GRA and LGR-to-BOA SARs for Salmon River Basin (A-Run) Hatchery Steelhead, 2008–2016. SARs (LGR-GRA) provided in Figure 4.9.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2008[B]	19,025	4.80	4.54	5.09	6.49	6.17	6.82
2009	29,289	1.91	1.78	2.03	2.52	2.37	2.65
2010	34,060	2.00	1.87	2.14	2.76	2.61	2.92
2011	31,933	1.13	1.04	1.23	1.68	1.56	1.80
2012	31,758	1.74	1.62	1.86	2.55	2.40	2.69
2013	30,145	1.58	1.45	1.69	2.10	1.95	2.23
2014	22,765	1.38	1.26	1.51	1.91	1.76	2.06
2015	21,625	0.14	0.10	0.19	0.16	0.12	0.21
2016	21,029	0.65	0.55	0.74	0.82	0.72	0.93
Arithmetic mean (incl. zeros)		1.70			2.33		
Geometric mean (excl. zeros)		1.24			1.67		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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, 2008–2016. SARs (LGR-GRA) provided in Figure 4.9.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2008	16,699	0.83	0.72	0.95	1.28	1.14	1.43
2009	15,736	0.75	0.64	0.87	1.12	0.98	1.27
2010	11,789	0.44	0.34	0.54	0.60	0.48	0.72
2011	11,149	0.19	0.12	0.26	0.39	0.29	0.48
2012	11,226	0.69	0.56	0.81	0.95	0.80	1.11
2013	14,190	0.40	0.31	0.49	0.49	0.39	0.59
2014	14,409	0.83	0.72	0.96	1.04	0.92	1.19
2015	12,600	0.05	0.02	0.08	0.05	0.02	0.08
2016	14,990	0.25	0.18	0.32	0.27	0.20	0.35
Arithmetic mean (incl. zeros)		0.49			0.69		
Geometric mean (incl. zeros)		0.38			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Table B.49. Overall LGR-to-GRA and LGR-to-BOA SARs for Clearwater River Basin (B-Run) Hatchery Steelhead, 2008–2016. SARs (LGR-GRA) provided in Figure 4.9.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA %SAR Estimate	LGR-to-GRA Non-parametric CI 90% LL	LGR-to-GRA Non-parametric CI 90% UL	LGR-to-BOA %SAR Estimate	LGR-to-BOA Non-parametric CI 90% LL	LGR-to-BOA Non-parametric CI 90% UL
2008	24,592	1.46	1.34	1.58	2.18	2.03	2.33
2009	28,521	1.04	0.94	1.14	1.48	1.37	1.59
2010	30,159	1.05	0.94	1.14	1.50	1.39	1.61
2011	34,958	0.40	0.35	0.46	0.59	0.52	0.65
2012	19,979	1.12	1.00	1.24	1.45	1.32	1.58
2013	27,765	0.58	0.51	0.66	0.70	0.61	0.78
2014	27,624	1.35	1.23	1.47	1.65	1.52	1.78
2015	27,102	0.17	0.13	0.21	0.21	0.17	0.26
2016	29,865	0.66	0.59	0.74	0.80	0.71	0.88
Arithmetic mean (incl. zeros)		0.87			1.17		
Geometric mean (excl. zeros)		0.74			0.98		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

Snake River hatchery Sockeye

Table B.50. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Hatchery Sockeye, 2009–2017 (SAWT = Sawtooth Hatchery, OXBH = Oxbow Hatchery, Oregon, SPRF = Springfield Hatchery). SARs (LGR-GRA) provided in Figure 4.10.

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	17,239	1.15	1.01	1.29	1.81	1.64	1.98
SAWT-2010[B]	----	---	---	---	---	---	---
SAWT-2011	26,157	0.10	0.06	0.13	0.19	0.14	0.23
SAWT-2012	21,441	0.12	0.08	0.16	0.29	0.23	0.35
SAWT-2013	19,060	0.15	0.11	0.21	2.74	2.54	2.95
SAWT-2014	18,191	0.46	0.38	0.55	0.74	0.63	0.85
SAWT-2015	16,919	0.14	0.09	0.19	0.25	0.18	0.32
Arithmetic mean (incl. zeros)		0.35			1.00		
Geometric mean (excl. zeros)		0.23			0.61		
OXBH-2009	2,234	2.01	1.48	2.52	2.95	2.31	3.57
OXBH-2010[B]	---	---	---	---	---	---	---
OXBH-2011	5,441	0.39	0.24	0.52	1.21	0.98	1.45
OXBH-2012	4,769	2.31	1.85	2.73	4.17	3.48	4.87
Arithmetic mean (incl. zeros)		1.56			2.76		
Geometric mean (excl. zeros)		1.21			2.46		
SPRF-2015[C]	10,730	0.00	0.00	0.03	0.00	0.00	0.03
SPRF-2016[C]	11,403	0.00	0.00	0.03	0.00	0.00	0.03
SPRF-2017[C,D]	5,725	0.00	0.00	0.05	0.00	0.00	0.05
Arithmetic mean (incl. zeros)		0.00			0.00		
Geometric mean (excl. zeros)[E]		---			---		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[D] Incomplete, 2-salt returns through July 31, 2019.

[E] Estimate of geometric mean not provided due to no years of SAR estimates above zero.

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	371	0.27	0.00	0.74	0.27	0.00	0.74
2007[B]	---	---	---	---	---	---	---
2008	301	1.33	0.33	2.48	1.99	0.69	3.39
2009	496	0.81	0.20	1.51	1.01	0.38	1.79
2010[C]	---	---	---	---	---	---	---
2011	1,467	0.68	0.36	1.06	0.95	0.55	1.39
Arithmetic mean (incl. zeros)		0.77			1.06		
Geometric mean (excl. zeros)		0.67			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 in 2006 and 2008-2009. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[B] SAR not possible due to low sample size.
[C] SAR not reported due to high estimated holdover rates.
[D] Due to no pre-assignments in 2011, 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 that year.

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	371	1.08	0.27	2.06	1.08	0.27	2.06
2007[B]	---	---	---	---	---	---	---
2008	301	2.32	0.96	3.81	3.32	1.69	5.11
2009	496	1.41	0.64	2.34	1.61	0.76	2.64
2010[C]	---	---	---	---	---	---	---
2011	1,467[D]	0.89	0.52	1.33	1.16	0.74	1.66
Arithmetic mean (incl. zeros)		1.43			1.79		
Geometric mean (excl. zeros)		1.33			1.61		

[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 in 2006 and 2008-2009. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[B] SAR not possible due to low sample size.
[C] SAR not reported due to high estimated holdover rates.
[D] Due to no pre-assignments in 2011, 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 that year.

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. SARs (with jacks) provided in Figure 4.11.

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	32,093	0.55	0.49	0.63	0.90	0.81	0.99
2007[B]	---	---	---	---	---	---	---
2008	12,302	1.06	0.90	1.22	1.86	1.65	2.09
2009	5,361	0.11	0.04	0.19	0.17	0.08	0.26
2010	14,013	0.80	0.68	0.92	1.03	0.89	1.17
2011	16,246	0.96	0.84	1.09	1.25	1.11	1.41
2012	14,836	0.71	0.61	0.83	1.00	0.88	1.14
Arithmetic mean (incl. zeros)		0.70			1.04		
Geometric mean (excl. zeros)		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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	32,093	0.86	0.78	0.95	1.26	1.15	1.36
2007[B]	---	---	---	---	---	---	---
2008	12,302	1.70	1.49	1.89	2.67	2.40	2.93
2009	5,361	0.21	0.11	0.31	0.26	0.15	0.38
2010	14,013	1.17	1.02	1.32	1.46	1.29	1.63
2011	16,246	1.49	1.33	1.64	1.83	1.66	2.01
2012	14,836	1.06	0.93	1.22	1.46	1.30	1.63
Arithmetic mean (incl. zeros)		1.08			1.49		
Geometric mean (excl. zeros)		0.91			1.23		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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 2016. SARs are calculated with and without jacks. SARs (without jacks) provided in Figure 6.1. SARs (with jacks) provided in Figure 4.11.

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	15,218	0.66	0.55	0.77	1.17	1.03	1.31
2009	5,919	0.19	0.10	0.29	0.37	0.24	0.50
2010	14,845	0.97	0.83	1.10	1.51	1.35	1.69
2011	17,103	0.95	0.82	1.06	1.34	1.19	1.48
2012	15,852	0.70	0.59	0.81	0.86	0.74	0.99
2013[C]	---	---	---	---	---	---	---
2014[C]	---	---	---	---	---	---	---
2015	12,084	0.14	0.09	0.20	0.31	0.23	0.39
2016[D]	12,246	0.13	0.08	0.19	0.15	0.10	0.21
Arithmetic mean (incl. zeros)		0.53			0.82		
Geometric mean (excl. zeros)		0.39			0.62		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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.

[C] Insufficient PIT-tags released for estimation of SARs.

[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.56. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Captain John Rapids Acclimation Pond, 2007 to 2016. 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	15,218	0.96	0.83	1.09	1.60	1.43	1.77
2009	5,919	0.25	0.15	0.37	0.46	0.31	0.60
2010	14,845	1.67	1.50	1.84	2.30	2.09	2.52
2011	17,103	1.47	1.31	1.62	1.95	1.77	2.11
2012	15,852	1.14	1.01	1.27	1.39	1.24	1.54
2013[C]	---	---	---	---	---	---	---
2014[C]	---	---	---	---	---	---	---
2015	12,084	0.26	0.18	0.33	0.47	0.37	0.58
2016[D]	12,246	0.19	0.13	0.25	0.20	0.14	0.27
Arithmetic mean (incl. zeros)		0.85			1.20		
Geometric mean (excl. zeros)		0.61			0.89		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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.

[C] Insufficient PIT-tags released for estimation of SARs.

[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.57. Overall LGR-to-GRA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Pittsburg Landing Acclimation Pond, 2006 to 2016. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.11.

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	14,915	0.12	0.08	0.17	0.23	0.17	0.30
2007[B]	---	---	---	---	---	---	---
2008	11,513	0.92	0.77	1.06	1.77	1.56	1.97
2009	4,905	0.22	0.12	0.34	0.35	0.22	0.48
2010	10,700	0.83	0.70	0.98	1.24	1.07	1.42
2011	13,914	0.72	0.61	0.85	0.95	0.81	1.08
2012	12,794	0.73	0.60	0.85	0.98	0.84	1.13
2013[C]	---	---	---	---	---	---	---
2014[C]	---	---	---	---	---	---	---
2015	9,233	0.25	0.17	0.34	0.39	0.28	0.50
2016[D]	10,054	0.20	0.13	0.28	0.25	0.17	0.34
Arithmetic mean (incl. zeros)		0.50			0.77		
Geometric mean (excl. zeros)		0.39			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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.

[C] Insufficient PIT-tags released for estimation of SARs.

[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.58. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Pittsburg Landing Acclimation Pond, 2006 to 2016. 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	14,915	0.19	0.13	0.25	0.34	0.26	0.41
2007[B]	---	---	---	---	---	---	---
2008	11,513	1.47	1.28	1.65	2.48	2.23	2.73
2009	4,905	0.27	0.14	0.39	0.41	0.27	0.56
2010	10,700	1.43	1.26	1.62	1.93	1.71	2.14
2011	13,914	1.20	1.05	1.36	1.45	1.29	1.63
2012	12,794	1.09	0.93	1.23	1.48	1.31	1.65
2013[C]	---	---	---	---	---	---	---
2014[C]	---	---	---	---	---	---	---
2015	9,233	0.36	0.26	0.46	0.54	0.41	0.67
2016[D]	10,054	0.32	0.23	0.42	0.37	0.27	0.48
Arithmetic mean (incl. zeros)		0.79			1.13		
Geometric mean (excl. zeros)		0.60			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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.

[C] Insufficient PIT-tags released for estimation of SARs.

[D] Incomplete, 3-salt returns through July 31, 2019.

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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	11,104	0.29	0.21	0.38	0.42	0.33	0.53
2007[B]	---	---	---	---	---	---	---
2008	5,734	0.70	0.52	0.91	1.17	0.93	1.43
2009	5,093	0.18	0.08	0.29	0.35	0.23	0.50
2010	4,273	0.63	0.43	0.84	0.94	0.70	1.20
2011	6,472	0.93	0.73	1.13	1.27	1.06	1.51
2012	5,588	0.41	0.27	0.55	0.48	0.33	0.64
Arithmetic mean (incl. zeros)		0.52			0.77		
Geometric mean (excl. zeros)		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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	11,104	0.47	0.36	0.59	0.64	0.52	0.77
2007[B]	---	---	---	---	---	---	---
2008	5,734	1.01	0.80	1.28	1.66	1.36	1.96
2009	5,093	0.31	0.18	0.45	0.49	0.33	0.65
2010	4,273	1.12	0.86	1.40	1.47	1.18	1.80
2011	6,472	1.47	1.23	1.73	1.82	1.57	2.11
2012	5,588	0.55	0.39	0.71	0.66	0.49	0.84
Arithmetic mean (incl. zeros)		0.82			1.12		
Geometric mean (excl. zeros)		0.71			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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. SARs (with jacks) provided in Figure 4.11.

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]	11,116	0.21	0.14	0.29	0.31	0.22	0.40
2007[C]	---	---	---	---	---	---	---
2008	7,876	0.36	0.25	0.47	0.69	0.53	0.85
2009	8,778	0.21	0.13	0.29	0.28	0.20	0.38
2010	10,969	0.79	0.65	0.93	0.96	0.80	1.12
2011	9,262	0.30	0.21	0.39	0.44	0.33	0.55
2012	8,041	0.52	0.39	0.66	0.70	0.54	0.85
Arithmetic mean (incl. zeros)		0.40			0.56		
Geometric mean (excl. zeros)		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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[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]	11,116	0.29	0.21	0.38	0.44	0.34	0.56
2007[C]	---	---	---	---	---	---	---
2008	7,876	0.57	0.43	0.72	0.95	0.77	1.15
2009	8,778	0.25	0.17	0.34	0.34	0.24	0.44
2010	10,969	1.32	1.15	1.50	1.54	1.36	1.74
2011	9,262	0.48	0.36	0.60	0.62	0.47	0.75
2012	8,041	0.86	0.69	1.04	1.11	0.91	1.32
Arithmetic mean (incl. zeros)		0.63			0.83		
Geometric mean (excl. zeros)		0.53			0.73		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[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. SARs (with jacks) provided in Figure 4.11.

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	11,977	0.21	0.14	0.28	0.30	0.22	0.38
2007[B]	---	---	---	---	---	---	---
2008	12,285	1.07	0.92	1.22	2.26	2.03	2.50
2009	15,173	0.05	0.03	0.08	0.14	0.09	0.20
2010	13,434	0.62	0.52	0.74	0.84	0.72	0.98
2011	10,494	0.34	0.25	0.44	0.44	0.33	0.55
2012	12,817	0.67	0.56	0.79	0.86	0.73	1.00
Arithmetic mean (incl. zeros)		0.49			0.81		
Geometric mean (excl. zeros)		0.34			0.56		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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	11,977	0.33	0.24	0.41	0.45	0.35	0.55
2007[B]	---	---	---	---	---	---	---
2008	12,285	1.76	1.57	1.95	3.26	2.98	3.54
2009	15,173	0.07	0.03	0.10	0.16	0.11	0.22
2010	13,434	0.94	0.81	1.08	1.21	1.06	1.39
2011	10,494	0.64	0.51	0.77	0.76	0.61	0.90
2012	12,817	1.07	0.92	1.23	1.34	1.16	1.52
Arithmetic mean (incl. zeros)		0.80			1.20		
Geometric mean (excl. zeros)		0.54			0.81		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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. SARs (with jacks) provided in Figure 4.11.

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
2007[B]	---	---	---	---	---	---	---
2008	5,578	0.90	0.70	1.12	2.22	1.87	2.57
2009	4,557	0.09	0.02	0.16	0.31	0.18	0.44
2010	---	---	---	---	---	---	---
2011	5,273	0.42	0.27	0.57	0.61	0.44	0.79
2012	5,069	0.41	0.27	0.57	0.61	0.44	0.79
Arithmetic mean (incl. zeros)		0.46			0.94		
Geometric mean (excl. zeros)		0.34			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2007[B]	---	---	---	---	---	---	---
2008	5,578	1.51	1.23	1.76	3.03	2.60	3.42
2009	4,557	0.11	0.04	0.19	0.33	0.20	0.47
2010	---	---	---	---	---	---	---
2011	5,273	0.74	0.55	0.95	1.06	0.84	1.31
2012	5,069	0.71	0.52	0.91	1.12	0.88	1.37
Arithmetic mean (incl. zeros)		0.77			1.39		
Geometric mean (excl. zeros)		0.54			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

[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	63,742	0.25	0.22	0.28	0.36	0.32	0.40
2007[B]	---	---	---	---	---	---	---
2008	61,837	0.64	0.59	0.70	1.09	1.01	1.16
2009	42,291	0.16	0.13	0.20	0.24	0.20	0.28
2010	44,129	0.52	0.46	0.58	0.83	0.75	0.91
2011	56,534	0.85	0.79	0.92	1.04	0.97	1.12
2012[C]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		0.48			0.71		
Geometric mean (excl. zeros)		0.41			0.61		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[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	63,742	0.37	0.33	0.40	0.48	0.44	0.53
2007[B]	---	---	---	---	---	---	---
2008	61,837	0.97	0.90	1.03	1.49	1.40	1.57
2009	42,291	0.23	0.19	0.27	0.31	0.27	0.36
2010	44,129	0.74	0.67	0.82	1.08	0.99	1.17
2011	56,534	1.32	1.24	1.40	1.55	1.47	1.65
2012[C]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		0.73			0.98		
Geometric mean (excl. zeros)		0.60			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.
[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. SARs (with jacks) provided in Figure 4.11.

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	2,816	0.57	0.35	0.84	0.71	0.47	1.00
2011	6,705	0.91	0.72	1.09	1.36	1.12	1.58
2012	5,106	0.84	0.63	1.07	0.92	0.70	1.15
Arithmetic mean (incl. zeros)		0.77			1.00		
Geometric mean (excl. zeros)		0.76			0.96		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

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	2,816	0.96	0.67	1.30	1.14	0.81	1.49
2011	6,705	1.67	1.40	1.92	2.40	2.08	2.70
2012	5,106	1.21	0.95	1.47	1.35	1.08	1.62
Arithmetic mean (incl. zeros)		1.28			1.63		
Geometric mean (excl. zeros)		1.25			1.55		

[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. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

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. SARs (with jacks) provided in Figure 4.11.

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	4,433	0.20	0.09	0.32	0.54	0.36	0.76
2011	6,610	0.82	0.65	0.99	1.09	0.89	1.30
2012	6,329	0.44	0.31	0.58	0.52	0.37	0.67
Arithmetic mean (incl. zeros)		0.49			0.72		
Geometric mean (excl. zeros)		0.42			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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and Logit link.

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	4,433	0.47	0.30	0.66	0.88	0.65	1.15
2011	6,610	2.01	1.74	2.31	2.48	2.18	2.80
2012	6,329	0.66	0.49	0.84	0.79	0.59	0.98
Arithmetic mean (incl. zeros)		1.05			1.38		
Geometric mean (excl. zeros)		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 Group T tags. CJS estimation of S1 uses both the juvenile detector at Lower Granite 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 and the Logit link.

Middle Columbia wild spring Chinook

Table B.73. Overall JDA-to-BOA SARs for John Day River Basin Wild Chinook, 2000 to 2017. SARs are calculated with and without jacks. SARs (with jacks provided in Figure 4.13).

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	1,300	10.77	9.15	12.33	11.00	9.33	12.62
2001	2,749	3.86	4.29	4.50	4.11	3.50	4.81
2002	2,513	3.78	3.03	4.52	3.98	3.22	4.73
2003	4,434	2.77	2.34	3.22	2.89	2.45	3.36
2004	2,805	3.14	2.46	3.81	3.32	2.60	4.00
2005	3,835	1.85	1.49	2.26	2.06	1.68	2.49
2006	2,237	2.06	1.68	2.49	2.06	1.56	2.57
2007	2,726	4.33	3.66	5.04	5.06	4.31	5.82
2008	2,956	5.51	4.76	6.30	6.26	5.44	7.09
2009	3,220	6.77	5.92	7.61	7.11	6.21	7.97
2010	3,098	3.55	3.02	4.16	4.84	4.20	5.53
2011	2,554	0.90	0.58	1.23	0.94	0.62	1.28
2012	4,723	3.13	2.64	3.66	3.83	3.29	4.42
2013	2,706	4.18	3.44	4.98	5.10	4.22	6.03
2014	2,204	3.81	2.95	4.68	4.22	3.33	5.10
2015	988	3.54	2.30	4.64	5.37	3.71	6.85
2016	2,231	2.11	1.57	2.67	2.64	2.03	3.29
2017[B]	1,322	0.76	0.40	1.18	1.06	0.62	1.58
Arithmetic mean (incl. zeros)		3.71			4.21		
Geometric mean (excl. zeros)		3.11			3.58		

[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 both the juvenile detector at John Day 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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.74. Overall MCN-to-BOA SARs for Yakima River Basin Wild Chinook, 2000 to 2017. SARs are calculated with and without jacks. No PIT-tagged smolts released in 2010 or 2014. SARs (with jacks) provided in Figure 4.13.

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	2,581	6.82	6.04	7.72	7.40	6.58	9.34
2001	521	1.54	0.75	2.52	1.92	0.98	3.04
2002	2,130	2.25	1.75	2.83	2.30	1.79	2.87
2003	2,143	2.47	1.97	3.03	2.89	2.34	3.50
2004	1,297	3.70	2.90	4.57	3.78	2.94	4.64
2005	521	1.34	0.57	2.22	1.34	0.57	2.22
2006	565	1.59	0.74	2.53	1.77	0.87	2.80
2007	362	1.93	0.84	3.17	1.93	0.84	3.17
2008	509	6.87	4.97	8.80	9.23	7.05	11.40
2009	983	4.99	3.85	6.29	5.60	4.35	6.97
2010[B]	---	---	---	---	---	---	---
2011	411	0.97	0.23	1.82	0.97	0.23	1.82
2012	826	2.79	1.89	3.88	3.27	2.28	4.43
2013	704	1.42	0.70	2.19	1.56	0.82	2.37
2014[B]	---	---	---	---	---	---	---
2015	238	2.10	0.57	4.11	2.52	0.76	4.86
2016[B]	---	---	---	---	---	---	---
2017[B]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		2.91			3.32		
Geometric mean (excl. zeros)		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 and the Logit link.

[B] Too few or no PIT-tags released to obtain reliable estimate of smolts arriving at MCN. Therefore, estimate of SAR not possible.

Table B.75. Overall MCN-to-MCA SARs for Yakima River Basin Wild Chinook, 2000 to 2017. 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
2000	2,581	5.85	5.15	6.68	5.85	5.15	6.68
2001	521	1.54	0.75	2.52	1.92	0.98	3.04
2002	2,130	2.16	1.66	2.74	2.21	1.70	2.81
2003	2,143	2.52	2.01	3.10	2.89	2.35	3.54
2004	1,297	3.47	2.65	4.32	3.62	2.77	4.47
2005	521	1.34	0.57	2.22	1.34	0.57	2.22
2006	565	1.42	0.61	2.31	1.59	0.74	2.58
2007	362	1.93	0.83	3.23	1.93	0.83	3.23
2008	509	5.70	3.94	7.35	8.05	5.96	10.12
2009	983	4.17	3.15	5.36	4.68	3.59	5.91
2010[B]	---	---	---	---	---	---	---
2011	411	0.73	0.00	1.43	0.73	0.00	1.43
2012	826	2.79	1.87	3.85	3.27	2.27	4.47
2013	704	1.56	0.82	2.40	1.71	0.93	2.59
2014[B]	---	---	---	---	---	---	---
2015	238	1.68	0.38	3.50	2.10	0.57	4.29
2016[B]	---	---	---	---	---	---	---
2017[B]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		2.46			2.99		
Geometric mean (excl. zeros)		2.13			2.49		

[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 and the Logit link.
[B] Too few or no PIT-tags released to obtain reliable estimate of smolts arriving at MCN. Therefore, estimate of SAR not possible.

Middle Columbia hatchery spring Chinook

Table B.76. Overall BON-to-BOA SARs for Carson Hatchery Chinook, 2000–2017. SARs are calculated with and without jacks. SARs (BON-to-BOA with jacks) provided in Figure 4.14.

Juvenile migration year	Smolts arriving BON[A]	BON-to-BOA without Jacks			BON-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	13,175	3.24	2.81	3.71	3.28	2.84	3.76
2001	12,806	1.74	1.50	1.99	1.76	1.52	2.01
2002	12,076	1.25	1.01	1.53	1.29	1.04	1.59
2003	12,450	0.27	0.20	0.37	0.27	0.20	0.37
2004[B]	---	---	---	---	---	---	---
2005	13,610	0.33	0.25	0.44	0.34	0.26	0.45
2006	10,155	0.62	0.48	0.79	0.65	0.51	0.83
2007[B]	---	---	---	---	---	---	---
2008	11,832	1.87	1.57	2.14	2.12	1.79	2.43
2009	11,647	1.83	1.52	2.15	1.90	1.58	2.22
2010	11,031	1.02	0.83	1.21	1.16	0.96	1.37
2011	11,041	0.45	0.32	0.60	0.47	0.34	0.62
2012	13,367	0.60	0.48	0.78	0.65	0.53	0.84
2013	13,239	1.19	0.97	1.44	1.25	1.03	1.52
2014	10,896	0.76	0.60	0.95	0.84	0.67	1.04
2015	10,243	0.55	0.42	0.67	0.58	0.45	0.71
2016	10,374	0.31	0.21	0.46	0.33	0.22	0.48
2017[B]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		1.07			1.13		
Geometric mean (excl. zeros)		0.83			0.87		

[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 and the Logit link function.
[B] Not calculated; release to BON survival estimate = 1.0

Table B.77. Overall REL-to-BOA[A] SARs for Carson Hatchery Chinook, 2000–2017. SARs are calculated with and without jacks.

Juvenile migration year	Tagged Smolts Released	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			90% LL	90% UL		90% LL	90% UL
2000	14,992	2.85	2.63	3.06	2.88	2.67	3.09
2001	14,978	1.49	1.33	1.65	1.51	1.34	1.68
2002	14,983	1.01	0.89	1.15	1.04	0.91	1.19
2003	14,975	0.23	0.17	0.29	0.23	0.17	0.29
2004[B]	14,973	0.62	0.52	0.73	0.65	0.54	0.75
2005	14,958	0.30	0.23	0.38	0.31	0.24	0.39
2006	14,971	0.42	0.34	0.51	0.44	0.35	0.53
2007[B]	14,943	0.56	0.46	0.66	0.64	0.54	0.76
2008	14,884	1.48	1.32	1.65	1.69	1.51	1.86
2009	14,975	1.42	1.26	1.58	1.48	1.32	1.64
2010	14,939	0.75	0.64	0.87	0.86	0.74	0.98
2011	14,953	0.33	0.26	0.41	0.35	0.27	0.43
2012	14,941	0.54	0.44	0.63	0.58	0.48	0.68
2013	14,906	1.05	0.91	1.19	1.11	0.97	1.25
2014	14,906	0.56	0.46	0.66	0.62	0.52	0.73
2015	14,734	0.38	0.30	0.46	0.40	0.32	0.48
2016	14,019	0.23	0.17	0.30	0.24	0.18	0.31
2017[C]	14,967	0.16	0.11	0.21	0.17	0.11	0.22
Arithmetic mean (incl. zeros)		0.80			0.84		
Geometric mean (excl. zeros)		0.60			0.64		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released from Carson NFH.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 2-salt returns through June 28, 2019.

Table B.78. Overall BON-to-BOA SARs for Warm Springs Hatchery Chinook (Deschutes River), 2007–2017. SARs are calculated with and without jacks. SARs (BON-to-BOA with jacks) provided in Figure 4.14.

Juvenile migration year	Smolts arriving at BON[A]	BON-to-BOA without Jacks			BON-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[B]	---	---	---	---	---	---	---
2009[B]	---	---	---	---	---	---	---
2010	8,294	0.37	0.26	0.49	0.64	0.49	0.80
2011	6,246	0.45	0.27	0.64	0.48	0.29	0.68
2012	8,112	1.21	0.86	1.56	1.58	1.16	1.98
2013	10,511	1.66	1.30	2.04	2.02	1.59	2.45
2014	9,554	1.38	1.06	1.72	1.60	1.25	2.00
2015	7,413	0.76	0.57	0.96	0.88	0.66	1.10
2016	7,625	0.51	0.34	0.72	0.76	0.53	1.05
2017[C]	6,511	0.12	0.03	0.32	0.14	0.03	0.37
Arithmetic mean (incl. zeros)		0.81			1.01		
Geometric mean (excl. zeros)		0.62			0.79		

[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 and the Logit link function..

[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 June 28, 2019.

Table B.79. Overall REL-to-BOA[A] SARs for Warm Springs Hatchery Chinook (Deschutes River), 2007–2016. SARs are calculated with and without jacks.

Juvenile migration year	Tagged Smolts Released	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
		%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL	%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL
2007[C]	19,698	0.30	0.24	0.37	0.37	0.30	0.44
2008[C]	19,337	0.84	0.74	0.94	1.07	0.95	1.18
2009[C]	19,926	0.65	0.56	0.75	0.70	0.61	0.80
2010	14,907	0.21	0.15	0.27	0.36	0.28	0.44
2011	14,924	0.19	0.13	0.24	0.20	0.14	0.26
2012	14,806	0.66	0.55	0.78	0.86	0.74	0.99
2013	14,877	1.18	1.04	1.32	1.43	1.26	1.59
2014	14,818	0.89	0.77	1.03	1.03	0.90	1.18
2015	14,915	0.38	0.30	0.46	0.44	0.34	0.52
2016	13,278	0.29	0.22	0.38	0.44	0.35	0.53
2017[D]	14,868	0.05	0.02	0.09	0.06	0.03	0.09
Arithmetic mean (incl. zeros)		0.51			0.63		
Geometric mean (excl. zeros)		0.38			0.48		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released from Warm Springs NFH.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Chinook smolts are released in fall and spring and form two different cohorts. Cannot distinguish between fall and spring PIT tag releases.
[D] Incomplete, 2-salt returns through June 28, 2019.

Table B.80. Overall MCN-to-BOA SARs for Cle Elum Hatchery Chinook, 2000-2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.14.

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	3.61	3.34	3.91	3.95	3.65	4.26
2001	9,269	0.28	0.20	0.37	0.29	0.20	0.38
2002	11,753	1.36	1.18	1.54	1.72	1.52	1.91
2003	11,974	0.59	0.48	0.71	0.86	0.72	1.00
2004	7,986	1.54	1.31	1.78	1.85	1.60	2.11
2005	5,789	0.66	0.48	0.84	0.78	0.59	0.98
2006	10,285	1.23	1.06	1.43	1.59	1.39	1.81
2007	12,654	1.01	0.87	1.16	1.51	1.32	1.69
2008	11,752	3.15	2.86	3.43	5.03	4.64	5.39
2009	15,386	1.82	1.64	2.00	2.29	2.08	2.50
2010	12,479	1.51	1.33	1.71	2.53	2.27	2.78
2011	11,886	0.93	0.79	1.08	1.20	1.03	1.37
2012	15,736	1.22	1.08	1.37	1.76	1.57	1.94
2013	13,261	1.38	1.20	1.54	1.95	1.74	2.17
2014	12,856	0.58	0.48	0.70	0.84	0.72	0.98
2015	10,639	1.02	0.85	1.20	1.86	1.62	2.11
2016	13,837	0.87	0.74	1.01	1.52	1.35	1.71
2017[B]	11,199	0.62	0.50	0.75	0.74	0.60	0.89
Arithmetic mean (incl. zeros)		1.30			1.79		
Geometric mean (excl. zeros)		1.09			1.49		

[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 and the Logit link function.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.81. Overall MCN-to-MCA SARs for Cle Elum Hatchery Chinook, 2000–2017. 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
2000	14,416	3.27	3.01	3.55	3.27	3.01	3.55
2001	9,269	0.26	0.17	0.34	0.27	0.18	0.36
2002	11,753	1.38	1.19	1.57	1.75	1.55	1.96
2003	11,974	0.63	0.51	0.75	0.94	0.80	1.08
2004	7,986	1.34	1.12	1.57	1.64	1.41	1.90
2005	5,789	0.59	0.42	0.77	0.73	0.54	0.93
2006	10,285	1.10	0.93	1.27	1.47	1.29	1.66
2007	12,654	0.86	0.74	0.99	1.32	1.15	1.49
2008	11,752	2.77	2.51	3.04	4.61	4.25	4.96
2009	15,386	1.57	1.40	1.74	2.03	1.83	2.23
2010	12,479	1.40	1.23	1.59	2.31	2.07	2.55
2011	11,886	0.87	0.73	1.01	1.12	0.95	1.29
2012	15,736	1.07	0.94	1.21	1.57	1.39	1.74
2013	13,261	1.33	1.15	1.50	1.87	1.66	2.07
2014	12,856	0.49	0.39	0.60	0.73	0.61	0.86
2015	10,639	0.85	0.69	1.01	1.61	1.38	1.82
2016	13,837	0.66	0.55	0.78	1.27	1.11	1.44
2017[B]	11,199	0.46	0.35	0.56	0.54	0.43	0.67
Arithmetic mean (incl. zeros)		1.16			1.61		
Geometric mean (excl. zeros)		0.97			1.34		

[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 and the Logit link function.
[B] Incomplete, 2-salt returns through June 28, 2019.

Middle Columbia wild Steelhead

Table B.82. Overall JDA-to-BOA SARs for Umatilla River Basin Wild Steelhead, 2011–2016. SARs provided in Figure 4.15.

Juvenile migration year	Smolts arriving JDA[A]	JDA-to-BOA		
		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL
2011	1,307	1.22	0.74	1.78
2012	816	5.14	3.46	6.85
2013	1,669	4.13	3.02	5.16
2014	5,294	4.78	4.08	5.51
2015	5,203	1.46	1.14	1.84
2016	3,536	2.63	2.09	3.18
Arithmetic mean (incl. zeros)		3.23		
Geometric mean (excl. zeros)		2.79		

[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 and the Logit link.

Table B.83. Overall JDA-to-BOA SARs for John Day River Basin Wild Steelhead, 2004–2016. SARs provided in Figure 4.15.

Juvenile migration year	Smolts arriving JDA[A]	JDA-to-BOA		
		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL
2004	2,583	4.26	3.50	5.02
2005	3,530	2.80	2.35	3.31
2006	1,923	3.33	2.64	3.99
2007	2,864	8.83	7.68	9.98
2008	3,033	10.35	9.26	11.40
2009	2,570	7.63	6.57	8.61
2010	3,194	6.07	5.13	6.84
2011	2,279	1.93	1.45	2.48
2012	3,125	5.57	4.71	6.55
2013	1,521	10.13	8.15	12.15
2014	1,299	5.08	3.79	6.47
2015	1,594	1.73	1.15	2.38
2016	1,120	5.36	4.15	6.59
Arithmetic mean (incl. zeros)		5.62		
Geometric mean (excl. zeros)		4.87		

[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 and the Logit link.

Table B.84. Overall BON-to-BOA SARs for Deschutes River Basin (Trout Creek, Buckhollow Creek, and/or Bakeoven Creek) Wild Steelhead, 2006–2016. SARs provided in Figure 4.15.

Juvenile migration year	Smolts arriving BON[A]	BON-to-BOA		
		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL
2006	802	8.36	5.79	11.39
2007	926	7.67	5.22	10.13
2008	1,321	9.62	7.20	12.36
2009	1,820	8.52	6.80	10.49
2010	813	3.94	2.64	5.54
2011	3,722	4.14	3.15	5.15
2012	2,928	4.99	3.49	6.53
2013	689	2.03	0.85	3.49
2014	682	5.42	2.89	8.17
2015	645	2.17	1.22	3.17
2016	660	5.15	3.38	6.98
Arithmetic mean (incl. zeros)		5.64		
Geometric mean (excl. zeros)		5.03		

[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 and the Logit link.

Table B.85. Overall MCN-to-BOA and MCN-to-MCA SARs for Yakima River Basin Wild Steelhead, 2002–2015. SARs (MCN-to-BOA) provided in Figure 4.15.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA			MCN-to-MCA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2002	365	7.94	5.07	10.73	6.03	3.62	8.39
2003	293	7.85	4.80	11.02	6.49	3.84	9.16
2004	387	2.84	1.44	4.38	2.58	1.17	4.10
2005	263	4.94	2.55	7.93	4.56	2.24	7.29
2006	397	4.03	2.41	5.92	3.27	1.88	5.07
2007	219	7.30	3.15	11.98	6.39	2.75	10.78
2008	235	8.92	5.24	12.78	8.07	4.64	11.74
2009	360	5.27	3.15	7.40	4.72	2.79	6.77
2010	336	5.66	2.86	8.76	4.47	2.15	7.08
2011	216	3.25	1.35	5.47	2.32	0.78	4.25
2012	427	6.80	4.11	9.42	4.69	2.66	6.67
2013	250	5.20	1.38	10.08	4.00	0.96	8.21
2014	329	5.78	3.29	8.32	5.17	2.84	7.49
2015	324	1.54	0.44	2.69	0.93	0.00	1.91
2016	308	3.25	1.30	5.91	3.25	1.30	5.91
Arithmetic mean (incl. zeros)		5.37			4.46		
Geometric mean (excl. zeros)		4.90			4.01		

[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 and the Logit link.

Middle Columbia wild subyearling fall Chinook

Table B.86. Overall MCN-to-BOA SARs for Hanford Reach subyearling wild fall Chinook, 2000-2016. SARs are calculated with and without jacks. SARs (MCN-to-BOA with jacks) provided in Figure 4.16.

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	4,555	2.66	2.25	3.08	2.86	2.41	3.28
2001	3,662	0.68	0.44	0.91	0.71	0.46	0.95
2002[B]	---	---	---	---	---	---	---
2003	930	0.43	0.10	0.79	0.43	0.10	0.79
2004	1,004	0.20	0.00	0.46	0.20	0.00	0.46
2005	6,539	0.26	0.16	0.36	0.29	0.18	0.41
2006[B]	---	---	---	---	---	---	---
2007	7,836	0.34	0.24	0.45	0.45	0.32	0.58
2008	5,528	2.04	1.69	2.44	2.32	1.91	2.75
2009	4,384	0.75	0.52	0.98	0.94	0.69	1.20
2010	1,433	2.65	1.89	3.41	3.00	2.18	3.73
2011	4,050	3.21	2.64	3.83	3.46	2.86	4.12
2012	1,407	1.71	1.09	2.35	1.78	1.15	2.46
2013	1,454	2.41	1.67	3.22	2.75	1.94	3.67
2014	3,423	0.67	0.44	0.91	0.85	0.60	1.11
2015	4,389	0.05	0.00	0.14	0.05	0.00	0.14
2016[C,D]	5,125	0.00	0.00	0.06	0.02	0.00	0.06
Arithmetic mean (incl. zeros)		1.20			1.34		
Geometric mean (excl. zeros)		0.77			0.66		

[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 and the Logit link.
[B] No PIT-tags releases in these years
[C] Due to zero adult returns, 90% confidence interval for MCN-to-BOA SAR (without jacks) is Clopper-Pearson binomial confidence interval (Clopper and Pearson 1934).
[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.87. Overall Rel-to-BOA[A] SARs for Hanford Reach subyearling wild fall Chinook, 2000-2016. SARs are calculated with and without jacks.

Juvenile migration year	Tagged Smolts Released	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			90% LL	90% UL		90% LL	90% UL
2000	10,967	1.10	0.94	1.27	1.19	1.01	1.35
2001	9,973	0.25	0.16	0.34	0.26	0.17	0.35
2002[C]	---	---	---	---	---	---	---
2003	2,975	0.13	0.03	0.24	0.13	0.03	0.24
2004	2,989	0.07	0.00	0.17	0.07	0.00	0.17
2005	22,634	0.08	0.04	0.11	0.08	0.05	0.12
2006[C]	---	---	---	---	---	---	---
2007	21,007	0.13	0.09	0.17	0.17	0.12	0.21
2008	16,651	0.68	0.58	0.79	0.77	0.65	0.88
2009	13,728	0.24	0.17	0.31	0.30	0.22	0.38
2010	4,850	0.78	0.58	0.99	0.89	0.66	1.11
2011	10,337	1.26	1.08	1.44	1.35	1.18	1.55
2012	4,885	0.49	0.33	0.68	0.51	0.35	0.70
2013	4,184	0.84	0.62	1.08	0.96	0.72	1.22
2014	9,940	0.23	0.15	0.31	0.29	0.21	0.38
2015	4,965	0.04	0.00	0.08	0.04	0.00	0.08
2016[D]	9,926	0.00	0.00	0.03	0.01	0.00	0.03
Arithmetic mean (incl. zeros)		0.42			0.47		
Geometric mean (excl. zeros)		0.28			0.24		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released into Hanford Reach.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] No PIT-tags released in these years
[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.88. Overall BON-to-BOA SARs for Deschutes River subyearling wild fall Chinook, 2011-2016. SARs are calculated with and without jacks. SARs (BON-to-BOA with jacks) provided in Figure 4.16.

Juvenile migration year	Smolts arriving BON[A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	5,689	2.39	1.54	3.32	3.06	2.03	4.18
2012	6,997	0.73	0.45	1.07	0.93	0.57	1.34
2013	8,229	0.60	0.38	0.86	0.94	0.61	1.34
2014	3,809	0.79	0.47	1.19	1.10	0.70	1.61
2015	4,963	0.26	0.11	0.46	0.32	0.14	0.53
2016[B]	3,562	0.31	0.12	0.56	0.62	0.27	1.00
Arithmetic mean (incl. zeros)		0.85			1.16		
Geometric mean (excl. zeros)		0.64			0.91		

[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 and the Logit link.
[B] Incomplete, 3-salt returns through July 31, 2019.

Table B.89. Overall Rel-to-BOA[A] SARs for Deschutes River subyearling wild fall Chinook, 2011-2016. SARs are calculated with and without jacks.

Juvenile migration year	Tagged Smolts Released	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			90% LL	90% UL		90% LL	90% UL
2011	19,897	0.68	0.58	0.78	0.87	0.77	0.98
2012	20,798	0.25	0.19	0.30	0.31	0.25	0.38
2013	26,322	0.19	0.14	0.23	0.29	0.24	0.35
2014	19,899	0.15	0.11	0.20	0.21	0.16	0.27
2015	24,930	0.05	0.03	0.08	0.06	0.04	0.09
2016[C]	24,492	0.04	0.02	0.07	0.09	0.06	0.12
Arithmetic mean (incl. zeros)		0.23			0.31		
Geometric mean (excl. zeros)		0.15			0.21		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released in Deschutes River.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 3-salt returns through July 31, 2019.

Middle Columbia hatchery subyearling fall Chinook

Table B.90. Overall BON-to-BOA SARs for Spring Creek Hatchery subyearling fall Chinook, 2008-2016. SARs are calculated with and without jacks.

Juvenile migration year	Release Month	Smolts arriving BON[A]	BON-to-BOA without Jacks %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	BON-to-BOA with Jacks %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008	March	5,916	0.34	0.20	0.52	0.42	0.26	0.63
2008[B]	April	---	---	---	---	---	---	---
2009[B]	April	---	---	---	---	---	---	---
2010	April	8,824	0.28	0.20	0.39	0.35	0.25	0.47
2011	April	8,554	0.15	0.09	0.24	0.15	0.09	0.24
2012[B]	April	---	---	---	---	---	---	---
2013	April	8,002	0.64	0.47	0.84	0.76	0.58	1.00
2014[B]	April	---	---	---	---	---	---	---
2015	April	6,466	0.14	0.06	0.23	0.29	0.17	0.43
2016[B,C]	April	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros) – April			0.30			0.39		
Geometric mean (excl. zeros) – April			0.25			0.33		
2008[B]	May	---	---	---	---	---	---	---
2009[B]	May	---	---	---	---	---	---	---
2010	May	5,929	0.22	0.12	0.33	0.25	0.15	0.37
2011[B]	May	---	---	---	---	---	---	---
2012[B,D]	May	---	---	---	---	---	---	---
2013	May	5,602	0.57	0.41	0.79	0.66	0.48	0.89
2014[B]	May	---	---	---	---	---	---	---
2015[B,E]	May	---	---	---	---	---	---	---
2016[B,C]	May	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros) – May			0.40			0.46		
Geometric mean (excl. zeros) – May			0.35			0.41		

[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 July 31, 2019.
[D] May release was rescheduled for April 30th.
[E] May release was rescheduled for April 27th.

Table B.91. Overall Rel-to-BOA[A] SARs for Spring Creek Hatchery subyearling fall Chinook, 2008-2015. SARs are calculated with and without jacks. SARs (Rel-to-BOA without jacks) provided in Figure 4.16.

Juvenile migration year	Release Month	Tagged Smolts Released	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
			%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL	%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL
2008	March	7,477	0.27	0.17	0.38	0.34	0.23	0.44
2008	April	3,953	0.63	0.43	0.86	0.81	0.58	1.06
2009	April	8,686	0.06	0.02	0.10	0.14	0.08	0.21
2010	April	8,962	0.28	0.19	0.38	0.35	0.25	0.46
2011	April	8,956	0.15	0.09	0.21	0.15	0.09	0.21
2012	April	8,772	0.28	0.19	0.38	0.34	0.24	0.44
2013	April	8,964	0.57	0.45	0.69	0.68	0.54	0.83
2014	April	8,873	0.08	0.03	0.14	0.14	0.08	0.20
2015[D]	April	7,844	0.11	0.05	0.18	0.24	0.15	0.33
2016[C]	April	8,959	0.16	0.09	0.23	0.22	0.15	0.31
Arithmetic mean (incl. zeros) – April			0.26			0.34		
Geometric mean (excl. zeros) – April			0.19			0.28		
2008	May	2,677	0.52	0.30	0.78	0.71	0.45	0.97
2009	May	5,950	0.22	0.12	0.32	0.27	0.17	0.39
2010	May	5,971	0.22	0.12	0.32	0.25	0.15	0.37
2011	May	5,983	0.23	0.13	0.35	0.23	0.13	0.35
2012[D]	May	5,978	0.23	0.13	0.33	0.27	0.17	0.38
2013	May	5,976	0.54	0.38	0.69	0.62	0.47	0.79
2014	May	5,993	0.02	0.00	0.05	0.02	0.00	0.05
2015[E]	May	5,983	0.10	0.03	0.17	0.22	0.12	0.32
2016[C]	May	5,995	0.10	0.05	0.17	0.10	0.05	0.17
Arithmetic mean (incl. zeros) – May			0.24			0.30		
Geometric mean (excl. zeros) – May			0.17			0.21		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released from Spring Creek NFH.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 3-salt returns through July 31, 2019.
[D] May release was rescheduled for April 30th.
[E] May release was rescheduled for April 27th.

Table B.92. Overall BON-to-BOA SARs for Little White Salmon Hatchery subyearling fall Chinook, 2008-2016. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving BON[A]	BON-to-BOA without Jacks			BON-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	14,351	1.75	1.53	1.97	1.85	1.62	2.09
2009	14,902	0.85	0.71	0.99	0.95	0.80	1.10
2010	14,997	2.71	2.39	3.05	1.78	2.45	3.12
2011	17,719	3.32	2.76	3.89	3.39	2.81	3.98
2012	16,455	0.74	0.58	0.90	0.78	0.61	0.95
2013	10,605	1.53	1.29	1.76	1.64	1.39	1.88
2014	8,266	0.36	0.25	0.49	0.36	0.25	0.49
2015	7,415	0.07	0.02	0.12	0.07	0.02	0.12
2016[B]	10,991	0.21	0.13	0.31	0.25	0.16	0.37
Arithmetic mean (incl. zeros)		1.28			1.23		
Geometric mean (excl. zeros)		0.76			0.76		

[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 and the Logit link.
[B] Incomplete, 3-salt returns through July 31, 2019.

Table B.93. Overall REL-to-BOA[A] SARs for Little White Salmon Hatchery subyearling fall Chinook, 2008-2018. SARs are calculated with and without jacks. SARs (Rel-to-BOA without jacks) provided in Figure 4.16.

Juvenile migration year	Tagged Smolts Released[A]	REL-to-BOA without Jacks			REL-to-BOA with Jacks		
		%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL	%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL
2008	24,885	1.01	0.91	1.11	1.07	0.96	1.17
2009	24,947	0.51	0.43	0.58	0.57	0.49	0.64
2010	24,950	1.63	1.49	1.76	1.67	1.54	1.80
2011	24,638	2.39	2.23	2.54	2.44	2.28	2.60
2012	24,947	0.49	0.41	0.56	0.52	0.44	0.59
2013	14,959	1.08	0.94	1.22	1.16	1.02	1.31
2014	14,925	0.20	0.14	0.26	0.20	0.14	0.26
2015	14,958	0.03	0.01	0.06	0.03	0.01	0.06
2016[C]	14,823	0.16	0.11	0.21	0.18	0.13	0.24
Arithmetic mean (incl. zeros)		0.83			0.87		
Geometric mean (excl. zeros)		0.47			0.49		

[A] SARs are calculated as number of adults at BOA divided by number of PIT-tagged smolts released from Little White Salmon NFH.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 3-salt returns through July 31, 2019.

Upper Columbia wild Chinook

Table B.94. Overall MCN-to-MCA SARs for Upper Columbia Wild Spring Chinook (Wenatchee River), 2007 to 2017. 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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2007	3,021	0.63	0.41	0.86	0.63	0.41	0.86
2008	5,735	2.42	2.06	2.81	2.55	2.18	2.96
2009	3,329	1.62	1.27	1.99	1.68	1.30	2.07
2010	4,830	1.18	0.93	1.45	1.47	1.18	1.76
2011	2,869	0.84	0.54	1.13	0.91	0.61	1.21
2012	3,789	0.74	0.52	0.96	0.92	0.69	1.18
2013	3,008	1.43	1.05	1.78	1.50	1.11	1.87
2014	3,951	0.68	0.47	0.90	0.84	0.60	1.08
2015	3,340	0.63	0.42	0.87	0.75	0.51	1.01
2016	2,747	0.87	0.57	1.18	1.13	0.78	1.46
2017[B]	4,522	0.27	0.15	0.39	0.27	0.15	0.39
Arithmetic mean (incl. zeros)		1.03			1.15		
Geometric mean (excl. zeros)		0.88			1.00		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.95. Overall MCN-to-BOA SARs for Upper Columbia Wild Spring Chinook (Wenatchee River), 2007 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.17.

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
2007	3,021	0.76	0.51	1.02	0.76	0.51	1.02
2008	5,735	2.76	2.38	3.17	2.89	2.50	3.33
2009	3,329	1.98	1.57	2.40	2.07	1.64	2.51
2010	4,830	1.37	1.09	1.64	1.70	1.38	2.00
2011	2,869	0.94	0.64	1.23	1.01	0.70	1.31
2012	3,789	0.96	0.70	1.20	1.13	0.87	1.42
2013	3,008	1.86	1.40	2.28	1.93	1.47	2.36
2014	3,951	0.91	0.67	1.18	1.11	0.84	1.40
2015	3,340	0.78	0.54	1.06	0.90	0.64	1.19
2016	2,747	1.06	0.75	1.38	1.38	1.01	1.75
2017[B]	4,522	0.33	0.20	0.48	0.33	0.20	0.48
Arithmetic mean (incl. zeros)		1.25			1.38		
Geometric mean (excl. zeros)		1.08			1.20		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.96. Overall MCN-to-RRA SARs for Upper Columbia Wild Spring Chinook (Entiat and Methow Rivers), 2006 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-RRA (without jacks)			MCN-to-RRA (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]	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	768	0.65	0.22	1.22	1.17	0.54	1.90
2016	858	0.47	0.12	0.90	0.70	0.24	1.17
2017[C,D]	726	0.00	0.00	0.41	0.14	0.00	0.41
Arithmetic mean (incl. zeros)		0.99			1.20		
Geometric mean (excl. zeros)		0.82			0.88		

[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 and the Logit link.

[B] 2006 is Entiat River only.

[C] Due to zero adult returns, 90% confidence interval for SAR without jacks is Clopper-Peason binomial confidence interval (Clopper and Pearson 1934)

[D] Incomplete, 2-salt returns through June 28, 2019.

Table B.97. Overall MCN-to-BOA SARs for Upper Columbia Wild Spring Chinook (Entiat and Methow Rivers), 2006 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.18.

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
2006[B]	927	0.43	0.11	0.84	0.54	0.20	0.96
2007	804	0.75	0.26	1.29	0.75	0.26	1.29
2008	4,901	2.94	2.53	3.36	3.26	2.83	3.73
2009	1,625	2.22	1.58	2.88	2.40	1.73	3.09
2010	3,236	1.85	1.47	2.27	1.98	1.57	2.39
2011	1,008	0.40	0.09	0.78	0.60	0.21	1.02
2012	2,039	1.23	0.82	1.68	1.77	1.28	2.30
2013	1,865	2.20	1.63	2.83	2.79	2.13	3.45
2014	2,456	1.75	1.31	2.22	1.87	1.39	2.35
2015	768	0.65	0.23	1.14	1.17	0.57	1.85
2016	858	0.70	0.25	1.24	1.17	0.58	1.79
2017[C]	726	0.14	0.00	0.40	0.28	0.00	0.63
Arithmetic mean (incl. zeros)		1.27			1.55		
Geometric mean (excl. zeros)		0.94			1.24		

[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 and the Logit link.
[B] 2006 is Entiat River only.
[C] Incomplete, 2-salt returns through June 28, 2019.

Table B.98. Overall RRE-to-RRA SARs for Upper Columbia Wild Spring Chinook (Entiat and Methow Rivers)[A], 2008 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-RRA (without jacks)			RRE-to-RRA (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[C]	9,309	1.30	0.98	1.65	1.47	1.11	1.86
2009[C]	3,253	0.92	0.66	1.35	0.98	0.71	1.44
2010_	5,292	0.96	0.74	1.21	1.04	0.79	1.28
2011	1,361	0.29	0.08	0.56	0.37	0.13	0.65
2012	3,474	0.69	0.46	0.94	1.01	0.70	1.31
2013	3,131	0.96	0.68	1.29	1.25	0.91	1.61
2014	4,276	0.75	0.54	0.99	0.77	0.57	1.02
2015	2,542	0.12	0.03	0.25	0.24	0.08	0.43
2016	2,127	0.19	0.05	0.35	0.28	0.09	0.49
2017[D,E]	1,204	0.00	0.00	0.25	0.08	0.00	0.25
Arithmetic mean (incl. zeros)		0.62			0.75		
Geometric mean (excl. zeros)		0.54			0.56		

[A] The Entiat/Methow wild Chinook aggregate is the same group as used for the MCN-to-BOA and MCN-to-MCA reaches. SARs are calculated as number of adults at RRA 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 and the Logit Link.
[C] Uses recaptures at Rocky Reach Dam. After 2009, both the new juvenile detector and recaptures at Rocky Reach Dam are used.
[D] Due to zero adult returns, 90% confidence interval for SAR without jacks is Clopper-Peason binomial confidence interval (Clopper and Pearson 1934)
[E] Incomplete, 2-salt returns through June 28, 2019.

Table B.99. Overall RRE-to-BOA SARs for Upper Columbia Wild Spring Chinook (Entiat and Methow Rivers)[A], 2008 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.18.

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	1.19	1.95	1.72	1.32	2.16
2009[C]	3,253	1.11	0.83	1.63	1.20	0.89	1.75
2010	5,292	1.13	0.89	1.39	1.21	0.95	1.48
2011	1,361	0.29	0.08	0.56	0.44	0.15	0.76
2012	3,474	0.72	0.47	0.98	1.04	0.73	1.34
2013	3,131	1.31	0.97	1.69	1.66	1.26	2.11
2014	4,276	1.01	0.77	1.31	1.08	0.83	1.39
2015	2,542	0.20	0.07	0.36	0.35	0.16	0.57
2016	2,127	0.28	0.10	0.50	0.47	0.23	0.74
2017[D]	1,204	0.08	0.00	0.24	0.17	0.00	0.38
Arithmetic mean (incl. zeros)		0.77			0.93		
Geometric mean (excl. zeros)		0.55			0.75		

[A] The Entiat/Methow wild Chinook aggregate is the same group as used for the MCN-to-BOA and MCN-to-MCA reaches. 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 and the Logit link.
[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 June 28, 2019.

Table B.100. Overall MCN-to-WEA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam), 2011 to 2016. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-WEA (without jacks)			MCN-to-WEA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	4,067	2.75	2.24	3.28	2.83	2.30	3.36
2012	5,946	0.76	0.55	0.98	0.87	0.67	1.12
2013	6,794	1.38	1.07	1.71	1.46	1.13	1.80
2014	1,492	0.13	0.00	0.34	0.13	0.00	0.34
2015[B]	800	0.00	0.00	0.37	0.00	0.00	0.37
2016[C]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		1.00			1.06		
Geometric mean (excl. zeros)		0.78			0.83		

[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 and the Logit link.
[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Not calculated, unreliable estimate of release to MCN survival (S1 = 1.0)

Table B.101. Overall MCN-to-BOA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam), 2011 to 2016. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.18.

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	4,067	4.01	3.36	4.66	4.13	3.46	4.81
2012	5,946	1.03	0.78	1.29	1.16	0.90	1.45
2013	6,794	1.81	1.44	2.20	1.91	1.53	2.34
2014	1,492	0.13	0.00	0.34	0.13	0.00	0.34
2015[B]	800	0.00	0.00	0.37	0.00	0.00	0.37
2016[C]	---	---	---	---	---	---	---
Arithmetic mean (incl. zeros)		1.40			1.47		
Geometric mean (excl. zeros)		0.99			1.05		

[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 and the Logit link.
[B] Due to zero adult returns, 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Not calculated, unreliable estimate of release to MCN survival (S1 = 1.0)

Table B.102. Overall RRE-to-WEA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam)[A], 2011 to 2016. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-WEA (without jacks) %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	RRE-to-WEA (with jacks) %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2011	5,982	0.74	0.59	0.92	0.84	0.67	1.02
2012	8,207	0.55	0.42	0.69	0.63	0.49	0.78
2013	8,280	1.14	0.92	1.35	1.20	0.97	1.42
2014	3,147	0.06	0.00	0.14	0.06	0.00	0.14
2015[C]	2,065	0.00	0.00	0.14	0.00	0.00	0.14
2016[C,D]	3,485	0.00	0.00	0.09	0.00	0.00	0.09
Arithmetic mean (incl. zeros)		0.42			0.46		
Geometric mean (excl. zeros)		0.41			0.44		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-MCA reaches. SARs are calculated as number of adults at WEA 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 and the Logit link.
[C] Due to zero adult returns, 90% confidence interval are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[D] Incomplete, 3-salt returns through July 31, 2019.

Table B.103. Overall RRE-to-BOA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam)[A], 2011 to 2015. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.18.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA (without jacks) %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	RRE-to-BOA (with jacks) %SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2011	5,982	2.72	2.34	3.14	2.81	2.41	3.23
2012	8,207	0.74	0.59	0.92	0.84	0.67	1.02
2013	8,280	1.49	1.24	1.73	1.57	1.30	1.81
2014	3,147	0.06	0.00	0.14	0.06	0.00	0.14
2015[C]	2,065	0.00	0.00	0.14	0.00	0.00	0.14
2016[D]	3,485	0.03	0.00	0.08	0.03	0.00	0.08
Arithmetic mean (incl. zeros)		0.84			0.89		
Geometric mean (excl. zeros)		0.35			0.37		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-MCA reaches. 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 and the Logit link.
[C] Due to zero adult returns, 90% confidence interval are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[D] Incomplete, 3-salt returns through July 31, 2019.

Upper Columbia hatchery Chinook

Table B.104. Overall MCN-to-MCA SARs for Leavenworth Hatchery spring Chinook, 2000 to 2017. 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		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	4,337	1.59	1.26	1.92	1.59	1.26	1.92
2001	3,823	0.16	0.05	0.26	0.16	0.05	0.26
2002	179,046	0.25	0.23	0.27	0.27	0.24	0.28
2003	153,762	0.34	0.32	0.36	0.36	0.34	0.39
2004	105,757	0.27	0.25	0.30	0.28	0.25	0.31
2005	7,882	0.08	0.03	0.13	0.10	0.05	0.17
2006	8,208	0.69	0.55	0.84	0.78	0.62	0.94
2007	8,820	0.37	0.28	0.48	0.43	0.32	0.55
2008	9,691	1.37	1.17	1.57	1.58	1.36	1.80
2009	6,964	0.46	0.32	0.60	0.52	0.38	0.66
2010	9,848	0.63	0.50	0.76	0.97	0.81	1.14
2011	6,567	0.27	0.17	0.38	0.30	0.20	0.42
2012	9,006	0.82	0.66	0.98	0.95	0.78	1.13
2013	9,224	0.62	0.48	0.75	0.70	0.56	0.86
2014	8,679	0.43	0.31	0.54	0.58	0.43	0.71
2015	7,900	0.09	0.04	0.14	0.15	0.08	0.23
2016	7,864	0.10	0.05	0.16	0.13	0.07	0.20
2017[B]	8,253	0.06	0.02	0.11	0.11	0.05	0.17
Arithmetic mean (incl. zeros)		0.48			0.55		
Geometric mean (excl. zeros)		0.32			0.39		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.105. Overall MCN-to-BOA SARs for Leavenworth Hatchery spring Chinook, 2000 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.19.

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	4,337	1.84	1.48	2.23	1.87	1.50	2.27
2001	3,823	0.24	0.11	0.37	0.24	0.11	0.37
2002	179,045	0.28	0.26	0.30	0.30	0.27	0.32
2003	153,762	0.42	0.39	0.44	0.44	0.41	0.47
2004	105,757	0.34	0.31	0.37	0.34	0.31	0.37
2005	7,882	0.09	0.04	0.15	0.11	0.05	0.19
2006	8,208	0.89	0.72	1.07	0.97	0.80	1.15
2007	8,820	0.46	0.36	0.59	0.53	0.41	0.66
2008	9,691	1.80	1.55	2.04	2.00	1.75	2.26
2009	6,964	0.59	0.44	0.75	0.65	0.50	0.81
2010	9,848	0.81	0.66	0.96	1.23	1.05	1.43
2011	6,567	0.35	0.23	0.47	0.38	0.26	0.51
2012	9,006	1.05	0.87	1.24	1.19	0.99	1.37
2013	9,224	0.68	0.54	0.83	0.76	0.60	0.92
2014	8,679	0.60	0.45	0.74	0.76	0.59	0.92
2015	7,900	0.14	0.07	0.21	0.20	0.12	0.29
2016	7,864	0.13	0.06	0.19	0.17	0.10	0.24
2017[B]	8,253	0.08	0.04	0.14	0.13	0.07	0.20
Arithmetic mean (incl. zeros)		0.60			0.68		
Geometric mean (excl. zeros)		0.41			0.48		

[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 and the Logit link.

[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.106. Overall MCN-to-WEA SARs for Winthrop Hatchery spring Chinook, 2009 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-WEA without Jacks			MCN-to-WEA 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
2009	761	0.66	0.22	1.22	0.92	0.37	1.55
2010	3,354	0.36	0.19	0.55	1.16	0.83	1.50
2011	2,214	0.59	0.33	0.86	0.72	0.44	1.02
2012	4,259	0.96	0.71	1.24	1.13	0.86	1.41
2013	8,944	1.06	0.85	1.25	1.53	1.28	1.75
2014	2,978	0.50	0.29	0.72	0.67	0.41	0.91
2015	5,189	0.37	0.22	0.51	0.50	0.34	0.67
2016	11,093	0.40	0.30	0.50	0.47	0.37	0.58
2017[B]	11,543	0.45	0.34	0.56	0.55	0.43	0.67
Arithmetic mean (incl. zeros)		0.59			0.85		
Geometric mean (excl. zeros)		0.55			0.79		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.107. Overall MCN-to-BOA SARs for Winthrop Hatchery spring Chinook, 2009 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.20.

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
2009	761	0.66	0.24	1.22	0.79	0.27	1.39
2010	3,354	0.51	0.30	0.74	1.37	1.00	1.76
2011	2,214	0.72	0.43	1.07	0.90	0.58	1.26
2012	4,259	1.06	0.80	1.35	1.22	0.95	1.53
2013	8,944	1.19	0.96	1.38	1.77	1.48	2.01
2014	2,978	0.57	0.34	0.81	0.81	0.52	1.08
2015	5,189	0.62	0.42	0.80	0.75	0.53	0.95
2016	11,093	0.56	0.44	0.68	0.63	0.51	0.76
2017[B]	11,543	0.67	0.54	0.80	0.77	0.62	0.93
Arithmetic mean (incl. zeros)		0.73			1.00		
Geometric mean (excl. zeros)		0.70			0.95		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through June 28, 2019.

Table B.108. Overall RRE-to-WEA SARs for Winthrop Hatchery spring Chinook[A], 2009 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-WEA without Jacks			RRE-to-WEA 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	0.12	0.86	0.60	0.21	1.12
2010	4,266	0.28	0.16	0.41	0.91	0.68	1.16
2011	3,147	0.41	0.23	0.62	0.51	0.31	0.73
2012	5,734	0.71	0.53	0.93	0.84	0.62	1.07
2013	11,249	0.84	0.70	0.99	1.22	1.05	1.40
2014	3,723	0.40	0.24	0.59	0.54	0.34	0.74
2015	7,472	0.25	0.16	0.35	0.35	0.23	0.46
2016	14,373	0.31	0.23	0.39	0.36	0.28	0.45
2017[B]	16,633	0.31	0.24	0.39	0.38	0.31	0.47
Arithmetic mean (incl. zeros)		0.44			0.63		
Geometric mean (excl. zeros)		0.40			0.58		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-WEA reaches. 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 and the Logit link.
[C] Incomplete, 2-salt returns through June 28, 2019.

Table B.109. Overall RRE-to-BOA SARs for Winthrop Hatchery spring Chinook[A], 2009 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.20.

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	0.12	0.86	0.51	0.16	1.00
2010	4,266	0.40	0.25	0.56	1.08	0.82	1.35
2011	3,147	0.51	0.32	0.73	0.64	0.43	0.88
2012	5,734	0.78	0.59	1.01	0.91	0.70	1.15
2013	11,249	0.94	0.79	1.10	1.40	1.21	1.60
2014	3,723	0.46	0.28	0.65	0.64	0.43	0.88
2015	7,472	0.43	0.30	0.56	0.52	0.38	0.66
2016	14,373	0.43	0.34	0.53	0.49	0.39	0.59
2017[B]	16,633	0.46	0.37	0.56	0.54	0.44	0.65
Arithmetic mean (incl. zeros)		0.54			0.75		
Geometric mean (excl. zeros)		0.51			0.70		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-WEA reaches. 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 and the Logit link.
[C] Incomplete, 2-salt returns through June 28, 2019.

Table B.110. Overall MCN-to-RRA SARs for Entiat Hatchery summer Chinook, 2011 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-RRA without Jacks			MCN-to-RRA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	5,707	0.63	0.45	0.80	1.29	1.05	1.55
2012	6,588	1.29	1.05	1.55	1.35	1.11	1.61
2013	6,299	2.60	2.21	3.01	2.79	2.37	3.20
2014	5,242	1.24	0.95	1.51	1.47	1.15	1.75
2015	5,023	0.08	0.02	0.15	0.08	0.02	0.15
2016	12,729	1.69	1.50	1.90	1.73	1.53	1.94
2017[B]	13,371	0.92	0.77	1.10	0.96	0.81	1.15
Arithmetic mean (incl. zeros)		1.21			1.38		
Geometric mean (excl. zeros)		0.85			0.99		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.111. Overall MCN-to-BOA SARs for Entiat Hatchery summer Chinook, 2011 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.20.

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	5,707	1.02	0.78	1.24	1.24	0.97	1.49
2012	6,588	2.22	1.85	2.58	2.29	1.93	2.65
2013	6,299	3.65	3.13	4.12	3.89	3.35	4.40
2014	5,242	1.72	1.34	2.04	1.96	1.56	2.32
2015	5,023	0.12	0.04	0.20	0.12	0.04	0.20
2016	12,729	2.43	2.19	2.69	2.47	2.23	2.73
2017[B]	13,371	1.23	1.04	1.45	1.31	1.10	1.52
Arithmetic mean (incl. zeros)		1.77			1.90		
Geometric mean (excl. zeros)		1.26			1.36		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.112. Overall RRE-to-RRA SARs for Entiat Hatchery summer Chinook[A], 2011 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-RRA without Jacks			RRE-to-RRA 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
2011	8,821	0.41	0.31	0.53	0.51	0.39	0.66
2012	8,858	0.96	0.79	1.15	1.00	0.83	1.20
2013	8,201	2.00	1.72	2.29	2.15	1.85	2.45
2014	8,570	0.76	0.60	0.93	0.90	0.73	1.08
2015	8,459	0.05	0.01	0.09	0.05	0.01	0.09
2016	17,174	1.25	1.11	1.40	1.28	1.14	1.43
2017[C]	19,575	0.63	0.54	0.73	0.66	0.57	0.76
Arithmetic mean (incl. zeros)		0.87			0.94		
Geometric mean (excl. zeros)		0.59			0.64		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-RRA reaches. 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 and the Logit link.
[C] Incomplete, 2-salt returns through July 31, 2019.

Table B.113. Overall RRE-to-BOA SARs for Entiat Hatchery summer Chinook[A], 2011 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.20.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA without Jacks			RRE-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
2011	8,821	0.66	0.52	0.82	0.80	0.65	0.97
2012	8,858	1.65	1.43	1.91	1.70	1.48	1.97
2013	8,201	2.80	2.46	3.16	2.99	2.62	3.36
2014	8,570	1.05	0.85	1.25	1.20	1.00	1.42
2015	8,459	0.07	0.02	0.12	0.07	0.02	0.12
2016	17,174	1.80	1.63	1.97	1.83	1.65	2.01
2017[C]	19,575	0.84	0.74	0.95	0.89	0.79	1.01
Arithmetic mean (incl. zeros)		1.27			1.35		
Geometric mean (excl. zeros)		0.86			0.92		

[A] This is the same group as used for the MCN-to-BOA and MCN-to-RRA 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 and the Logit link.
[C] Incomplete, 2-salt returns through July 31, 2019.

Upper Columbia wild Steelhead

Table B.114. Overall MCN-to-MCA and MCN-to-BOA SARs for Upper Columbia Wild Steelhead (Wenatchee, Entiat, and Methow Rivers), 2006 to 2016. MCN-to-BOA SARs provided in Figure 4.21.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-MCA			MCN-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
2006[B]	472	1.69	0.77	2.72	1.91	0.90	2.93
2007	891	3.81	2.64	5.07	4.49	3.19	5.84
2008	2,268	4.89	5.54	7.74	6.66	5.54	7.74
2009	1,642	3.71	2.90	4.60	4.38	3.44	5.36
2010	1,442	3.33	2.50	4.25	3.61	2.77	4.55
2011	1,052	1.14	0.63	1.75	1.24	0.69	1.85
2012	730	5.07	3.45	6.47	6.17	4.30	7.68
2013	1,121	3.92	2.65	5.45	4.46	3.04	6.15
2014	1,138	2.81	1.90	3.63	3.60	2.55	4.53
2015	1,250	0.32	0.08	0.62	0.40	0.12	0.77
2016	219	1.37	0.29	2.80	1.37	0.29	2.80
Arithmetic mean (incl. zeros)		2.91			3.48		
Geometric mean (excl. zeros)		2.33			2.72		

[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 and the Logit link.
[B] 2006 is Entiat River only, all other years are Entiat, Methow, and Wenatchee combined.

Table B.115. Overall RRE-to-RRA and RRE-to-BOA SARs for Upper Columbia Wild Steelhead (Entiat and Methow Rivers)[A], 2008–2016. . RRE-to-BOA SARs provided in Figure 4.21.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-RRA %SAR Estimate	RRE-to-RRA Non-parametric CI 90% LL	RRE-to-RRA Non-parametric CI 90% UL	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	3.23	2.33	4.29	4.77	3.43	6.36
2009[C]	2,707	1.88	1.26	2.65	2.29	1.60	3.18
2010	2,147	1.72	1.24	2.19	1.91	1.43	2.39
2011	1,385	0.87	0.49	1.28	0.87	0.49	1.30
2012	986	3.04	2.05	4.26	3.65	2.56	4.98
2013	1,288	2.64	1.84	3.50	3.18	2.27	4.14
2014	1,662	1.56	1.05	2.14	1.99	1.40	2.64
2015	1,207	0.17	0.00	0.36	0.25	0.08	0.50
2016	212	1.42	0.27	3.26	1.42	0.27	3.26
Arithmetic mean (incl. zeros)		1.84			2.26		
Geometric mean (excl. zeros)		1.44			1.74		

[A] The Entiat/Methow wild steelhead aggregate is a subgroup of that used for the MCN-to-RRA and MCN-to-BOA reaches (excluding Wenatchee). SARs are calculated as number of adults at RRA or 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 and the Logit link.

[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.116. Overall MCN-to-MCA and MCN-to-BOA SARs for Upper Columbia Hatchery Steelhead released into the Wenatchee River Basin (Eastbank and Chelan Hatcheries), 2003–2016. MCN-to-BOA SARs provided in Figure 4.22.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-MCA			MCN-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
2003	13,387	2.01	1.79	2.24	2.35	2.11	2.59
2004	9,207	1.03	0.84	1.24	1.46	1.23	1.71
2005	14,721	0.72	0.61	0.84	0.90	0.77	1.03
2006	4,045	1.85	1.49	2.23	2.30	1.89	2.73
2007	3,504	1.57	1.21	1.92	2.05	1.62	2.49
2008	4,692	4.82	4.20	5.39	5.75	5.02	6.40
2009	4,603	2.17	1.81	2.61	2.65	2.26	3.12
2010	4,419	3.08	2.53	3.63	3.60	2.98	4.21
2011	5,613	1.43	1.14	1.71	1.57	1.27	1.88
2012	8,463	1.50	1.26	1.74	1.97	1.68	2.25
2013	8,398	2.01	1.70	2.30	2.26	1.94	2.58
2014	3,902	1.33	1.02	1.68	1.82	1.45	2.23
2015	2,536	0.04	0.12	0.00	0.04	0.00	0.12
2016	5,677	0.81	0.61	1.04	1.02	0.79	1.27
Arithmetic mean (incl. zeros)		1.74			2.12		
Geometric mean (excl. zeros)		1.26			1.54		

[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 and the Logit link.

Upper Columbia wild Sockeye

Table B.117. Overall MCN-to-MCA and MCN-to-BOA SARs for Wenatchee River Wild Sockeye, 2014–2017. MCN-to-BOA SARs provided in Figure 4.23.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-MCA %SAR Estimate	MCN-to-MCA Non-parametric CI 90% LL	MCN-to-MCA Non-parametric CI 90% UL	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL
2014	1,838	2.34	1.68	3.02	2.77	2.04	3.49
2015	1,870	1.28	0.80	1.77	1.39	0.90	1.90
2016	264	1.52	0.38	2.92	1.52	0.38	2.92
2017[B]	555	0.18	0.00	0.52	0.18	0.00	0.52
Arithmetic mean (incl. zeros)		1.33			1.47		
Geometric mean (excl. zeros)		0.95			1.01		

[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 and the Logit link.
[B] Incomplete, 2-salt returns through July 31, 2019.

Table B.118. Overall MCN-to-WEA and MCN-to-BOA SARs for Okanogan River Wild Sockeye, 2013–2016. MCN-to-BOA SARs provided in Figure 4.23.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-WEA %SAR Estimate	MCN-to-WEA Non-parametric CI 90% LL	MCN-to-WEA Non-parametric CI 90% UL	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL
2013[B]	2,114	4.11	2.88	5.30	7.66	5.60	9.56
2014[B]	2,170	2.35	1.75	2.94	2.90	2.24	3.61
2015	2,538	1.22	0.79	1.71	1.58	1.04	2.16
2016[B]	4,501	1.31	0.99	1.62	1.76	1.35	2.14
2017[B,C]	5,842	0.12	0.05	0.20	0.12	0.05	0.20
Arithmetic mean (incl. zeros)		1.82			2.80		
Geometric mean (excl. zeros)		1.13			1.49		

[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] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.
[C] Incomplete, 2-salt returns through July 31, 2019.

Table B.119. Overall RRE-to-WEA and RRE-to-BOA SARs for Okanogan River Wild Sockeye, 2013–2017. RRE-to-BOA SARs provided in Figure 4.23.

Juvenile migration year	Smolts arriving RRE[A]	RRE-to-WEA %SAR Estimate	RRE-to-WEA Non-parametric CI 90% LL	RRE-to-WEA Non-parametric CI 90% UL	RRE-to-BOA %SAR Estimate	RRE-to-BOA Non-parametric CI 90% LL	RRE-to-BOA Non-parametric CI 90% UL
2013[B]	2,012	4.32	3.50	5.24	8.05	6.82	9.31
2014[B]	2,937	1.74	1.36	2.16	2.15	1.72	2.63
2015	3,064	1.01	0.72	1.32	1.31	0.97	1.66
2016[B]	5,782	0.97	0.78	1.18	1.30	1.06	1.55
2017[B,C]	5,956	0.12	0.05	0.19	0.12	0.05	0.19
Arithmetic mean (incl. zeros)		1.63			2.59		
Geometric mean (excl. zeros)		0.98			1.29		

[A] Estimated population of tagged study fish alive to RRE 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 and the Logit link.

[B] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.

[C] Incomplete, 2-salt returns through July 31, 2019.

Upper Columbia wild and hatchery Chinook, Steelhead, and Sockeye Tagged at Rock Island Dam

Table B.120. Overall RIS-to-MCA SARs for Upper Columbia Wild and Hatchery Yearling Chinook tagged at Rock Island Dam, 2000 to 2017. SARs are calculated with and without jacks.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-MCA (without jacks)			RIS-to-MCA (with jacks)		
		%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL	%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL
2000	3,989	0.85	0.63	1.13	0.85	0.63	1.13
2001	1,837	0.00	0.00	0.16	0.00	0.00	0.16
2002	3,987	0.08	0.02	0.19	0.08	0.02	0.19
2003[C]	--	--	--	--	--	--	--
2004	910	0.00	0.00	0.33	0.00	0.00	0.33
2005	723	0.00	0.00	0.41	0.00	0.00	0.41
2006	1,127	0.09	0.00	0.42	0.09	0.00	0.42
2007	859	0.00	0.00	0.35	0.00	0.00	0.35
2008	843	0.12	0.01	0.56	0.47	0.16	1.08
2009	688	0.58	0.20	1.33	0.58	0.20	1.33
2010	799	0.50	0.17	1.14	0.50	0.17	1.14
2011	1,338	0.07	0.00	0.35	0.30	0.10	0.68
2012	1,702	0.18	0.05	0.45	0.35	0.15	0.69
2013	5,484	0.88	0.68	1.11	1.02	0.81	1.27
2014	5,189	0.42	0.29	0.60	0.60	0.43	0.81
2015	5,554	0.40	0.27	0.57	0.41	0.28	0.59
2016	5,060	0.40	0.26	0.53	0.49	0.34	0.65
2017[D]	2,405	0.04	0.00	0.12	0.21	0.08	0.37
Arithmetic mean (incl. zeros)		0.27			0.35		
Geometric mean (excl. zeros)		0.23			0.37		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at MCA divided by number of smolts marked and released at Rock Island Dam.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] No data in 2003 due to bypass inoperable during spring outmigration
[D] Incomplete, 2-salt returns through July 31, 2018.

Table B.121. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Yearling Chinook tagged at Rock Island Dam, 2000 to 2017. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.25.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA (without jacks)			RIS-to-BOA (with jacks)		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			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[C]	--	--	--	--	--	--	--
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	5,484	1.13	0.91	1.39	1.33	1.09	1.62
2014	5,189	0.60	0.43	0.81	0.77	0.58	1.00
2015	5,554	0.62	0.37	0.71	0.54	0.39	0.73
2016	5,060	0.53	0.38	0.69	0.67	0.47	0.87
2017[D]	2,405	0.12	0.00	0.25	0.29	0.12	0.50
Arithmetic mean (incl. zeros)		0.37			0.46		
Geometric mean (excl. zeros)		0.32			0.43		

[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.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] No data in 2003 due to bypass inoperable during spring outmigration
[D] Incomplete, 2-salt returns through July 31, 2019.

Table B.122. Overall RIS-to-MCA SARs for Upper Columbia Wild and Hatchery subyearling Chinook tagged at Rock Island Dam, 2000 to 2016. SARs are calculated with and without jacks.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-MCA (without jacks)			RIS-to-MCA (with jacks)		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			90% LL	90% UL		90% LL	90% UL
2000	4,073	1.67	1.35	2.04	1.67	1.35	2.04
2001	4,484	0.02	0.00	0.11	0.02	0.00	0.11
2002	4,800	0.83	0.63	1.08	0.94	0.72	1.20
2003	4,338	0.16	0.08	0.30	0.16	0.08	0.30
2004	3,183	0.03	0.00	0.15	0.03	0.00	0.15
2005	3,547	0.42	0.26	0.65	0.48	0.31	0.72
2006	4,208	0.52	0.35	0.75	0.57	0.39	0.80
2007	3,596	0.19	0.09	0.37	0.25	0.13	0.44
2008	3,678	0.68	0.47	0.95	0.71	0.50	0.98
2009	1,889	0.48	0.25	0.83	0.48	0.25	0.83
2010	3,625	0.66	0.46	0.93	0.66	0.46	0.93
2011	4,387	1.57	1.28	1.92	1.62	1.32	1.97
2012	3,656	0.90	0.66	1.21	0.96	0.71	1.27
2013	4,021	1.02	0.77	1.32	1.19	0.93	1.52
2014	4,690	0.15	0.07	0.28	0.17	0.08	0.31
2015	3,117	0.00	0.00	0.10	0.00	0.00	0.10
2016[C]	4,069	0.07	0.00	0.15	0.07	0.00	0.15
Arithmetic mean (incl. zeros)		0.55			0.59		
Geometric mean (excl. zeros)		0.33			0.35		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at MCA divided by number of smolts marked and released at Rock Island Dam.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 3-salt returns through July 31, 2019.

Table B.123. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery subyearling Chinook tagged at Rock Island Dam, 2000 to 2016. SARs are calculated with and without jacks. SARs (with jacks) provided in Figure 4.25.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA (without jacks)			RIS-to-BOA (with jacks)		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			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	0.98	0.76	1.25	1.04	0.81	1.32
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	0.86	0.62	1.15	0.88	0.64	1.18
2011	4,387	2.12	1.77	2.51	2.17	1.82	2.56
2012	3,656	1.12	0.85	1.45	1.18	0.90	1.51
2013	4,021	1.47	1.17	1.82	1.67	1.35	2.04
2014	4,690	0.23	0.13	0.39	0.26	0.15	0.41
2015	3,117	0.00	0.00	0.10	0.00	0.00	0.10
2016[C]	4,069	0.07	0.00	0.15	0.07	0.00	0.15
Arithmetic mean (incl. zeros)		0.71			0.75		
Geometric mean (excl. zeros)		0.51			0.54		

[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.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] Incomplete, 3-salt returns through July 31, 2019.

Table B.124. Overall RIS-to-MCA and RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Steelhead tagged at Rock Island Dam, 2000 to 2016. RIS-to-BOA SARs provided in Figure 4.25.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-MCA			RIS-to-BOA		
		%SAR Estimate	Exact Binomial CI[B]		%SAR Estimate	Exact Binomial CI[B]	
			90% LL	90% UL		90% LL	90% UL
2000	3,946	0.68	0.48	0.94	1.42	1.12	1.77
2001	4,027	0.02	0.00	0.12	0.07	0.02	0.19
2002	3,996	1.40	1.11	1.75	1.88	1.54	2.27
2003[C]	---	---	---	---	---	---	---
2004	2,627	0.19	0.08	0.40	0.30	0.15	0.55
2005	2,850	0.63	0.41	0.94	0.77	0.52	1.10
2006	3,181	0.75	0.52	1.06	0.88	0.63	1.20
2007	3,551	0.73	0.51	1.01	0.90	0.66	1.21
2008	6,052	2.41	2.10	2.73	3.21	2.84	3.60
2009	5,304	0.87	0.67	1.11	1.09	0.87	1.36
2010	6,629	0.97	0.78	1.19	1.22	1.01	1.47
2011	7,224	0.43	0.31	0.58	0.58	0.44	0.75
2012	5,943	0.76	0.58	0.97	0.99	0.79	1.23
2013	5,255	0.84	0.64	1.08	1.07	0.84	1.33
2014	6,276	0.69	0.52	0.88	0.92	0.73	1.15
2015	5,705	0.09	0.03	0.18	0.09	0.03	0.18
2016	6,154	0.34	0.23	0.47	0.37	0.24	0.52
Arithmetic mean (incl. zeros)		0.74			0.99		
Geometric mean (excl. zeros)		0.50			0.70		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at MCA or BOA divided by number of smolts marked and released at Rock Island Dam.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] No data in 2003 due to bypass inoperable during spring outmigration.

Table B.125. Overall RIS-to-MCA and RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Sockeye tagged at Rock Island Dam, 2000 to 2017. RIS-to-BOA SARs provided in Figure 4.25.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-MCA			RIS-to-BOA		
		%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL	%SAR Estimate	Exact Binomial CI[B] 90% LL	Exact Binomial CI[B] 90% UL
2000	656	1.52	0.83	0.83	1.98	1.18	3.13
2001	491	0.00	0.00	0.00	0.00	0.00	0.61
2002	2,090	0.19	0.07	0.07	0.29	0.13	0.57
2003[C]	--	--	--	--	--	--	--
2004	1,083	0.83	0.43	0.43	0.74	0.37	1.33
2005[B]	887	0.00	0.00	0.00	0.00	0.00	0.34
2006	3,600	0.86	0.62	0.62	1.08	0.82	1.41
2007	2,082	0.82	0.52	0.52	0.86	0.56	1.28
2008	1,910	6.18	5.30	5.30	7.80	6.81	8.89
2009	2,059	3.79	3.12	3.12	5.88	5.05	6.80
2010	3,527	2.24	1.85	1.85	2.86	2.42	3.37
2011	2,977	1.51	1.16	1.16	1.98	1.58	2.46
2012	3,231	3.25	2.75	2.75	4.18	3.61	4.80
2013	2,674	4.45	3.81	3.81	6.21	5.46	7.03
2014	3,059	0.75	0.51	0.51	0.98	0.71	1.33
2015	1,689	0.59	0.32	0.32	0.71	0.41	1.15
2016	4,109	0.92	0.68	0.68	0.92	0.68	1.17
2017[D]	2,210	0.27	0.09	0.09	0.27	0.09	0.45
Arithmetic mean (incl. zeros)		1.66			2.16		
Geometric mean (excl. zeros)		1.23			1.50		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at MCA or BOA divided by number of smolts marked and released at Rock Island Dam.
[B] 90% confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[C] No data in 2003 due to bypass inoperable during spring outmigration.
[D] Incomplete, 2-salt returns through July 31, 2019.

First Year Estuary and Ocean Survival Rates

Table B.126. Estimation of first year estuary and ocean survival rates, So1, for Snake River wild spring/summer Chinook 1994–2017 based on CSS parameter estimates for SAR, in-river survival, proportion transported and *D*. S.oa (Col. R.) and S.o1 provided in Figure 4.27.

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	0.59	0.66	0.49	0.52	0.74%	0.91%	0.014	0.018	0.023
2007	0.67	0.21	0.91	0.72	1.09%	1.30%	0.015	0.018	0.023
2008	0.58	0.46	0.73	0.64	3.24%	4.27%	0.050	0.067	0.086
2009	0.64	0.42	0.74	0.68	1.61%	2.16%	0.024	0.032	0.042
2010	0.62	0.40	0.81	0.69	0.93%	1.20%	0.014	0.017	0.022
2011	0.67	0.35	0.49	0.60	0.36%	0.47%	0.006	0.008	0.010
2012	0.68	0.21	0.53	0.65	1.43%	1.90%	0.022	0.029	0.036
2013	0.63	0.35	0.99	0.75	1.36%	1.76%	0.018	0.023	0.030
2014	0.64	0.34	1.38	0.88	0.57%	0.71%	0.006	0.008	0.010
2015	0.47	0.16	2.11	0.72	0.29%	0.36%	0.004	0.005	0.006
2016	0.55	0.25	1.41	0.75	0.38%	0.51%	0.005	0.007	0.008
2017[A,B]	0.55	0.11	---	---	0.15%	0.24%	---	---	---
geometric mean	0.515	0.480	0.715	0.634	0.75%	0.97%	0.013	0.016	0.021

[A] Incomplete, 2-salt returns through June 28, 2019.
[B] There were too few adults in T_0 and/or C_0 group to estimate *D* and, therefore, could not estimate system survival, S.oa, or S.o1.

Table B.127. Estimation of first year estuary and ocean survival rates, So1, for Snake River wild steelhead 1997–2016 based on CSS parameter estimates for SAR, in-river survival, proportion transported and *D*. S.oa (Col. R.) and S.o1 provided in Figure 4.27.

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	0.67	0.65	0.68	0.67	1.14%	1.97%	0.017	0.030	0.034
2007	0.45	0.40	1.47	0.85	2.57%	3.43%	0.030	0.041	0.046
2008	0.56	0.41	0.69	0.61	3.21%	4.48%	0.053	0.074	0.085
2009	0.61	0.45	0.84	0.71	2.45%	3.67%	0.035	0.052	0.061
2010	0.57	0.35	0.88	0.67	1.73%	2.47%	0.026	0.037	0.042
2011	0.62	0.48	0.78	0.69	1.27%	1.92%	0.018	0.028	0.031
2012	0.67	0.23	0.64	0.66	2.54%	3.54%	0.038	0.053	0.061
2013	0.55	0.47	1.27	0.88	1.99%	2.81%	0.023	0.032	0.037
2014	0.65	0.55	1.49	1.10	1.34%	2.18%	0.012	0.020	0.022
2015	0.35	0.20	0.63	0.40	0.10%	0.21%	0.002	0.005	0.006
2016	0.39	0.33	0.65	0.47	0.78%	1.04%	0.017	0.022	0.023
geometric mean	0.408	0.550	0.937	0.790	1.35%	1.95%	0.018	0.025	0.028

All other appendices will be included in the Final Draft