COMPARATIVE SURVIVAL STUDY (CSS)
of PIT-Tagged Spring/Summer Chinook and Steelhead
In the Columbia River Basin

Ten-year Retrospective Analyses Report

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Executive Summary

The Comparative Survival Study (CSS) oversight committee prepared the Ten Year Summary Report to address the overarching recommendation of the Independent Scientific Advisory Board (ISAB) that was provided as a result of the ISAB review of the 2005 Comparative Survival Study Annual Report. The ISAB's specific technical recommendations are also addressed. This Ten Year Summary Report utilizes a holistic approach to describe study methods and assess the data available from ten years of juvenile salmon and steelhead PIT tagging and PIT tag detections. The PIT tag recovery data are analyzed in a retrospective style to accommodate utilization of all available juvenile and adult recovery data for the period 1996 through 2005.

The Ten Year Summary Report aggregates the available data within years regarding environmental variability and migration timing for the assessment of juvenile reach survivals and Smolt to Adult Return (SAR). The data are additionally aggregated across years to assess trends and variability in SARs. These new analyses provide an additional perspective for the CSS results that increases the utility of the CSS data for making management decisions.

Report Structure

The Ten Year Summary Report contains eight chapters and eight appendices. Chapter 1 provides the purpose of the Ten Year Summary Report, a brief description of the CSS, a brief description of the ISAB review, and the organization of the report. Chapter 2 presents an assessment of juvenile salmon and steelhead travel time, and survival and the influence of managed river conditions including flow, water particle travel time, and spill levels. The influence of temperature and turbidity are also assessed. Chapter 3 presents the methods and results for SAR computations, compares SARs and ratios of SARs (TIR and D) for groups of smolts with different hydrosystem migration experiences. Chapter 3 also presents methods and results for computing system survival. The inter-annual variability for these parameters is displayed. Chapter 4 presents the methods and results for probability distributions of SAR, TIR and D for wild Chinook and Steelhead. These distributions provide an additional representation of the inter-annual variation in survival rates. Chapter 5 presents the methods and results for overall SARs for wild Snake River spring/summer Chinook and steelhead population aggregates and addresses the extent to which these population aggregates are meeting the Northwest Power and Conservation Council (2003) interim biological objectives. The influence of in-river, estuary/early ocean, and off-shore environmental variables and arrival timing at Bonneville Dam on overall SARs were evaluated. The SARs for the Snake River wild population aggregates are also compared to SARs for wild population aggregates from the Mid-Columbia to evaluate the influence of experiencing different migration conditions within the hydrosystem for fish that share a common environment during their estuary and early ocean migration/rearing experience. Chapter 6 presents information on the partitioning of life cycle survival data for hatchery Chinook with focus on survival from release to Lower Granite Dam and adult survival during upstream migration through the hydrosystem and return to the hatcheries. The potential for juvenile migration experience (in-river and transported groups) to result in differences in adult migrant survival, timing and duration was tested. The role of environmental factors (flow, spill and temperature) on adult migrant survival was also assessed. Chapter 7 presents an investigation of the potential impact that violations of key assumptions of the Cormack-Jolly Seber (CJS) may have on our ability to obtain estimates of reach survival rates and other study parameters through two sets of simulations. Chapter 8 concludes the report by presenting key findings, continuing and future CSS implementation, and recommending guidance for future study design and implementation to address critical uncertainties and improve the reliability of CSS survival estimates. The utility and role of CSS data and survival estimates for informing hydrosystem managers regarding the response of fish populations to management actions is also presented. Appendix A describes the logistics of tagging and releasing fish and data collection and summarization for the study. Appendix B presents the computational formulas for estimating the study parameters of the CSS and describes the underlying assumptions inherent in the estimates. Appendix C presents the 2006 CSS Design and Analysis Report (Ryding 2006). Appendix D presents the entire available time series of marking data, survival estimates, and estimates of major CSS study parameters. Appendix E presents tables of the data generated for key CSS parameters. Appendix F contains timing plots for wild and hatchery Chinook and steelhead at Lower Granite and Bonneville dams. Appendix G displays the past comments received on the CSS Report from the ISAB/ISRP and the response to those comments. Last, Appendix H contains a glossary of terms used in this document and their definitions.

Synopsis of Key Findings

- The CSS is a large scale field study (more than 2 million marked smolts), begun in 1996, that has successfully implemented PIT tag marking of juvenile wild and hatchery spring/summer Chinook and steelhead across a wide geographic area through coordination with multiple jurisdictions within the Snake and Columbia River watersheds.
- The combination of the CSS marking program and utilization of the PIT tag sort by code separation equipment and software has generally produced sufficient sample sizes for the various treatment groups specified in the study plans.
- Assessment of juvenile fish passage through the hydrosystem indicates that reach-specific travel times, instantaneous mortality rates and survival rates are influenced by managed river conditions including flow, water particle travel time and spill. Strong seasonal patterns were also identified.
- The relationships which are identified for juvenile fish survival and managed river conditions provides an example of how the CSS PIT tag results could be used to predict the influence of management strategies on migration and survival rates of in-river juvenile migrants.
- Through the implementation of its study objectives the CSS addressed the overall question of whether collecting juvenile fish and transporting them downstream in barges and trucks and releasing them below Bonneville Dam was compensating for the effects of the FCRPS on survival of Snake Basin spring/summer Chinook and steelhead migrating through the hydrosystem (Mundy et al. 1994). The CSS results indicate that the SARs of transported fish relative to in-river migrants varied across species and between wild and hatchery origins. Wild spring/summer Chinook on average showed no benefit from transportation (TIR~1.0), except in the severe drought year (2001). Hatchery spring/summer Chinook responded more positively to transportation with TIR averages across hatcheries ranging from ~1.1 to 1.5. Wild and hatchery steelhead responded most

positively to transportation with average TIR for wild steelhead ~ 1.7 and average TIR for hatchery steelhead 1.5. Substantial differential delayed transport mortality (D<1.0) was evident for both species and across wild and hatchery groups for each species. Overall SARs for wild spring/summer Chinook (geometric mean 0.9%, range 0.3%-2.4%) and wild steelhead (geometric mean 1.6%, range 0.3%-2.9%) fell short of the NPPC SAR objectives (2% minimum, 4% average for recovery). In addition the SAR values for these Snake River Basin groups were only ¼ those of similar downriver populations which migrated through a shorter segment of the hydropower system. Because the CSS SAR results fail to meet the NPCC SAR objectives, it appears that collecting and transporting juvenile spring/summer Chinook and steelhead at Snake River Dams did not compensate for the effects of the FCRPS on the survival of these fish while migrating through the hydrosystem. The CSS overall SARs are also insufficient to meet broad sense recovery goals which include providing harvestable surplus (future target population levels eg. CBFWA goals and subbasin plans) for wild Snake River Basin spring/summer Chinook and steelhead.

- A portion of the observed difference in survival for transportation and in-river groups is due to mortality and/or straying that occurs during the adult upstream migration. Adults that were transported from LGR as smolts returned to LGR at a 10% lower rate than those with either an in-river smolt history or those that were transported from LGS or LMO. Differences in adult survival from LGR to the hatcheries were not detected based on relative proportions of adults with the transportation and in-river juvenile migration histories.
- Simulation model analysis of the impact that violations of key CJS assumptions have on the accuracy of reach survival rates and other CSS parameters indicated that the study parameters are robust to population changes in survival rates and collection probabilities over time. However, the parameter estimates are not as robust to population changes as survival rates between segments of a common population (based on prior passage experience).
- The implementation of the CSS study and the associated analyses have provided a long time series of survival rates principally to assess the relative survival of in-river and transportation juvenile migration histories for wild and hatchery spring/summer Chinook and steelhead. The relationship of these various survival rates to hydrosystem operational conditions was assessed while considering the influence of variable environmental conditions. The CSS study results identify hydrosystem conditions that can optimize survival of fish migrating in-river. The results of these assessments provide the regional managers with the basis to develop tools to evaluate the effects of hydrosystem operational alternatives. Development of these tools should assist managers in their efforts to ensure protection and restoration of salmon populations. The CSS results (chapter 4) also provide information to assess where and when during the migration season the transported groups of fish exhibit the highest survival. The integration of the seasonal transportation SARs with the reach survival estimates (chapter 2) has the potential to help determine the proportion of fish to be left in-river to optimize the overall seasonal survival rate.
- The CSS SAR and reach survival estimates provided in the Ten Year Summary Report provide time series data which have been valuable for status and trend monitoring and

provide key information to assess action effectiveness for some of the past hydrosystem actions.

Future of the CSS

In addition to the value and utility that the CSS time series data provides for the assessment of past conditions and actions, these time series of CSS survival estimates provide a critical baseline that should be continued for the purpose of assisting in the assessment of future hydrosystem management actions. In the future the CSS should maintain the existing time series of PIT tag information and also augment this with additional tags for some groups and additional tagged groups that will increase the utility of the survival estimation capability for the CSS. The CSS Oversight Committee recommends the following:

- investigate methods to improve adult LGR to hatchery return estimates.
- continue to exercise care to avoid bias in the various parameter estimates by continued evaluation of key assumptions of the CJS model regarding constraints and limitation on the experimental design.
- continue to evaluate the relationships between environmental parameters within and outside the hydrosystem and the CSS parameter estimates.
- develop techniques to evaluate the relationship between population overall SARs and recruit /spawner data.
- continue to provide a large and robust data set through the maintenance of consistent and continuous mark groups throughout the Columbia River Basin that other entities may utilize and incorporate into their scientific investigations.
- continue to coordinate the CSS mark and data management with other research and monitoring programs in the Columbia Basin to provide and improve efficiencies for PIT tagging, tag detections, data management, and data accessibility.

Chapter 1.

A Retrospective Summary of Ten Years of Comparative Survival Study -- Methods, Analyses, and Interpretation of Results

Introduction

Completion of this report marks the 11th outmigration year of hatchery spring Chinook salmon marked with Passive Integrated Transponder (PIT) tags through the Comparative Survival Study (CSS; BPA Project 199602000) and 6th complete brood year return as adults of those PIT-tagged fish. The primary purpose of this report is to synthesize the results of this ongoing salmon and steelhead survival study, the analytical approaches that were employed, and the evolving improvements to the study to date and into the future that were reported in CSS annual progress reports. Specifically, this report addresses the constructive comments of the most recent regional technical review conducted by the Independent Scientific Advisory Board (ISAB 2006).

The CSS began in 1996 with the objective of establishing a long term dataset of the survival rate of annual generations of salmon from their outmigration as smolts to their return to freshwater as adults to spawn (Smolt to Adult Return Ratio; SAR). The study was implemented with the express need to address the question whether collecting juvenile fish at dams and transporting them downstream in barges and trucks and releasing them downstream of Bonneville Dam was compensating for the effect of the Federal Columbia River Power System (FCRPS) on survival of Snake Basin spring/summer Chinook salmon migrating through the hydrosystem. All of the Chinook evaluated in the CSS study exhibit a stream-type life history. All study fish used in this report were uniquely identifiable based on a PIT tag implanted in the body cavity during the smolt life stage and retained through their return as adults. These tagged fish can then be detected as juvenile and adults at several locations of the Snake and Columbia rivers. Reductions in the number of individuals detected as the tagged fish grow older provide estimates of survival. This allows comparisons of survival over different life stages between fish with different experiences in the hydrosystem (e.g. transportation vs. inriver migrants and migration through various numbers of dams) as illustrated in Figure 1.1.

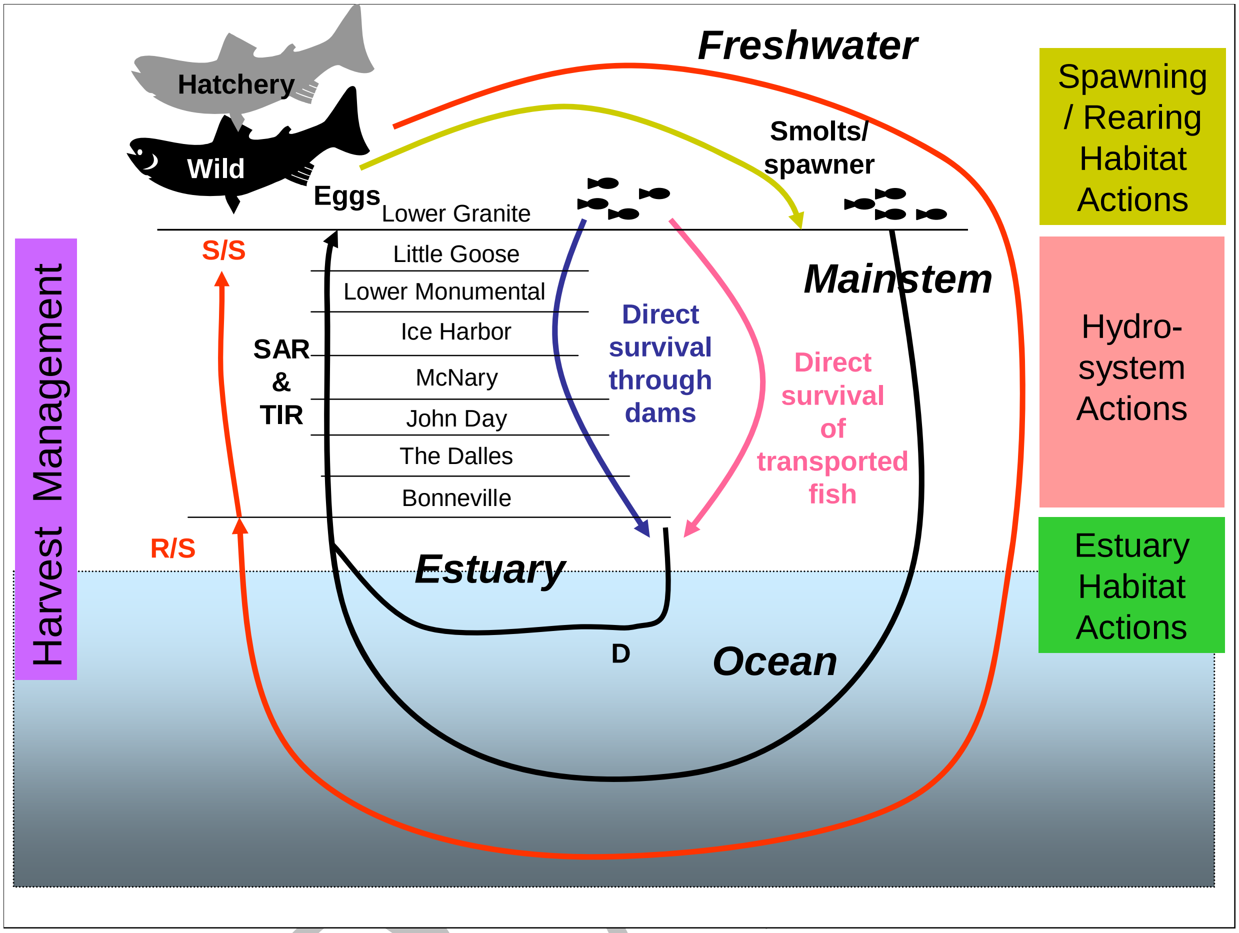
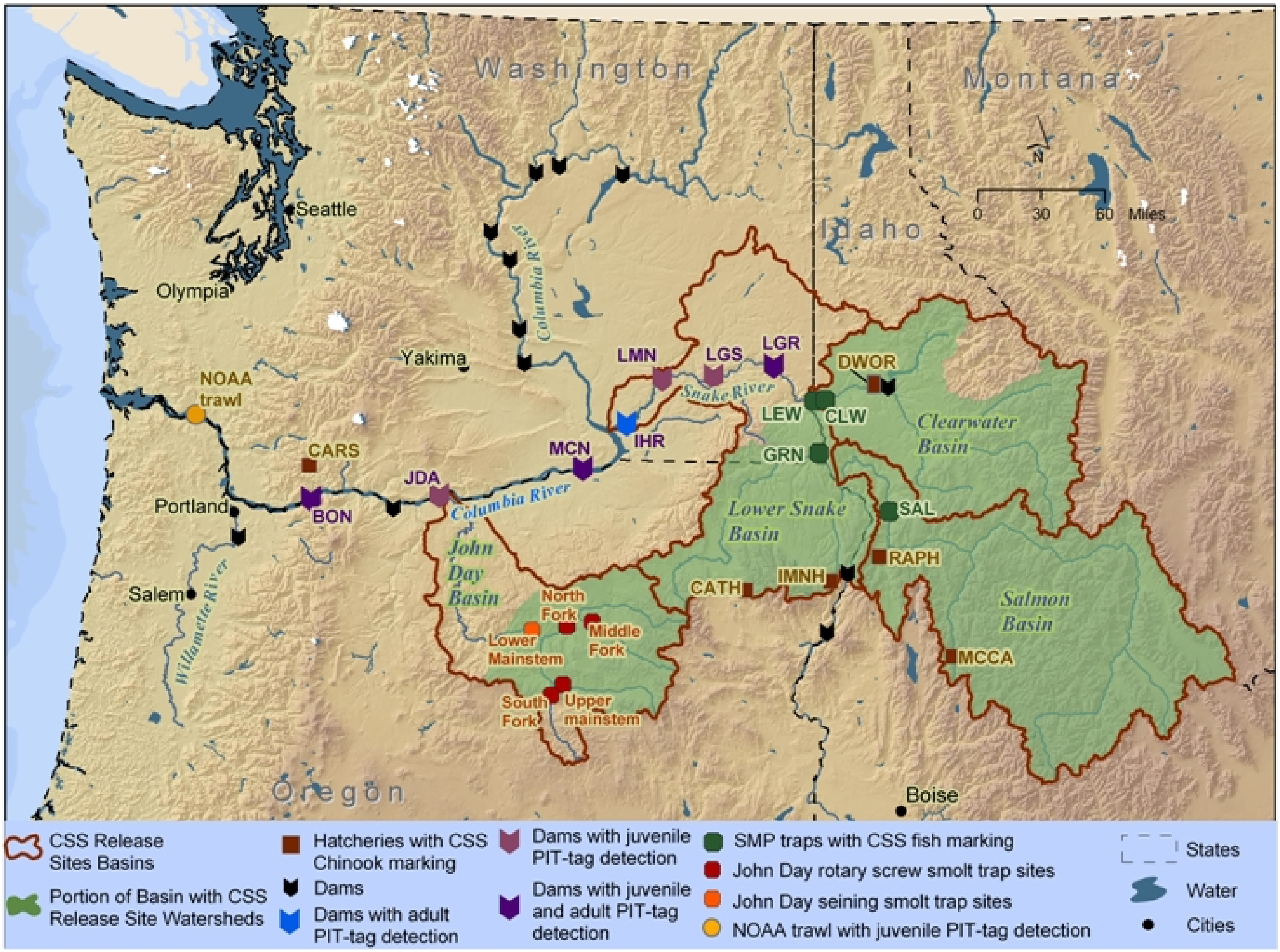


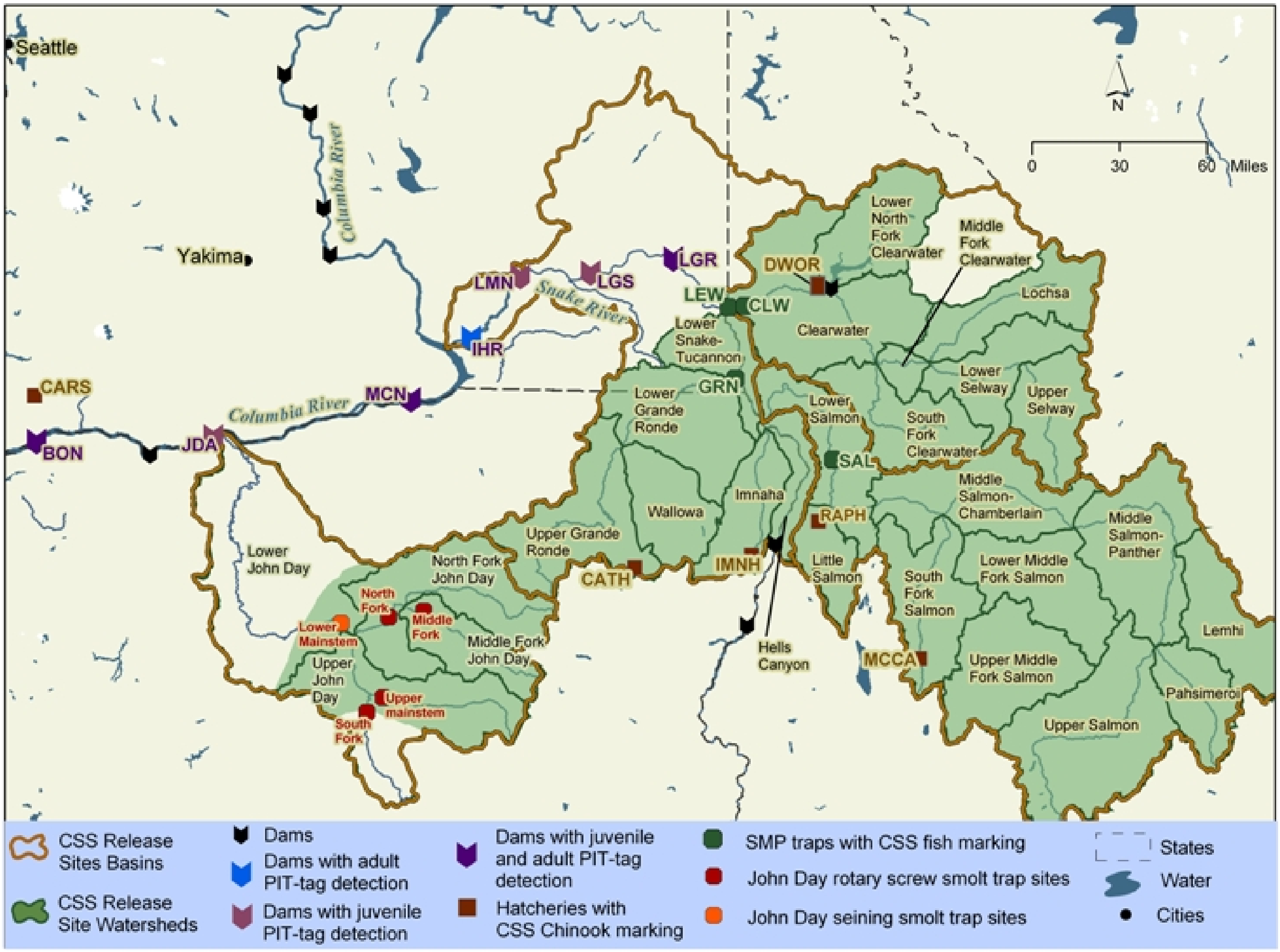
Figure 1.1. Salmonid life cycle in the Snake River and lower Columbia River basins (Source: Marmorek et al. 2004).

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 Bonneville Power Administration (BPA). Study design and analyses are conducted through a CSS Oversight Committee 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. The location of all tagging sites is identified in Figures 1.2 and 1.3. 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 BPA: http://www.efw.bpa.gov/searchpublications/index.aspx?projid=+).



Map 1 -- CSS PIT-tag release locations and PIT-tag detection sites in the Columbia River Basin.

Figure 1.2. CSS PIT tag release locations and PIT-tag detection sites in the Columbia River Basin.



Map 2-- CSS PIT-tag release watersheds and PIT-tag detection sites in the Columbia River Basin.

Figure 1.3. CSS PIT-tag release watersheds and PIT-tag detection sites in the Columbia River Basin.

Scientific Review

Since inception of the CSS, extensive regional technical reviews have been conducted regularly by the Independent Scientific Review Panel (ISRP), ISAB, National Oceanic and Atmospheric Administration Fisheries (NOAA-F), BPA, and others. The ISAB reviewed the 2005 annual CSS report at the request of the NPCC. The NPCC's questions to the ISAB were the following:

1. *Are the design, implementation, and interpretation of the statistical analyses underpinning the report based on the best available methods? Does the ISAB have suggestions for improving the analyses?*
2. *What is the applicability of the CSS results, taking into account whatever scientific criticisms of the analyses that the ISAB decides are valid, if any? In other words, what weight should the analyses be given and what qualifiers should be considered when using the analyses for decision-making?* (ISAB 2006-3).

In its review of the 2005 report, the ISAB observed that short of having a controlled and manipulated experimental design, the CSS has performed well doing the next best thing – documenting survival of as many fish as possible through their life cycle under whatever conditions prevail that impact survival. With continued monitoring, survival data over a wider range of environmental conditions will accumulate that can provide more functional correlations with environmental or hydro operational changes. While a number of improvements can be made, the CSS continues to remain a good, long-term monitoring program. Its methods will continue to improve and the results will become evermore valuable with more years, as periodic peer reviews and agency input continues.

The overarching comment by the ISAB was that a 10-year summary report that provides "an in-depth description of methods and detailed analyses and interpretation of the data in a retrospective style" was needed that gave an overall comparison of study results among and within all the years of the CSS study period, an analytical interpretation of those results, and the conclusions drawn to date. Their major criticisms of the 2005 annual progress included that the report did not describe clearly and comprehensively all the study methods for collecting and evaluating survival data (and thus, formulas used in analyses appear "complicated and convoluted"), did not present the cumulative data sets and summaries for the entire period of record, did not provide enough detail on the characteristics of the tagged release groups (primarily size at release), needed to ensure assumptions and their rationale were clearly described, and would benefit by considering comparative analyses of differential survival among groups of fish in addition to transport *vs* inriver fish. Integrating the annual reports will ensure consistency of the evaluations of a growing body of survival information and clarify ongoing adaptive improvements to study design, data summaries, and analytical approaches; make the continuing study easier to read and review; and strengthen the link of the study results to decision making regarding operation of the FCRPS and protection of fish.

Development of the Comparative Survival Study

The motivation for the CSS began with the region's fishery managers expressing concern that the benefits of transporting juvenile fish around the dams (to mitigate the impacts of the

FCRPS) were less than anticipated (Olney et al.1992, Mundy et al. 1994, and Ward et al.1997). Experiments conducted by NMFS prior to the mid-1990s sought to assess whether collecting juvenile fish at dams and transporting them in trucks or barges and releasing them downstream of Bonneville Dam could increase survival beyond that of smolts that migrated inriver through the dams and impoundments. Beginning in 1981, collecting fish at the lower Snake River dams and transporting them was institutionalized as an operational program by the U.S. Army Corps of Engineers (USACE).

Despite collection and transportation operations, abundance of Snake River spring/summer Chinook salmon continued to decline. Fisheries that had been conducted at moderate levels in the Columbia mainstem during the 1950s and 1960s were all but closed by the mid-1970s. In 1992, the spring/summer Snake River evolutionarily significant unit (ESU) was listed under the federal Endangered Species Act (ESA). Spawning ground survey results in the mid-1990's indicated virtually complete brood year failure for some wild populations. For hatchery fish, low abundance was a concern as the Lower Snake River Compensation Plan (LSRCP) hatcheries began to collect program broodstock and produce juveniles.

The region expressed differences of opinion about the efficacy of transportation. These opinions ranged from transportation being the best option to mitigate for the impacts of the FCRPS, to presenting evidence that survival of transported fish was insufficient to overcome the impacts of the FCRPS for Snake Basin salmon. While the survival of fish transported around the FCRPS could be demonstrated to be generally higher than survival of juveniles that migrated in the river, evidence on whether transportation increased survival enough to increase abundance of wild populations was unavailable. Regardless of whether evidence existed to demonstrate that survival of transported fish was higher than fish migrating inriver, if the overall survival rate (egg to spawner) was insufficient for populations to at least persist, the issue would be moot (Mundy et al. 1994).

Shortcomings of the methods that had been used to estimate survival rates for transported fish and compare them to non-transported fish resulted from the collection and handling protocols, the marking and recovery technology used, the study objectives, the definition and use of a control population, and inconsistency and duration of survival studies (Olney et al.1992, Mundy et al. 1994, and Ward et al.1997). In the first juvenile fish studies transported and inriver fish groups were handled differently. Whereas transported fish were captured at dams, tagged, and placed in trucks or barges, some inriver control groups of fish were transported back upstream for release. These marked inriver fish were therefore subjected to the same hydrosystem impacts multiple times (unlike the unmarked outmigration at large), whether they were collected and transported or remained inriver. The early mark-recapture studies used coded-wire tags (CWT) and freeze brands to mark juveniles collected at the dams. Because these marks were applied in mass tag groups, origin of individual fish could not be identified and tag information from coded-wire-tagged fish could only be obtained from dead individuals. Because these fish were collected at the dams, the origin of the fish from within the Snake River Basin was unknown. Evidence suggested that the process of guiding and collecting fish for either transport or for study purposes through bypasses contributed to juvenile fish mortality and was cumulative when fish were bypassed multiple times. If mortality caused by collection and bypass differentially impacted the study fish, and was not representative of the inriver migrant run at large, measures of the efficacy of transportation would be biased.

New mark-recapture technology using PIT-tags made improvements to evaluation of the efficacy of transportation to recover salmon populations possible. The CSS design uses this technology to improve upon past studies. All study fish are uniquely identified with a PIT tag. To ensure all fish transported or migrating inriver experience the same effects from handling (thus improving the utility of an inriver control group relative to transportation) during tagging and release, fish are tagged at hatcheries and wild fish are tagged at subbasin and mainstem outmigrant traps upstream of the FCRPS (Figures 1.2 and 1.3). PIT-tagged juveniles are released near their marking station, allowing the numbers of fish and distribution across subbasins of origin to be predetermined. Recapture information can be collected without sacrificing each fish, and lower impacts due to trapping and handling occur where automated detection stations exist.

Within the Columbia and Snake river mainstems, PIT-tag detectors at the dams 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 and 1.3). Given sufficient numbers of fish among release groups and appropriate distribution across subbasins, ESUs, hatchery *vs* wild, and outmigration season, survival rates of subgroups of fish with unique life history experience, or aggregate groups with common life history experiences can be estimated at discrete or combined life stages throughout their life cycle. The CSS PIT-tagging design and application allows the use of the Cormack-Jolly-Seber (CJS) method with multiple mark-recapture information to estimate survival of the total number of fish estimated to approach the upper most dam, and thus represent the conditions that the majority of fish migrating through the hydrosystem experienced.

Another goal of the CSS study was to compare overall survival for Snake River spring/summer Chinook with those from downriver populations which are less influenced by the hydrosystem. The upriver/downriver population comparison was initiated primarily to provide information relevant to the patterns observed in spawner-recruit (SR) patterns between upriver and downriver stream-type Chinook (e.g.,Petrosky and Schaller 1992, Schaller et al. 1999, Deriso et al. 2001, Schaller and Petrosky *in press*). These comparison of SR patterns indicated productivity and survival rates of Snake River populations declined more than those of downriver populations, coincident with development and operation of the FCRPS. The SR comparisons also provided evidence of delayed mortality of in-river migrants from the Snake River (Peters and Marmorek 2001; CSS Delayed Mortality Workshop proceedings, Marmorek et al. 2004; Schaller and Petrosky in press). Our specific interest through the CSS was whether upriver/downriver differences in overall survival for wild and/or hatchery stream-type Chinook (with more precise estimates from PIT tagged groups) were consistent with the differential mortality estimated from SR models for wild populations. We also compared biological characteristics (smolt FL, migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation.

CSS Survival Parameter Estimates

The CSS estimates a number of survival rate parameters at various life stages and estimates ratios of survival rates at various life stages. The study parameters are defined in each chapter and in the glossary in Appendix H. The key survival rates and comparative survival terms are as follows.

S is the term used for reach- or life-stage specific survival. Details on subscripts are reported in the individual chapters.

Smolt to Adult Return ratio (SAR) is the survival from a beginning point as a smolt to an ending point as an adult. SARs are calculated from LGR to LGR and can also be estimated at BON to BON or LGR, or below BON to BON.

TIR is a ratio of SARs that relates survival of transported fish to inriver migrants. The ratio is the SAR of fish transported from LGR to BON and returning as adults, divided by the SAR of fish outmigrating from LGR to BON and returning to LGR as adults.

D is the estuary and ocean survival rate of Snake River transported fish relative to fish that migrate inriver through the FCRPS. It is a ratio of SARs similar to the TIR, except the starting point for juvenile outmigrating fish is below Bonneville Dam.

Report Organization

This report has eight chapters, including the introduction, followed by eight 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 recent comments by the ISAB as well as previous reviewers.

Chapter 2 summarizes and synthesizes the results that have been obtained to date through the CSS on the responses of juvenile yearling Chinook salmon and steelhead to conditions experienced within the hydrosystem. First, we develop and summarize seasonal travel time and survival rate estimates for juvenile yearling Chinook and steelhead. Second, we develop and summarize estimates of their instantaneous (daily) mortality rates. Third, we develop models for characterizing the associations between environmental factors and fish travel time and survival. In our examination of survival, we compare two analytical approaches for characterizing temporal variation in survival rates: 1) using multiple linear regression techniques to examine the relationship between survival rates and mainstem environmental variables; and 2) integrating multiple linear regressions of fish travel time and instantaneous mortality rates (mortality per day) to mainstem environmental variables for predicting survival rates. This analysis provides an example of how the CSS PIT tag results could be used in a predictive fashion to characterize the influence of management strategies on inriver juvenile survival rates, while directly accounting for uncertainty in measurement and environmental variability.

Chapter 3 estimates SARs and makes comparisons between survival rates for groups of smolts with different hydrosystem experiences from a common start and end point. In addition, survival rates for wild and hatchery Chinook and Steelhead are compared. It provides details of a bootstrap approach to estimate the associated variances surrounding the survival estimates. Estimates are made for survival of migrating smolts over different reaches within the hydrosystem, SARs for inriver and transported smolts, and ratios of SARs. The SAR ratios are TIR ($SAR_{transport}/SAR_{inriver}$ from LGR smolts to LGR adults) and D ($SAR_{transport}/SAR_{inriver}$ from BON smolts to LGR adults). These ratios are used to evaluate the effectiveness of the transportation program. The estimates of in-river reach survivals, Ds, proportions transported, and transport survival are used to compute system survival. System survival is an index of the success of the overall juvenile downstream migration for in-river and transported fish, accounting for differential post-Bonneville survival of transported fish..

Chapter 4 combines data from multiple years of the CSS PIT tag studies to facilitate inferences about the long term distribution and expectation of SAR, TIR, and D estimates for wild Chinook and steelhead. The analysis derives distributions for key parameters representing inter-annual environmental variation in survival rates. First, these probability distributions of transport and inriver SARs are derived by treating the entire juvenile migration season as a single group. Then in order to assess the trend in survival rates over the season, the probability distributions of SARs are derived by dividing the entire juvenile migration season into three periods (early, middle, and late).

Chapter 5 presents overall SAR trends for the PIT-tagged wild and hatchery Chinook and steelhead used in the CSS and examines the extent to which wild SARs meet the regional objectives of maintaining levels from 2 to 6% (NPCC 2003) across years. Short and long-term trends in wild Chinook SARs are compared to indices of environmental conditions in the mainstem and during the early ocean life stages. Wild SARs in aggregate are also compared across broad geographic scales within the Interior Columbia Domain from the Mid-Columbia to Snake River ESUs where fish experience different outmigration conditions, yet share a common environment in the estuary and during early ocean life stages. Biological characteristics (smolt fork length (FL), migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations are also compared, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation.

Chapter 6 develops a long-term index of survival rates from release of yearling Chinook smolts at hatcheries to return of adults to hatcheries. This includes partitioning survival rates of smolts from hatchery to LGR, smolts from LGR to adult returns at LGR and adult returns at LGR back to the hatchery. The capability of estimating the relative adult passage success between Bon-LGR became possible in 2002 because adult PIT tag detection devices were completed in the adult ladders at BON and LGR. Adult migration (BON-LGR) survival is quantified for both transport and in-river study categories and tested for differences in migration survival, timing, and duration between groups. Additionally, the role of environmental factors (flow, spill, and temperature) on the upstream survival of salmon is evaluated.

Chapter 7, through two sets of simulations, investigates the impact that violations of key assumptions of the Cormack-Jolly-Seber (CJS) method may have on the ability to obtain accurate estimates of reach survival rates and other study parameters. In particular, the simulations directly address the assumptions that “all fish in a release group have equal detection and survival probabilities” (i.e., this equality is within the same inriver reach or at the same dam, and may differ across the different reaches and dams) and “previous detections have no influence on subsequent survival or detection probabilities” (i.e., no downstream difference due to whether fish were collected and bypassed as opposed to passed undetected in spill or turbines).

In the first set of simulations, the emphasis was on the population characteristics of survival rates and collection probabilities that could change over time at the dams where transportation was taking place. These are parameters that will affect how many smolts are estimated within each of the CSS's three study categories (detected and transported, detected and bypassed, or undetected at the Snake River collector dams) and thus affect estimates of SARs, TIR,and D.

In the second set of simulations, the emphasis is on the population characteristics of survival rates and collection probabilities that could change at successive dams for two subsets of the population as a result of how each subset had passed a previous dam. An additional component of this set of simulations is an assessment of how best to estimate the numbers of smolts in each of the CSS's three study categories when applying the current approach of splitting releases into two pre-assigned groups – one to reflect the experience of the untagged run-at-large, and the other to provide reach survival estimates.

Chapter 8 concludes the report by presenting key findings; describing continuing and future PIT tag-release/recapture efforts, data summarization and analyses; and recommending how to guide future study designs to address critical uncertainties and improve the reliability of CSS survival estimates for informing decisions regarding hydrosystem management actions.

Appendix A describes the logistics of tagging and releasing fish and data collection and summarization for the study. These include the sources of study fish by origin and release location, interrogation sites and years of operation, definitions of study groups and areas for which SARs were computed. The evolution of CSS logistical methods to improve estimation techniques is described in this appendix.

Appendix B presents the computational formulas for estimating the study parameters of the CSS and describes the underlying assumptions inherent in the estimates. In addition to describing the formulas for each parameter, the methods of calculating bootstrapped confidence intervals for SARs, ratios of SARs, and D are presented. The evolution of CSS statistical approaches in quantify characteristics of the population parameter estimates is described.

Appendix C describes the CSS methodology for obtaining unbiased TIR estimates. This appendix was prepared by Kristen Ryding for the CSS 2006 annual report.

Appendix D presents the entire available time series of numbers of PIT-tagged wild and hatchery juvenile Chinook salmon and steelhead used in the CSS analyses. It presents survival estimates by year, study group, and origin. Estimates of the major CSS study parameters (S, SAR, TIR, and D) are presented by species, origin, and treatment, including confidence intervals as sample sizes allow.

Appendix E presents tables of initial values, bootstrap averages, standard deviations, coefficient of variation, and 90% parametric and non-parametric confidence intervals of key CSS parameters for PIT-tagged wild Chinook 1994-2004, hatchery Chinook (individually for each facility) 1997-2004, wild steelhead 1997-2003, and hatchery steelhead 1997-2003 originating above Lower Granite Dam.

Appendix F presents plots of timing of PIT-tagged wild and hatchery Chinook and steelhead at Lower Granite Dam for upriver stocks and at Bonneville Dam for upriver and downriver stocks.

Appendix G presents details on previous reviews of the CSS and its results by the ISAB and ISRP.

Appendix H is a glossary that describes and defines the key concepts, parameters, and acronyms used in this report.

Chapter 2.

Travel Time, Survival, and Instantaneous Mortality Rates of Yearling Chinook and Steelhead through the Lower Snake and Columbia Rivers, and their Associations with Environmental Variables

Introduction

The yearling Chinook and steelhead that have been PIT-tagged through the CSS and other marking efforts allow for monitoring the effects of environmental factors and hydrosystem management actions during the juvenile life stage on these two species of management concern. Two key fish responses that can be monitored are the rate or amount of time taken to travel through various points along the migration corridor (Berggren and Filardo 1993, Smith et al. 2002) and survival rates using mark-recapture methods (Burnham et al. 1987, Smith et al. 2002).

Previous research on juvenile Snake River yearling Chinook and steelhead have identified strong associations between flow variables and migration rates (Raymond 1979, Sims and Ossiander 1981, Berggren and Filardo 1993, Smith et al. 2002). While associations between migration rates and flow variables have been well-established, several different approaches have been used to characterize the flow variables themselves: flow (Smith et al. 2002), flow^{-1} (Berggren and Filardo 1993), water transit time (FPC 2006), and flow variability (Berggren and Filardo 1993, Smith et al. 2002). Although flow variables appear to be a primary driver of migration rates, associations with other factors such as temperature, season (e.g., Julian date) and spill have also been identified (Berggren and Filardo 1993, Smith et al. 2002, FPC 2006).

Research on the factors influencing survival rates has been somewhat less conclusive. Using Snake River PIT-tag data collected between 1995 and 1999, Smith et al. (2002) concluded that correlations between river discharge and survival, and between fish travel time and survival, were neither strong nor consistent across years. However, it is important to note that high variability in the survival rate estimates (due to the use of daily release groups) and relatively high flows across years may have inhibited the identification of the proximate factors associated with survival in Smith et al. (2002). Simms and Ossiander (1981) found that when Snake River flows exceeded 100,000 ft^3/s, the survival of yearling Chinook salmon and steelhead remained somewhat constant. Smith et al. (2002) did develop a model that included flow, temperature, date, and year effects for characterizing steelhead survival.

The long-term implementation of the CSS has allowed for the monitoring of migration and survival rates of juvenile salmonids both within-seasons and across-years. During the 1998-2006 implementation of the CSS, there has been a large degree of contrast in the variables that may influence fish travel times and survival through the hydrosystem. Having greater contrast in the environmental and management factors, with replication within-seasons and across-years, should assist in the identification of the important factors that influence migration and survival rates. For yearling Chinook, tagging levels have been large enough to allow for comparisons between hatchery and wild rearing types, providing opportunity to investigate the importance of rearing type on their responses to environmental conditions during their juvenile migrations.

In this chapter, we summarize and synthesize the results that have been obtained to date through the CSS on the responses of juvenile yearling Chinook salmon and steelhead to conditions experienced within the hydrosystem. First, we develop and summarize within-season travel time and survival rate estimates for juvenile yearling Chinook and steelhead. Second, we develop and summarize estimates of within-season instantaneous (daily) mortality rates. Third, we develop models for characterizing the associations between environmental factors and fish travel time and survival. In our examination of survival, we compare two analytical approaches for characterizing temporal variation in survival rates: 1) using multiple linear regression techniques to examine the relationship between survival rates and mainstem environmental variables; and 2) integrating multiple linear regressions of fish travel time and instantaneous mortality rates (mortality per day) to mainstem environmental variables for predicting survival rates.

Methods

Yearling Chinook and steelhead used in this analysis consisted of fish PIT-tagged both at hatcheries and fish traps upstream of Lower Granite Dam (LGR) and those tagged and released at LGR. In this analysis, we define the hydrosystem as the overall reach between Lower Granite Dam and Bonneville (BON) Dam. There are six dams between LGR and BON: Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and The Dalles. We divided the hydrosystem into two reaches for summarizing fish travel time and survival: Lower Granite Dam to McNary (MCN) Dam and McNary Dam to Bonneville Dam. 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 McNary Dam.

Fish travel time

We define fish travel time (*FTT*) as the number of days spent migrating each of the two reaches, LGR-MCN and MCN-BON. We utilized a cohort-based approach for characterizing fish travel times for weekly groups of fish. 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 the number of days between release at LGR until detection at MCN for each fish detected at MCN. Because the distribution of fish travel times was often right-skewed, we used the median to characterize the central tendency of the fish travel time distributions. We used bootstrapping to estimate the variance of the median FTT_i for each weekly cohort (Efron and Tibshirani 1993). The bootstrapping procedure consisted of resampling the distribution of observed travel times, with replacement, 10,000 times and calculating the median *FTT* for each bootstrap sample. The variance of the 10,000 bootstrap samples of the median *FTT* constituted our estimate of the variance of median FTT_i for each weekly release cohort *i*. In preliminary plots of the data, we noticed exponential associations and heteroscedasticity between some of the environmental variables and median FTT_i. In order to linearize these associations, stabilize the variances, and better approximate normality for the subsequent regressions (Netter and Wasserman 1987), we also calculated median $\log_e(FTT_i)$ and used the same bootstrapping procedure described above to estimate the variance of median $\log_e(FTT_i)$. We implemented the same approach for both yearling Chinook and steelhead, for both the LGR-MCN and MCN-BON reaches.

For yearling Chinook, we calculated median 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 median FTT_i for six weekly cohorts from April 26 through June 5. For steelhead, we calculated median FTT_i for six weekly cohorts from April 17 through May 28 in the LGR-MCN reach. Hatchery and wild rearing types of steelhead were combined for both reaches. In the MCN-BON reach, we calculated median FTT_i for six weekly cohorts of steelhead from April 27 through June 7.

Survival

We used Cormack-Jolly-Seber (CJS) methods to estimate survival rates through the two reaches based on detections at the dams and in a PIT-tag trawl operating below Bonneville Dam (Cormack 1964, Jolly 1965, Seber 1965, Burnham et al. 1987). For each species and Chinook rearing type in the LGR-MCN reach, we estimated the survival rates for each weekly cohort. Due to lower numbers of PIT-tagged fish detected at MCN, we developed survival estimates for three, two-week cohorts for yearling Chinook and two, three-week cohorts for steelhead in the MCN-BON reach. We calculated Chi-square adjusted variances (using the $\hat{c}$ variance inflation factor) for each survival rate estimate ($\hat{S}$) (Burnham et al. 1987:244-246). Using this delineation for the cohorts, the average coefficient of variation (CV) across the weekly survival rate estimates in the LGR-MCN reach was 7% for wild yearling Chinook, 7% for hatchery yearling Chinook, and 13% for steelhead (combined hatchery and wild). In the MCN-BON reach, the average CV across the survival rate estimates was 14% for yearling Chinook (hatchery and wild combined, two-week cohorts) and 30% for steelhead (hatchery and wild combined, three-week cohorts). Each release cohort was identified by the Julian day of the midpoint of the cohort.

Similar to the observations on fish travel time, we noticed some exponential associations and heteroscedasticity in preliminary plots of the survival data against environmental variables. In order to linearize these associations, stabilize the variances, and better approximate normality for the subsequent regressions, we also calculated $\log_e(\hat{S})$. By definition, using a log-transformation of $\hat{S}$ assumes that $\hat{S}$ is lognormally distributed. There is both empirical evidence and a theoretical basis for assuming that a lognormal distribution is a reasonable approximation for characterizing variability in survival rates (Peterman 1981, Hilborn and Walters 1992:264-266). In addition, the log-transformation can greatly reduce the high degree of correlation between $\hat{S}$ and var($\hat{S}$) (Burnham et al. 1987:211-212). For lognormally distributed random variables, the variance of $\log_e(x)$ is (Blumenfeld 2001):

$$\mathrm{var}[\log_e(x)] = \log_e(1+[cv(x)]^2)\,. \tag{2.1}$$

Instantaneous mortality rates

Ricker (1975) provides a numerical characterization of survival:

$$S = \frac{N_t}{N_0} = e^{-Zt}, \tag{2.2}$$

where S is a survival rate, 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 total instantaneous mortality rate, in units of t^{-1}. Eqn. 2.2 is the solution to the differential equation

$$\frac{\partial N}{\partial t} = -ZN, \qquad [2.3]$$

and the instantaneous mortality rate Z can be interpreted as negative Malthusian population growth (Quinn and Deriso 1999). Rearranging Eqn. 2.2, Z can be estimated as

$$Z = \frac{-\log_e(S)}{t}. \qquad [2.4]$$

In our application, we calculated instantaneous mortality rates (in units of d^{-1}) for each survival cohort using Eqn. 2.4. We used the CJS estimates of survival for each cohort ($\hat{S}_i$) in the numerator and used the median $F\hat{T}T_i$ in the denominator of Eqn. 2.4. While individuals in each release cohort have variable individual *FTT's*, we used the median $F\hat{T}T_i$'s in the denominator of Eqn. 2.4 to characterize the cohort-level central tendency in the amount of time required to travel a reach. Combining the cohort-level survival rate estimates ($\hat{S}_i$) with the cohort-level median $F\hat{T}T_i$ estimates, we estimated the cohort-level instantaneous mortality rates using Eqn. 2.4.

Both $\hat{S}_i$ and median $F\hat{T}T_i$ are random variables subject to sampling and process error. To calculate the variance of the $\hat{Z}_i$, we used the formula for the variance of the quotient of two random variables (Blumenfeld 2001):

$$\mathrm{var}(\hat{Z}_i) = \mathrm{var}\left(\frac{x}{y}\right) \cong \left(\frac{x}{y}\right)^2 \left(\frac{\sigma_x^2}{x^2} + \frac{\sigma_y^2}{y^2} - \frac{2\,\mathrm{cov}(x,y)}{xy}\right), \qquad [2.5]$$

substituting $-\log_e(\hat{S}_i)$ for x and median $F\hat{T}T_i$ for y, with variances estimated using Eqn. 2.1 and bootstrapping, respectively.

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 group between dams was estimated, and we calculated the average flow, flow^{-1}, water transit time, spill percentage, temperature (based on tailwater TDGS monitor data) and turbidity values as indicators of conditions each group experienced while passing through the reach. Conditions at down-stream dams were averaged over a seven-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 Lower Granite to Little Goose Dam 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 Little Goose Dam were then calculated. At each downstream dam, environmental variables were calculated in a similar manner. Since no PIT-tag detection data were available until 2005 at Ice Harbor Dam, the travel time to Ice Harbor Dam was estimated as 43% of the total travel time from Lower Monumental Dam to McNary Dam (corresponding to the relative distance to Ice Harbor Dam relative to McNary Dam). The overall reach environmental variables were the average of these dam-specific calculated values for flow, flow^{-1}, spill percentage, temperature and turbidity, while for water transit time the sub-reach values were summed for a reach water transit time.

In additional to calculating physical environmental variables associated with each cohort, we also calculated several biological variables to characterize the seasonal relative abundance of various smolt categories. The Smolt Monitoring Program passage index at each of the dams provides information on the timing and relative abundance of smolts (FPC 2006). For the LGR-MCN reach, we calculated the total of the daily passage index estimates at LGR of combined (hatchery and wild) yearling Chinook, steelhead, and both species combined for each release cohort. These cohort-specific relative abundance estimates were then standardized across the season to have a mean of zero and a standard deviation of one. The same methods were used to derive standardized relative abundance estimates for the yearling Chinook cohorts in the MCN-BON reach, using the passage index values at MCN. For steelhead in the MCN-BON reach, because only two, three-week cohorts were analyzed, we calculated the relative abundances as the proportion of the three-week passage index totals passing in each cohort. For example, if the sum of the passage index at MCN for the first three-week cohort was 400,000 steelhead smolts and the sum for the second three-week cohort was 600,000 smolts, the relative abundance proportions would have been 0.4 and 0.6.

Variable selection and model building

We used linear regression techniques to evaluate the associations between the environmental variables and median *FTT*, survival (*S*), and instantaneous mortality (*Z*). Because bivariate plots indicated that median $F\hat{T}T_i's$ and $\hat{S}_i's$ may be exponential functions of the environmental variables, we modeled median $\log_e(F\hat{T}T_i)$ and $\log_e(\hat{S}_i)$ as the dependent variables. The $\log_e$ transformations were also implemented to help reduce heteroscedasticity and better approximate normality in the regressions. It was unclear whether the $\hat{Z}_i$ should be log-transformed, so we evaluated modeling both $\hat{Z}_i$ and $\log_e(\hat{Z}_i)$ as the dependent variables. To account for potential differences in the precision of the dependent variable estimates, we evaluated both weighted and unweighted regressions. There were substantial differences among the variance estimates for the $\hat{S}_i$ and $\hat{Z}_i$ across cohorts and years, but the median $F\hat{T}T_i's$ were generally quite precise (CV's typically less than 2%). For the weighted regressions, we examined weighting by the inverse-variance, inverse-CV, and inverse-CV^2.

We adopted an information-theoretic paradigm for examining the degree of association between environmental variables and the dependent variables (Burnham and Anderson 2002). For each regression that was fit, we calculated the Akaike's Information Criterion for small sample sizes (AICc) and the Bayesian Information Criterion (BIC). The AICc and BIC scores were used to evaluate the relative degree of fit for the combinations of explanatory variables examined. Combinations of explanatory variables were evaluated by their resulting AICc- and BIC-values, with lower values indicating better fits to the data. Both the AICc and BIC measure the likelihood of an approximating model, while accounting for the number of parameters estimated within the model. Our process for model building began by examining AICc and BIC scores for each variable, one at a time. Based on the results of this exercise, we then examined multiple-variable models using the top-ranked variables identified in the first round of fitting. As multiple-variable models were fit and ranked according to their AICc and BIC scores, we examined the sign of the parameter coefficients for plausibility and eliminated models with implausible coefficient signs. For example, if a model estimated a positive coefficient for the effect of flow on median *FTT*, then that model would have been deemed implausible and eliminated from further consideration. Combinations of the top-ranked variables were incorporated until the AICc and BIC scores indicated that adding additional variables did not improve model fit. While not used in the selection of variables and the model building process, we also calculated the coefficient of determination (R^2) and the adjusted coefficient of determination (R^2_{adjust}) to quantify the relative amount of the variation explained by the various candidate models.

Comparing survival modeling approaches

We evaluated two survival modeling approaches: modeling survival directly as a function of environmental variables, and modeling survival through integrated models of fish travel time and instantaneous mortality (i.e., Eqn. 2.2), with each component model being a function of environmental variables. The approach for fitting the components of the integrated models (modeling *FTT* and *Z*) is described above. We adopted a similar approach for fitting models that characterized survival directly as a function of environmental variables. Individual variables were fit and ranked according to their AICc scores, and combinations of the top-ranked variables were incorporated until the AICc and BIC scores indicated that adding additional variables did not improve fit.

Once the best-fitting sets of environmental variables had been selected for the models of both survival modeling approaches, we compared the AIC values for their degree of fit to the survival data, accounting for the number of parameters estimated.

Results

Environmental conditions across years

The environmental conditions experienced by cohorts of juvenile yearling Chinook and steelhead have varied considerably over the period of 1998-2006 (Figures 2.1 and 2.2). Over this time period in the LGR-MCN reach, flows have generally decreased, water transit times have generally increased, and the average percent spilled has generally decreased (Figure 2.1). Exceptions to these generalizations are years 2001 and 2006. In 2001, flows were low, water transit times were high, and no spill was provided at the dams. In 2006, flows were high and water transit times were low, but the average percent spill was at an intermediate level. Over the 1999-2006 time period in the MCN-BON reach, flows have generally decreased, water transit times have generally increased, and the average percent spilled has not changed appreciably. Similar to the LGR-MCN reach, exceptions to these generalizations are years 2001 and 2006. In 2001, flows were low and water transit times were high, and a small amount of spill was provided at the dams. In 2006, flows were high and water transit times were low, but spill remained similar to past years.

Fish travel time, survival, and instantaneous mortality over time

LGR-MCN reach

The median fish travel times, survival rates, and instantaneous mortality rates expressed by cohorts of juvenile yearling Chinook and steelhead have also varied considerably over the period of 1998-2006 in the LGR-MCN reach (Figures 2.3-2.5). While there are some special cases, median FTT generally decreases over the season, survival rates either remain constant (yearling Chinook) or decrease (steelhead) over the season, and instantaneous mortality rates increase over the season. Across years, median fish travel times have remained relatively constant, survival rates have generally decreased, and instantaneous mortality rates have generally increased (Figure 2.7).

Sufficient numbers of PIT-tags were available to compare the median fish travel times, survival rates and instantaneous mortality rates expressed by wild versus hatchery yearling Chinook (Figure 2.6). When aligned by release cohort, wild and hatchery yearling Chinook expressed similar median fish travel times, survival rates, and instantaneous mortality rates. There were cases where the rates differed substantially between rearing-types (e.g., survival and instantaneous mortality rate estimates for the last cohort in 1998), but these large differences were typically associated with imprecise estimates for one of the rearing types.

<u>*MCN-BON reach*</u>

In the MCN-BON reach, cohorts of yearling Chinook and steelhead expressed within-season median fish travel time patterns similar to those in the LGR-MCN reach (Figure 2.11). Median FTT generally decreased over the migration season, but steelhead in 1999 and 2000 maintained low median FTTs throughout the season. Yearling Chinook in 2001 demonstrated the largest within-season variation in median FTTs, ranging from 20 days early in the season to 6 days late in the season. Due to imprecision in the survival rate estimates, patterns in the survival rates and instantaneous mortality rates in the MCN-BON reach are difficult to discern (Figures 2.12-2.13). For steelhead, survival rates generally decrease over the season and instantaneous mortality rates generally increase over the season. However, for yearling Chinook no general patterns were evident in either the survival rates or instantaneous mortality rates.

Modeling median FTTs

<u>*LGR-MCN reach*</u>

Models that included WTT, average percent spill, and Julian day explained 81-92% of the variation in median *FTTs* (Figure 2.8, Tables 2.1, 2.4, 2.7-2.9). For wild Chinook, hatchery Chinook, and hatchery and wild steelhead, median FTTs decreased with Julian day and the average percent spilled, and increased with WTT (Table 2.4). The proportion of variation in median FTTs explained was highest for wild Chinook ($R^2 = 0.92$), followed by hatchery and wild steelhead ($R^2 = 0.90$) and hatchery and wild Chinook ($R^2 = 0.81$) (Table 2.1). Of the three ways of characterizing flow (i.e., WTT, $flow^{-1}$, and flow), WTT best explained variation in median FTTs, followed closely by $flow^{-1}$ and then by flow (Tables 2.7-2.9).

<u>*MCN-BON reach*</u>

Similar to the results for the LGR-MCN reach, models that included WTT, average percent spill, and Julian day explained 91-95% of the variation in median *FTTs* (Figure 2.14, Tables 2.1, 2.4, 2.13-2.14). For both species, median FTTs decreased with Julian day and the average percent spilled, and increased with WTT (Table 2.4). The proportion of variation in median FTTs explained was higher for Chinook (R2 = 0.95) than for steelhead (R2 = 0.90). Also similar to the LGR-MCN results, WTT explained more of the variation in median FTTs than did $flow^{-1}$ or flow (Tables 2.13-2.14).

<u>Modeling instantaneous mortality rates and survival</u>

LGR-MCN reach

For wild Chinook and hatchery Chinook, models that included Julian day and WTT explained 41-48% of the variation in *Zs* (Figure 2.10, Tables 2.1, 2.5, 2.10-2.11). For hatchery and wild steelhead, a model that included Julian day, flow, and the average percent spilled explained 54% of the variation in Zs (Figure 2.10, Tables 2.1, 2.5, 2.12).

Combining the models for the median FTTs and Zs and using Eqn. 2.2 explained 52-81% of the variation in survival rates of Chinook and steelhead (Figure 2.9, Table 2.1). More variation could be explained in steelhead survival rates ($R^2 = 0.81$) than in wild Chinook ($R^2 = 0.61$) or hatchery Chinook ($R^2 = 0.52$).

The models for characterizing instantaneous mortality rates provide information on how and why mortality rates may vary (Figure 2.17). For wild Chinook in the LGR-MCN reach, instantaneous mortality rates are estimated to remain low throughout the season when water transit times are short (5-d). As water transit times get longer, instantaneous mortality rates rise rapidly over the season.

MCN-BON reach

For hatchery and wild Chinook, a model that included Julian day explained 15% of the variation in Zs (Figure 2.16, Tables 2.1,2.5,2.15). For hatchery and wild steelhead, a model that included temperature explained 52% of the variation in Zs (Figure 2.16, Tables 2.1, 2.5, 2.16).

Combining the models for the median FTTs and Zs and using Eqn. 2.2 explained 52-70% of the variation in survival rates of Chinook and steelhead (Figure 2.15, Table 2.1). More variation could be explained in steelhead survival rates ($R^2 = 0.70$) than in Chinook survival rates ($R^2 = 0.52$).

Comparison of survival modeling approaches

Integrating models of FTT and instantaneous mortality resulted in lower AIC scores than models that modeled survival directly for wild Chinook and hatchery and wild steelhead in the LGR-MCN reach (Table 2.2). In general, the same variables were selected using the two approaches (e.g., combinations of WTT, average spill and Julian day) and the integrated approach required the estimation of more parameters than the approach of modeling survival directly. But despite the additional parameters, the AIC scores were 3-16 AIC points lower for the integrated approach. In addition, the integrated approach lends itself to developing an understanding of how and why mortality rates, and hence survival rates, may be changing over time (Figures 2.10, 2.16).

Discussion

In this analysis we provided an extensive synthesis of the patterns of variation in juvenile yearling Chinook and steelhead fish travel time and survival within the hydrosystem. In addition to these commonly-used metrics, we developed and reported estimates of instantaneous mortality rates for these two species in two reaches within the hydrosystem. We found substantial variation in median fish travel time, survival, and instantaneous mortality rates both within-seasons and across years.

We then developed models for characterizing the observed variation in median fish travel times, survival rates and instantaneous mortality rates. Our approach provides a useful characterization of the seasonal and annual changes in median FTT, instantaneous mortality rates (Z) and survival. In general, we were able to explain most of the variation in median fish travel times through combinations of water transit time, Julian day and average percent spilled. We were also able to explain a large proportion of the variation in instantaneous mortality rates through combinations of WTT, Julian day, average percent spilled, flow, and temperature.

Through the identification of the proximate factors associated with the observed variation, these models may improve the understanding of the mechanistic causes of this variation.

Several patterns have emerged from the examination of instantaneous mortality rates. First, for both species, instantaneous mortality rates in the MCN-BON reach are roughly double those in the LGR-MCN reach (Table 2.3). This means that one additional day spent in the lower reach will result in twice the level of mortality that would occur with an additional day spent in the upper reach. Average instantaneous mortality rates in the lower reach are 11.2% for steelhead. This implies that a half-day reduction in median FTT would result in 5.6% mortality instead of 11.2% mortality. Second, for both reaches, instantaneous mortality rates of steelhead are roughly double those of yearling Chinook (Table 2.3). This means that for each day spent in the upper segment, an average of 7% of the juvenile steelhead versus 3% of the yearling Chinook will perish. For each day spent in the lower segment, an average of 11.2% of the juvenile steelhead versus 6.6% of the yearling Chinook will perish.

We found that estimates of survival in the MCN-BON reach have substantial uncertainty. As a result, estimates of instantaneous mortality rates in this reach also have substantial uncertainty. More effort (PIT-tags) is needed in the lower reach for reducing this uncertainty. Given that temperature was not identified as a primary factor in the upper reach where the data were more precise, the identification of temperature in the lower reach as a primary determinant of instantaneous mortality rates in steelhead may be a spurious correlation. Temperature is highly correlated with the factors identified as influencing mortality rates in the upper reach (i.e., WTT and Julian date). A model based on WTT and Julian day was capable of explaining 80% of the variation in temperature in the lower river (Table 2.6). Alternatively, the factors influencing mortality rates in the lower reach may be different than those operating in the upper reach. Either way, additional PIT-tagging efforts or allowing a higher proportion of fish to migrate in-river through the Snake and Columbia rivers would certainly help resolve some of these questions.

The models developed here provide useful tool for predicting the effects of alternative hydrosystem management actions. Some of these could include changes in water volume, volume shaping/timing, spill levels and timing, or changes in reservoir elevations. At a minimum, these models provide a basis for hypothesis development for use in adaptive management experiments on the hydrosystem.

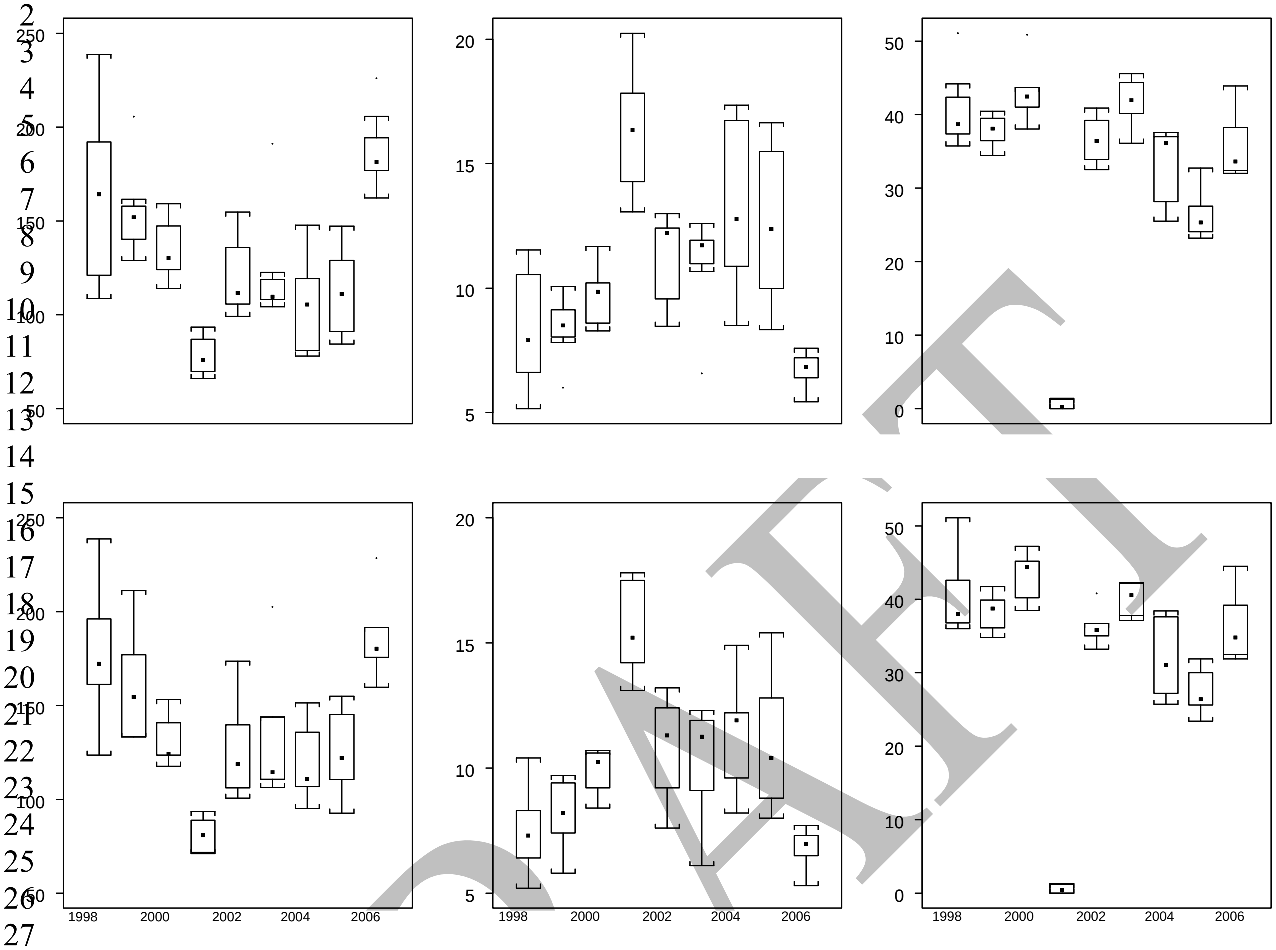


Figure 2.1. Boxplots of flow (left column, KCFS), water transit time (center column, days) and average percent spill (right column, %) experienced by cohorts of wild yearling Chinook (top row) and hatchery and wild steelhead (bottom row) in the LGR-MCN reach during 1998-2006.

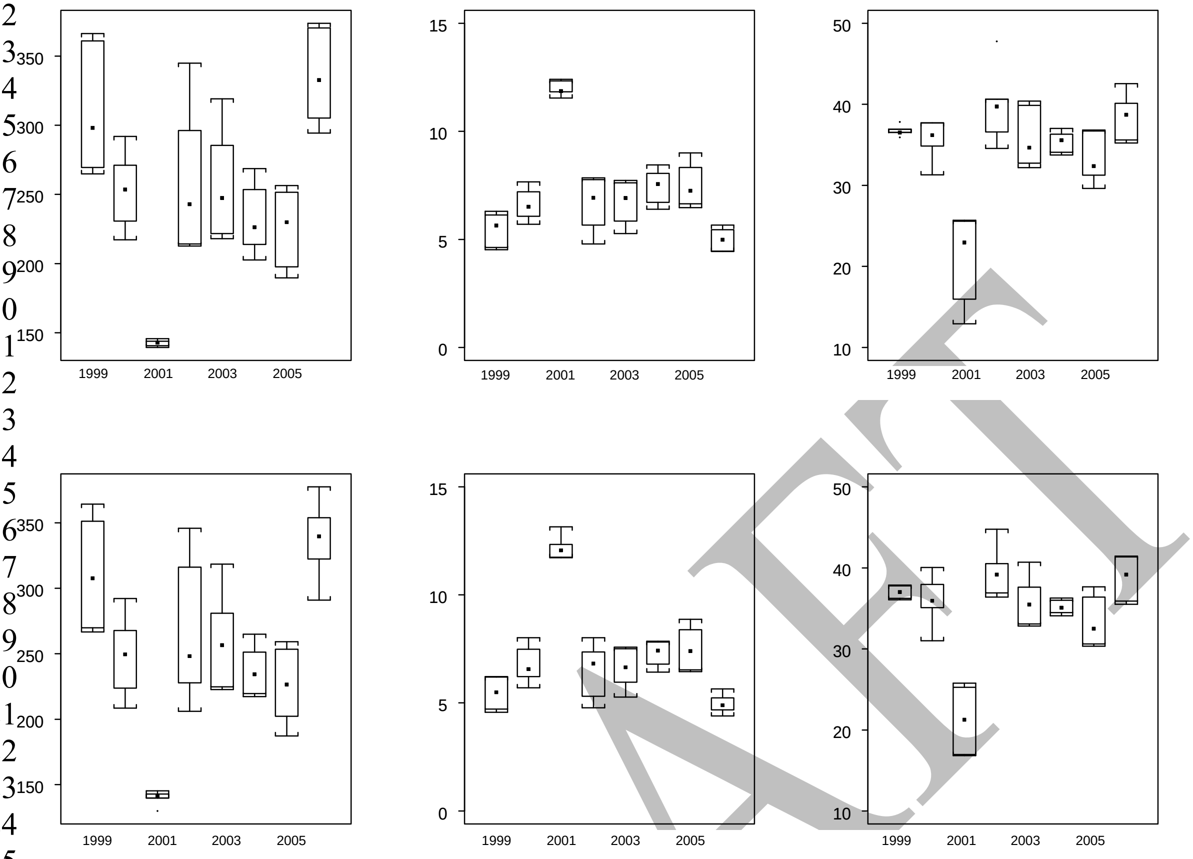


Figure 2.2. Boxplots of flow (left column, KCFS), water transit time (center column, days) and average percent spill (right column, %) experienced by cohorts of hatchery and wild yearling Chinook (top row) and steelhead (bottom row) in the MCN-BON reach during 1999-2006.

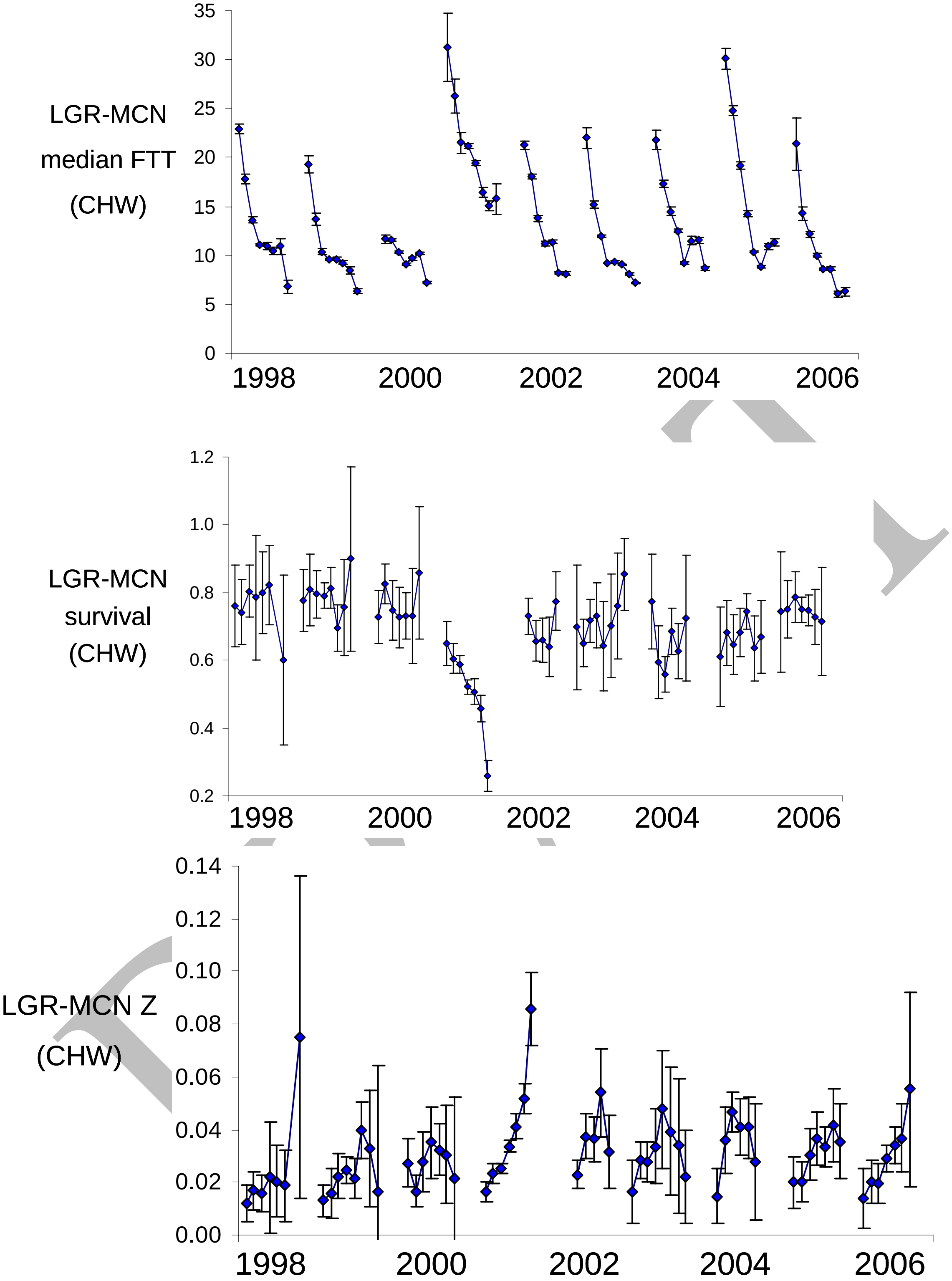


Figure 2.3. Estimates of median FTT, survival rates and instantaneous mortality rates for wild yearling Chinook in the LGR-MCN reach. Estimates are plotted with their corresponding 95% confidence intervals.

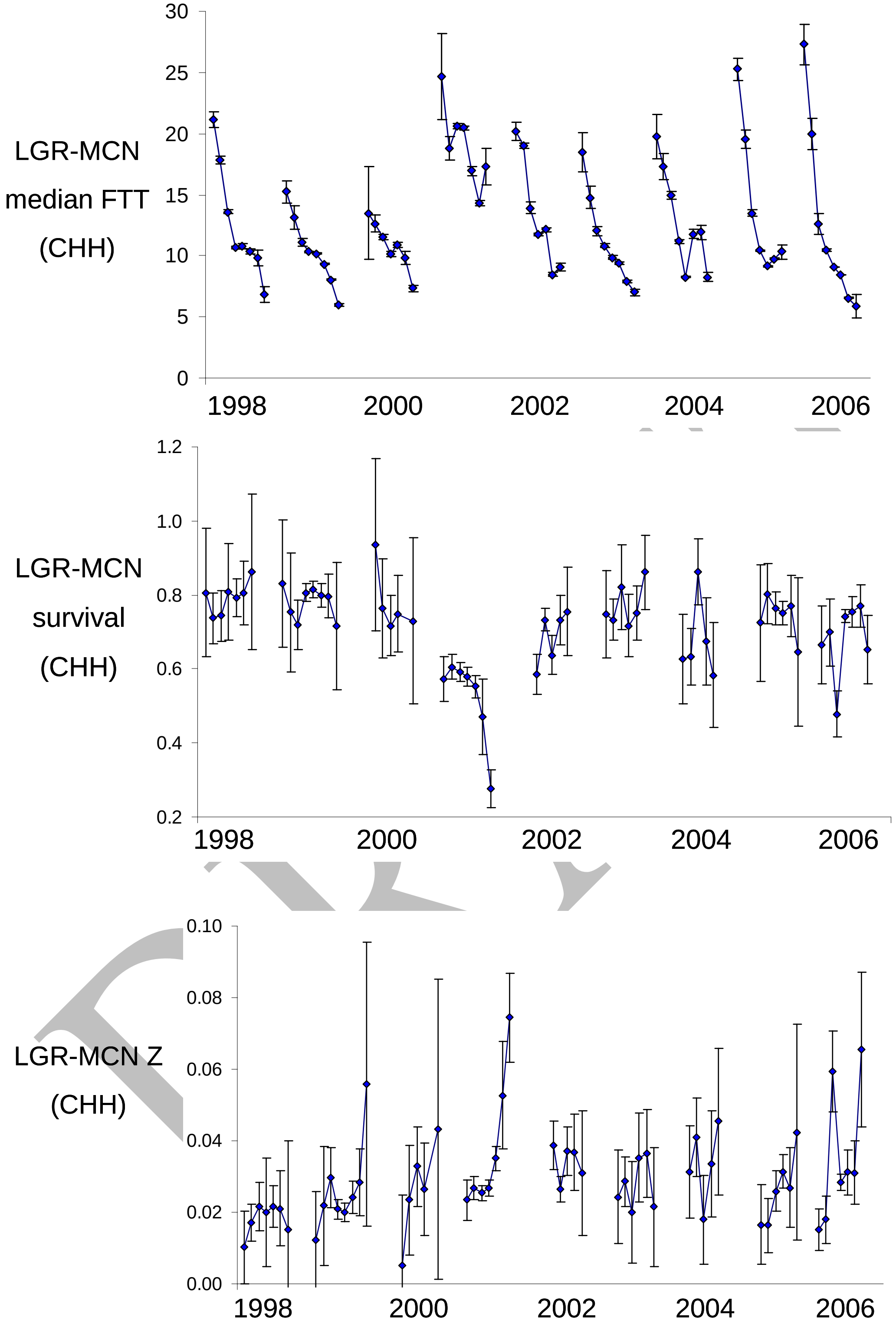


Figure 2.4. Estimates of median FTT, survival rates and instantaneous mortality rates for hatchery yearling Chinook in the LGR-MCN reach. Estimates are plotted with their corresponding 95% confidence intervals.

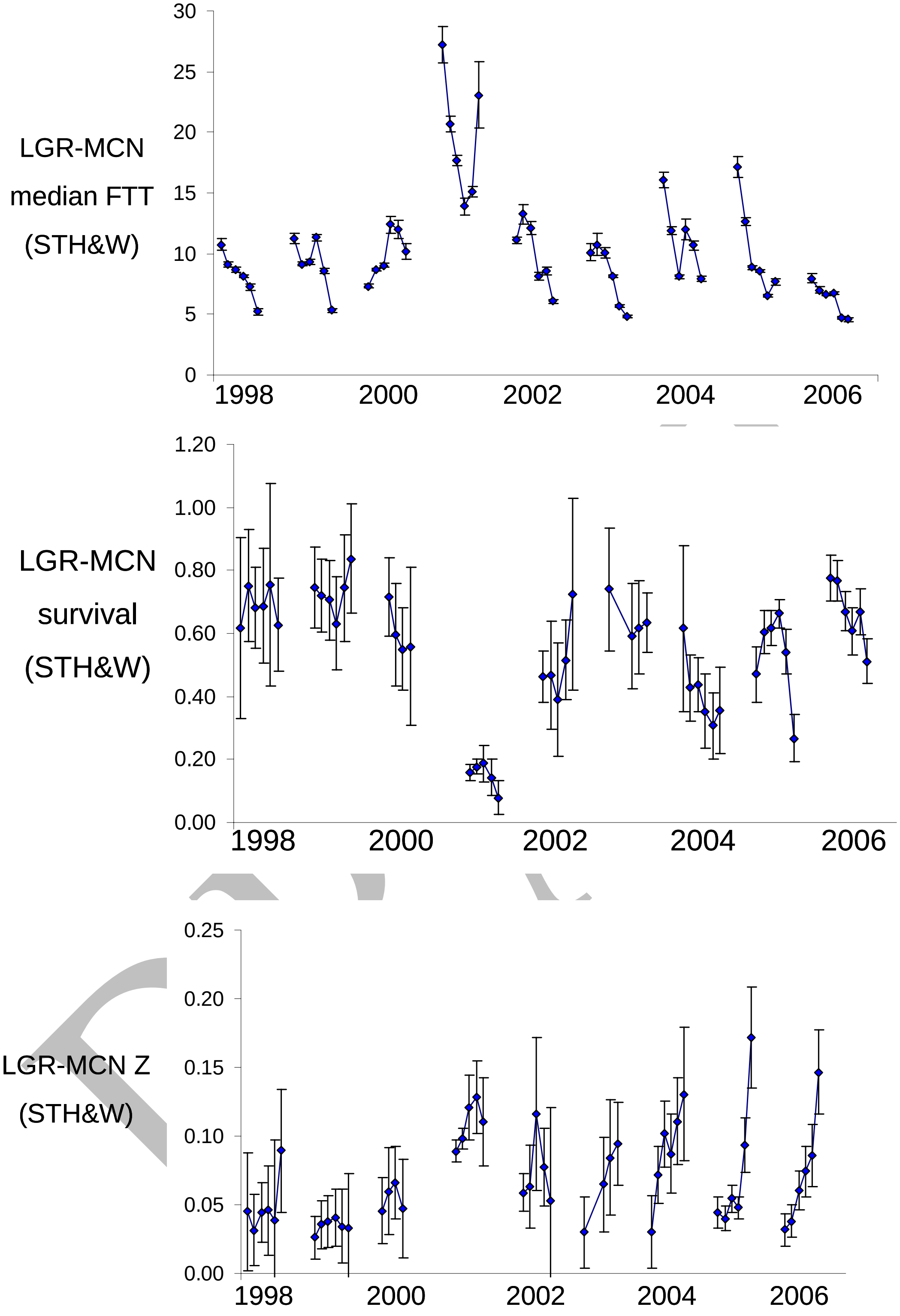


Figure 2.5. Estimates of median FTT, survival rates and instantaneous mortality rates for hatchery yearling Chinook in the LGR-MCN reach. Estimates are plotted with their corresponding 95% confidence intervals.

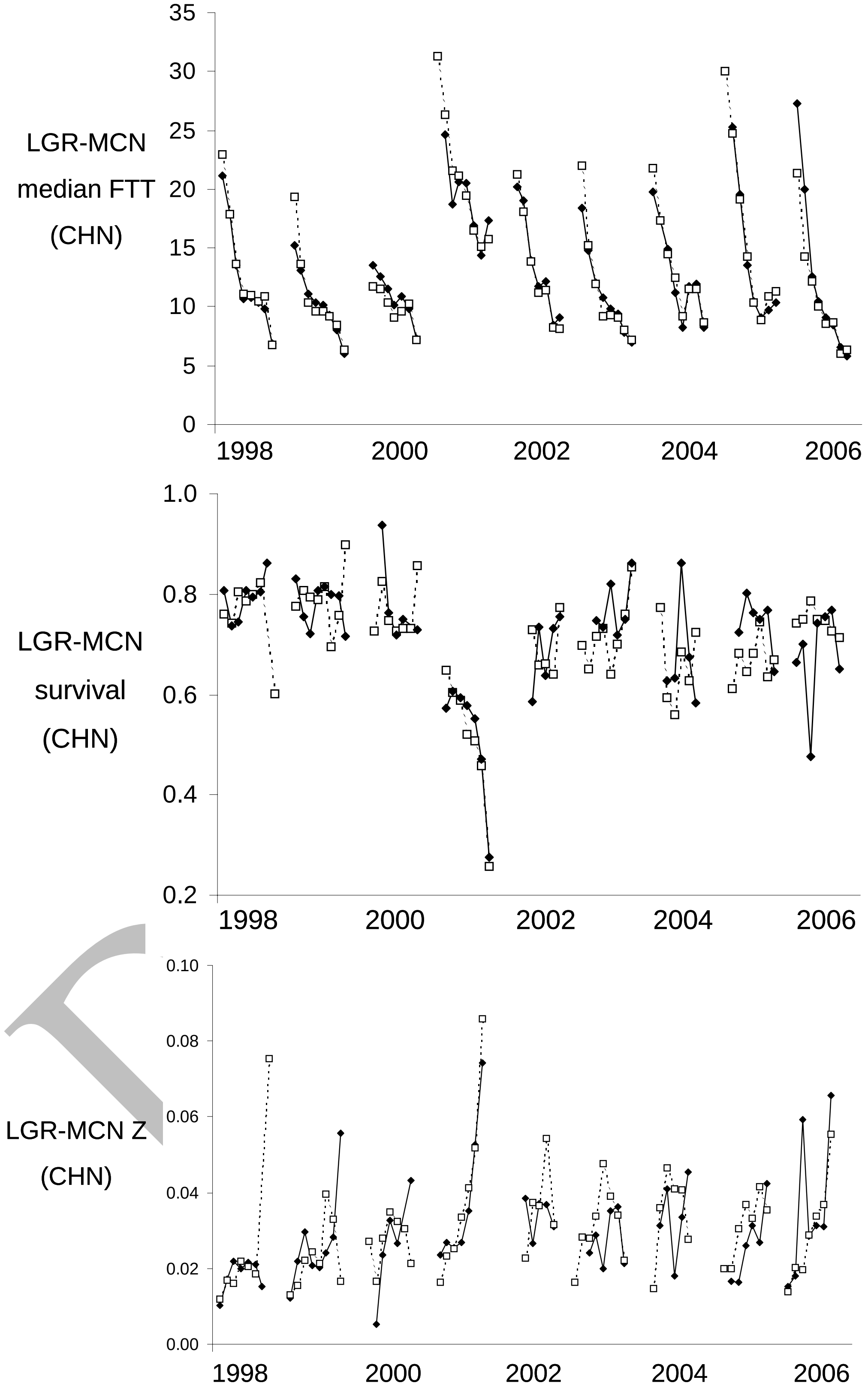


Figure 2.6. Estimates of median FTT, survival rates and instantaneous mortality rates for wild (open squares) and hatchery (closed diamonds) yearling Chinook in the LGR-MCN reach.

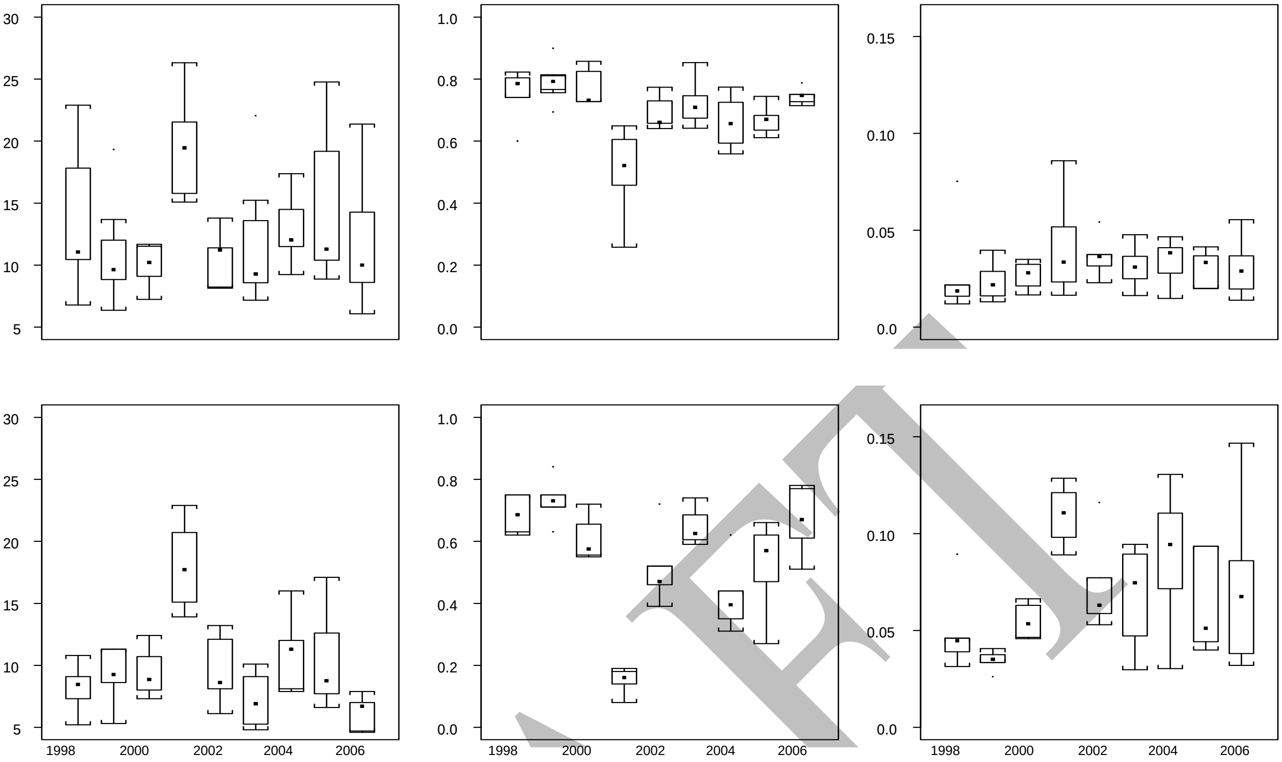


Figure 2.7. Boxplots of LGR-MCN estimates of median fish travel time (left column, days), survival (middle column) and instantaneous mortality (Z) (right column) for cohorts of wild yearling Chinook (upper row), hatchery and wild steelhead (lower row) for migration years 1998-2006.

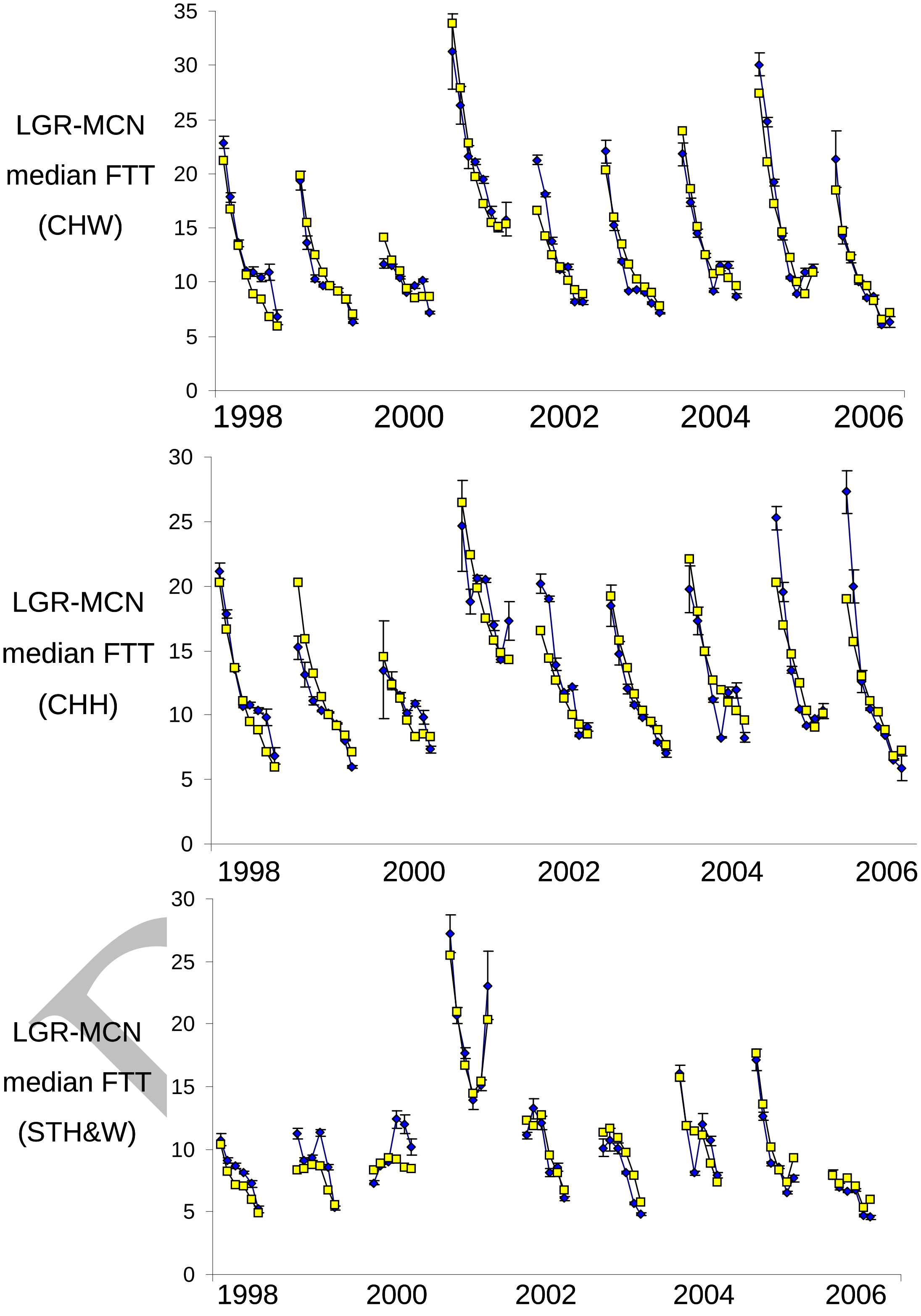


Figure 2.8. Observed LGR-MCN median FTT (d) (filled diamonds, with 95% confidence intervals) and model predictions for median FTT (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006.

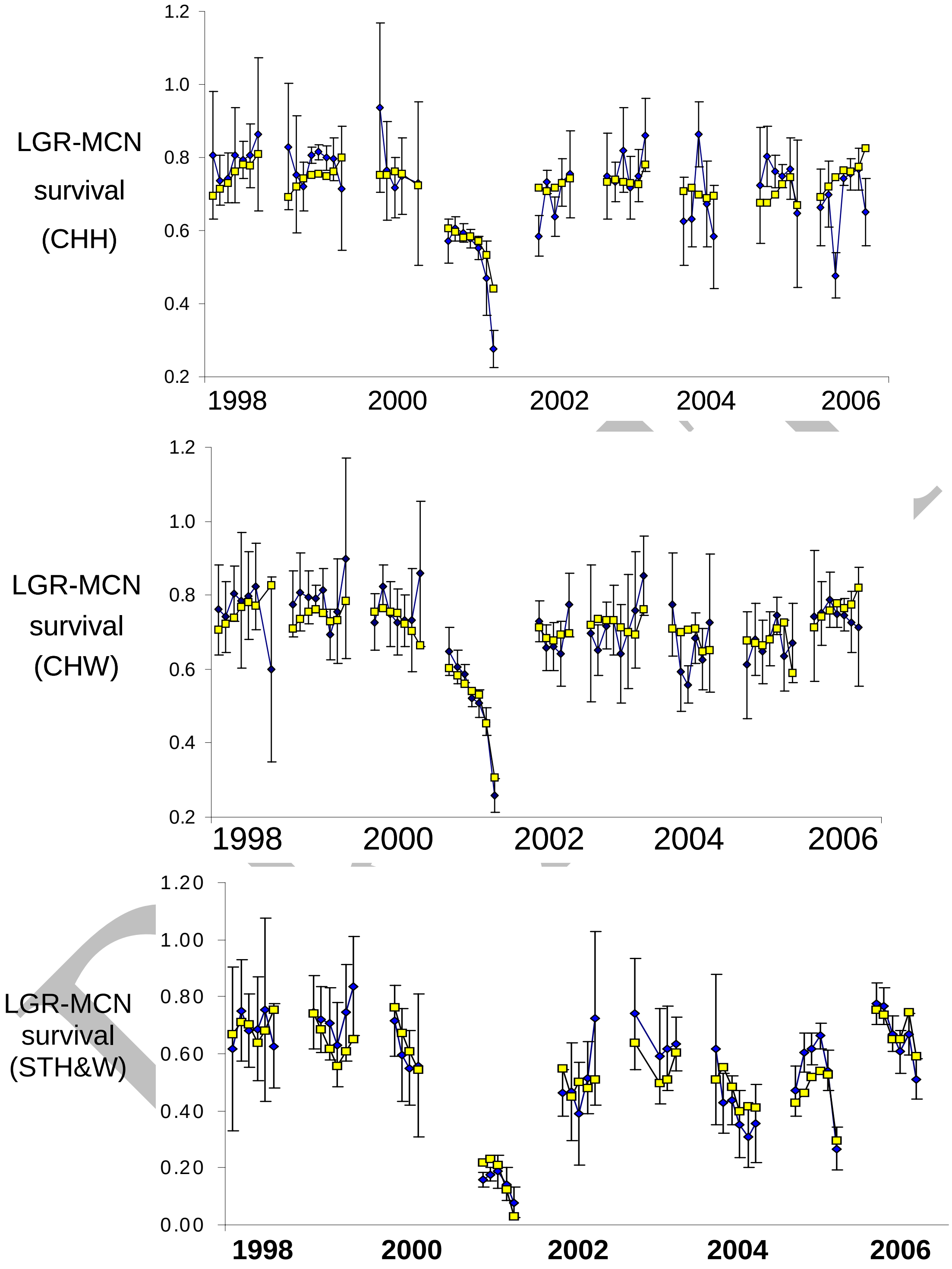


Figure 2.9. Observed LGR-MCN survival (filled diamonds, with 95% confidence intervals) and model predictions for survival (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006.

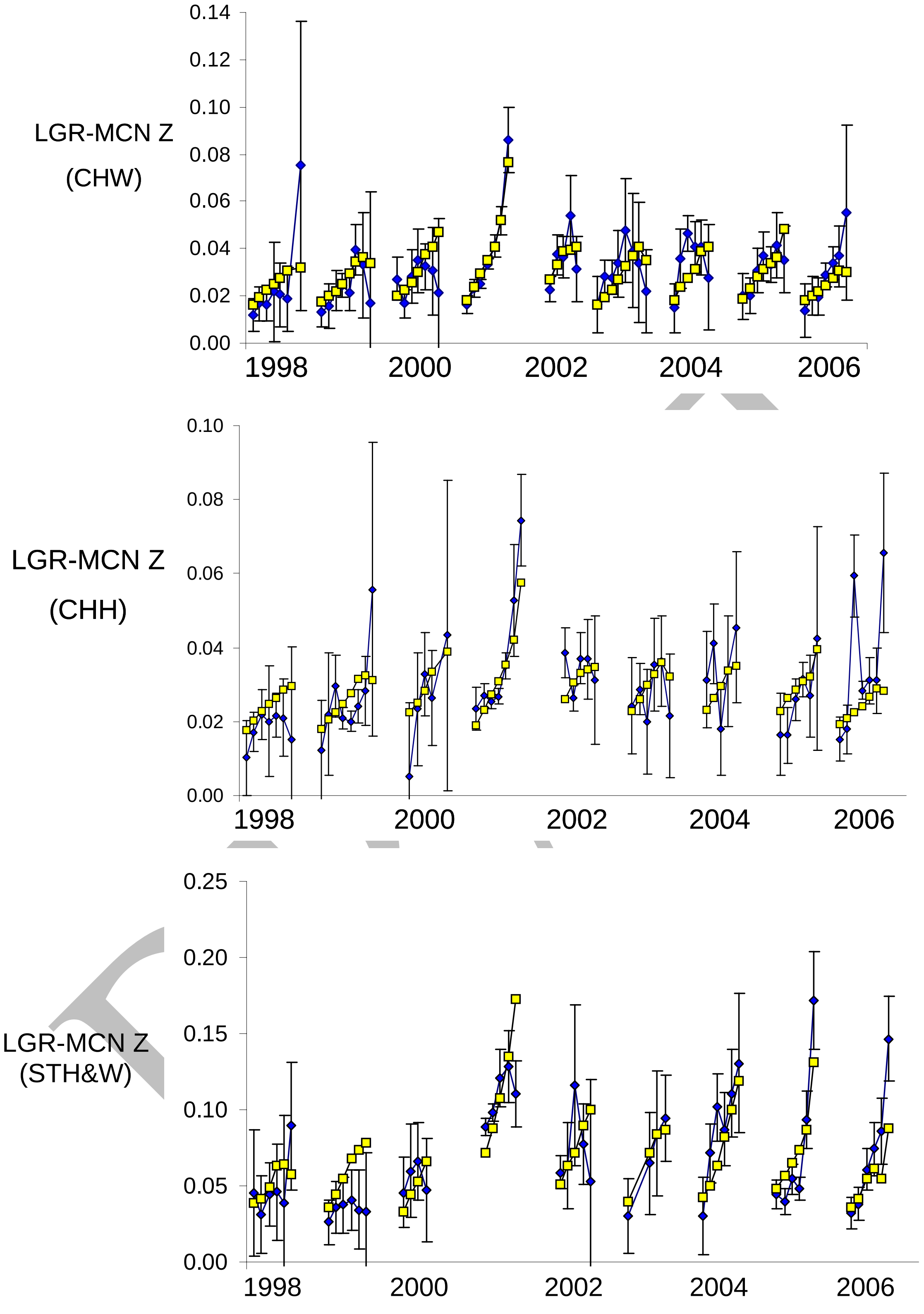
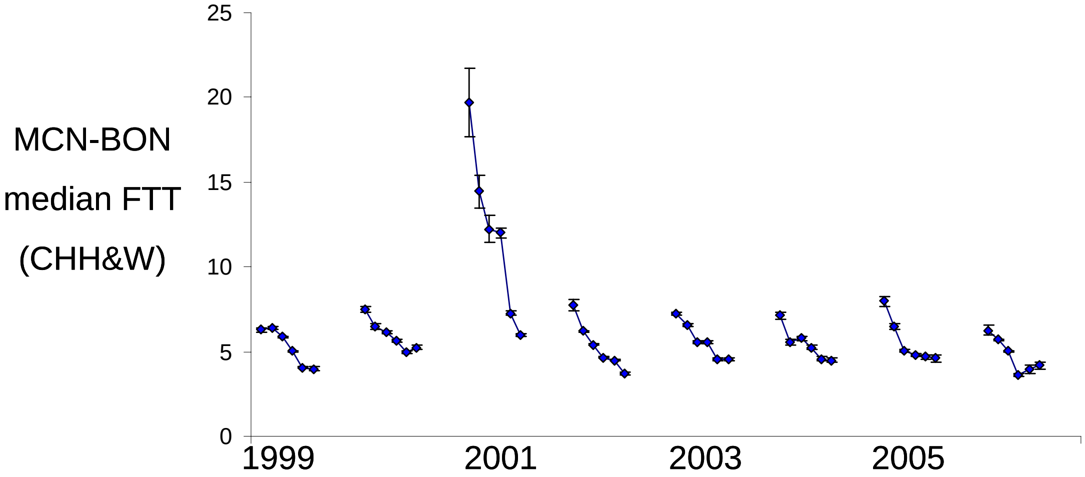


Figure 2.10. Observed LGR-MCN Z (filled diamonds, with 95% confidence intervals) and model predictions for Z (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006.



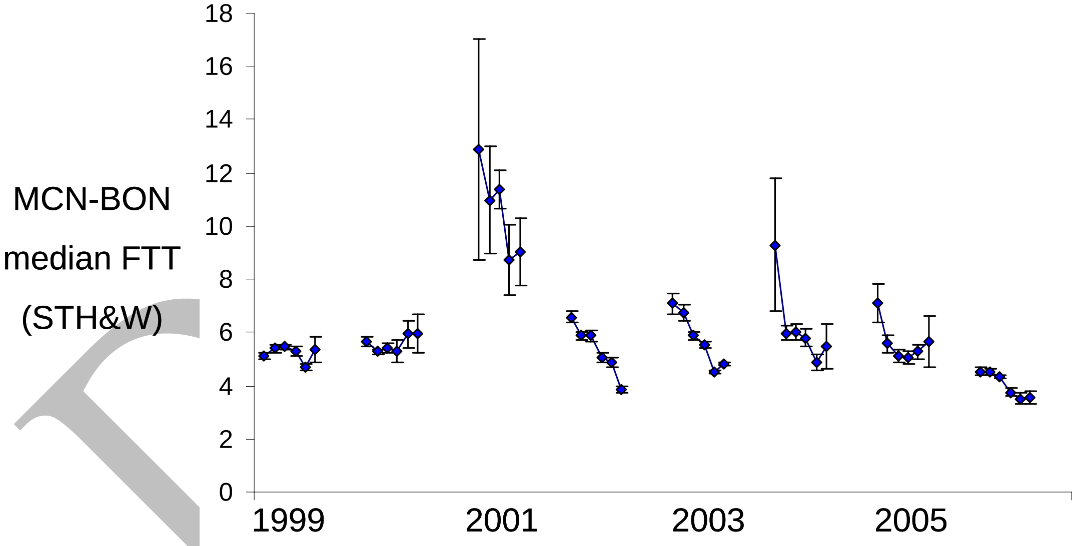


Figure 2.11. MCN-BON median FTT (d) with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006.

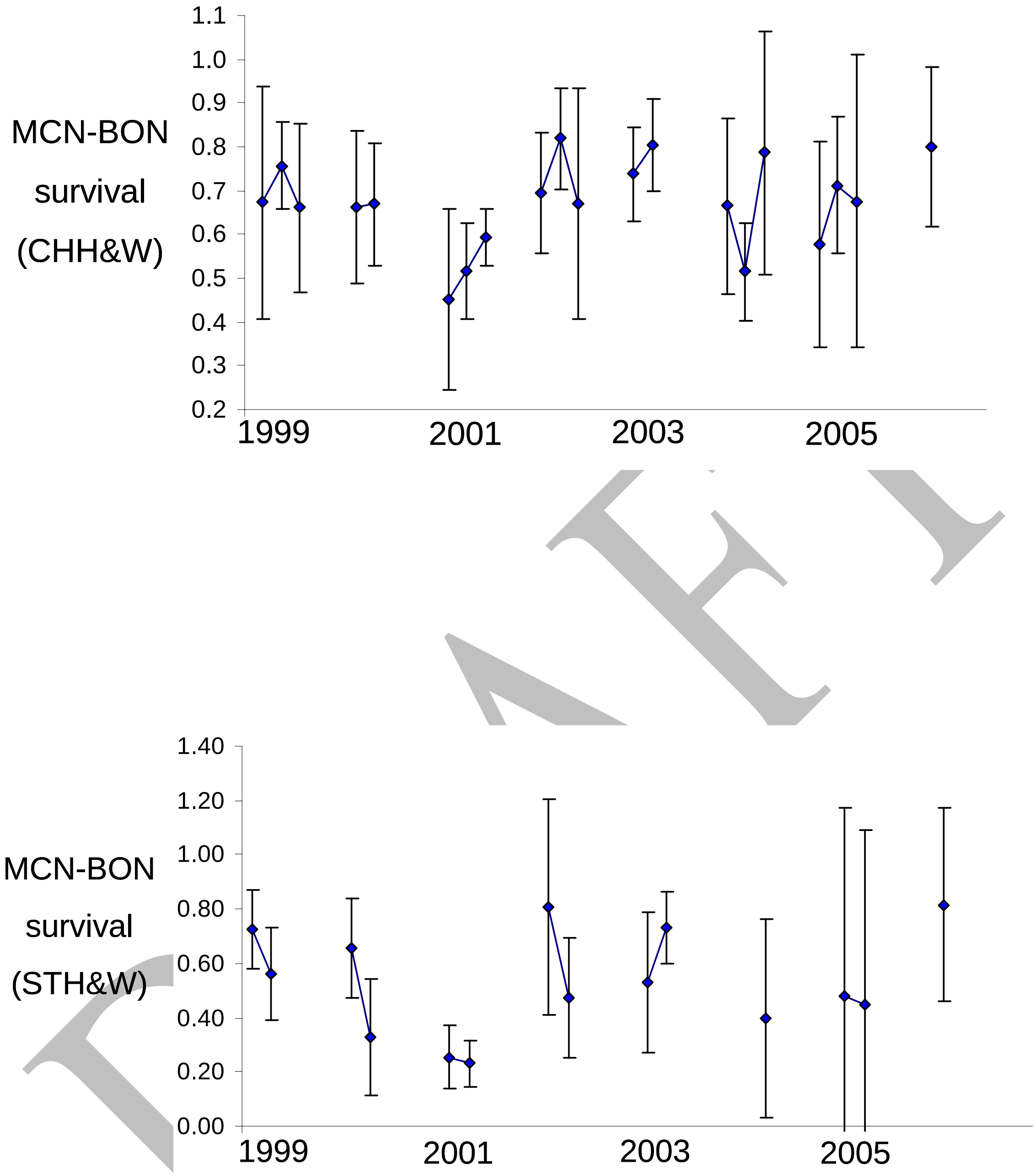


Figure 2.12. MCN-BON survival with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

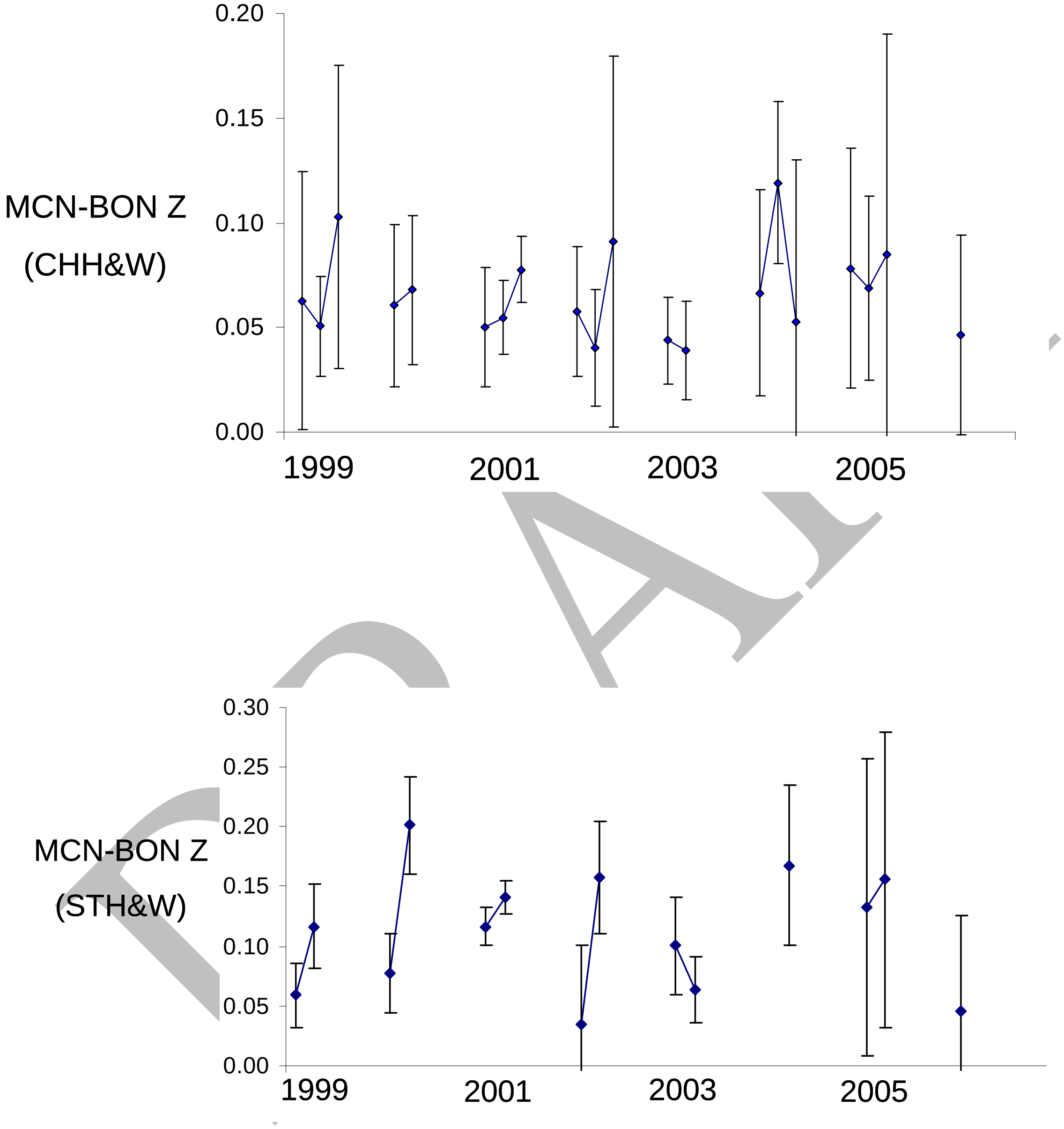


Figure 2.13. MCN-BON Z with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

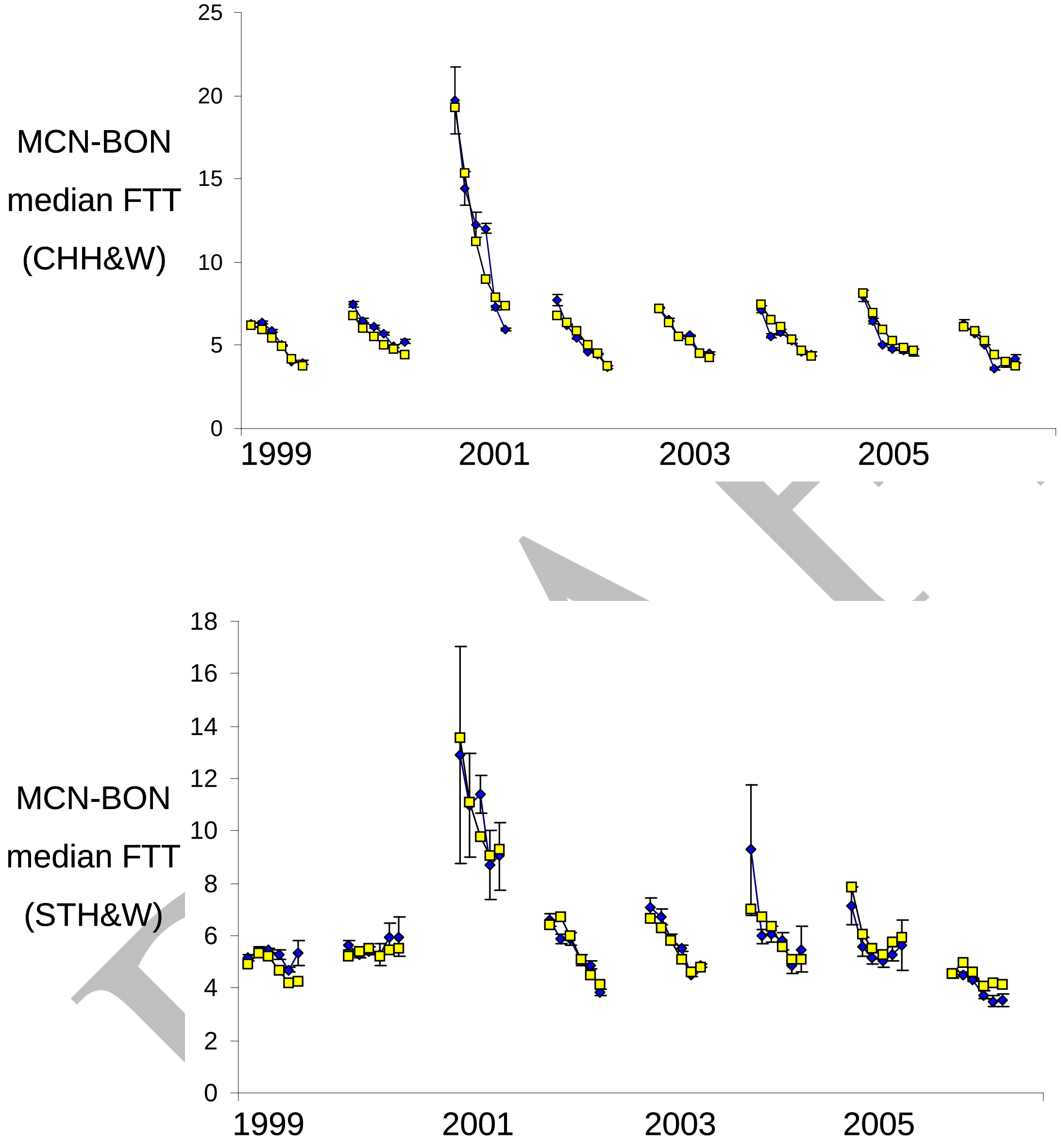


Figure 2.14. Observed MCN-BON median FTT (d) (closed diamonds) with 95% confidence intervals and predicted median FTT (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006.

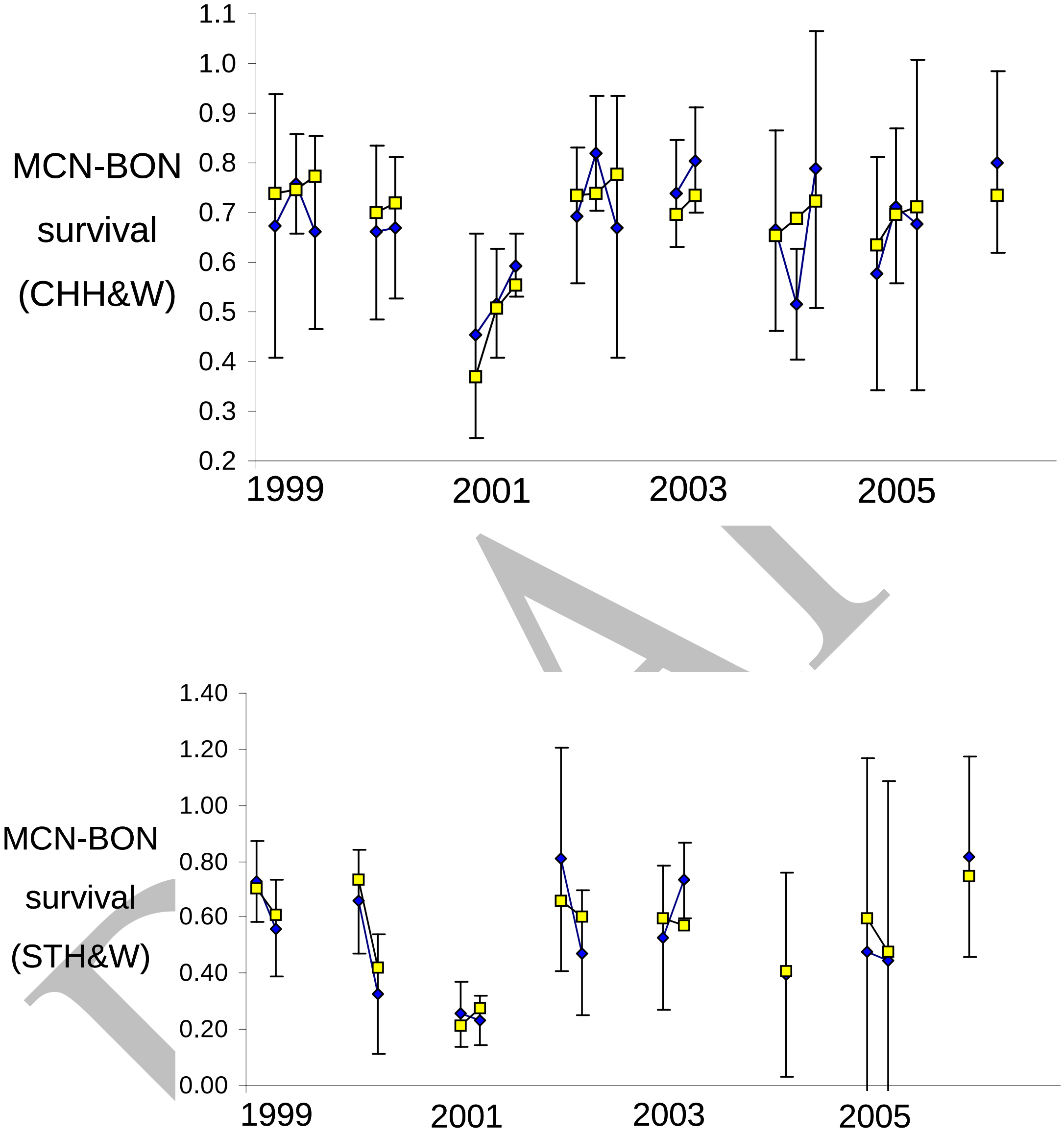


Figure 2.15. Observed MCN-BON survival (closed diamonds) with 95% confidence intervals and predicted survival (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

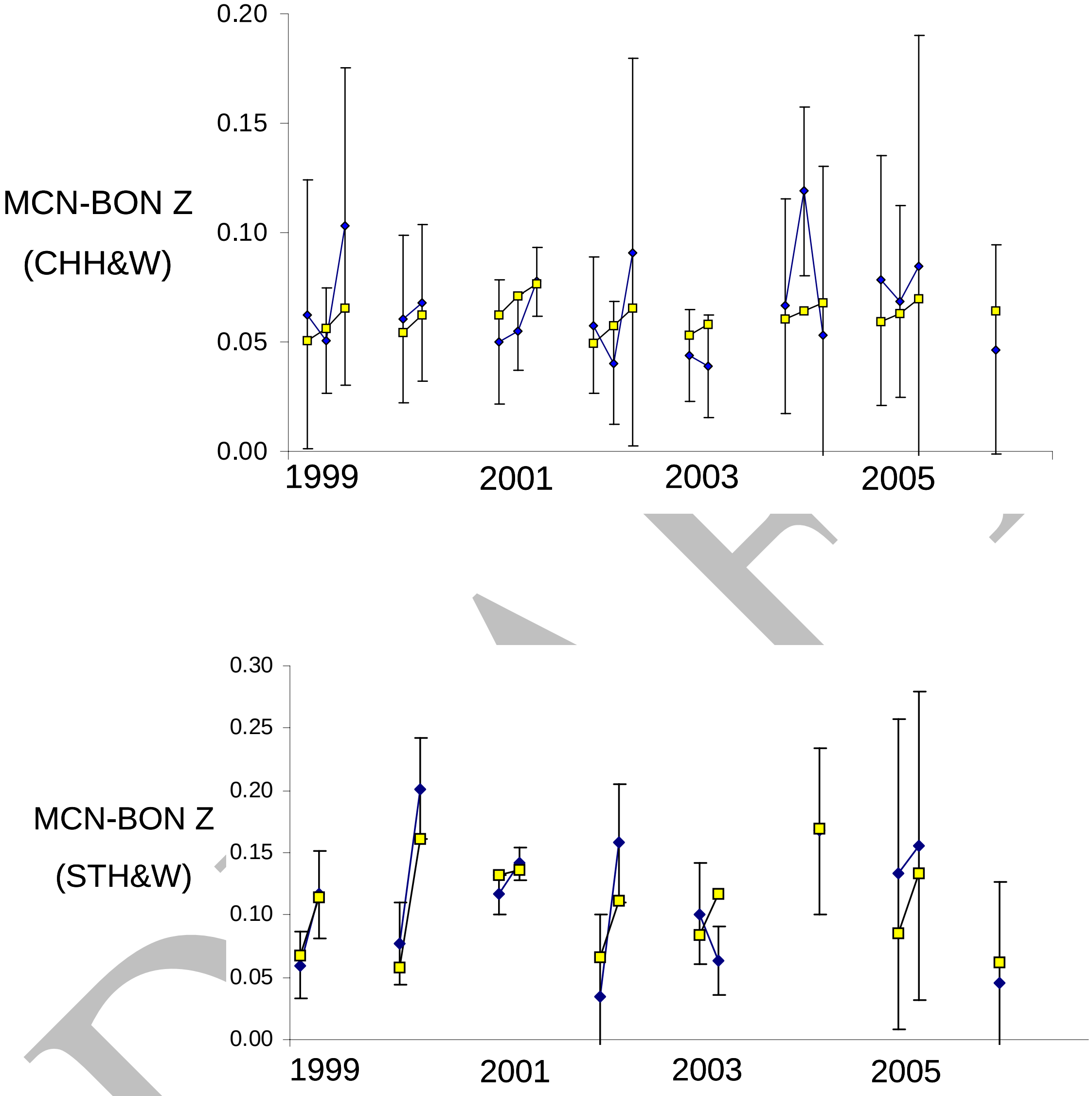


Figure 2.16. Observed MCN-BON Z (closed diamonds) with 95% confidence intervals and predicted Z (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

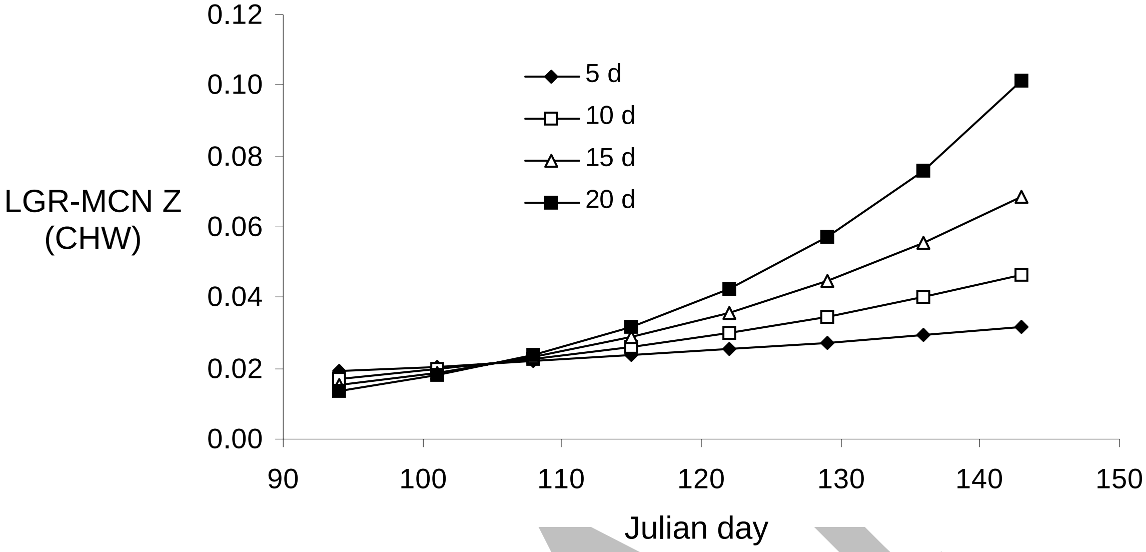


Figure 2.17. Model predictions of LGR-MCN Z for wild yearling Chinook as a function of Julian day and LGR-MCN water transit times of 5-, 10-, 15-, and 20-d.

Table 2.1. Proportion of variation explained (R^2 values) for the models characterizing yearling Chinook and steelhead survival, instantaneous mortality (Z), and median FTT in the LGR-MCN and MCN-BON reaches.

Reach	Species & rearing type	Survival	Z	Median FTT
LGR-MCN	CHW	0.61	0.48	0.92
LGR-MCN	CHH	0.52	0.41	0.81
LGR-MCN	STH&W	0.81	0.54	0.90
MCN-BON	CHH&W	0.52	0.15	0.95
MCN-BON	STH&W	0.70	0.52	0.91

Table 2.2. Comparison of AIC values and number of parameters estimated for the two survival modeling approaches evaluated, for hatchery and wild steelhead and wild Chinook in the LGR-MCN reach.

	STH&W		CHW	
Survival modeling approach	AIC	Parameters	AIC	Parameters
Integrating FTT & Z models	-223.4	9	-321.5	10
Modeling survival directly	-220.3	7	-305.0	6

Table 2.3. Mean and median observed Z across cohorts and years for wild yearling Chinook, hatchery yearling Chinook and combined hatchery and wild steelhead in the LGR-MCN reach, and combined hatchery and wild yearling Chinook and steelhead in the MCN-BON reach.

	LGR-MCN			MCN-BON	
	CHW	CHH	STH&W	CHH&W	STH&W
mean Z	0.031	0.029	0.069	0.066	0.112
median Z	0.029	0.027	0.060	0.061	0.117

Table 2.4. Parameter estimates and equations characterizing median fish travel time (FTT) in the LRG-MCN and MCN-BON reaches for juvenile Chinook and steelhead.

Species & rearing type		LGR-MCN reach					
		Intercept	julian	julian^2	wtt	wtt^2	avg.spill
CHW	log (med.FTT) =	9.88113	-0.11467	0.00041	0.10396	-0.00323	-0.01125
		Intercept	julian	julian^2	wtt	wtt^2	avg.spill
CHH	log (med.FTT) =	8.66140	-0.09052	0.00031	0.08991	-0.00304	-0.01214
		Intercept	julian	wtt	avg.spill		
STH&W	log (med.FTT) =	2.14389	-0.00530	0.09391	-0.00513		

Species & rearing type		MCN-BON reach					
		Intercept	julian	wtt	wtt^2	avg.spill	avg.spill^2
CHH&W	log (med.FTT) =	4.54247	-0.01316	0.02353	0.00253	-0.06485	0.00076
		Intercept	wtt	julian	wtt:julian	avg.spill	
STH&W	log (med.FTT) =	-0.06639	0.38787	0.00844	-0.00198	-0.00480	

Table 2.5. Parameter estimates for equations characterizing instantaneous mortality rates (Z) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.

Species & rearing type		LGR-MCN reach		
		Intercept	wtt	julian:wtt
CHW	log (Z) =	-3.84782	-0.21805	0.00207
		Intercept	wtt	julian:wtt
CHH	log (Z) =	-3.80965	-0.16449	0.00154
		Intercept	julian^2	flow:avg.spill
STH&W	log (Z) =	-4.26255	0.000119	-9.0483E-05

Species & rearing type		MCN-BON reach	
		Intercept	julian
CHH&W	Z =	-0.04554	0.00084
		Intercept	temp
STH&W	Z =	-0.11920	0.01684

Table 2.6. Parameter estimates for model characterizing temperature in the MCN-BON reach.

	MCN-BON reach		
	Intercept	julian	wtt
temperature =	-3.30935	0.10885	0.28529

Table 2.7. CHW FTT, LGR-MCN

vars	AIC	BIC	rsq	rsq.a
ju,jusq,wt,wtsq,sp	-77.7	-62.0	0.92	0.92
ju,jusq,wt,sp	-73.1	-59.6	0.89	0.88
ju,wt,sp	-55.5	-44.3	0.85	0.85
ju,jusq,sp	-54.6	-43.4	0.86	0.86
ju,jusq,wt	-43.8	-32.6	0.83	0.83
ju,jusq,wt,wtsq	-41.9	-28.4	0.83	0.82
ju,jusq,fl	-37.0	-25.8	0.82	0.82
ju,jusq,tu	-15.2	-3.9	0.76	0.75
ju,jusq,te	-8.2	3.0	0.72	0.71
ju,jusq	8.3	17.3	0.63	0.62
ju	12.6	19.3	0.58	0.58
wt	23.8	30.5	0.54	0.54
inv.fl	24.5	31.2	0.52	0.52
fl	34.3	41.0	0.43	0.43
sp	53.4	60.1	0.26	0.26
te	61.8	68.5	0.14	0.14
tu	67.7	74.4	0.08	0.08

Table 2.8. CHH FTT, LGR-MCN

vars	AIC	BIC	r.sq	r.sq.a
ju,jusq,wt,wtsq,sp	-56.8	-41.2	0.81	0.80
ju,jusq,wt,sp	-54.6	-41.2	0.79	0.78
ju,wt,sp	-48.2	-37.1	0.76	0.75
ju,fl,sp	-48.0	-36.9	0.76	0.76
ju,wt,sp,spsq	-47.4	-34.1	0.75	0.74
ju,wt,sp,wtsq	-47.2	-33.9	0.77	0.76
ju,sp	-43.7	-34.8	0.76	0.76
ju,wt	-25.0	-16.1	0.65	0.64
ju,fl	-19.6	-10.8	0.63	0.63
ju	3.2	9.9	0.54	0.54
ju,jusq	3.8	12.7	0.55	0.55
jusq	11.1	17.7	0.48	0.48
inv.fl	25.3	32.0	0.37	0.37
wt	25.8	32.5	0.37	0.37
fl	29.9	36.5	0.31	0.31
sp	46.4	53.1	0.19	0.19
te	48.1	54.8	0.14	0.14
tu	57.7	64.4	0.03	0.03

Table 2.9. STH&W FTT, LGR-MCN

vars	AIC	BIC	rsq	rsq.a
wt,ju,sp,yr	-60.3	-48.3	0.93	0.92
wt,ju,sp	-40.7	-30.7	0.90	0.90
wt,ju	-37.4	-29.5	0.87	0.87
wt	-35.2	-29.3	0.88	0.88
inv.fl	-33.6	-27.6	0.87	0.87
wt,sp	-35.6	-27.6	0.89	0.89
wt,te	-33.2	-25.3	0.88	0.87
fl	-16.0	-10.0	0.73	0.73
sp	27.5	33.4	0.55	0.55
tu	38.1	44.1	0.27	0.27
ju	44.7	50.7	0.13	0.13
te	56.1	62.1	0.01	0.01

Table 2.10. CHW Z, LGR-MCN

vars	AIC	BIC	rsq	rsq.a
wt,ju:wt,yr	4.5	15.1	0.49	0.48
wt,ju:wt	13.0	21.5	0.48	0.47
wt,ju:wt,ju:st.l	13.7	24.3	0.49	0.47
ju,ju:wt	15.9	24.4	0.46	0.45
ju:tu	23.3	29.7	0.34	0.34
ju:wt	23.9	30.2	0.46	0.46
wt,ju	21.8	30.4	0.40	0.39
ju:te	24.7	31.1	0.34	0.34
ju	25.2	31.6	0.34	0.34
tu,ju:tu	23.1	31.6	0.35	0.33
tu,ju:wt	24.5	33.0	0.46	0.45
wt,ju:tu	24.7	33.2	0.33	0.31
te,ju:wt	25.8	34.3	0.46	0.45
ju,te	25.9	34.4	0.35	0.34
ju,sp	26.5	35.0	0.35	0.34
te	46.0	52.3	0.26	0.26
tu	64.7	71.1	0.10	0.10
ju:sp	73.4	79.8	0.09	0.09
sp	73.7	80.0	0.02	0.02
fl	74.5	80.9	0.00	0.00
wt	75.0	81.4	0.01	0.01

Table 2.11. CHH Z, LGR-MCN

vars	AIC	BIC	rsq	rsq.a
wt,ju:wt,ch.l,yr	28.1	40.2	0.46	0.43
wt,ju:wt,yr	30.7	40.9	0.44	0.42
wt,ju:wt,ch.l	34.9	45.0	0.42	0.40
wt,ju:wt,c.l	34.9	45.1	0.42	0.40
wt,ju:wt	37.6	45.7	0.41	0.40
ju	39.9	46.0	0.31	0.31
ju,ju:wt	38.3	46.5	0.39	0.38
ju,sp	39.3	47.4	0.36	0.35
ju,wt	40.1	48.2	0.35	0.34
ju,te	40.2	48.3	0.36	0.35
ju,tu	40.6	48.7	0.32	0.31
wt,ju:wt,sp	39.1	49.2	0.42	0.39
wt,ju:wt,te	39.3	49.4	0.42	0.39
wt,ju:wt,tu	39.6	49.7	0.41	0.38
te	45.1	51.2	0.32	0.32
ju,wt,sp	41.2	51.3	0.37	0.34
tu	55.1	61.2	0.05	0.05
sp	57.8	63.9	0.05	0.05
wt	59.2	65.2	0.00	0.00

Table 2.12. STH&W Z, LGR-MCN

vars	AIC	AICc	BIC	rsq	rsq.a
jusq,fl:sp	33.6	34.6	41.1	0.54	0.53
ju,fl:sp	33.7	34.6	41.1	0.55	0.54
ju,sp	34.1	35.0	41.6	0.51	0.50
ju,sp,wt:sp	33.8	35.3	43.2	0.54	0.52
ju,sp,fl:sp	34.5	35.9	43.9	0.54	0.51
ju,jusq,fl:sp	35.6	37.0	45.0	0.55	0.52
te:ju	46.4	47.0	52.0	0.41	0.41
te,ju	46.6	47.5	54.0	0.40	0.39
te	47.4	47.9	53.0	0.34	0.34
ju	56.2	56.8	61.8	0.35	0.35
sp	64.5	65.1	70.1	0.20	0.20
inv.fl	70.3	70.8	75.9	0.07	0.07
wt	72.6	73.2	78.2	0.04	0.04
fl	73.0	73.6	78.6	0.04	0.04

Table 2.13. CHH&W FTT, MCN-BON

vars	AIC	BIC	rsq	rsq.a
wt,ju,sp,wtsq,spsq	-79.8	-66.7	0.95	0.94
wt,ju,sp,wtsq	-74.4	-63.2	0.94	0.93
wt,ju,sp	-68.5	-59.1	0.92	0.92
wt,ju,jusq,sp	-68.8	-57.6	0.92	0.92
wt,ju	-50.6	-43.1	0.84	0.84
wt,ju,jusq	-49.7	-40.4	0.84	0.83
wt,te	-35.9	-28.4	0.77	0.77
wt,sp	-16.8	-9.3	0.76	0.76
wt	-9.7	-4.1	0.64	0.64
inv.fl	-7.7	-2.0	0.61	0.61
wt,fl	-8.4	-0.9	0.65	0.65
sp	-4.8	0.8	0.76	0.76
fl	1.9	7.5	0.49	0.49
ju	16.4	22.0	0.24	0.24
jusq	16.7	22.3	0.24	0.24
te	36.2	41.8	0.00	0.00

Table 2.14. STH&W FTT, MCN-BON

vars	AIC	BIC	rsq	rsq.a
wt,ju,sp,wt:	-78.5	-67.4	0.91	0.90
wt,ju,spsq	-70.0	-60.8	0.87	0.86
wt,co,sp	-69.9	-60.6	0.87	0.86
wt	-57.3	-51.7	0.78	0.78
wt,sp	-56.3	-48.9	0.79	0.78
inv.fl	-53.8	-48.2	0.77	0.77
fl	-45.4	-39.8	0.72	0.72
sp	-17.4	-11.9	0.61	0.61
ju	15.0	20.5	0.05	0.05
te	18.0	23.6	0.03	0.03

Table 2.15. CHH&W Z, MCN-BON

vars	AIC	AICc	BIC	rsq	rsq.a
ju	-90.6	-89.1	-87.6	0.15	0.15
te	-90.5	-89.0	-87.5	0.15	0.15
ju,sp	-91.3	-87.1	-86.4	0.25	0.15
ju,te	-89.0	-86.3	-85.0	0.17	0.12
ju,wt	-88.9	-86.2	-84.9	0.15	0.10
ju,te,wt	-90.5	-86.2	-85.5	0.24	0.14
ju,fl	-88.8	-86.1	-84.8	0.15	0.10
sp	-87.4	-85.9	-84.4	0.01	0.01
fl	-87.3	-85.8	-84.3	0.02	0.02
wt	-87.3	-85.8	-84.3	0.01	0.01

Table 2.16. STH&W Z, MCN-BON

vars	AIC	AICc	BIC	rsq	rsq.a
te	-46.9	-44.5	-44.9	0.60	0.60
ju	-45.6	-43.2	-43.7	0.22	0.22
te,st.ra	-46.8	-42.4	-44.3	0.77	0.75
ju,te	-45.7	-41.2	-43.1	0.47	0.41
ju,te,st.ra	-48.2	-40.7	-45.0	0.56	0.46
ju,wt	-45.0	-40.5	-42.4	0.41	0.36
ju,wt,st.ra	-47.0	-39.5	-43.8	0.48	0.36
fl	-40.9	-38.5	-39.0	0.40	0.40
inv.fl	-40.7	-38.3	-38.8	0.44	0.44
wt	-40.7	-38.3	-38.8	0.44	0.44
sp	-39.9	-37.5	-38.0	0.32	0.32
st.ra	-39.9	-37.5	-38.0	0.02	0.02

Chapter 3.

SAR, TIR and *D* for Hatchery and Wild Spring/Summer Chinook Salmon and Steelhead: Patterns and Significance

Introduction

A major objective of the CSS is to develop a long-term index of transport to inriver smolt-to-adult survival rates (SARs) for Snake River hatchery and wild spring/summer Chinook and steelhead. While the overall SAR of transported and in-river Snake River fish in aggregate is of interest, much inference and modeling designed to aid in management has employed estimates of ratios of the survival rates of fish that are transported relative to fish which migrate entirely in-river. This includes computing annual ratios of transport SAR to in-river SAR (measured from LGR to LGR) with associated confidence intervals, and estimation of the ratio of transport to in-river SARs, measured from below Bonneville Dam (*D*).

SARs and their ratios (TIR and *D*) can be estimated for the entire migration year or for blocks within a migration year. Analyses in recent years have investigated variation in SARs (and ratios of SARs) as a function of arrival timing at transport projects, or at Bonneville dam. Within-season differences in the expected TIR at particular collector projects could have implications for management of the hydrosystem for minimizing impacts to salmon and steelhead. Analyses of with-in season variation also enables exploration of some hypotheses about the magnitude and causes of hydrosystem-related delayed mortality. In Chapter 4, we include analyses of PIT-tag data for wild Chinook and steelhead that look at within-season variation in SARs of both transported and untransported fish.

Within-season estimates of SARs and their ratios are complicated by the limited number of fish (especially wild fish) able to be marked, and the low number of adult returns that result from subsets of the migration. These low numbers result in wide confidence intervals (or inability to make confidence intervals of ratios), making analysis and inference especially difficult. Further, estimation of SARs of true control fish by day or week is impossible on fine time scale, due to the inability to know on which days they passed a collector project. Lastly, the patterns of survival may differ between different species (or origins) which are transported contemporaneously. These complicating factors may limit the ability to optimize transportation strategies and minimize harm to listed species. In the meantime, we still must determine both the short-term and long-term utility of transportation under large inter-annual environmental variation and sometimes large sampling error.

Most of our estimates are made on an annual basis. Consistent with its original purpose, CSS design—from estimation of number of marked hatchery fish needed to analytical formulas—was done with the goal of obtaining annual estimates of SARs and ratios of SARs in mind. Annual estimates are needed to fit retrospective models and test hypotheses. Other metrics of hydrosystem performance are estimated annually, even though they too have a seasonal component. For instance, downstream in-river survival probability is undoubtedly influenced by environmental conditions which change within a migration season, yet annual estimates of annual survival rate are made (e.g. Williams et al. 2001). It's also impossible to assign true control in-river (C_0) fish a passage date at a collector project, making it impossible to estimate seasonal trends in SARs or TIRs for this group. Therefore, any inferences about temporal variation in in-river SARs of the general population must be indirect. Annual estimates also allow investigation of the magnitude of inter-annual variation in these parameters, which has consequences for population viability, and allow comparison to target values to meet management objectives.

A common comparison between transported fish and fish migrating in-river is made by estimating the ratio of smolt-to-adult (SAR) from LGR as smolts and back to LGR as adults. The transport LGR-LGR SAR divided by the inriver LGR-LGR SAR is called the "Transport:In-river" ratio, or TIR. D is related to TIR, but compares the BON-LGR SAR of transported fish and in-river fish. A D equal to one indicates that there is no difference in survival rate (after hydrosystem passage), while a *D* less than one indicates that transported smolts die at a higher rate after release than smolts that have migrated through the hydrosystem, and a *D* greater than one indicates that transported fish survive better after BON. Because no transported smolts and only a small number of in-river smolts are enumerated at BON, the BON-LGR SAR is estimated from the LGR-LGR SAR, estimates of in-river survival rates (through the hydrosystem), and assumed direct transport survival rate.

Both TIR and *D* estimates provide useful information about the efficacy of the transportation program, though they provide answers to different questions. Estimates of TIR address the question of whether transportation provides a benefit to smolt-to-adult survival, compared to leaving smolts to migrate in-river, under the hydrosystem as currently configured. Since these ratios compare SARs starting from collector projects, they do not by themselves provide a direct estimate of any delayed (post-Bonneville) mortality specific to transported fish. In contrast, estimates of *D* help isolate mortality occurring outside the hydrosystem from mortality occurring within the hydrosystem ("direct mortality"), which is useful for hypothesis generation and testing. The overall value of transportation in avoiding jeopardy and promoting recovery depends on hydrosystem survival (defined below), which accounts for all direct and indirect mortality effect of the hydrosystem, and which is sensitive to the amount of delayed mortality of both transported and untransported fish. A parameter representing *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. 2005).

Under the assumption that there is no density dependent mortality subsequent to the downstream hydrosystem migration, all mortality attributable to the juvenile hydrosystem migration can be encapsulated in one expression, which has been referred to as "hydrosystem survival". It is similar in concept to "system survival" (e.g. Peters and Marmorek 2001), with an additional term to represent delayed mortality of untransported fish. Neither system survival nor hydrosystem survival is an actual survival rate; because *D* is a ratio of survival rates which is not constrained to be less than or equal to one, it is possible for hydrosystem or system survival to be greater than one. System survival can be thought of as the weighted average survival rate of all smolts (transported and in-river) through the hydropower system with the survival rate of transported smolts discounted (inflated) by their estimated survival disadvantage (advantage), relative to in-river smolts, after arriving below Bonneville Dam. Hydrosystem survival uses the expression for system survival, with the survival rate of both transported and in-river fish further decremented by any mortality below Bonneville dam hypothesized to occur as a result of passing in-river through the hydrosystem.

In this chapter we describe how survival over different life stages through the use of these PIT-tags can be estimated. In addition, we provide details of a bootstrap approach to estimate the associated variances surrounding these estimates. We also employ methods to estimate distributions of key parameters representing inter-annual environmental variation. Estimates for migrating smolts are made for survival rates over different reaches of the hydro system, survival of smolts-to-adults (SARs) from collector projects back to LGR and BON back to LGR, TIR, and *D*.

Methods

Wild smolts collected in the Snake River and hatchery smolts are PIT-tagged and released above LGR dam (see Appendix A for details). The PIT tags are glass-encapsulated transponders, 11-12 mm in length. Individual PIT tags can be implanted into the fish's underbelly using a hand-held syringe. These tags are generally retained and function throughout the life of the fish. Each PIT tag has a unique code that is used to identify an individual.

The PIT-tagged wild Chinook and wild and hatchery steelhead used in the CSS analyses were obtained from all available marking efforts in the Snake River basin above Lower Granite Dam. 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 2004 (Table D-1). 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 1997 to 2003 (Table D-3). Hatchery steelhead from each tributary, plus PIT-tag releases in the mainstem Snake River at the Lewiston trap and below Hells Canon Dam, were represented in the PIT-tag aggregates for migration years 1997 to 2003 (Table D-4). The hatchery steelhead comprising the PIT-tag aggregate appear to be well spread across the drainages above LGR.

Hatchery yearling spring and summer Chinook were PIT-tagged for the CSS at specific hatcheries within the four drainages above Lower Granite Dam including the Clearwater, Salmon, Imnaha, and Grande Ronde Rivers (Table D-2). Hatcheries that accounted for a major portion of the Chinook production in their respective drainage were selected. Since study inception, the CSS has PIT-tagged juvenile Chinook at McCall, Rapid River, Dworshak, and Lookingglass hatcheries. Chinook tagged at Lookingglass Hatchery included an Imnaha River stock released in the Imnaha River drainage and a Catherine Creek stock released in the Grande Ronde River drainage. This latter stock became available to the CSS in 2001 after the Lookingglass Hatchery complex changed its operation to rearing only Grande Ronde River basin endemic stocks. Based on past estimates of SARs, sufficient numbers of smolts were tagged to ensure enough returning adults for computing statistically rigorous smolt-to-adult survival rates.

The PIT tags are read as the fish pass through the coils of a detector. Detectors have been installed at six Snake and Columbia River dams, including LGR, LGS, LMN, McNary (MCN), John Day (JDA), and BON (Figure 1.2 and 1.3). After arriving at LGR dam they can go through three different routes of passage; they can go over the spillway or into the powerhouse where they either go through the turbines or diverted with screens and pipes into the collection and bypass facility. Those fish that pass the dams over the spillway or through the dams are not detected. The collection and bypass facilities are equipped with PIT-tag detectors and record the fish identification number and the time and date detected. Fish that are not PIT-tagged and enter the collection facility are generally put in trucks or barges and transported to below BON dam. PIT-tagged smolt, however, are often returned to the river. These routes of passage can occur at LGR, LGS, and LMN dams. In addition, PIT tag detections are obtained from a special trawling operation (TWX) by NMFS in the lower Columbia River in the vicinity of Jones Beach. PIT tagged returning adults entering the fish ladders at LGR dam are detected at nearly 100% probability.

All attempts were made to make the PIT-tagged fish as representative of their untagged cohorts as possible. At trapping sites, sampling and tagging occur over the entire migration season. At the hatcheries, fish were obtained across a wide a set of ponds and raceways to more accurately represent production. Tag loss and mortality of PIT tagged fish were monitored, and the tagging files were transferred to the regional PTAGIS database in Portland, OR. The study requires that PIT-tagged fish are not necessarily routed or diverted in the proportions that non-tagged fish are at collector projects; consequently adjustments are made (described below) in estimation to more closely represent the experience of run-of-the-river (non-tagged) fish.

PIT-tagged fish are released upstream from LGR reservoir where they were seined and marked and at LGR where they are marked after collection. Other investigators (Sanford and Smith, 2002; Paulsen and Fisher, 2005; Budy and Schaller, 2007) have used smolt released both above LGR and at LGR for their estimates of SARs. Because all Snake River spring/summer Chinook must pass through LGR reservoir, we believe that smolt released upstream from LGR most closely reflect the impacts of the Lower Snake and Columbia River hydrosystem on in-river migrating fish and thus we use only these release groups in composing the C_0 group in this analysis. Because fish marked at LGR have to be collected at LGR dam, and hence would not have a similar experience as “true in-river” (C_0) fish (explained in more detail below).

Estimation Overview

Generally we estimate the survival of various life stages through release and return numbers of tagged fish. First, we know the number of original release tagged fish. These tagged fish migrate downstream to the ocean but must first pass LGR dam. They can pass this dam either through the turbines or over the spillway, where they are not detected, or through the bypass/collection system that is equipped with PIT tag detectors. The general non-tagged population arriving at LGR are put into barges or trucks if they enter the bypass/collection system. Some of the tagged fish entering the collection/detection facility are transported but, for study purposes, some are returned to the river below the dam where they continue their migration to LGS. At LGS and LMN the same three routes of passage are possible. By comparing the number of smolts detected at both dams to the number detected at each dam, an estimate of the probability of being detected is possible, and ultimately an estimate of survival. In the simplest case, multiplying the survival rate between release and LGR provides the number of smolts arriving at LGR. Because several more detection sites are located downstream including a trawl detector below the last dam, survival and removal using mark-recapture techniques can be estimated through to BON. Thus, the number of tagged smolts arriving at BON dam can also be estimated. The number of adults returning to LGR from an estimated number of smolts at either LGR or BON provides an estimate of SAR. Finally, these SARs can be compared between routes of passage, for example smolts that were barged around the hydrosystem versus those that migrated through the hydrosystem.

Assessment of the variance of estimates of survival rates and ratios is necessary to describe the precision of these estimates for statistical inference and to help facilitate efficient monitoring of actions to mitigate effects of the hydrosystem. 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, we developed a bootstrapping approach where all quantities are estimated, and then a new sample of fish is drawn with replacement from the original sample, and the quantities estimated again. This resampling with replacement is conducted over thousands of iterations to produce a distribution of values that describes the mean and variance associated with the estimate.

Below and in Appendix B, we present more detailed approaches used to estimate survival and associated variances for various life stages (and comparisons). We have developed a computer program to estimate the following quantities and confidence intervals. We estimate: survival from hatchery release to LGR, reach survival estimates between each of the dams equipped with PIT tag detectors; survival from outbound arrival at LGR dam until return to LGR as adults (LGR-LGR SARs); survival from outbound arrival at BON dam to LGR dam as adults (BON-LGR SARs); and the ratio of these SARs for smolts with different routes of passage through the hydrosystem.

Estimation of in-river survival rates

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. The Cormack-Jolly-Seber (CJS) method (Cormack 1964; Jolly 1965; Seber 1965) was used to obtain point estimates of survival and corresponding standard errors. The total PIT tagged original release group to estimate survival for up to six reaches between release site and tailrace of Bonneville Dam (survival estimates S_1 through S_6). An estimate of survival was considered unreliable when its coefficient of variation exceeded 25%. An overall survival probability from LGR-BON, referred to as S_R, describes the direct impacts of the hydrosystem on the in-river population of smolts, and is the product of the reach survival estimates. Estimates of individual reach survival (e.g. LGR-LGS) can exceed 100%; however, this is often associated with an underestimate of survival in preceding or subsequent reaches. Therefore, when computing an overall multi-reach survival estimate, we allow individual reach survival estimates to exceed 100%.

The total number of reaches for which survival was estimable was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was limited PIT tag detection capability at John Day Dam and the NMFS trawl. Therefore, reliable survival estimates in those years were possible only to the tailrace of Lower Monumental Dam or McNary Dam. In years subsequent to 1998, reliable survival estimates to the tailrace of John Day Dam have been possible in most cases. When direct estimates of S_R were not possible or were unreliable an expansion was necessary. Survival estimates over the longest reach possible were converted to survival per km using the number of km in that reach. The survival per km estimates were then expanded to the number of km between LGR and BON. This approach has a drawback in that the per km survival rates generated in the Snake River are generally lower than the per km survival rates observed in the lower Columbia River based on data from migration years when survival components in the higher Columbia River are directly computable. Therefore, direct estimates of in-river survival over the longest reach possible are preferable.

Estimation of smolts in study categories

For convenience, we make comparisons between SARs of groups of smolts with different hydrosystem experiences from a common starting and end point. Thus, LGR-LGR SARs must be estimated for all groups even if a smolt was not detected at LGR dam. The population of PIT-tagged study fish arriving at LGR is partitioned into three categories of smolts related to the manner of subsequent passage through the hydrosystem. Fish are "destined" to either (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 Bonneville Dam. These three ways of hydro system passage define the study categories C_0, C_1 and T_0, respectively, of the CSS. The T_0 group can be further broken down into three groups depending on the project from which fish are transported.

The PIT-tagged study groups should mimic the experience of the non-tagged fish that they represent. For example, only first-time detected tagged smolts at a dam may be considered for in the transportation since non-tagged smolts are nearly always transported when they enter a bypass/collector facility (where PIT tag detectors are in operation) at a Snake River dam. Smolts arriving at LGR destined for the transport pathway include a larger group than the sum of smolts actually transported at all projects, because some smolts die while migrating in-river from LGR to either LGS or LMN. Therefore, an estimated survival rate is needed to convert actual transport numbers at LGS and LMN into their LGR starting number (in LGR equivalents). The PIT-tagged fish destined for transportation at LGR, LGS, and LMN together form Category T_0. Using the definitions presented in the following text box, the formula for estimating the number of fish in Category T_0 is

$$T_0 = X_{12} + X_{102}/S_2 + X_{1002}/S_2S_3. \qquad [3.1]$$

Symbol Definitions:

n_2 (or X_{12}) = number of smolts transported at LGR
n_3 (or X_{102}) = number first-detected and transported at LGS
n_4 (or X_{1002}) = number first-detected and transported at LMN

S_1 = estimated survival from hatchery release site to LGR tailrace
S_2 = estimated survival from Lower Granite tailrace to LGS tailrace
S_3 = estimated survival from Little Goose tailrace to LMN tailrace
p_2 = estimated collection efficiency at LGR

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
m_{15} = number of fish first detected at MCN
m_{16} = number of fish first detected at JDA
m_{17} = number of fish first detected at BON
m_{18} = number of fish first detected at lower Columbia River trawl

d_2 = number of fish removed at LGR regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_3 = number of fish removed at LGS regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_4 = number of fish removed at LMN regardless of prior capture history (includes transported fish, site-specific mortalities, unknown disposition fish, and fish accidentally removed at LMN for use in NMFS survival study at Ice Harbor Dam)

d_0 = site-specific removals at dams below LMN of fish not detected previously at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
d_1 = site-specific removals at dams below Lower Monumental Dam of fish previously detected at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
Note: both d_0 and d_1 are inflated by a constant factor of 2 to offset the approximate 50% survival rate to the lower Columbia River of fish starting at LGR

AT_{LGR} = tally of adults of smolts transported at LGR, capture history "12000000"
AT_{LGS} = tally of adults of smolts transported at LGS, capture history "10200000"
AT_{LGR} = tally of adults of smolts transported at LGR, capture history "10020000"

The PIT-tagged smolts that migrate through the hydrosystem but pass the Snake River dams undetected defines the group most representative of the non-tagged smolts that migrate in-river, and these constitute category C_0. The reason only non-detected smolts are used in this category is because detected fish must have entered the detection/collection facility where the non-tagged fish are normally removed for transportation. This group's starting number is also computed in LGR equivalents, and therefore requires estimates of survival. To estimate the number of smolts that were not detected at any of the collector projects, the number of smolts first detected (transported and non-transported) at LGR, LGS, and LMN (in LGR equivalents) is subtracted from the total number of smolts estimated to arrive at LGR. The number of Chinook smolts arriving at LGR dam was estimated by dividing the number of smolts detected at LGR by the CJS estimate of seasonal LGR collection efficiency specific for the Chinook group of interest. Smolts detected at MCN, JDA, and BON are not excluded from the C_0 group since fish entering the bypass facilities at these projects, both tagged and untagged, are generally returned to the river. Using symbols defined in the text box, the formula for estimating the expected number of fish in Category C_0 is

$$C_0 = m_{12}/p_2 - (m_{12} + m_{13}/S_2 + m_{14}/S_2S_3) - 2d_0 \qquad [3.2]$$

where:

$p_2 = m_{12} /(m_{12} + Z_2(R_2/r_2))$
$Z_2 = m_{13} + m_{14} + m_{15} + m_{16} + m_{17} + m_{18}$,
$R_2 = (m_{12} - d_2)$, and
$r_2 = m_{23} + m_{24} + m_{25} + m_{26} + m_{27} + m_{28}$

The last group of interest is comprised of fish that are detected at one or more Snake River dams and remain in-river below LMN. These PIT tagged fish form Category C_1. The C_1 category exists 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 regards to possible effects of passing through Snake River dam bypass/collection systems on subsequent survival, and in investigating cross-season trends in SARs. Using symbols defined in the text box, the formula for estimating the expected number of fish in Category C_1 is

$$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/S_2 + (m_{14} - d_4)/S_2S_3 - 2d_1. \qquad [3.3]$$

Estimation of SARs and Ratios of SARs for Study Categories

LGR has been the primary upriver evaluation site for many objectives of the CSS. Adults detected at LGR are 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 are automatically assigned to Category C_0). In this analysis, the adult count is the sum of all 2-ocean and 3-ocean returning Chinook or sum of all 1-, 2-, and 3-ocean returning steelhead for the category of interest. All Chinook jacks (1-ocean) and mini-jacks (0-ocean) are excluded from the adult count.

The formula for computing SARs by study category are:

$$SAR_2(T_0) = \{AT_{LGR} + AT_{LGS} + AT_{LMN}\}/ T_0 \qquad [3.4]$$

$$SAR(C_0)=\{AC_0\}/C_0 \qquad [3.5]$$

$$SAR(C_1)=\{AC_1\}/C_1 \qquad [3.6]$$

In Appendix B an alternative method of estimating the SAR, which uses a weighted-average of dam-specific SAR, is also presented.

The difference between SAR(T_0) and SAR(C_0) was characterized as the ratio of this pair of SARs and is denoted as the TIR:

$$\text{TIR} = \text{SAR}_2(T_0)/\text{SAR}(C_0) \qquad [3.7]$$

Estimation of D

Methods to estimate LGR-LGR SARs for transported SAR(T_0) and in-river SAR(C_0) fish have been described above. This measurement of survival from smolt-to-adults includes survival rates through the hydropower system for transported and for in-river smolts as well as survival after smolts pass Bonneville Dam (BON) and return to LGR. Like the TIR, the parameter D is the ratio of survival of transported smolts relative to smolts migrating in-river; however, survival is estimated from BON-LGR SAR. 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. However, with D values averaging around 0.5 for hatchery and wild Chinook in recent years, there is evidence that the post-BON survival rate of in-river fish is higher than that of transported fish.

D is computed as the ratio of post-Bonneville Dam survival rate of Category T_0 transported fish to post-Bonneville Dam survival rate of Category C_0 in-river fish. Thus,

$$D = \text{BON-LGR } SAR(T_0) \,/\, \text{BON-LGR } SAR(C_0) \qquad [3.8]$$

However, the total number of smolts passing BON is not observed. Therefore, to estimate BON-LGR SARs for transported and in-river migrating fish, the hydrosystem survival rates S_T and S_R are removed from their respective LGR-LGR SAR values. The resulting estimate of D is

$$D = [\text{SAR}(T_0) \,/\, S_T] \,/\, [\text{SAR}(C_0) \,/\, S_R\,] \qquad [3.9]$$

where S_R is the estimated in-river survival from LGR tailrace to BON tailrace and S_T is the assumed direct transportation survival rate (0.98) adjusted for in-river survival to the respective transportation sites for those fish transported from LGS or LMN .

In the denominator of D (in-river portion), the quotient is simply SAR(C_0)/ S_R, where S_R is estimated through the CJS estimate (expanded to the entire hydro system if necessary). Errors in estimates of S_R influence the accuracy of D estimates. Recall that when it was not possible to estimate CJS in-river survival directly to Bonneville Dam tailrace, an expansion based on a “per km” survival rate obtained from an upstream reach, where survival may be directly estimated. was then applied to the remaining downstream reach.

In the numerator of D (transportation portion), the quotient is SAR(T_0)/S_T, where S_T reflects an adjustment of the project-specific proportions of the transported PIT-tagged fish to mimic the proportions of untagged fish transported at the different projects. Calculation of S_T takes into account an estimate of survival to each transportation site, effectively putting S_T into LGR equivalents as is SAR(T_0), with a fixed 98% survival rate for the fish once they are placed into the transportation vehicle (truck or barge). The resulting formula for estimating S_T uses estimates of the total number of PIT tagged fish that would have been transported at each dam (estimates t_j for the jth dam) if all PIT tagged fish had been routed to transport at the same rate as the untagged fish. The S_T estimate is

$$S_T = 0.98 * [t_2 + t_3 + t_4] / [t_2 + (t_3/S_2) + (t_4/S_2S_3)]. \qquad [3.10]$$

where the t_js are estimates of the fraction of PIT tagged fish that would have been transported at each dam (t_j for the jth dam) if all PIT tagged fish had been routed to transport at the same rate as the untagged fish.

The LGR equivalent transport SAR [SAR(T_0)] is used for reporting annual estimates of SARs, TIR, and *D*. However, project specific TIR and *D* values are also useful for passage modeling and inferences about relative utility of transportation from different projects. Project specific TIRs can be calculated from the project-specific transport SARs and using SAR(C_0) for LGR, and dividing SAR(C_0) by the appropriate reach survival estimates, to get an estimate of in-river SAR from the lower transport projects. *D*s for LGR transport, LGS transport, and LMN transport, respectively, can be calculated from SARs and survival probabilities as follows:

$$D_1 = \frac{SAR_{T1} \cdot S_R}{SAR_{C1} \cdot S_{T.}}; \qquad [3.11]$$

$$D_2 = \frac{SAR_{T2} \cdot S_R}{SAR_{C2} \cdot S_{T.} \cdot S_2}; \qquad [3.12]$$

$$D_3 = \frac{SAR_{T3} \cdot S_R}{SAR_{C3} \cdot S_{T.} . \cdot S_2 \cdot S_3}. \qquad (3.13)$$

Hydrosystem survival is expressed by calculating pathway probabilities of the different migration rates and assigning to each pathway the appropriate parameters reflecting survival (or relative survival) through the appropriate reaches and processes. The pathway probabilities function as weights which reflect the proportional contribution to overall migration success of fish migrating in each pathway. Over the period of the study, spring migrating Chinook and steelhead can be grouped into three pathways: 1) fish that are transported from LGR; 2) fish that are transported from LGS; 3) fish that are transported from LMN; and 4) fish that migrate in-river through the entire hydrosystem. Pathway probabilities for the run at large are directly calculable from the detection probabilities at the collector projects, under the case that all non-PIT tagged fish collected at the first three dams are transported (which has been the case since the initiation of CSS). In this case, the probabilities (π) for the four pathways are

$$\pi_1 = P_2, \qquad [3.14]$$

$$\pi_2 = P_3(1 - P_2), \qquad [3.15]$$

$$\pi_3 = P_4(1 - P_3)(1 - P_2), \qquad [3.16]$$

$$\pi_R = 1 - \pi_1 - \pi_2 - \pi_3, \qquad [3.17]$$

where the subscripts 1 through 3 on π represent fish transported at LGR, LGS, LMN, respectively, the subscript R represents fish not transported, and the Ps are detection probabilities at each of the collector projects (2 = LGR, 3 = LGS, 4 = LMN).

Hydrosystem survival can then be written in terms of the direct and delayed survival probabilities experienced in sequence by fish migrating in a particular pathway:

$$\mathrm{H} = \left(\pi_1 D_1 + \pi_2 S_2 D_2 + \pi_3 S_2 S_3 D_3\right) S_{T.} \left(1 - L_R\right) + \pi_R S_R \left(1 - L_R\right) \qquad [3.18]$$

where

D_i = D value for fish transported from project i;
S_i = survival probability from the tailrace of site i to $i+1$ for fish passing in-river—e.g.
S_2 = in-river survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam;
$S_{T.}$ = Survival of fish during transport; usually assumed to be independent of transport project and equal to .98;
S_R = Survival of fish migrating entirely in-river from LGR dam to below BON;
L_R = Delayed (latent) hydrosystem mortality of fish passing in-river.

Since L_Rs are not estimated by CSS, here we estimate only system survival, which can be derived from the expression for hydrosystem survival by omitting terms containing L_R.

D values for all transport projects combined into Lower Granite equivalents can be used for a simplified version of system survival. In this case, the proportion of the migration transported from each of the transport projects is summed to derive π_T and the D-value computed from SAR(T_0) (D_0) is used instead of SARs from individual projects. The probability of the in-river pathway is simply $1 - \pi_T$.

The formulas above do not include a term for survival rate in part of the hydrosystem, namely the first pool and dam (LGR). This is because survival rates cannot be estimated for this exact reach—in CSS, S_1 is estimated from initial release points (hatchery or trap for wild fish), all of which are upstream from the start of LGR pool. This survival rate therefore includes mortality prior to encounter with the hydrosystem. Since S_1 is not included, S_R and H will tend to underestimate the actual mortality caused by the hydrosystem.

Results

Wild spring/summer Chinook

Estimated numbers of wild Chinook smolts in each study category are presented in Table D-5 along with the estimated population of tagged fish arriving at Lower Granite Dam. The table provides a bootstrapped 90% confidence interval around each estimate, along with the number of returning adults in each study category. On average, only about 4.3% of the returning PIT-tagged wild Chinook detected at Lower Granite Dam were jacks and thus exclude from the estimation of SARs (Table D-39). Most PIT-tagged wild Chinook are in the C_1 study category due to the default operation of routing most PIT-tagged fish back to the river at the Snake River collector dams. Until 2002, the number of PIT-tagged wild Chinook actually transported has been relatively small relative to the number of untagged wild Chinook transported. Beginning in 2002, the CSS coordinated with IDFG, ODFW, and CTRUIR research programs to purposely route 50% of the first-time detected PIT-tagged wild Chinook smolts at the Snake River transportation facilities to the raceways for transportation. This action has provided more PIT-tagged wild Chinook smolts in the transportation category in recent years. The individual reach survival estimates used to expand PIT-tag smolt counts in each study category to LGR equivalents are presented in Table D-31 for each migration year.

Because of the low number of PIT-tagged wild Chinook smolts transported and small number of returning adults, this study's ability to detect potential differences in site-specific SARs has been limited. The 90% confidence intervals of the site-specific SARs are extremely wide and overlapping across all three dams in each year of study (Berggren *et al.* 2006). However, this does not impact the conduct of this study since our goal is to create an overall multi-dam estimate of transportation SAR for comparison with the SARs of in-river migrants.

The completion of the adult returns for migration year 2003 and addition of migration year 2004 with 2-Ocean returns has shown two sequential years with extremely low estimated $SAR_{LGR\text{-}to\text{-}LGR}$ (Figure 3.1, Table D-13), not exceeding 0.35% in any study category. Wild spring/summer Chinook appear to be back at the pre-1997 levels, which does not bode well for recovery efforts. Marmorek et al. (1998) recommended levels above 2% to maintain a stable population and levels above 4% for recovery. SAR levels above 2% have recently been estimated in only a few years with specific study categories (e.g., transport T_0 Category in 1999 and inriver C_0 Category in 1997, 1999, and 2000). Only in migration year 2001 was the transport $SAR_2(T_0)$ significantly higher than that of the in-river migrants based on non-overlapping 90% confidence intervals. The point estimates of SARs for the different groups, along with 90% confidence limits from the bootstrap, are shown in Table D-13. PIT-tagged wild Chinook smolts with a prior detection at a collector dam in the Snake River (C_1 Group) show a lower SAR than those smolts undetected at these dams (C_0 Group). During the 11-yr period 1994 to 2004, $SAR(C_1)$ averaged approximately 32% lower than $SAR(C_0)$.

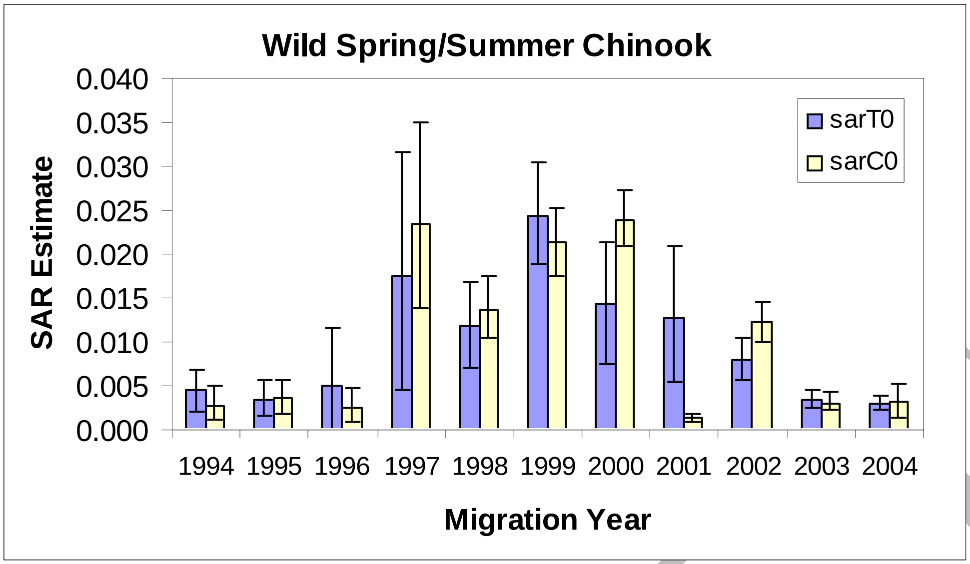


Figure 3.1. Estimated $SAR_{LGR\text{-}to\text{-}LGR}$ for PIT-tagged wild Chinook aggregate in transport [SAR(T_0)] and in-river [SAR(C_0)] study categories for migration years 1994 to 2004 (only 2-Ocean adult returns for 2004).

The estimated transport SAR to in-river SAR ratio (TIR) for the PIT-tagged wild spring/summer Chinook is presented in Table D-21. The TIR ratio for 2001 was 9-fold higher than the geometric mean of other years. The lower limit of the 90% confidence interval for TIR exceeded a value of 1 only in 2001, indicating a significantly higher SAR for transported wild Chinook than in-river fish in that year. The estimated in-river survival from LGR tailrace to BON tailrace (S_R) and D for the PIT-tagged wild spring/summer Chinook aggregate group is also presented in Table D-21 for migration years 1994 through 2004. The 10-yr geometric mean (excluding 2001) of S_R was 0.46, while the 2001 S_R value was half that average at 0.23. With S_R averaging under 50%, the geometric mean TIRs should have exceeded 2.0 if delayed mortality was no greater for transported wild Chinook smolts after release below BON than for in-river migrants, but that was not the case. In the absence of this differential delayed mortality, D should average 1. However, for wild Chinook, the 10-yr geometric mean (excluding 2001) of D was 0.49, while the 2001 D estimate was slightly greater than 2. The 90% confidence intervals around the estimated D show relatively low precision in most of the years available, indicating the difficulty of getting precise D estimates with small sample sizes of PIT-tagged wild Chinook available. Comparisons of the trends in S_R, TIR, and D of PIT-tagged wild Chinook and hatchery Chinook are presented in Figures 3.8 to 3.10, respectively, and discussed later in the hatchery Chinook section.

Pathway probabilities indicate that a large majority of wild Chinook smolts are transported. The transport fraction is particularly large when spill at the collector projects is low or non-existent, as in 2001 (Table 3.1). The fraction of the population migrating in-river is highly variable, ranging from less than 1 percent to more than a quarter.

Table 3.1. Estimated pathway probability (π_i) for different routes of passage for wild spring/summer Chinook, and for transport as a whole (π_T). Subscripts 1-3 represent the three Snake River transport projects; subscript *R* is the in-river route.

Year	π_1	π_2	π_3	π_R	π_T
1994	0.453	0.168	0.157	0.222	0.778
1995	0.514	0.221	0.131	0.134	0.866
1996	0.343	0.244	0.169	0.244	0.756
1997	0.382	0.226	0.155	0.238	0.762
1998	0.478	0.239	0.115	0.168	0.832
1999	0.262	0.446	0.163	0.129	0.871
2000	0.333	0.291	0.114	0.262	0.738
2001	0.831	0.140	0.020	0.009	0.991
2002	0.241	0.306	0.188	0.265	0.735
2003	0.409	0.239	0.070	0.283	0.717
2004	0.652	0.237	0.046	0.066	0.934

System survival varied widely over the time period, with the highest value in 2001, due to the especially high value of the *D* estimate (Table 3.2).

Table 3.2. Estimated system survival for wild Chinook.

Year	System survival
1994	0.318
1995	0.412
1996	0.788
1997	0.421
1998	0.550
1999	0.691
2000	0.358
2001	2.139
2002	0.480
2003	0.646

Hatchery spring/summer Chinook

Throughout this report, we classify the Imnaha River Chinook as a summer stock (contrary to ODFW classification) due to its high return rate of jacks and later timing of its returning adults, which coincides with the summer stock from McCall Hatchery stock. The average percentage of the total return that return as jacks was higher for the summer Chinook stocks than for the spring Chinook stocks, and was the highest for Chinook from Imnaha River AP. This highly variable jack return rate among the hatcheries and the extremely low jack return rate observed with the wild Chinook is one reason that SARs computed in the CSS report include 2-ocean and 3-ocean returning adults and no jacks. The full age composition of the returning jacks and adults for each migration year 1997 to 2004 is shown in Table D-41.

Estimated numbers of hatchery Chinook smolts in each study category are presented in Tables D-6 to D-10 for fish from Rapid River, Dworshak, Catherine Creek, McCall, and Imnaha hatcheries, respectively, along with the estimated population of tagged fish arriving at Lower

Granite Dam. The table provides a bootstrapped 90% confidence interval around each estimate, along with the number of returning adults in each study category.

Because of the low number of PIT-tagged smolts transported from LGS prior to 2000 and from LMN in any year, and small number of returning adults from these sites' transported fish, this study's ability to detect potential differences in site-specific SARs has been limited. The 90% confidence intervals of the site-specific SARs are extremely wide and overlapping across all three dams in all years of study (Berggren *et al.* 2006). However, this does not impact the conduct of this study since our goal is to create an overall multi-dam estimate of transportation SAR for comparison with the SARs of in-river migrants.

Transportation provided benefits most years to Snake River hatchery spring/summer Chinook from 1997-2004; however benefits varied among hatcheries (Figures 3.2 to 3.6, see Tables D-14 to D-18 for estimated SARs in each study category). A non-overlapping 90% confidence interval occurred between $SAR_2(T_0)$ and $SAR(C_0)$ in 6 of the 8 years for McCall Hatchery summer Chinook (Table D-17), but only in one year (2001) for Dworshak Hatchery spring Chinook (Table D-15).

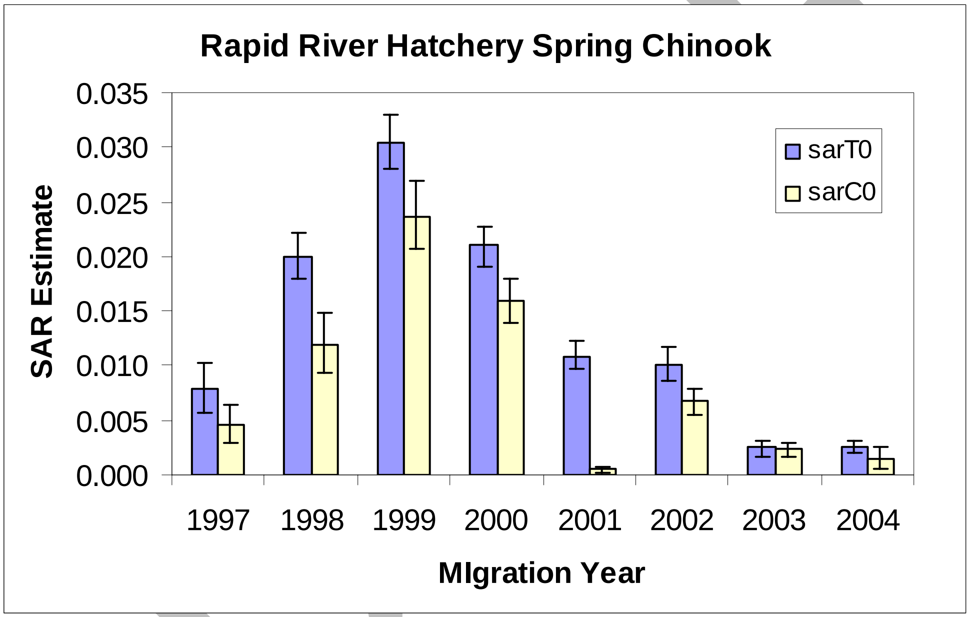


Figure 3.2. Trend in estimated transport and inriver SARs for Rapid River Hatchery spring Chinook for migration years 1997 to 2004 (latter with 2-ocean adult returns).

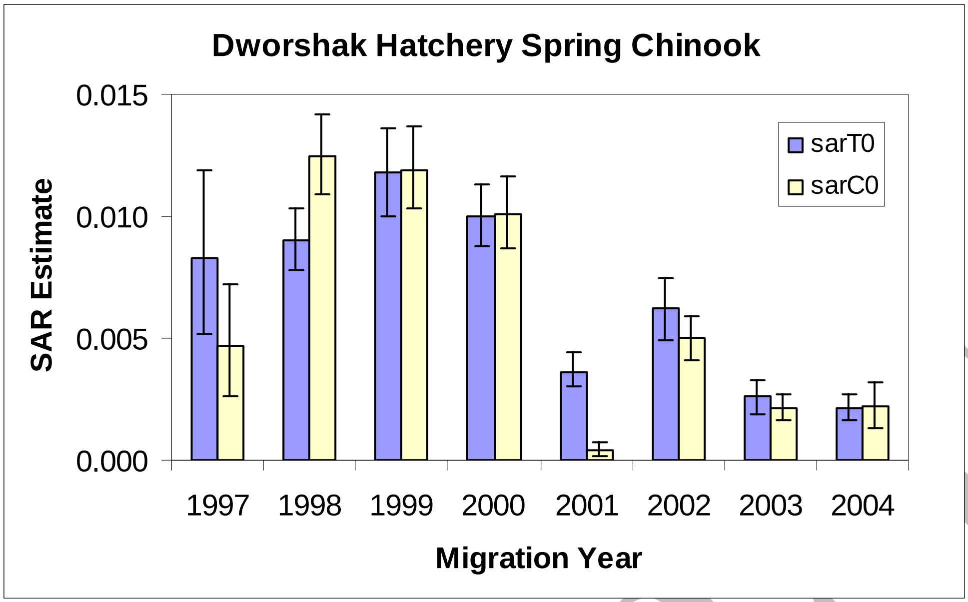


Figure 3.3. Estimated transport and inriver SARs for PIT-tagged Dworshak Hatchery spring Chinook for migration years 1997 to 2004 (latter with 2-ocean adult returns).

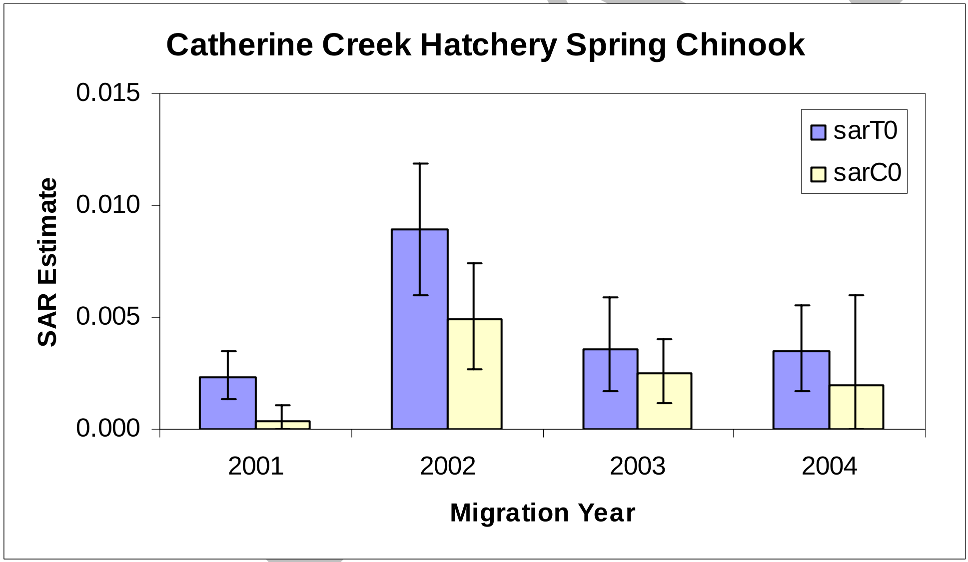


Figure 3.4. Estimated transport and inriver SARs for PIT-tagged Catherine Creek Acclimation Pond spring Chinook for migration years 2001 to 2004 (latter with 2-ocean adult returns).

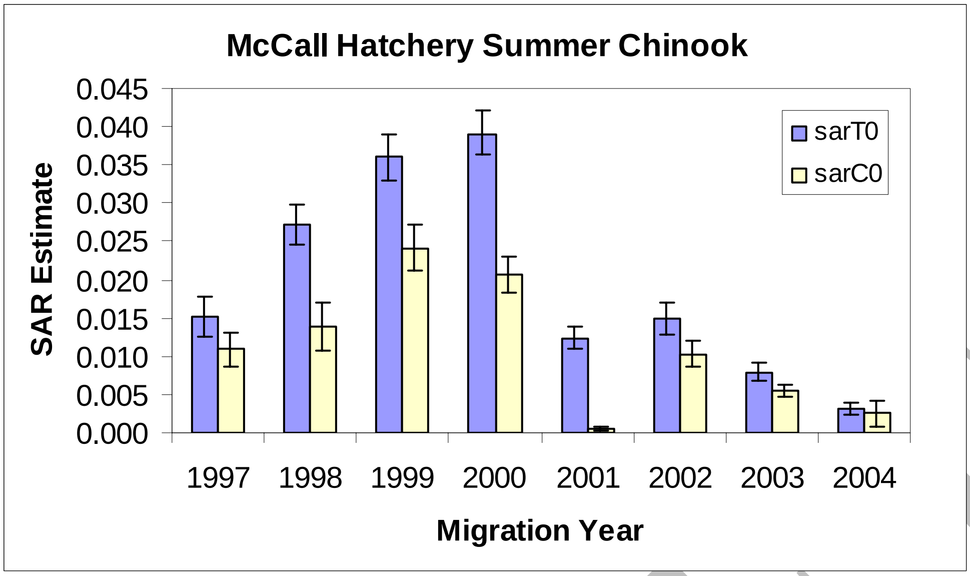


Figure 3.5. Estimated transport and inriver SARs for PIT-tagged McCall Hatchery summer Chinook for migration years 1997 to 2004 (latter with 2-ocean adult returns).

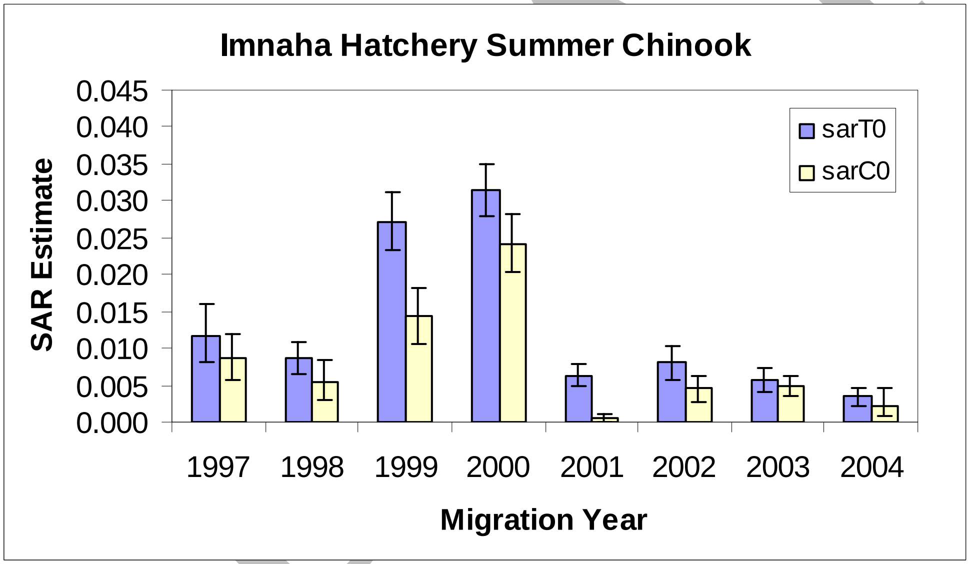


Figure 3.6. Estimated transport and inriver SARs for PIT-tagged Imnaha River Acclimation Pond summer Chinook for migration years 1997 to 2004 (latter with 2-ocean adult returns).

The trend in annual $SAR_{LGR\text{-}to\text{-}LGR}$ for each hatchery and wild Chinook is presented in Figure 3.7. These annual SARs are computed using the estimated proportion transported and migrating in-river for the run-at-large as weights with the study specific SARs from the 2006 CSS Annual Report (see Appendix F in Berggren *et al.* 2006). A general pattern of increasing SARs from 1997 to 1999 and decreasing SARs from 1999 to 2001 is shown for hatchery Chinook from McCall, Rapid River, and Dworshak hatcheries. Unlike the other three hatcheries, the SARs of Imnaha Hatchery Chinook dipped in 1998 and peaked in 2000. The annual trends observed for the PIT-tagged wild sp/su Chinook aggregate was similar to that of Imnaha Hatchery Chinook from 1997 to 1999 and similar to that of Rapid River Hatchery Chinook from 1999 to 2001. A slight increase in annual overall SAR was seen in 2002 after the drought year of 2001, followed by a large drop again in 2003 and low levels continuing in 2004. From the patterns of annual SARs the Rapid River Hatchery Chinook had the most similar trend as the PIT-tagged wild Chinook aggregate across the 8 years of adult returns for the four hatcheries continuously used in the CSS since 1997.

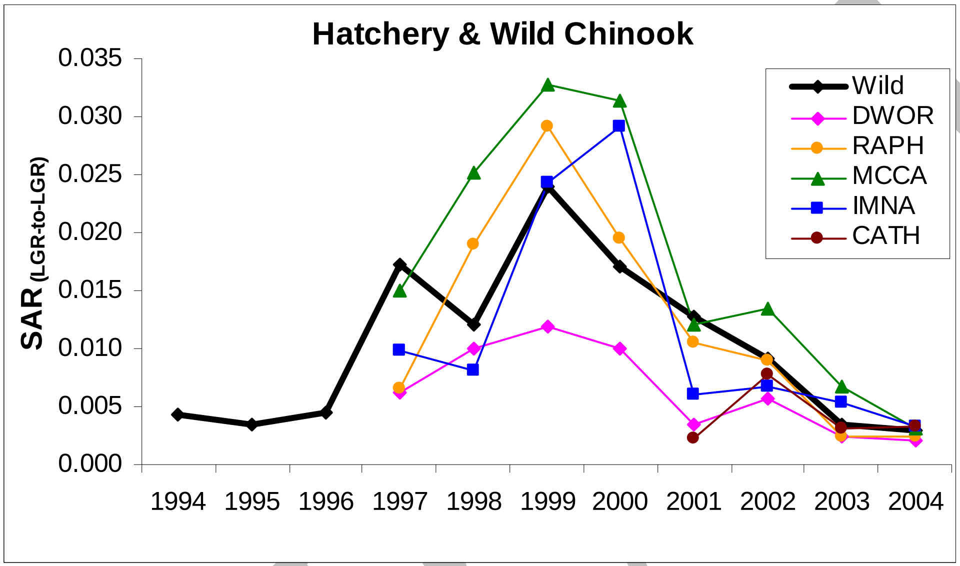


Figure 3.7. Trend in estimated annual $SAR_{LGR\text{-}to\text{-}LGR}$ for hatchery and wild sp/su Chinook; based on SAR estimates in transport and inriver categories weighted by estimated proportion of run-at-large in each category for migration years 1994 to 2004 (only 2-ocean adult returns for 2004).

Estimated in-river survival rates from Lower Granite Dam tailrace to Bonneville Dam tailrace (S_R) were low in 2004, ranging between 0.33 and 0.44 for hatchery Chinook from Rapid River, Catherine Creek, Imnaha, and McCall facilities, whereas Dworshak Hatchery Chinook had an in-river survival rate estimate of 0.50 for 2004, which is close in magnitude to its 7-yr geometric mean (0.54) of covering 1997-2000 and 2002-2004 (Tables D-22 to D-26). Although not as low at the in-river survival estimates during the drought year 2001, the 2004 estimates for the other four hatcheries were well below their 7-yr geometric means ranging between 0.49 and 0.54. The individual reach survival estimates for each migration year and hatchery used to compute S_R are presented in Tables D-32 to D-36. Annual trends in S_R over the period 1994 to 2004 (hatchery Chinook beginning 1997) are presented in Figure 3.8 for both wild and hatchery Chinook.

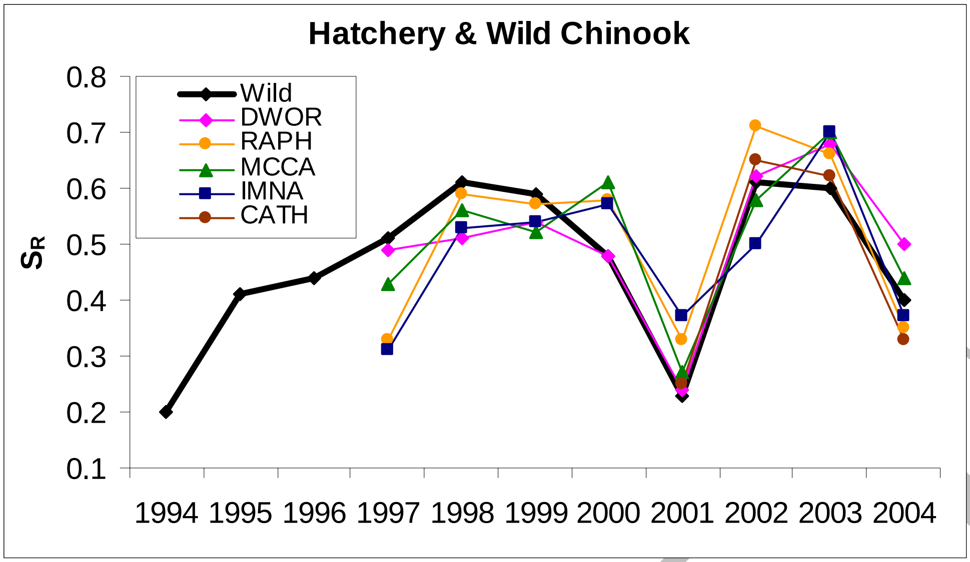


Figure 3.8. Trend in in-river survival (*S_R*) for PIT-tagged Snake River wild and hatchery spring/summer Chinook in migration years 1994 to 2004.

Excluding migration year 2001, which had TIRs exceeding 5 in all hatchery groups, geometric mean TIRs covering the seven years from1997-2000 and 2002-2004 have been around 1.5 for Rapid River, Imnaha, and McCall Hatchery Chinook (Tables D-22, D-26, and D-25, respectively). For Dworshak Hatchery Chinook, the 7-yr geometric mean TIR was less than 1.1 (Table D-23). Although Catherine Creek AP hatchery Chinook have a shorter time series of data (Table D-24), its TIRs tend to follow the former three hatcheries closer than Dworshak Hatchery. Trends in TIR (log transformed) are presented in Figure 3.9. A significant increase in the transport SAR over the in-river SAR is found when the lower limit of the 90% confidence interval of the TIR estimates is greater than 1. This did not occurring with any of the five hatcheries in 2004. In prior years, estimated TIRs significantly greater than 1 were observed in most years for Rapid River and McCall hatchery Chinook and about half the time for Imnaha AP hatchery Chinook. Significant TIRs were not observed for Dworshak Hatchery Chinook.

In the absence of this differential delayed mortality, D should average close to 1. However, except for 2001 when estimated D was greater than 1 at each hatchery, the remaining years have seen a 7-yr geometric mean D of 0.62 at Dworshak Table D-23), 0.78 at Imnaha (Table D-26), 0.81 at Rapid River (Table D-22), and 0.88 at McCall (Table D-25) hatcheries. Trends in *D* (log transformed) are presented in Figure 3.10.

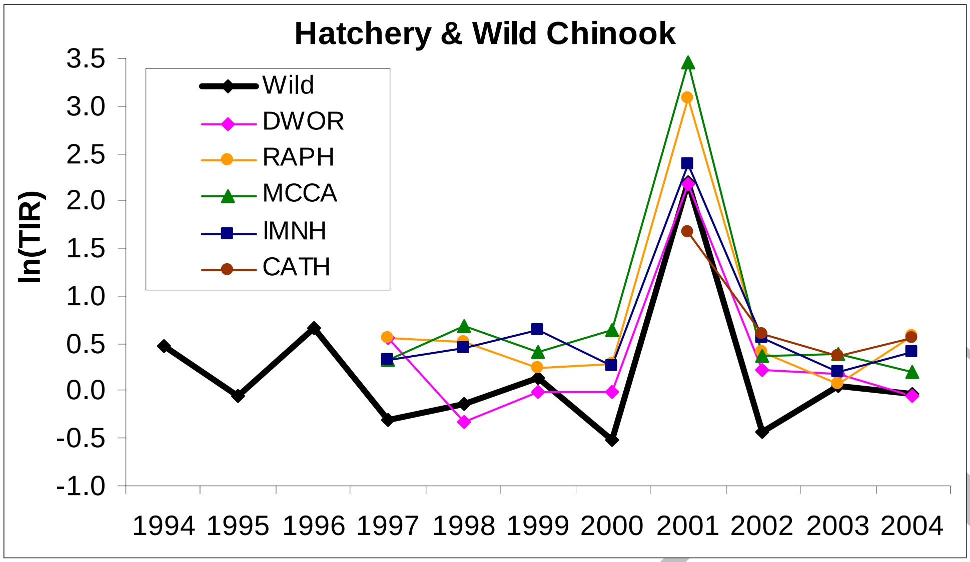


Figure 3.9. Trend in TIR ratio (log-transformed) for PIT-tagged Snake river hatchery and wild Chinook for migration years 1994 to 2004.

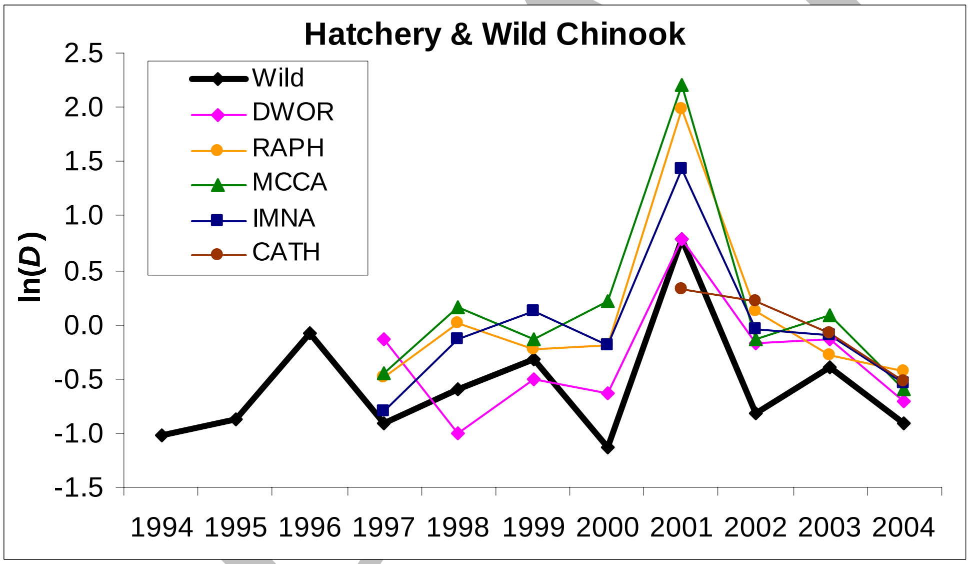


Figure 3.10. Trend in *D* (log-transformed) for PIT-tagged Snake River hatchery and wild Chinook in migration years 1994-2004.

While wild and hatchery populations demonstrated differences in magnitude for some parameters (TIR, *D*, and SARs), the annual patterns of these parameters were similar among wild and hatchery populations. In-river survival (S_R) of the wild population tracked closely with survival of hatchery populations across years (Figure 3.8). While TIRs were higher for Snake River hatcheries than for wild fish, the TIR pattern for the wild population tracked well with those of the hatchery populations across years (Figure 3.9). Similarly, Snake River hatchery fish had higher *D* values than wild fish, but wild and hatchery *D*s also tracked well across years

(Figure 3.10). SARs for wild Snake River spring/summer Chinook were intermediate to the different hatcheries, but like other metrics, hatchery SARs tracked wild SAR patterns (Figure 3.7).

Given the high variability in survival for Snake River Chinook populations, we will most likely encounter future years when the abundance of wild juveniles is too low for generating a reliable SAR estimate. In that situation, we will need to rely on surrogate estimates from hatchery-produced fish. This provides a rationale for establishing the relationship between survival of wild and hatchery populations under similar migration, climate, and ocean conditions

Wild steelhead

The estimated number of PIT-tagged wild steelhead smolts (with bootstrapped 90% confidence intervals) arriving at LGR for each CSS study category, T_0, C_0, and C_1, is presented in Table D-11 along with the associated number of returning adults in each study category. Through migration year 2002, few PIT-tagged wild steelhead are in the T_0 study category due to the default operation of routing most PIT-tagged fish back to the river at the Snake River collector dams. Until 2003, the number of PIT-tagged wild steelhead actually transported has been relatively small relative to the number of untagged wild steelhead transported. Beginning in 2003, more PIT-tagged wild steelhead have become available in the transport group as state and tribal research programs allowed a portion of their PIT-tagged wild steelhead smolts to be routed to the raceways at Snake River transportation facilities.

Obtaining a valid estimate of the number of PIT-tagged wild steelhead in Category C_0 in 2001 is problematic due to apparent large amount of residualism that year. This is based on the finding that most in-river migrants with an adult return were holdovers. Six of the eight adult returns of Category C_1 wild steelhead from migration year 2001 were actually detected in the lower river in 2002. For the three PIT-tagged wild steelhead adult returns with no detection in 2001, it was more likely these fish either completed their smolt migration in 2002 or passed undetected into the raceways during a computer outage in mid-May at LGR than traversed the entire hydrosystem undetected in 2001, when <1% of the wild steelhead run-at-large was estimated to be "destined" to ever pass all three Snake River collector dams through turbines (no spill route available). Because of the uncertainty in passage route and timing of the undetected PIT-tagged wild steelhead smolts in 2001, the in-river SAR utilizing fish from Category C_1 rather than Category C_0 will be used in comparisons with the transport SARs that year.

Significant differences in estimated SARs between transported and in-river migrants were also observed for migration years 2001 and 2002 (Figure 3.11). Relative to the 7-year average SAR(C_0) of wild steelhead that passed the three collector dams undetected, a 138% higher transportation average $SAR_2(T_0)$ and 27% lower bypass average SAR(C_1) was estimated (Table D-19).

The trend in annual $SAR_{LGR\text{-}to\text{-}LGR}$ for wild steelhead is compared to that of wild Chinook in Figure 3.12. These annual SARs are computed using the estimated proportion transported and migrating in-river for the run-at-large as weights with the study specific SARs from the 2006 CSS Annual Report (see Appendix F in Berggren *et al.* 2006). The general pattern of increasing SARs from 1997 to 1999 and decreasing SARs is similar between wild steelhead and wild Chinook, but wild steelhead had lower SARs than wild Chinook in 1997 and 1998 and higher SARs in 1999 to 2003.

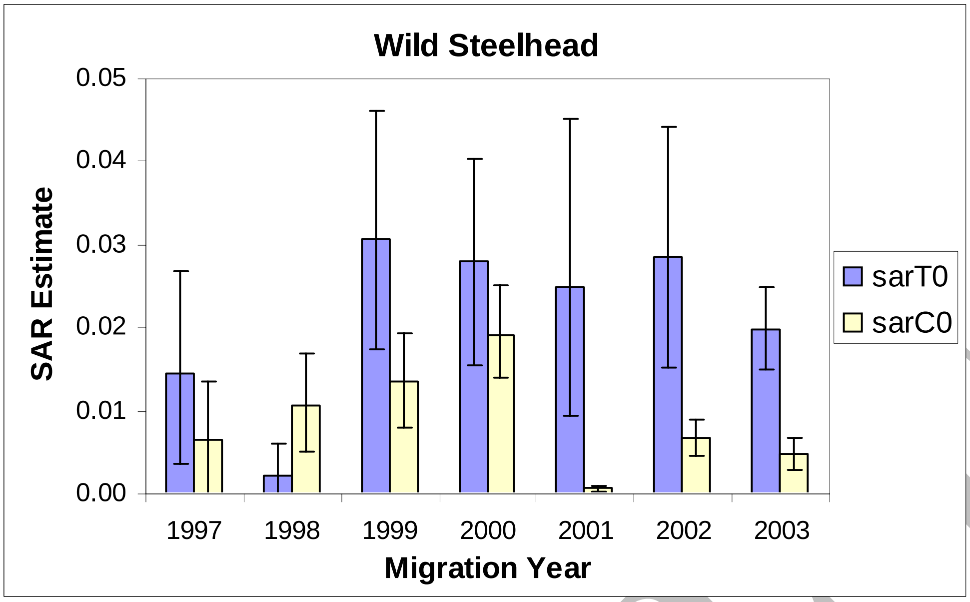


Figure 3.11. Estimated transport and inriver SARs (with 90% confidence intervals) for PIT-tagged wild steelhead aggregate for migration years 1997 to 2003 (incomplete 2003 returns).

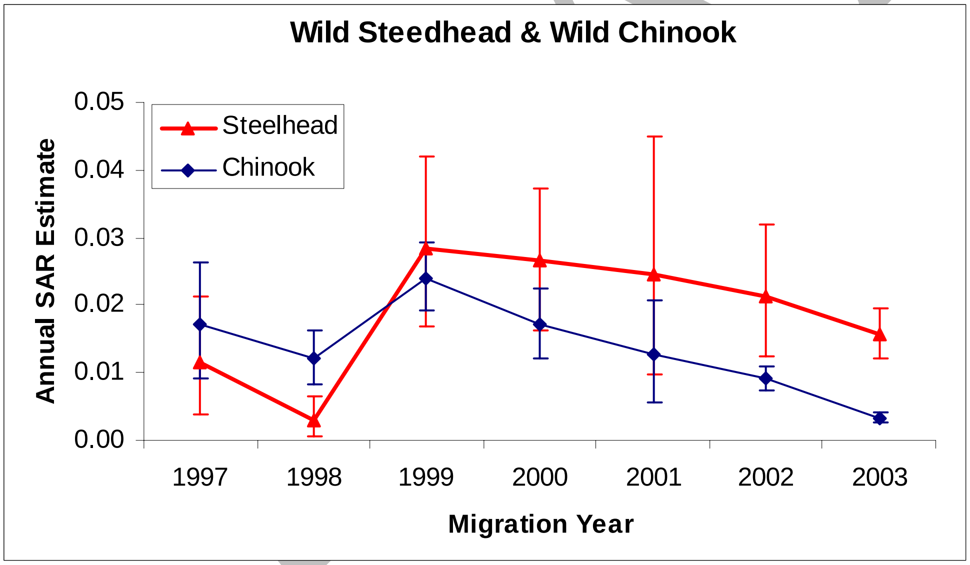


Figure 3.12. Estimated annual SAR for wild steelhead compared to wild Chinook with 90% confidence intervals; based on SAR estimates in transport and inriver categories weighted by estimated proportion of run-at-large in each category for migration years 1997 to 2003.

The estimated in-river survival from LGR tailrace to BON tailrace (S_R), TIR, and D for the PIT-tagged wild steelhead aggregate group are presented in Table D-27 for migration years 1997 to 2003. The individual reach survival estimates for each migration year used to obtain S_R are presented in Table D-37. The geometric mean of S_R for 1997 to 2002, excluding 2001, was

0.44. Over these same six years, the wild Chinook S_R estimates had a geometric mean of 0.56, which was 27% higher. Figures 3.13 and 3.14 show the trend in annual S_R estimates and TIR estimates for wild steelhead compared to wild Chinook for 1997-2003. A TIR estimate > 2 with a corresponding *D* estimate > 1 occurred in 5 of 7 years for PIT-tagged wild steelhead (3 of the 5 TIRs and 2 of the 5 *D* estimates were significant based on the lower limit of the 90% confidence interval). In contrast, the PIT-tagged wild Chinook had only a single TIR estimate > 2 (and significantly > 1), in drought year 2001, and the corresponding *D* estimate, though > 1, was not significant based on the lower limit of the 90% confidence intervals. Excluding 2001, the geometric mean TIR of 1.72 for wild steelhead was double that computed for wild Chinook over these same six years (geometric mean of 0.82). The resulting *D* estimates for 1997-2000 and 2002-2003 had a geometric mean of 0.80 for wild steelhead and 0.50 for wild Chinook (trend across years shown in Figure 3.15). These data suggest a very different response to transportation as a recovery tool for listed wild Chinook and wild steelhead.

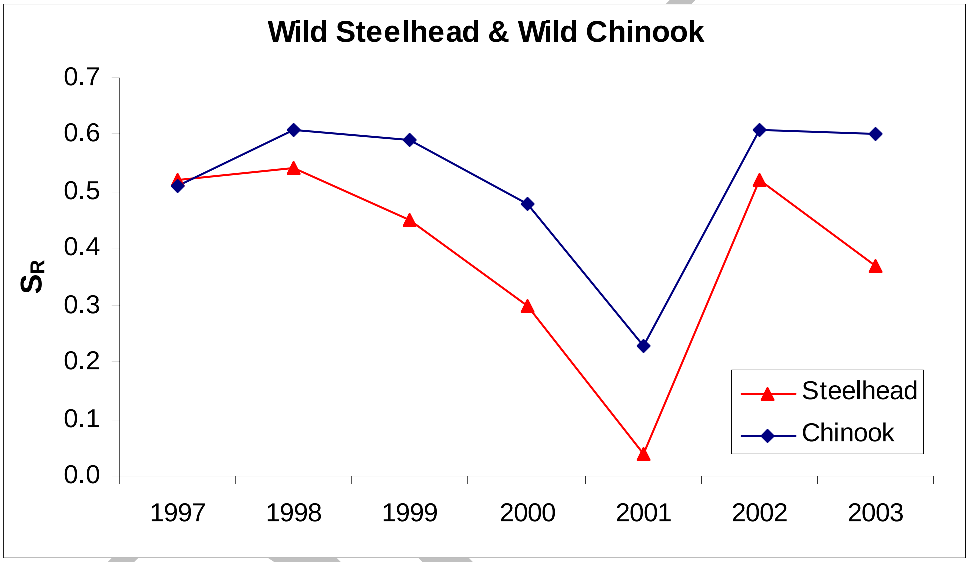


Figure 3.13. Trend in in-river survival (S_R) for PIT-tagged Snake River wild steelhead and wild Chinook for migration years 1997 to 2003.

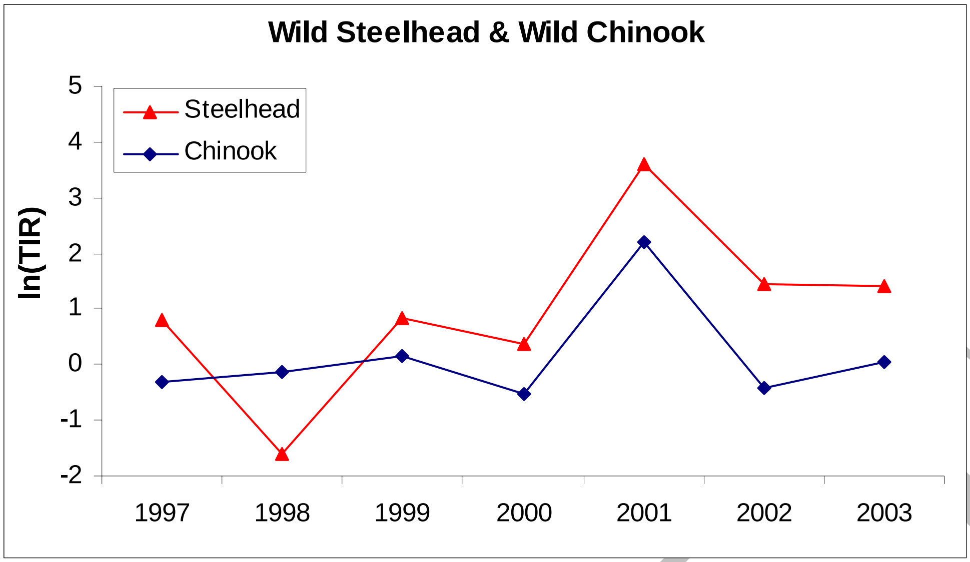


Figure 3.14. ln($SAR_2(T_0)/SAR(C_0)$) for PIT-tagged wild steelhead and wild Chinook from migration years 1997 to 2003.

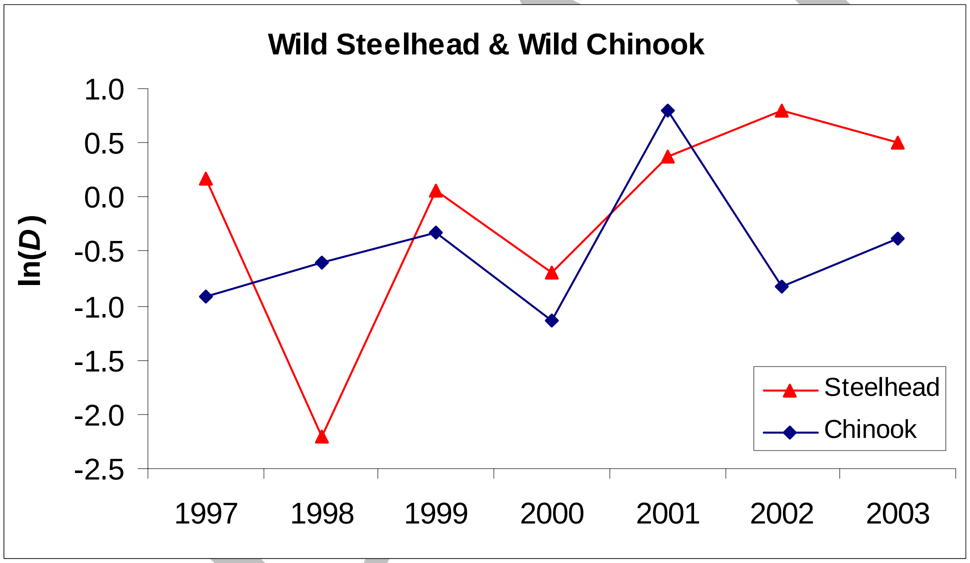


Figure 3.15. Trend in *D* (log-transformed) for PIT-tagged Snake River wild steelhead and wild Chinook in migration years 1997-2003.

Pathway probabilities indicate that a large majority of wild steelhead smolts are transported. The transport fraction is particularly large when spill at the collector projects is low or non-existent, as in 2001 (Table 3.3). The fraction of the population migrating in-river is somewhat less variable from year to year than for wild Chinook, though it has been relatively high in the most recent years. Wild steelhead system survival varied considerably less over the time period than did system survival of wild Chinook, with values often over 1, due to the relatively high *D* estimates (Table 3.4).

Table 3.3. Estimated pathway probability (π_i) for different routes of passage for wild steelhead, and for transport as a whole. Subscripts 1-3 represent the three Snake River transport projects; subscript *R* is the in-river route.

Year	π_1	π_2	π_3	π_R	π_T
1997	0.561	0.219	0.102	0.119	0.881
1998	0.618	0.171	0.108	0.103	0.897
1999	0.355	0.378	0.150	0.116	0.884
2000	0.517	0.245	0.104	0.135	0.865
2001	0.895	0.082	0.016	0.007	0.993
2002	0.317	0.238	0.135	0.310	0.690
2003	0.392	0.257	0.100	0.252	0.748

Table 3.4. Estimated system survival for wild steelhead.

Year	System survival
1997	1.081
1998	0.153
1999	0.979
2000	0.464
2001	1.420
2002	1.677
2003	1.081

Hatchery Steelhead

The estimated number of PIT-tagged wild steelhead smolts (with bootstrapped 90% confidence intervals) arriving at LGR for each CSS study category, T_0, C_0, and C_1, is presented in Table D-12 along with the associated number of returning adults in each study category. Until 2003, the number of PIT-tagged hatchery steelhead transported has been small relative to the number of untagged hatchery steelhead transported. Beginning in 2003, more PIT-tagged wild steelhead have become available in the transport group as hatchery research programs started routing a portion of their PIT-tagged hatchery steelhead smolts to the raceways at Snake River transportation facilities.

Because of the low number of PIT-tagged smolts transported and small number of returning adults, this study's ability to detect potential differences in site-specific SARs has been limited. The 90% confidence intervals of the site-specific SARs are extremely wide and overlapping across all three dams in all years of study (Berggren *et al.* 2006). However, this does not impact the conduct of this study since our goal is to create an overall multi-dam estimate of transportation SAR for comparison with the SARs of in-river migrants.

Obtaining a valid estimate of the number of PIT-tagged hatchery steelhead in Category C_0 in 2001 is problematic due to residualism just as it was for PIT-tagged wild steelhead. One of the 3 adult returns of Category C_1 hatchery steelhead from migration year 2001 was actually detected in the lower river in 2002. There were two PIT-tagged hatchery steelhead adult returns with no smolt detection in 2001. As noted with wild steelhead, these two "never detected" hatchery steelhead were more likely to have completed their smolt migration in 2002 or have been inadvertently transported from LGR without detection there. Because of the uncertainty in passage route and timing of the undetected PIT-tagged hatchery steelhead smolts in 2001, fish from Category C_1 will be used in the transport versus in-river migration comparisons for that year.

The SARs for hatchery steelhead from migration year 2003 was 1.81% for transported fish, but below 0.7% for the in-river migrants (Table D-20). These differences were significant based on non-overlapping 90% confidence intervals. Significant differences in estimated SARs between transported and in-river migrants were also observed for migration years 2000 and 2001 (Figure 3.16). Relative to the 7-year average SAR(C_0) of hatchery steelhead that passed the three collector dams undetected, a 72% higher transportation average $SAR_2(T_0)$ and 31% lower bypass average SAR(C_1) was estimated (Table D-20). The pattern and relative magnitude of these differences between the study categories was similar for both wild and hatchery steelhead (Figures 3.11 and 3.16, respectively).

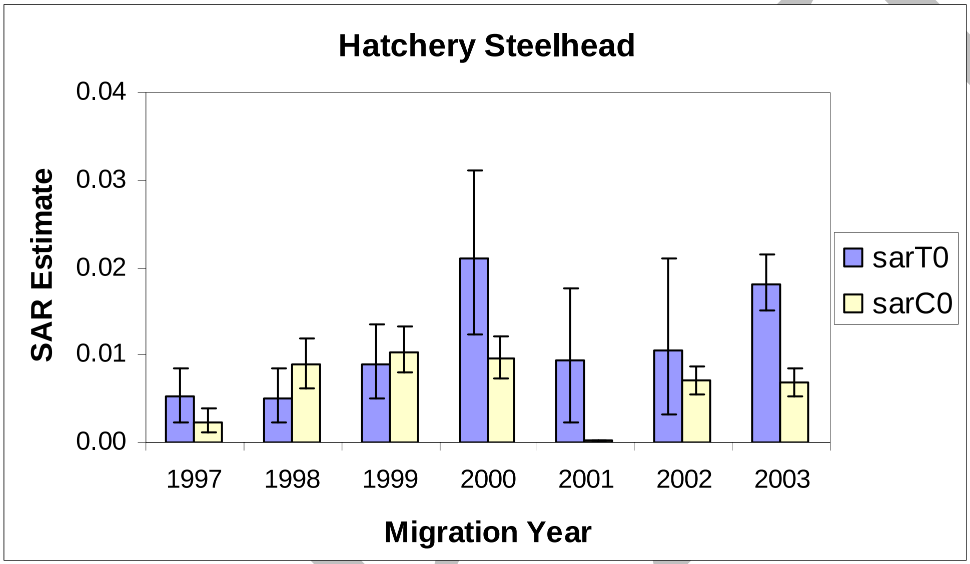


Figure 3.16. Estimated transport and inriver SARs for PIT-tagged hatchery steelhead aggregate for migration years 1997 to 2003 (incomplete returns for 2003).

The 2003 overall estimate of $SAR_{LGR\text{-}to\text{-}LGR}$ for Snake River hatchery steelhead was 1.46%, which is not as high as the estimate for 2000, but still above the other five years since 1997. These annual SARs are computed using the estimated proportion transported and migrating in-river for the run-at-large as weights with the study specific SARs from the 2006 CSS Annual Report (see Appendix F in Berggren *et al.* 2006). The annual time series of aggregate hatchery steelhead SARs were lower than the corresponding annual time series of aggregate wild steelhead SARs in all but one year between 1997 and 2002 (Figure 3.17), but only significantly lower in 1999 based on non-overlapping 90% confidence intervals.

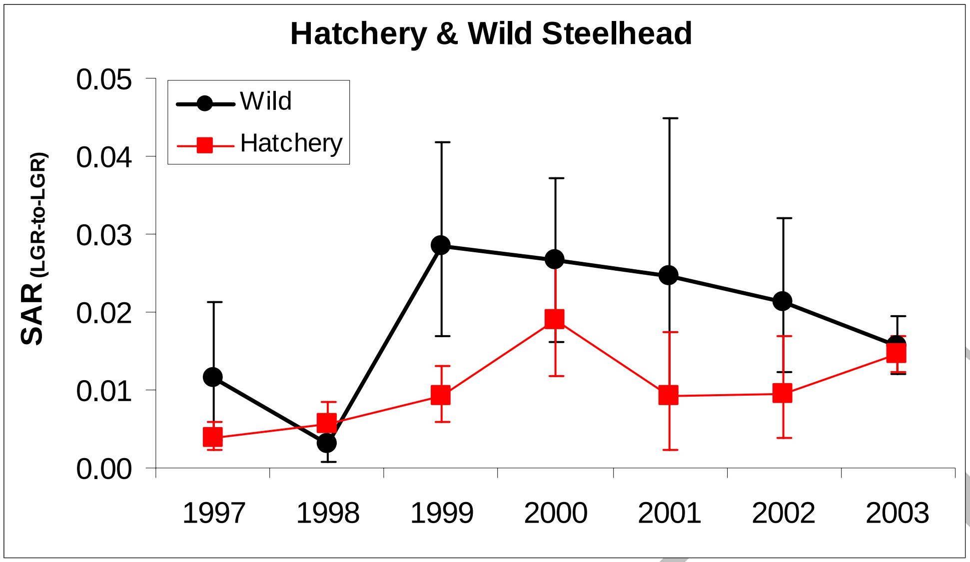


Figure 3.17. Trend in estimated annual SAR for hatchery and wild steelhead with 90% confidence intervals; based on SAR estimates in transport and inriver categories weighted by estimated proportion of run-at-large in each category for migration years 1997 to 2003 (incomplete 2003 returns).

The estimated in-river survival from LGR tailrace to BON tailrace (S_R), transport SAR to in-river SAR ratio (TIR), and delayed mortality *D* for the PIT-tagged hatchery steelhead aggregate group are presented in Table D-28 for migration years 1997 to 2003. The individual reach survival estimates for each migration year used to obtain S_R are presented in Table D-38. The geometric mean of S_R for 1997 to 2002, excluding 2001, was 0.41, similar to what was estimated for wild steelhead. Figure 3.18 shows the tend in annual $\mathrm{S_R}$ estimates for wild steelhead compared to hatchery steelhead for 1997-2003. A TIR estimate > 2 with corresponding estimated *D* >1 occurred in 2 of 7 years for PIT-tagged hatchery steelhead (only 2003 was significant based on the lower limit of the 90% confidence interval) (Figures 3.19 and 3.20). Migration year 2001 had very large estimated TIR and *D*, but the precision in these estimates was extremely low. Excluding 2001, the geometric mean TIR of 1.46 for hatchery steelhead was approximately 15% lower than that estimated for wild steelhead. The *D* estimates for 1997-2000 and 2002-2003 had a geometric mean of 0.64 for hatchery steelhead, approximately 20% lower than the geometric mean *D* of 0.80 estimated for wild steelhead. Although differences arise between the estimates for wild and hatchery steelhead, these data suggest that steelhead as a whole have a very different response to transportation as a recovery tool than do the listed wild Chinook.

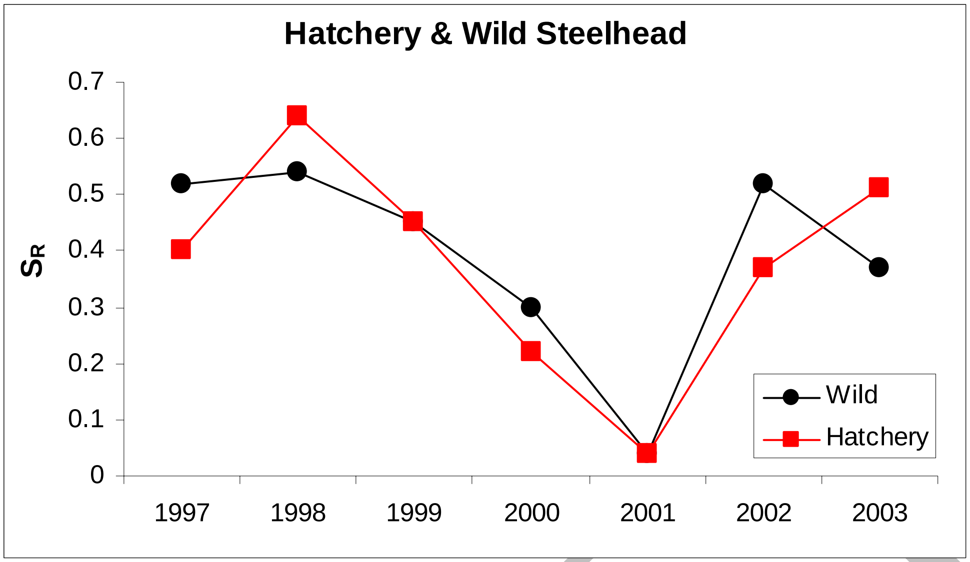


Figure 3.18. Trend in in-river survival (S_R) for PIT-tagged Snake River hatchery and wild steelhead for migration years 1997 to 2003.

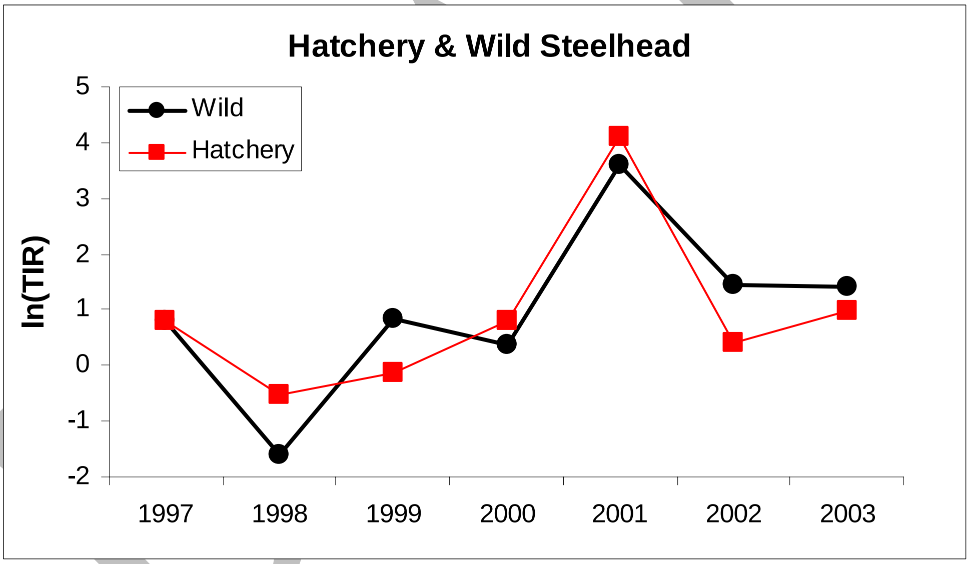


Figure 3.19. Trend in TIR (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997 to 2003.

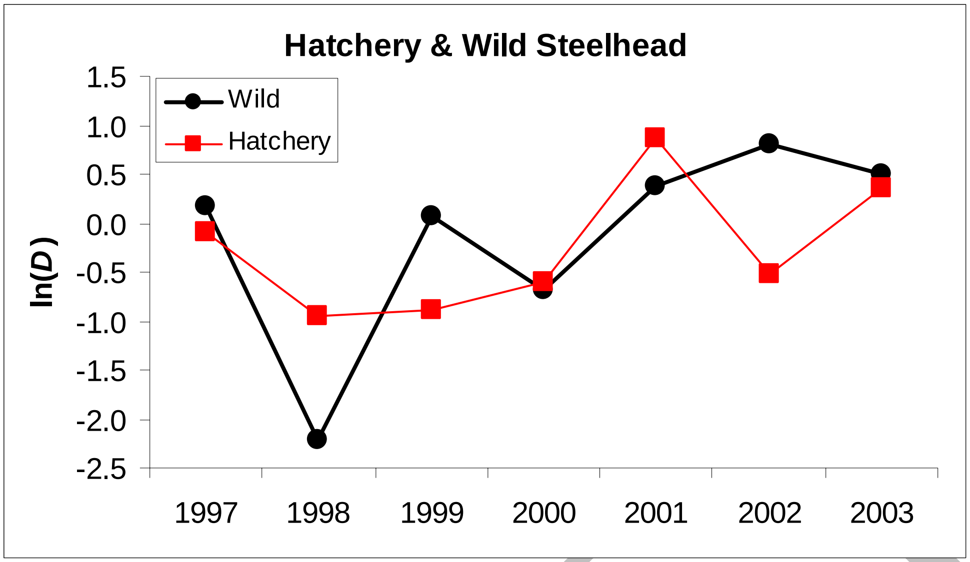


Figure 3.20. Trend in *D* (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997-2003.

Discussion

The annual SARs (LGR smolts-to-LGR adults) for wild Snake River spring/summer Chinook has been highly variable, rising from below 0.5% before 1997 to highs of 2.4% in 1999 before dropping each year to below 0.35 % in 2003 and 2004 (2-ocean returns). Current overall annual $SAR_{LGR\text{-}to\text{-}LGR}$ estimates are far below the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003) and estimated as needed for keeping the stocks stable (Marmorek et al. 1998).

Due to the low number of adult returns, determining with a high degree of confidence whether in a given year transportation improved overall survival of wild spring/summer Chinook, compared to leaving fish in-river, is generally not possible. However, over a range of environmental conditions, the TIR was only once significantly greater than 1. Transportation appeared to provide little or no benefit to wild spring/summer Chinook during the conditions experienced in most years during 1994-2004, except during the severe drought year 2001. The 10-year geometric mean (excluding 2001) ratio of SARs of transported to in-river migrants (TIR) was 0.99, while in 2001, the TIR was approximately 9-fold higher. TIR was significantly > 1 in only 2001. This unweighted geometric mean does not take into account the magnitude of uncertainty of point estimates in the individual years, an issue that is addressed in Chapter 4.

Delayed mortality of transported wild spring/summer Chinook smolts was apparently substantial most years relative to that of in-river migrants, based on a 10-yr geometric mean *D* estimate (excluding 2001) of 0.49, indicating transported smolts died at twice the rate as in-river migrants once they passed BON tailrace. The 90% confidence interval was below 1 in six of the ten years. In 2001, *D* was greater than 2, indicating in-river migrants died at twice the rate of transported smolts in the estuary and ocean.

The estimated in-river survival of wild spring/summer Chinook from LGR tailrace to Bonneville Dam (BON) tailrace 0.46 (geometric mean) for 1994-2004 (excluding 2001, when estimated survival was 0.23).

Though their confidence intervals overlapped in every year but one, during the 11-yr period 1994 to 2004, SAR(C_1) averaged approximately 32% lower than SAR(C_0) for wild spring/summer Chinook. The higher mortality of C_1 fish, which are bypassed at one or more of the collector projects, is consistent with the hypothesis of delayed mortality due to hydrosystem passage experience.

SARs (LGR-to-LGR) for hatchery Snake River spring/summer Chinook have shown similar patterns as wild Chinook during 1997-2004, although the actual survival rates have differed among hatcheries and between spring and summer runs. For spring Chinook hatcheries, SARs for Rapid River Hatchery have exceeded those of Dworshak Hatchery, and SARs of hatchery summer Chinook (particularly from McCall) have exceeded those of hatchery spring Chinook. SARs of most hatchery Chinook (except Dworshak) have equaled or exceeded the SARs of wild Chinook in migration years 1997-2004.

In general, transportation provided benefits most years to Snake River hatchery spring/summer Chinook from 1997-2004; however benefits varied among hatcheries. Omitting 2001 (when all TIRs exceeded 5), the 7-year geometric mean TIR ranged was 1.08 at Dworshak, 1.46 at Rapid River, 1.50 at Imnaha and 1.54 at McCall hatcheries, indicating a higher return rate for the transported Chinook from the latter three hatcheries. Although based on a shorter time series, annual TIRs at Catherine Creek AP hatchery Chinook have remained greater than 1.

Delayed mortality of transported hatchery spring and summer Chinook smolts was evident most years relative to that of in-river migrants, based on estimated values of *D*. Except for 2001 when all *D* values exceeded 1, the other seven years produced geometric mean *D* values of 0.62 at Dworshak, 0.78 at Imnaha, 0.81 at Rapid River, and 0.89 at McCall hatcheries.

The 7-yr (1997-2000, 2002-2004) geometric mean of the estimated in-river reach survival rate of hatchery spring/summer Chinook from LGR tailrace to BON tailrace ranged from 0.49 to 0.54 across hatcheries. In 2001, the estimated reach survival rate ranged from 0.27 to 0.37 across hatcheries.

During the 8-yr period 1997 to 2004, SAR(C_1) has remained lower than lower than SAR(C_0) for Chinook from Rapid River, Dworshak, Imnaha, and McCall hatcheries, though significantly different only in 1998 for Dworshak and McCall Hatchery Chinook and 1999 for Rapid River Hatchery Chinook.

While wild and hatchery populations demonstrated differences in magnitude for some parameters (TIR, D and SARs), the annual patterns of these parameters for wild and hatchery populations were highly correlated.

Wild steelhead from the Snake River basin had higher estimated annual SARs (indexed LGR to LGR) than hatchery steelhead in 6 of the 7 migration years (1997 to 2003). Wild steelhead had four years with annual SARs greater than the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003).

The pattern of decreasing estimated annual SARs for wild steelhead parallels that of wild Chinook, though the decline over the migration years 1999 to 2003 is less pronounced.

Transportation seems to provide benefit to wild and hatchery Snake River steelhead (over fish that migrated in-river); the geometric mean TIR (1997-2000, 2002-2003) was 1.72 wild stocks and 1.46 for hatchery stocks. Migration year 2001 had very high but imprecise TIRs, for both wild and hatchery steelhead.

Delayed mortality was evident with transported wild and hatchery steelhead relative to in-river migrants as the geometric mean *D* for 1997-2003 (excluding 2001) was 0.80 for wild stocks and 0.64 for hatchery stocks. Migration year 2001 estimated *D*s were >1 for wild and hatchery steelhead. Confidence intervals were wide due to small sample size.

Given small sample sizes and wide confidence intervals for both wild and hatchery steelhead, it is premature to conclude whether hatchery steelhead can serve as surrogates for wild steelhead. However, trends in S_R and TIRs were similar between wild and hatchery steelhead.

Chapter 4.

Estimating Environmental Stochasticity in SARs, TIRs, and *D*s

Introduction

Individual annual estimates of SARs and their ratios provide indicators of the efficacy of actions designed to improve hydrosystem and post-hydrosystem survival of Snake River migrating smolts. However, both measurement and process (environmental) variation in annual results make inference about the underlying means of these metrics problematic. Several questions must be addressed. In estimating central tendencies, how much credibility should be given to estimates of SARs and ratios of SARs in different years, given that low number of adult returns in some years lead to very low precision of estimates? What is the relative effectiveness of different transport/in-river strategies at optimizing Snake River spring/summer Chinook and steelhead SARs over many years?

Inter-annual variation in TIR (and *D*) for both wild Chinook and steelhead may be large and can be expected to influence population viability, if a large portion of the fish are transported. For parameter estimates for wild (ESA-listed) fish in particular, sampling variance may also be substantial, since these fish are opportunistically sampled and tend to be available for capture and tagging in much lower numbers than hatchery fish. Survival rates to adult return to freshwater (SARs) are generally on the order of 1%. Because sampling variance is inversely related to the number of adult returns, this means that the number of tagged smolts in each group of interest is a limiting factor in statistical inference about differences in annually estimated survival rates between groups. The confounding effect of this combined variation on inferences about these parameters can be seen in annual estimates (Chapter 3), where annual confidence bounds on TIR and *D* are wide and overlap target values in most years.

Combining data from multiple years may allow us to better estimate the long-term distributions and expected values of these indicators of survival during and subsequent to the hydrosystem migration, thereby facilitating relevant inferences. A previous analysis explored how the power of hypothesis tests and confidence intervals about the mean value of *D* increased with the number of years included in the study (PATH 2000, Appendix F). However, that analysis did not attempt to separate sampling from process errors in estimating the true distribution of *D*, nor did it produce probability distributions of the parameter. Using PIT-tag data over multiple years and assuming sampling error in SAR estimates is binomial, the statistical independence of sampling and process error allows an estimate of variance due to sampling error to be removed from inter-annual variance in SAR estimates. This leaves an estimate of environmental variance alone. The variance of distributions of the TIRs can be estimated from these SAR variances, accounting for any covariance between transport and in-river SARs, potentially producing narrower confidence intervals than previous methods.

With the methods presented here, distributions are produced which reflect the maximum likelihood distribution of true TIRs and *D*s over the time period. These distributions are produced for each collector project and can be used in prospective modeling under the assumption that future TIRs or *D*s will on average resemble those from the estimation period. Alternatively, the methods can be used in monitoring and evaluation to estimate variation in realized TIRs under the implemented management regime. The initial in-river population used is "true controls" (C_0 fish), i.e. fish that are not detected at any of the collector projects, and hence aren't transported the way the system is currently operated. The method can be extended to use other in-river groups, depending on the management question of interest.

When survival rates are estimated from counts of individuals (from a census or from marking a sample of the population) at the start and end of the interval, the sampling error is binomial (assuming minimal error in enumerating individuals) and can be removed from the variance estimated from a time series of such survival rate estimates. One method is to use a beta-binomial likelihood function to estimate the underling parameters of a beta distribution representing distribution of actual survival rates. Kendall (1998) used census data and a likelihood function that assumed binomial demographic error and underlying, beta-distributed environmental stochasticity. Morris and Doak (2002) also note the flexibility of the beta distribution and recommend it as ideal for modeling variability in survival rates, and they recommend and describe Kendall's method to remove sampling error from environmental variance.

The current approach is based on the methods of Akçakaya (2002) for estimating variance in survival rates, and the assumption that long-term distributions of SARs would approximate a beta distribution. Akçakaya's paper presented a simpler and lower-bias alternative to the approach of Kendall (1998). The analysis presented here differs from that in Berggren et al. (2005) in that: 1) this analysis is extended to include wild steelhead; 2) SARs, TIRs and *D*s are estimated for each transport project separately; 3) the method of producing parameters for distributions of TIRs that include covariance between transport and control SARs is modified (since the earlier analytical method was strictly correct only for ratios of binomial, rather than beta, random variables, and led to underestimates of variance).

The distribution of the annual ratios of survival of transported smolts to that of run-of-the-river untransported smolts for both wild Snake River spring/summer Chinook and Snake River steelhead can be approximated by a lognormal distribution derived from the methods and data described below. The variance of the distribution reflects the fact that the SARs of transported and untransported smolts often appear to be highly correlated within years. Distributions are derived and presented separately for each transport project. In each case, the in-river group represents untagged, untransported smolts.

These analyses present distributions of TIRs and *D*s reflecting inter-annual variability due to environmental conditions. These can be used in conjunction with passage and life cycle models to explore the effects of different strategies involving transportation of smolts. The distributions can also be used for statistical inference in answering questions such as "Does transportation of species X from dam Y provide a benefit compared to leaving fish in-river under a particular hydrosystem management strategy?" An obvious test value for an if-then decision related to this kind of question is TIR = 1. Levels of acceptable Type I and II errors appropriate to the framing of the research question could be chosen, or the question could be framed in terms of the degree of confidence (credibility) to invest in the hypothesis that over the long term TIR is greater than 1.

Methods

In estimating the parameters of the SAR beta distributions, demographic variance was removed from total inter-annual variance, leaving an estimate of environmental variance, as detailed in Berggren et al. (2005). As in Berggren et al., the in-river SAR distributions are derived using Akçakaya's (2002) weighted method for both total and demographic variance. This is equivalent to weighting the estimates from each year by inverse variance. The number of smolts falling into the in-river category at LGS and LMN was estimated by multiplying the estimate of C_0 smolts at LGR from Berggren et al. by the point estimate of survival rate for the appropriate reach(es).

Unlike Berggren et al. (2005), transport SARs were also calculated using the weighted method. In this analysis, since transport SARs are estimated separately for each transport project, the complications of combining estimates from different projects into a single index of transport SAR don't apply, so the weighted method was more appropriate. For instance, when estimating an LGR equivalent transport SAR in a given year, the proportion of all PIT-tagged transported fish transported at a particular project may not reflect the proportion of the transported run-at-large fish transported from that project. This complication requires adjusting the portions of PIT-tagged transported smolts at each project to better reflect the run-at-large experience. However, in estimating individual project SARs and TIRs, this adjustment is unnecessary.

We used Akçakaya's method to estimate the variance in PIT-tag SAR estimates from sampling error, and remove it from the total variance in the time series. The mean and total variance can be estimated in different ways: unweighted (i.e., each annual estimate gets the same weight in calculating mean and variance); or weighted in some manner, where the influence of each year's estimate reflects some measure of precision and/or relevance of that estimate. Akçakaya (2002) cites Kendall (1998) as pointing out that different ways of calculating variance reflect different assumptions about the reliability of individual estimates. Akçakaya recommends that in general, weighted methods should be used when the variation in sample size results from variation in sampling effort. For our purposes, the number of PIT-tagged smolts in a category can be considered an index of sampling effort and a correlate of precision of the estimate. However, independent of considerations of sample size, individual year estimates for PIT-tagged fish in a particular category may be more or less representative, depending on how well they reflect the experience of the relevant untagged population, and how large a portion of the total population of smolts that category represented in that year. Although most of the analyses here focus on annual SAR estimates, the methods can also be used to explore within-season patterns in SARs. The migration season could be broken into segments based on arrival timing at a collector project, and the method applied to each of the segments, to test for differences in SARs among them.

We use the total weighted variance method used by Akçakaya (2002) and Kendall (1998: equation 1) to estimate the multi-year mean and variance of both transport and in-river SARs:

$$\operatorname{var}(p) = \frac{\sum_{t=1}^{Y} N_t (p_t - \bar{p})^2}{\sum_{t=1}^{Y} N_t}, \qquad [4.1]$$

where $\bar{p} = \sum_{t=1}^{Y} m_t / \sum_{t=1}^{Y} N_t$ and Y = number of years of data, m_t = number of survivors remaining (i.e., returning adults) from N_t individuals in year t. This is equivalent to weighting the estimates from each year by inverse variance. Weighting by the inverse relative variance gives cohorts with more precise survival estimates greater representation (Sandford and Smith 2002). The weighting methods for both transport and in-river SARs ensure that the contribution of each year to demographic variance is proportional to the year's contribution to total variance.

The number of transported PIT-tagged fish from a particular project is known from summing fish with the appropriate capture history code. The number of smolts falling into the in-river category at Lower Granite Dam can be taken directly from capture histories if C_1 fish are used (Berggren et al. 2005), or estimated if C_0 fish are used, according to the methods of Berggren et al. (2005). For the lower projects, C_0 smolts alive at those projects can be estimated by multiplying the estimate of C_0 smolts at LGR from Berggren et al. (2005) by the point estimate of survival rate for the appropriate reach(es).

The values for the mean and remaining variance of the time series for a given SAR are then converted into the parameters of a beta distribution, using

$$a = m\left(\frac{m(1-m)}{s^2} - 1\right) \qquad [4.2]$$

and

$$b = (1-m)\left(\frac{m(1-m)}{s^2} - 1\right) \qquad [4.3]$$

where m is the estimate of the mean and s^2 is the estimate of the variance, after Kendall (1998) equations 7 and 8. The resulting distributions reflect an estimate of variance due only to environmental stochasticity in SARs over time. The resulting distributions of each particular measure under environmental stochasticity can also be used to estimate the standard error of the mean value, based on the number of years of data used.

A distribution of the aggregate SAR, taking into account survival rates of fish in the different pathways and the pathway probabilities, can be derived as well. Treating the pathway probabilities (π_i) from Chapter 3 as random variables with mean and variance estimated from annual estimates in Table 3.1 or 3.3 of Chapter 3, using the mean and variance of pathway-specific SARs estimated as described, along with estimated distributions of reach survival rates S_2, S_3, and S_R (described below), the following formulas allow estimation of mean and variance of the aggregate SAR :

$$E[XY] = \mu_X \, \mu_Y;\ Var(XY) = \mu_X^2\sigma_Y^2 + \mu_Y^2\sigma_X^2 + \sigma_X^2\sigma_Y^2 \qquad [4.4]$$

$$E[X+Y] = \mu_X + \mu_Y;\ Var(X+Y) = \sigma_X^2 + \sigma_Y^2 + 2\sigma_{XY} \qquad [4.5]$$

where X and Y are random variables and σ_{XY} is the covariance between X and Y (Blumenfeld 2001). The use of Equations 4 assumes that covariance is negligible among the components of survival of a particular pathway (e.g. the reach survival rate from LGR to LGS doesn't correlate strongly with SAR of fish transported from LGS, which is supported by observed correlation coefficients of 0.21 for Chinook and -0.15 for steelhead). In contrast, annual SARs of fish traveling by the different pathways tend to be positively correlated (though the pathway probabilities are negatively correlated with each other). Hence, in adding the contribution of each pathway to overall SAR, measured covariance is included in estimating the overall variance (Equations 5). The annual contribution of each pathway is estimated by multiplying the total annual survival rate estimate of that pathway by the annual pathway probability estimate. Estimated first is covariance between pathway 1 and 2 , then covariance between pathway 3 and the sum of the contributions of pathways 1 and 2, and then between pathway 4 and the sum of the contributions of pathways 1, 2, and 3. Equations 4 and 5 are then used with the mean and variance of the time series pathway probabilities and the estimated distributions of reach survival rates and SARs, with measurement variance removed, to derive the mean and variance of the overall SAR distribution. A beta distribution is then fit to the mean and variance as before.

Simulations of the ratio of independent beta random variables (using the parameters estimated for SARs as described above) indicated that the distribution of a large number of realizations of the ratio appeared to closely approximate the lognormal distribution. This assumption can be examined analytically, as the exact distribution of the ratio of beta random variables has been worked out.

The exact form of the ratio of two standard, independently distributed beta random variables was derived by Pham-Gia (2000). The probability density function is a complex expression of beta functions and the Gauss hypergeometric function in three parameters, and can be calculated using appropriate software (e.g., Mathematica™). The parameters of the lognormal distribution describing the ratio of the SARs are derived from statistics of the simulated TIRs or *D*s. If $Y = \ln(X)$ is normally distributed with mean, μ, and variance, σ^2, then X is said to be lognormally distributed with parameters μ and σ. If E[X] and Var[X] are the mean and variance, respectively, of the untransformed variable X, then equations 14.8a and 14.8b of Johnson et al. (1994) can be rearranged to get

$$\mu = \ln\left(E[X]\right) - \frac{\sigma^2}{2} \qquad [4.6]$$

$$\text{and } \sigma^2 = \ln\left(\frac{Var[X]}{E[X]^2} + 1\right). \qquad [4.7]$$

The parameters μ and σ can then be computed from the mean and variance of X (in this case, simulated ratios of beta random variables).

The ratio of correlated beta random variables, reflecting observed correlation between annual in-river and transport SARs, was simulated using the CORAND array function from the Excel add-in SimTools (http://home.uchicago.edu/~rmyerson/addins.htm) and the BETAINV function of Microsoft Excel™. For the correlation coefficients observed, this method provides two beta random variables with the intended distributions, with a median correlation approximately equal to the nominal correlation. The resulting distributions of simulated TIRs with positive correlations between the SARs were approximately lognormal, with smaller variances than simulations using the same beta parameters and assuming complete independence (r = 0) of SARs.

D can be simulated by using the same distributions of SARs as used to simulate *TIR*, incorporating distributions of reach survival and the direct (assumed constant) survival until barge release of transported juveniles. Distributions of reach survival rates, reflecting environmental variance alone, are derived from annual CSS estimates of mean and standard deviation, by again assuming independence of sampling and process error. The square of the bootstrapped standard deviation of annual estimates of reach survival was used for sampling error. In a given year, the total number of reaches for which survival was estimable was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was limited PIT tag detection capability at John Day and Bonneville dams and the NMFS trawl. Therefore, reliable survival estimates in those years were possible only to the tailrace of Lower Monumental Dam or McNary Dam. In years subsequent to 1998, reliable survival estimates to the tailrace of John Day Dam or Bonneville Dam have been possible in most cases. When direct estimates of S_R were not possible or were unreliable an expansion was necessary. Survival estimates over the longest reach possible were converted to survival per km using the number of km in that reach. The survival per km estimates were then expanded to the number of km between LGR and BON. The amount of the expansion is indicated in Tables C-5 and C-10 for Chinook and steelhead, respectively.

Means and variances of S_R in years where expansion of directly estimated survival rates is necessary are estimated in a different manner here than in Section 3.1. The mean and variance of the longest reach for which survival was estimated was computed from the bootstrap mean and standard deviation of individual reach estimates. The overall mean and variance of the longest directly estimated reach was estimated using the formulas for product of two random variables (X and Y), with means μ_X and μ_Y and variances σ_X^2 and σ_Y^2, respectively (Blumenfeld 2001) (Eqn. 4.4).

The delta method (Oehlert 1992; Zhou 2002) for approximating the variance of a function of a random variable is then used to derive the mean and variance of S_R. For a function g of a random variable X (Blumenfeld 2001) ,

$$E(g(X)) \approx g(\mu_X) + \frac{1}{2}g''(\mu_X)\sigma_X^2 \text{ and } Var(g(X)) \approx g'(\mu_X)^2\sigma_X^2 . \qquad [4.8]$$

For the present case, $g(X) = S_R = S_d^F$, so

$$\mu_R = \mu_d^F + \frac{F}{2}(F-1)\mu_d^{F-2}\sigma_d^2 \text{ and } \sigma_R^2 = \left(F\mu_d^{F-1}\right)^2\sigma_d^2 \qquad [4.9]$$

where the d subscript indicates the longest directly estimated reach, R corresponds to the whole reach (as in S_R), and F is equal to 1/(1- expansion percentage) where expansion percentage is from Table C-5 or C-10).

As with SARs, we used the total weighted variance method used by Akçakaya (2002) and Kendall (1998: equation 1) to estimate the multi-year mean and variance reach survival probabilities. In this case, the inverse relative variances of the annual estimates were used as the weights (Sandford and Smith 2002) . The weighted sampling error variance was then subtracted from the weighted total variance. The resulting estimates of the environmental variance, together with weighted means, were then used in equations **[2]** and **[3]** to derive the parameters of a beta distribution. The reach survival distributions estimated are S_R, S_2, and S_3.

Distributions of project-specific *D* are then generated by simulating the ratio of correlated beta random variables representing transport and in-river SARs, as before for TIR, and multiplying and dividing by the appropriate beta distributions of reach survival probabilities (and fixed transport survival = .98) according to the formulas

$$D_1 = \frac{SAR_{T1} \cdot S_R}{SAR_{C1} \cdot S_{T.}}; \qquad [4.10]$$

$$D_2 = \frac{SAR_{T2} \cdot S_R}{SAR_{C2} \cdot S_{T.} \cdot S_2}; \qquad [4.11]$$

$$D_3 = \frac{SAR_{T3} \cdot S_R}{SAR_{C3} \cdot S_{T.} \cdot S_2 \cdot S_3}. \qquad [4.12]$$

These values are generated 25000 times, and the resulting distributions of parameter values are fit to a lognormal, as done earlier for TIR.

Previous analysis suggests that there may be seasonal trends in SARs for hatchery and wild yearling migrant Chinook. These analyses have suggested that TIR (and *D*) tends to increase over the migration season (e.g. see Figure C2 in Marmorek et al. 2004). Such a pattern may reveal one mechanism by which hydrosystem experience can affect survival below Bonneville dam, and it can have implications for transportation strategy. Patterns for steelhead are not as pronounced, and average TIRs have tended to be above 1 across the migration season.

Data from PIT-tagged wild Chinook and steelhead were used to investigate the consistency of seasonal variation in SARs between years. As for annual estimates, the method uses an assumption of binomial sampling error in the SAR estimates to remove measurement error variance from total variance to estimate inter-annual process error (environmental) variance. Instead of using data from each migration year in the aggregate to estimate environmental variance in SARs, here the data from each of three periods within the migration season is treated separately. The resulting distributions can be then be used to derive estimates of, for instance, the frequency with which true SAR would be within management targets for each of the time periods. In this analysis, LGR is the only transport project investigated (though the exercise could be performed for other projects). In contrast to the analysis using annual data, the in-river fish used here are "C_1" fish—PIT-tagged fish detected at LGR dam. The "true control" (C_0) fish cannot be used to estimate within-season trends in SARs—since a C_0 smolt is not detected at LGR (or any of the collector projects), a date of passage at collector project cannot be accurately assigned to it. Note that C_1 fish generally exhibit lower SARs than C_0 fish (see Appendix Tables D-13 through D-20).

Results

Table 4.1 shows the estimated parameters of the beta distributions representing transport and in-river SAR from each transport project, and the observed correlation between them. The estimated probability density functions (PDFs) of SARs from the three transport projects, and from untransported fish, are plotted in Figures 4.1 and 4.2 for Chinook and steelhead, respectively. The details of the estimation of the contributions of the various pathways to the overall wild Chinook SAR distribution are provided in Table D-29; the overall SAR PDF is shown in Figure 4.3.

Table 4.1. Parameters of SAR distributions for wild spring/summer Chinook and Steelhead, and observed correlation coefficient between point estimates of annual T and C_0 SARs. Migration years 1994-2003 for Chinook; 1997-2002 for steelhead.

	Transport		Control		
Species / Project	**Alpha**	**Beta**	**Alpha**	**Beta**	**Corr Coeff**
Chinook LGR	1.54	210	2.04	169	0.65
Chinook LGS	3.09	330	2.11	159	0.75
Chinook LMN	1.26	212	2.05	140	0.61
Steelhead LGR	14.6	621	5.96	534	*
Steelhead LGS	3.66	178	3.84	315	*
Steelhead LMN[1]	2.84	144	3.07	239	*

[1] For transport SARs, demographic variance estimate was higher than total variance, so total variance was used in calculating beta distribution parameters.

[*] Because of small N_t (few transported tagged steelhead smolts), observed correlations were low and likely spurious. Correlation coefficient was set to 0 in deriving TIR distribution

The figures indicate that SARs of the individual components are generally less than target minimum SAR for recovery (2%). In fact, regardless of pathway, wild Chinook SARs of PIT-tagged fish rarely fall into the target region. Migrants which remain in-river appear generally to survive at the highest rate. The aggregate SAR distribution for Chinook indicates that overall SARs of the migration rarely fall in the desired range; in fact, average SAR over the time period is estimated to be 0.82%, less than half the lower end of the desired range. For steelhead, SARs are higher than for Chinook, and transported groups tend to have higher survival rates than untransported fish.

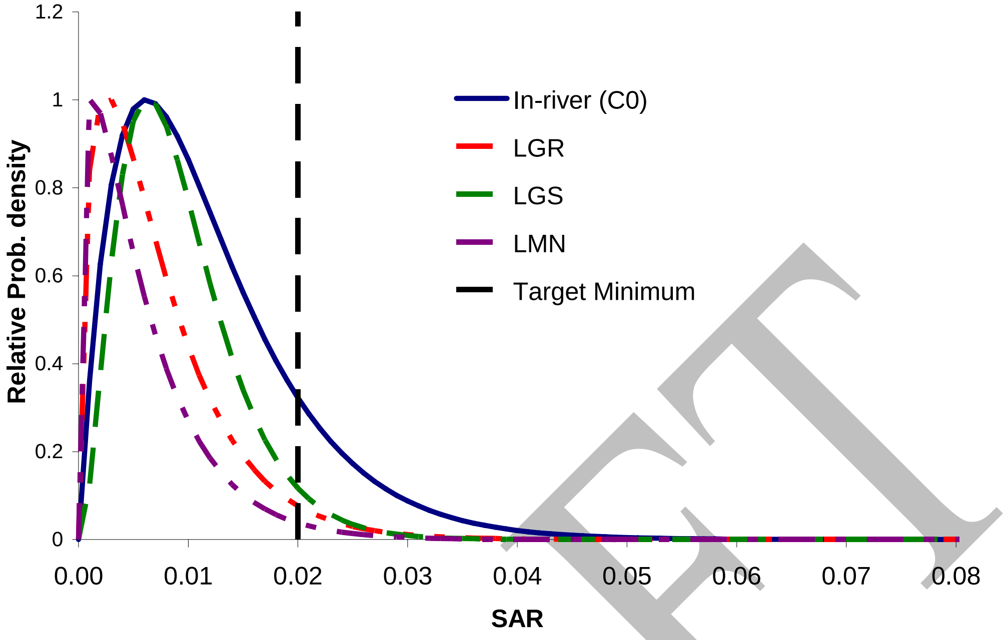


Figure 4.1. Probability density functions for SARs for wild Chinook transported from LGR, LGS, and LMN dams, and for true in-river (C_0) Chinook. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Also shown is 2% SAR target. Data from migration years 1994 – 2003.

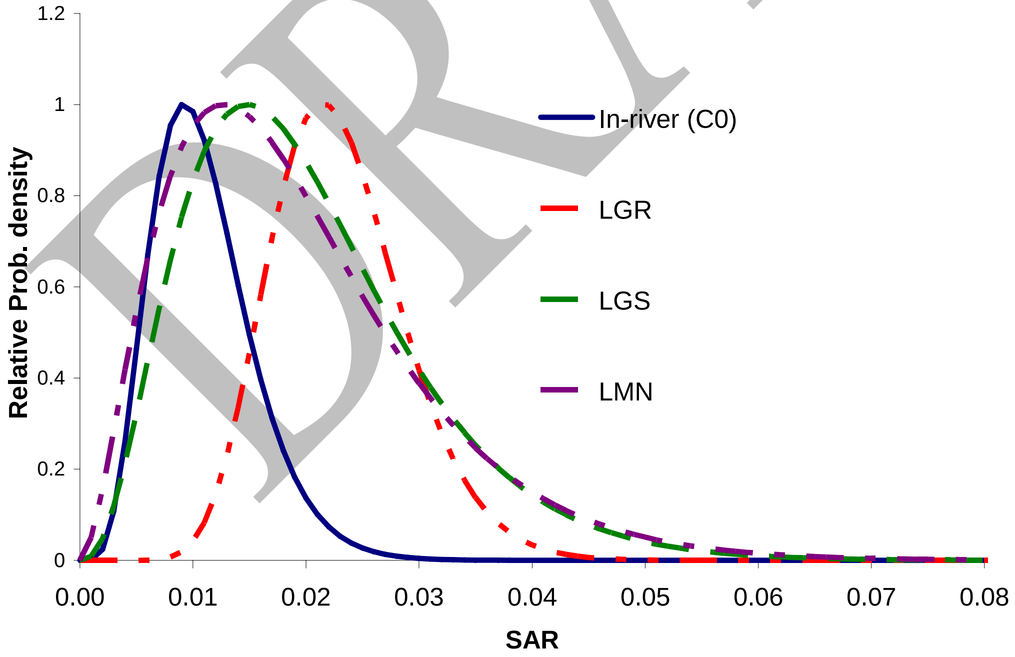


Figure 4.2. PDFs for SARs for wild steelhead transported from LGR, LGS, and LMN dams, and for true in-river (C_0) steelhead. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Data from migration years 1997 – 2002.

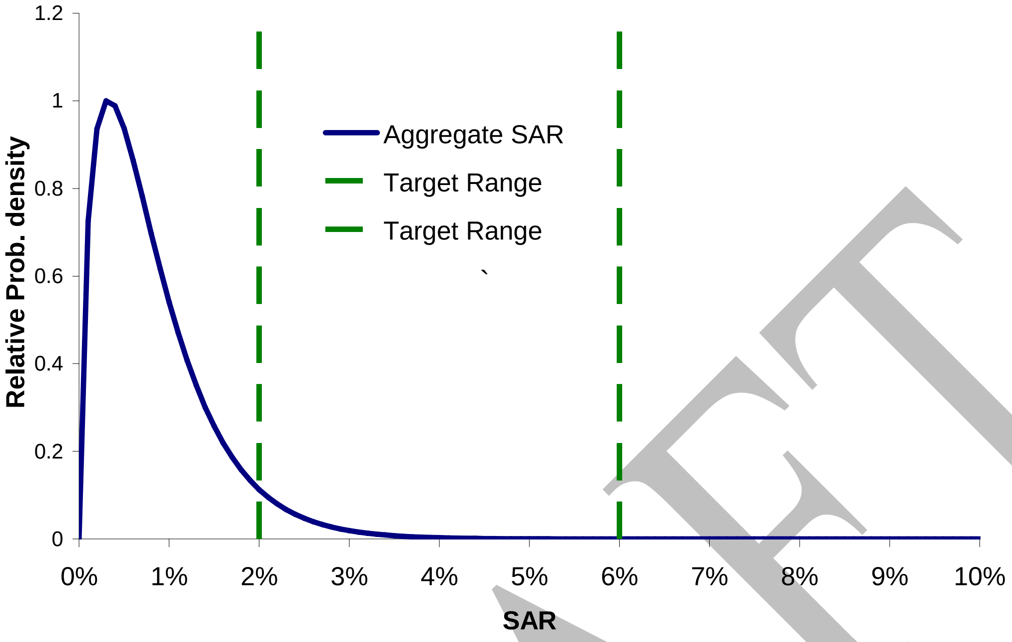


Figure 4.3. Distribution of aggregate wild Chinook SAR; data from migration years 1994 – 2003. Mean = 0.82%

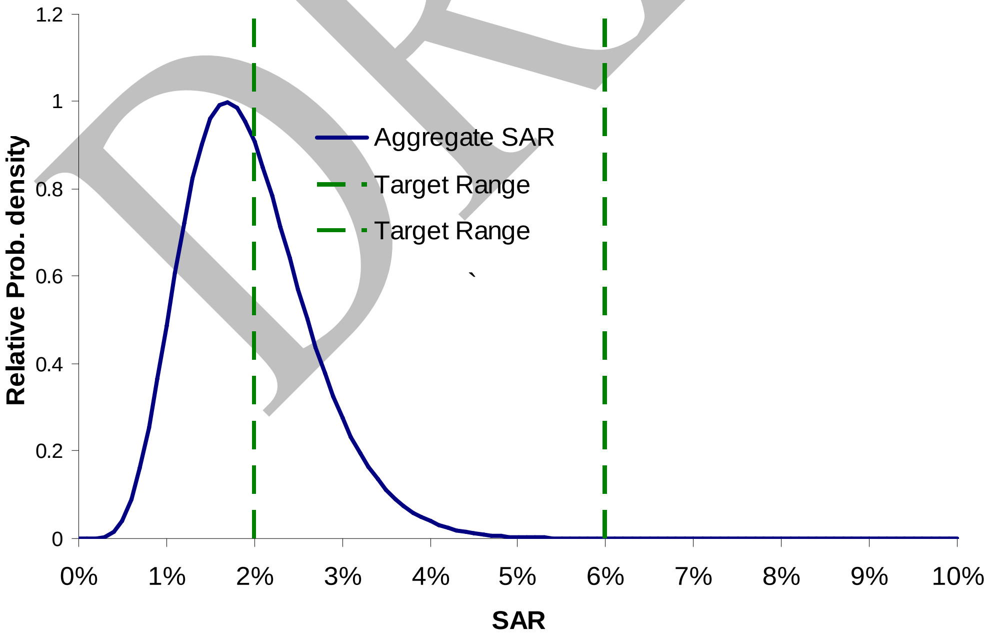


Figure 4.4. Distribution of aggregate wild steelhead SAR; data from migration years 1997 – 2002. Mean = 1.95%.

To test the goodness of the lognormal assumption used in specifying distributions of ratios of SARs, 25,000 realizations of the ratio of two beta random variables were simulated and recorded, using the parameters derived from the data for steelhead LMN transport and in-river SAR beta distributions. From the simulated values, the parameters of a lognormal were estimated as described above. The exact distribution was computed per Pham-Gia (2000) from the same SAR beta distribution parameters and plotted along with the lognormal distribution. The lognormal distribution is easier to implement for modeling than the exact PDF, and appears to provide a good approximation to the exact distribution, for the beta parameters examined (Figure 4.5).

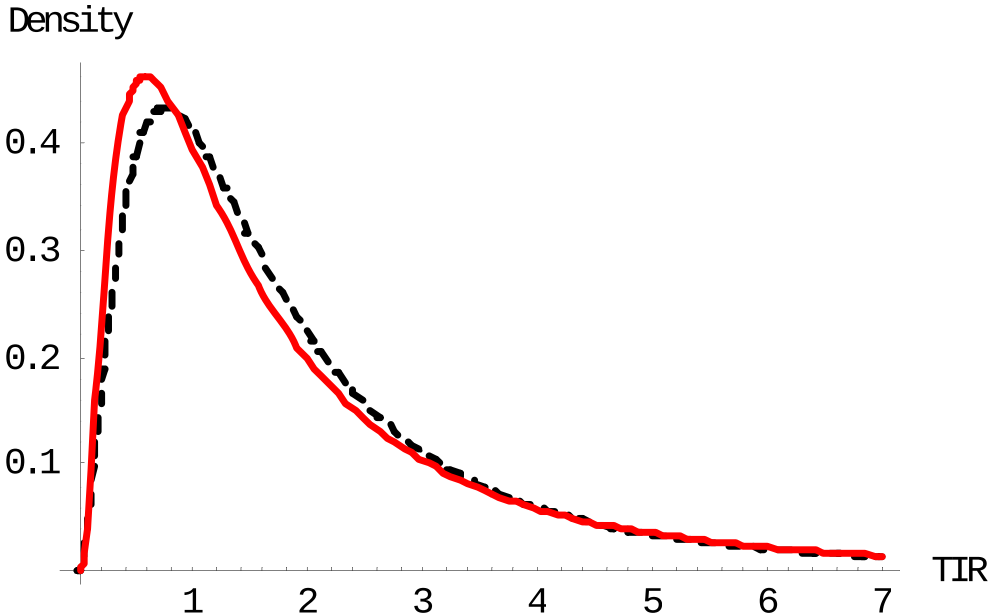


Figure 4.5. Exact probability density function of ratio of beta random variables, based on parameters of steelhead SARs from LMN (dashed line); lognormal approximation using values for μ and σ fit to 25000 values of simulated TIR (solid red line).

The parameters of the resulting project- and species-specific TIR distributions were calculated as described, using the SAR parameters shown in Table 4.1. The resulting lognormal parameters, along with median and mean of the distributions, are shown in Table 4.2. PDFs and cumulative density functions (CDFs) of the distributions are shown in Figures 4.6 – 4.8 (Chinook) and Figures 4.9 – 4.11 (steelhead).

Table 4.2. Species- and project-specific parameters of lognormal TIR distributions for implementation of the hypothesis, with mean and median of distributions. Lognormal fit to output from 25000 iterations. SAR data from 1994-2003 migration years (Chinook); 1997-2002 migration years (Steelhead).

Species	**Project**	**μ**	**σ**	**Median**	**Mean**
Chinook	LGR	-0.589	0.732	0.555	0.725
Chinook	LGS	-0.319	0.642	0.727	0.893
Chinook	LMN	-1.050	0.788	0.350	0.477
Steelhead	LGR	0.772	0.534	2.16	2.50
Steelhead	LGS	0.477	0.829	1.61	2.27
Steelhead	LMN	0.356	0.950	1.43	2.24

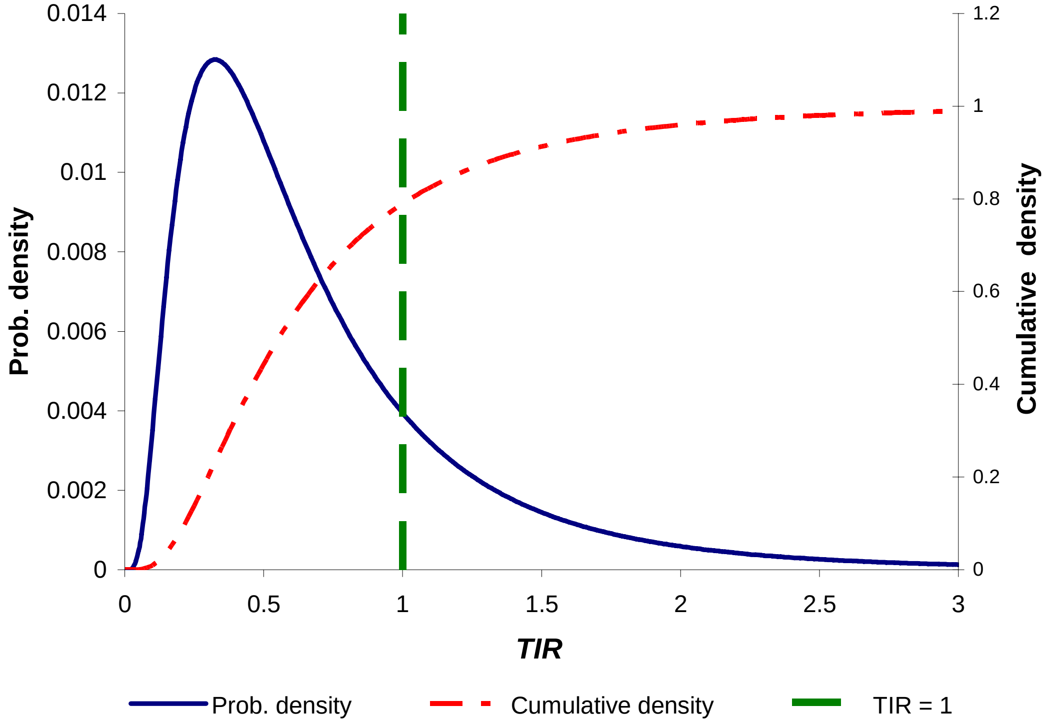


Figure 4.6. Estimated lognormal distribution of TIR for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.

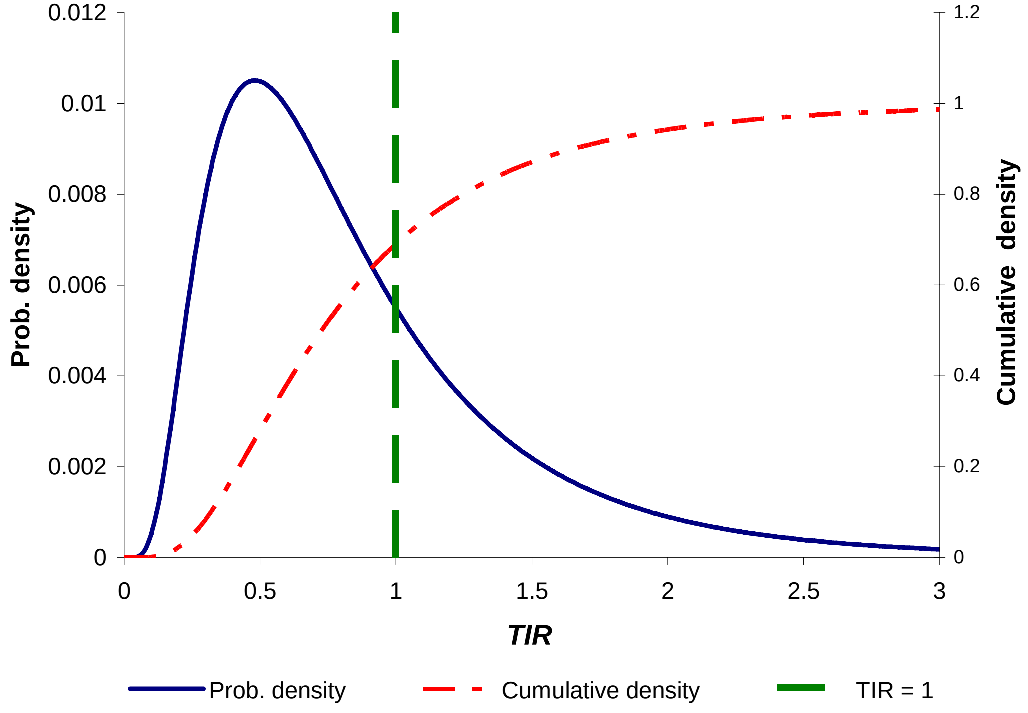


Figure 4.7. Estimated lognormal distribution of TIR for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.

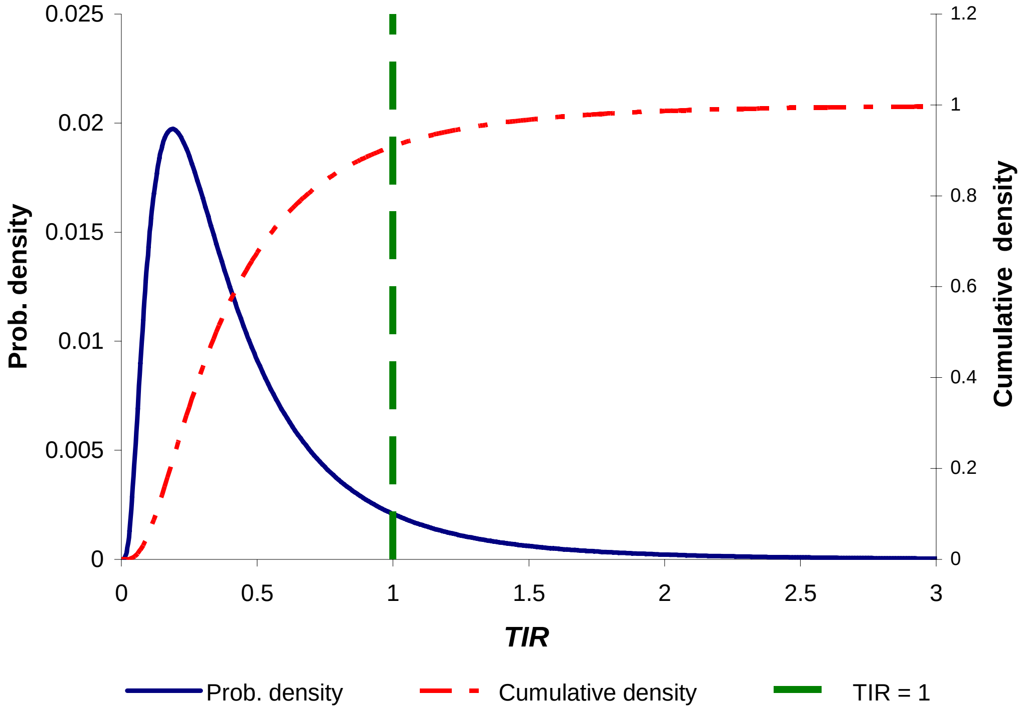


Figure 4.8. Estimated lognormal distribution of TIR for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.

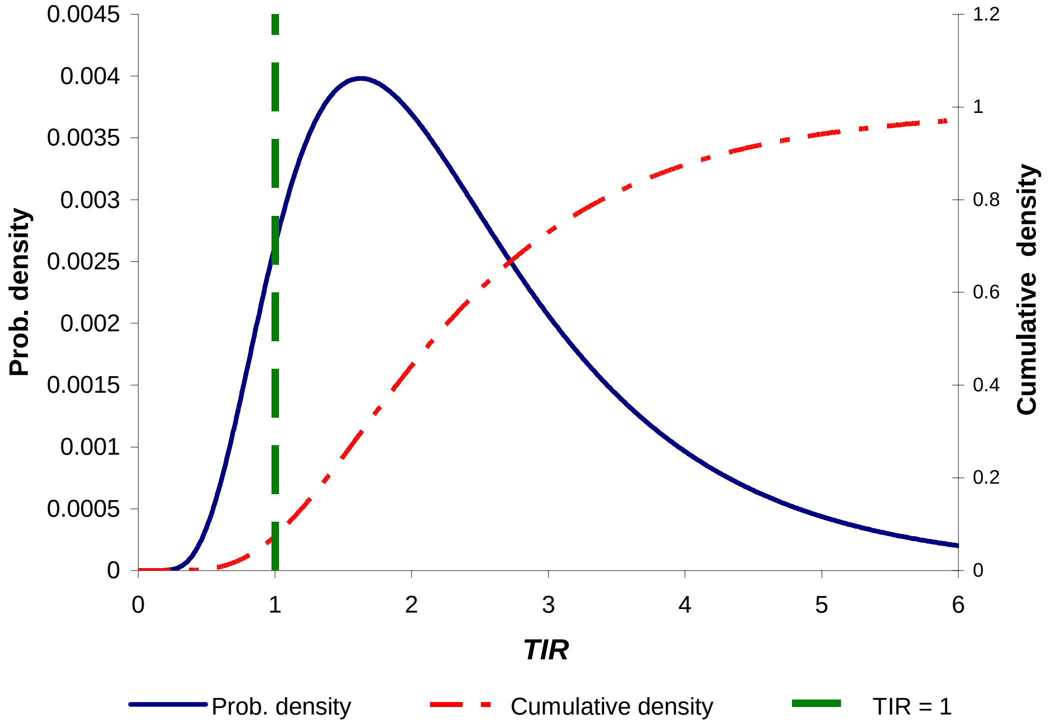


Figure 4.9. Estimated lognormal distribution of TIR for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.

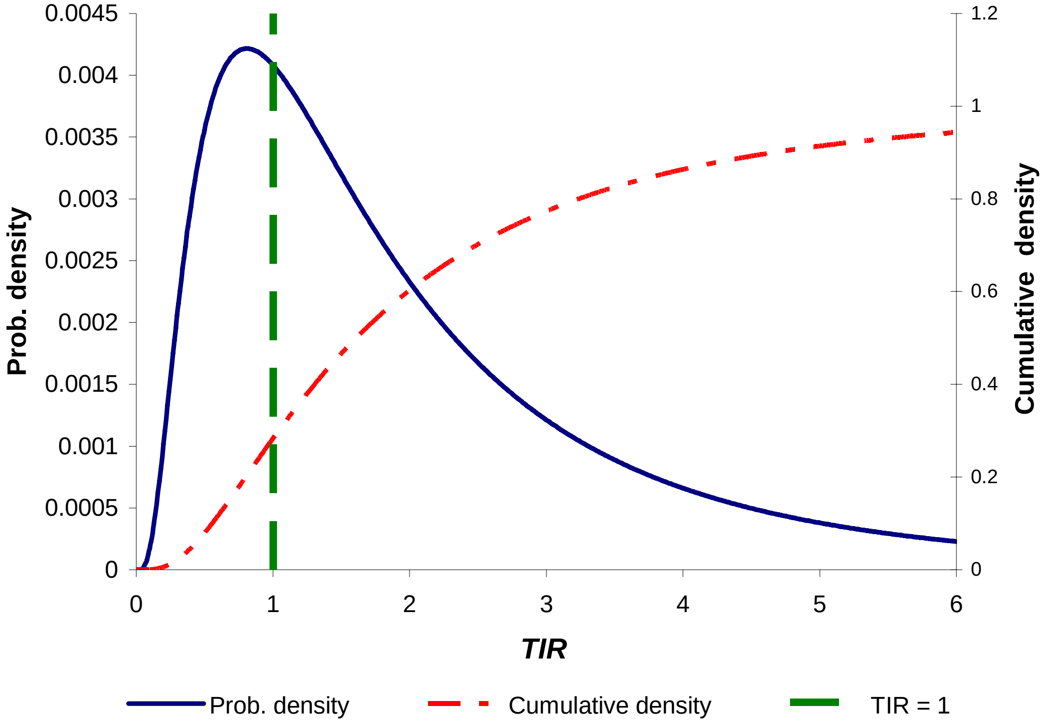


Figure 4.10. Estimated lognormal distribution of TIR for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.

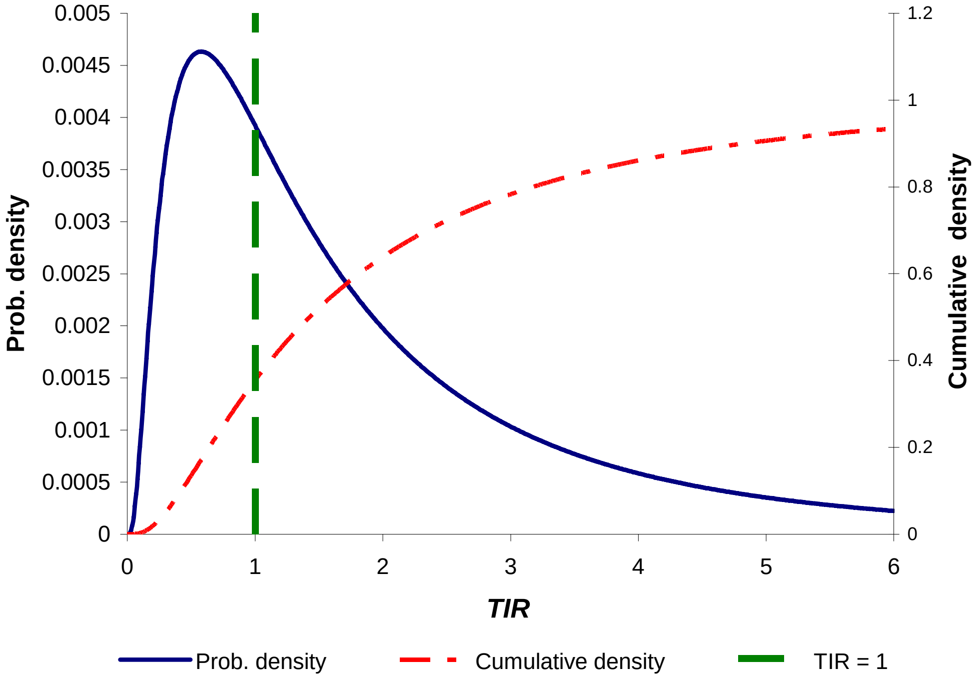


Figure 4.11. Estimated lognormal distribution of TIR for wild steelhead transported from LMN. Data from 1997 – 2002 migration years.

The figures show that TIRs for wild Chinook are generally below 1.0, indicating that transportation does not on average provide greater survival than that realized from migrating in-river through the system, if not bypassed at transportation projects. Transportation of wild Chinook from Lower Monumental Dam seems particularly ineffective, with the mean TIR less than 0.5. For steelhead, the results are considerably different (Figures 4.9-4.11), with both median and mean TIRs greater than one at all projects. TIR declines consistently as transport project gets lower in the system.

Details of estimated distributions of environmental variance in reach survival rates are shown in Table 4.3. These parameters are used with the SAR parameters, as described, to produce distributions of environmental stochasticity in *D* for both Chinook and steelhead. The resulting lognormal parameters, and the mean and median of the *D* distributions, are shown in Table 4.4. These distributions (PDFs and CDFs) are plotted in Figures 4.12 – 4.14 (Chinook) and Figures 4.15 – 4.17 (steelhead).

Table 4.3. Weighted mean, estimated standard deviation of environmental variance, and parameters of beta distribution, reach survival rates used to calculate *D*. Spring/summer Chinook data from 1994-2003 migration years; steelhead data from 1997-2002 migration years.

Species	Reach	Mean	Std. deviation	Alpha	Beta
Chinook	S_R	0.488	0.149	5.04	5.27
Chinook	S_2	0.930	0.030	68.0	5.09
Chinook	S_3	0.880	0.074	16.3	2.22
Steelhead	S_R	0.405	0.110	7.73	11.4
Steelhead	S_2	0.890	0.074	15.2	1.87
Steelhead	S_3	0.891	0.121	5.01	0.611

Table 4.4. Species- and project-specific parameters of lognormal *D* distributions for implementation of the hypothesis. Lognormal fit to output from 25000 iterations. SAR data from 1994-2003 migration years (Chinook); 1997-2002 migration years (steelhead).

Species	Project	μ	σ	Median	Mean
Chinook	LGR	-1.353	0.824	0.258	0.363
Chinook	LGS	-0.965	0.671	0.381	0.477
Chinook	LMN	-1.628	0.911	0.196	0.297
Steelhead	LGR	-0.149	0.594	0.862	1.028
Steelhead	LGS	-0.310	0.840	0.733	1.043
Steelhead	LMN	-0.294	0.995	0.745	1.223

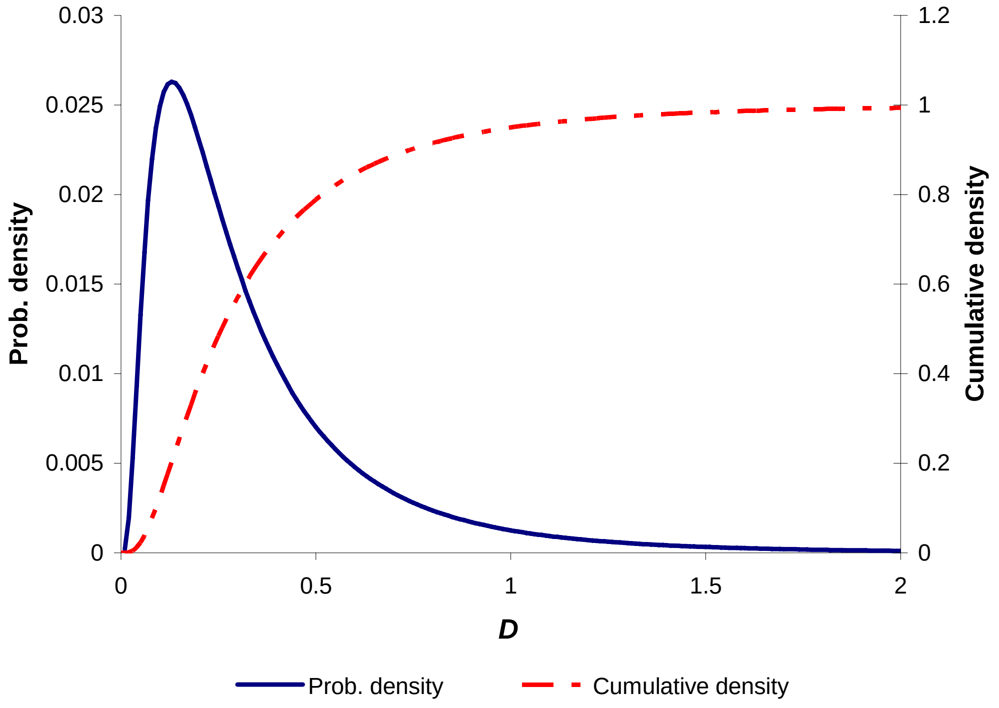


Figure 4.12. Estimated lognormal distribution of *D* for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.

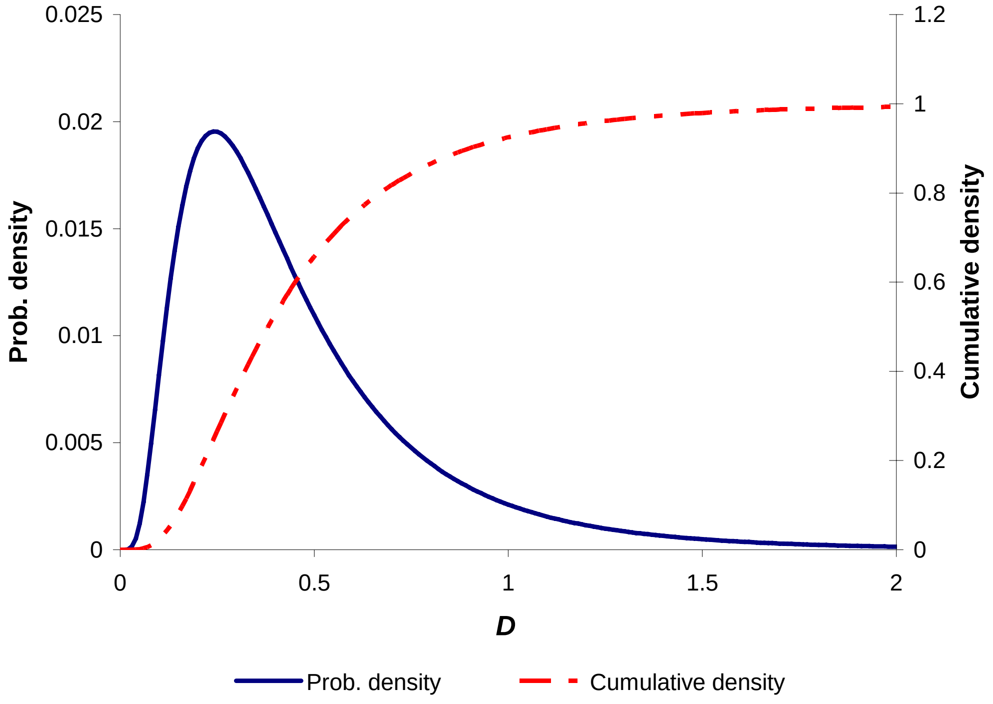


Figure 4.13. Estimated lognormal distribution of *D* for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.

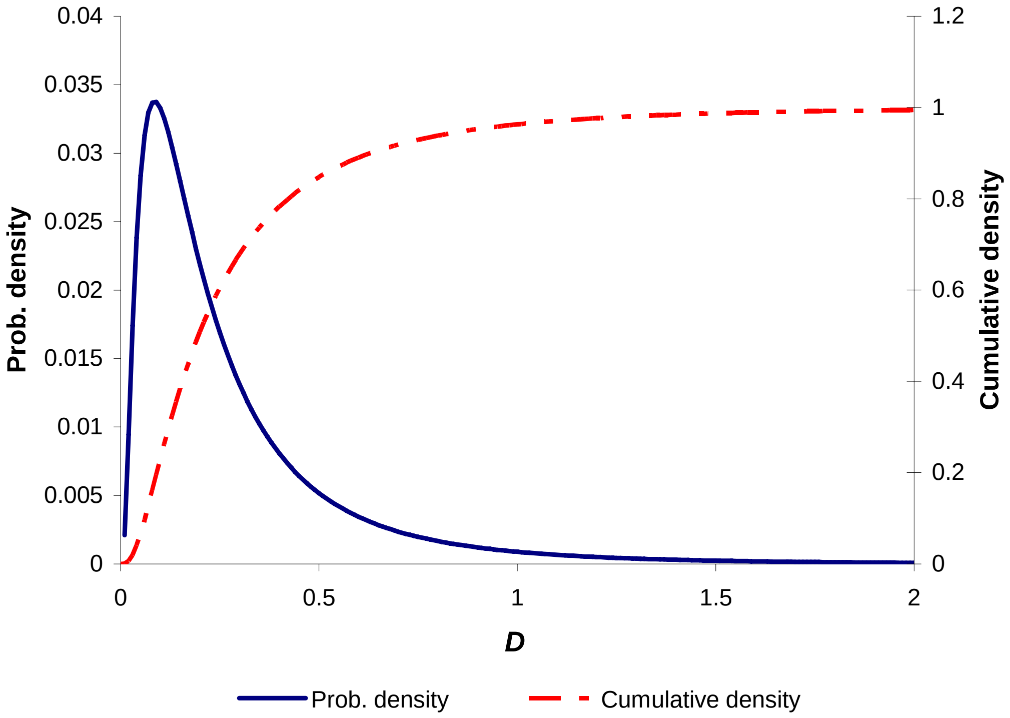


Figure 4.14. Estimated lognormal distribution of *D* for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.

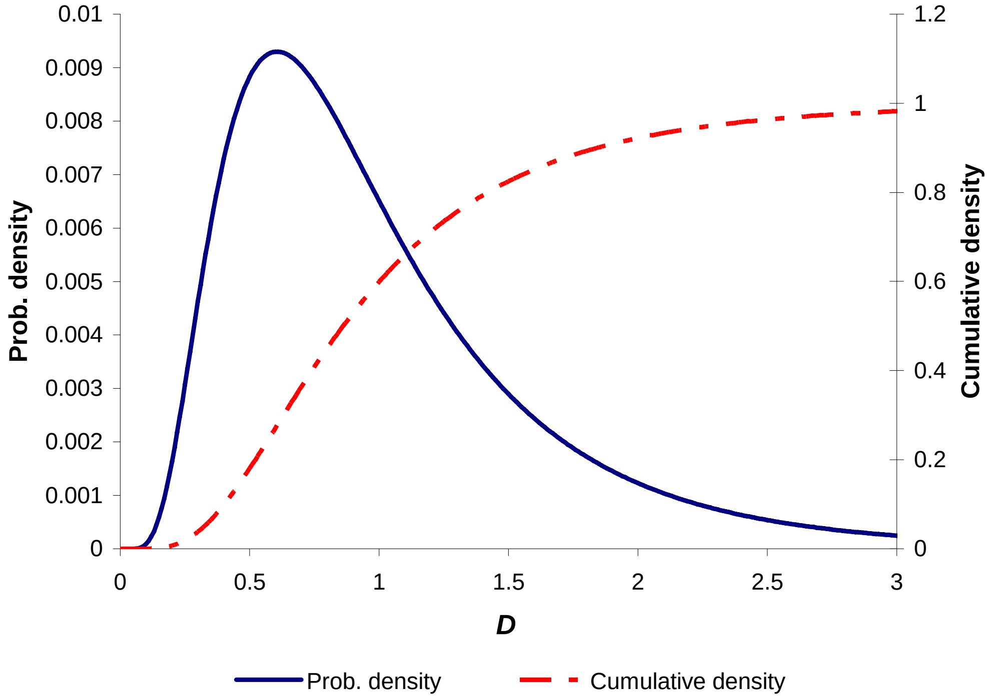


Figure 4.15. Estimated lognormal distribution of *D* for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.

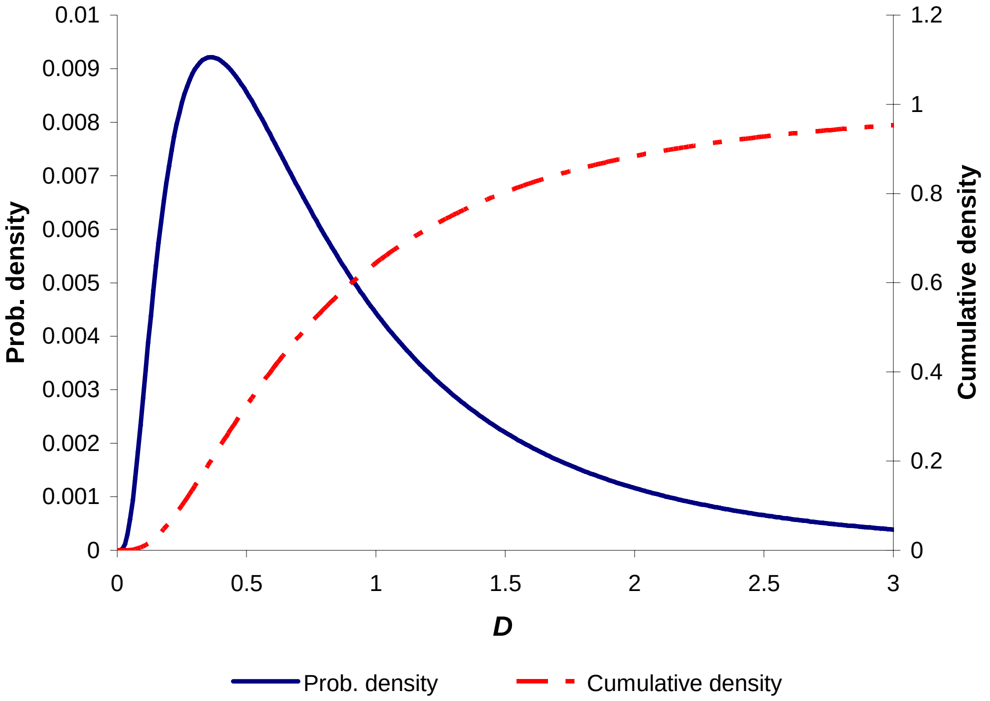


Figure 4.16. Estimated lognormal distribution of *D* for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.

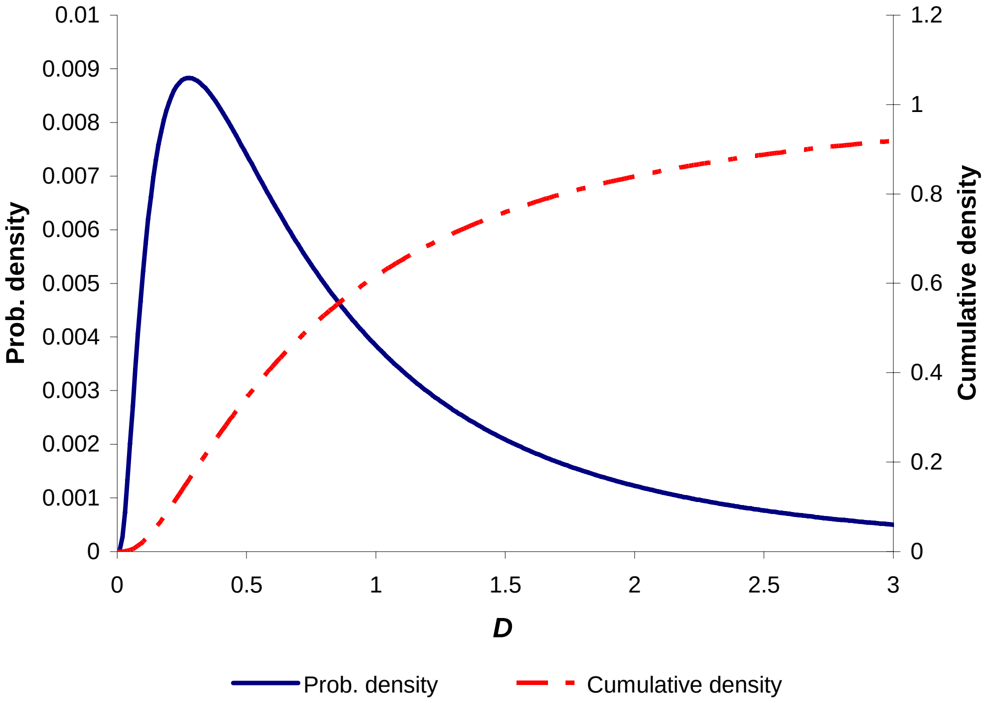


Figure 4.17. Estimated lognormal distribution of *D* for wild steelhead transported from LMN. Data from 1997 – 2002 migration years.

The resulting distributions indicate that *D* is usually substantially below 1 for Chinook, implying that there is substantial delayed (post-hydrosystem) mortality experienced as a consequence of being transported below the hydrosystem. Based on the median values, in more than half of the annual migrations, we can expect delayed transport mortality of 60% or more for wild Chinook. In contrast, *D* distributions for wild steelhead indicate expected values much closer to one. Most of the time, regardless of transport project, we can expect steelhead *D* to be less than one (medians in Table 4.4); however, *D*s equal to or greater than one can be expected to occur much more frequently than for Chinook, and the mean *D* values are all around 1. Consequently, expected delayed mortality due to transport is considerably less for steelhead than for Chinook.

Within-season variation

Each migration year, the season was broken into three periods based on detection date at LGR: Before Apri1 26, April 26 to May 10, and after May 10. This resulted in approximately equal total numbers of PIT-tagged fish in each group, over the six year period for Chinook. Summary information from the resulting SAR distributions is presented in the Tables 4.5 and 4.6 below. It appears that SARs can vary substantially over the season. Inspecting the distributions of transport and C_1 SARs for Chinook suggests that although transport SARs are somewhat higher later in the season than earlier (Fig. 4.18 and Table 4.5), C_1 SARs decline dramatically in the middle and end of the season (Fig. 4.19 and Table 4.5). This suggests that the primary reason for the increasing trend in TIRs observed in previous investigations is the dramatic decline in the success of the C_1 migration as the season progresses.

SARs for wild transported steelhead show a modest increasing trend over the season (Table 4.6 and Figure 4.20), while, as for Chinook, C_1 SARs exhibit a dramatic drop-off as the season progresses (Table 4.6 and Figure 4.21). We cannot estimate within-season SARs for the C_0 fish. However, across-years the C_0 SARs are greater than the C_1 SARs (Figure 4.22)

Table 4.5. Mean SARs and variances for early, mid and late periods, for migrating wild Chinook from LGR dam. Data from migration years 1998-2003.

Period	**T smolts**	**Mean SAR(T)**	**C_1 smolts**	**Mean SAR(C_1)**
Before 4/26	4059	0.76%	15380	1.76%
4/26 – 5/10	2366	1.39%	19568	1.05%
After 5/10	3022	1.09%	15348	0.53%

Table 4.6. Mean SARs and variances for early, mid and late periods, for migrating wild steelhead from LGR dam. Data from migration years 1997-2002.

Period	**T smolts**	**Mean SAR(T)**	**C_1 smolts**	**Mean SAR(C_1)**
Before 4/26	404	2.72%	6574	1.89%
4/26 – 5/10	468	3.21%	13872	0.47%
After 5/10	314	3.50%	8913	0.46%

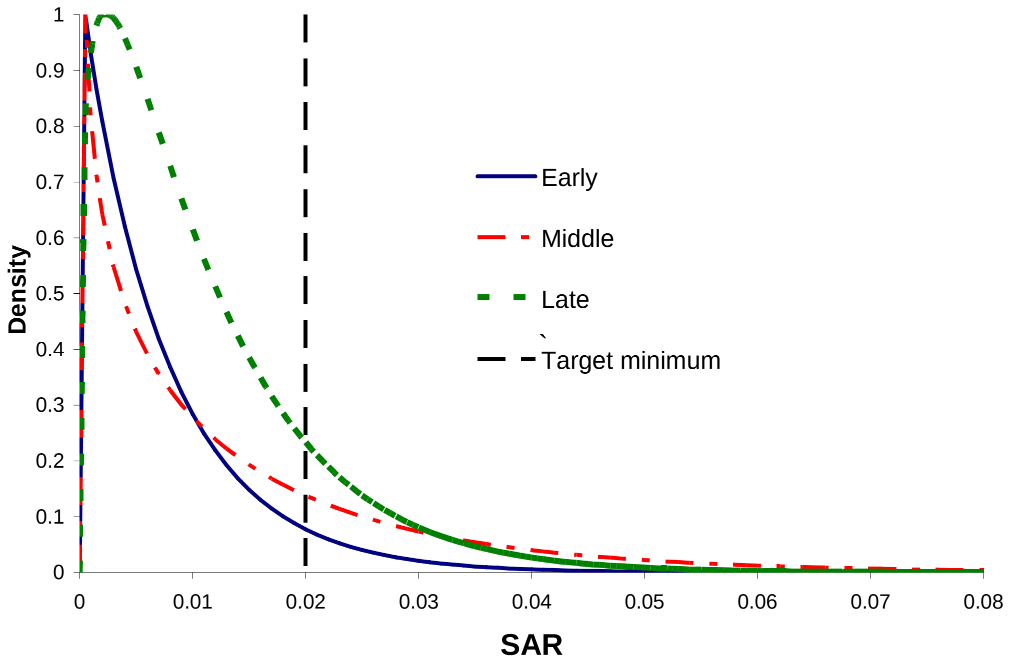


Figure 4.18. PDFs for SAR of wild Chinook transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Also shown is 2% SAR target. Data from migration years 1998-2003.

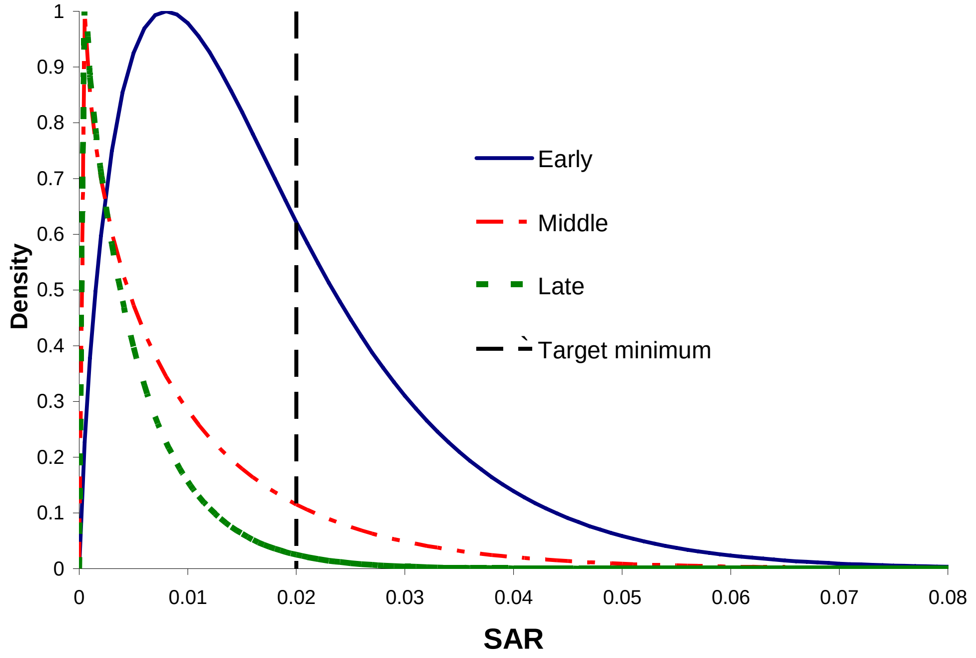


Figure 4.19. PDFs for SAR of wild Chinook migrating in-river (C_1)from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Also shown is 2% SAR target. Data from migration years 1998-2003.

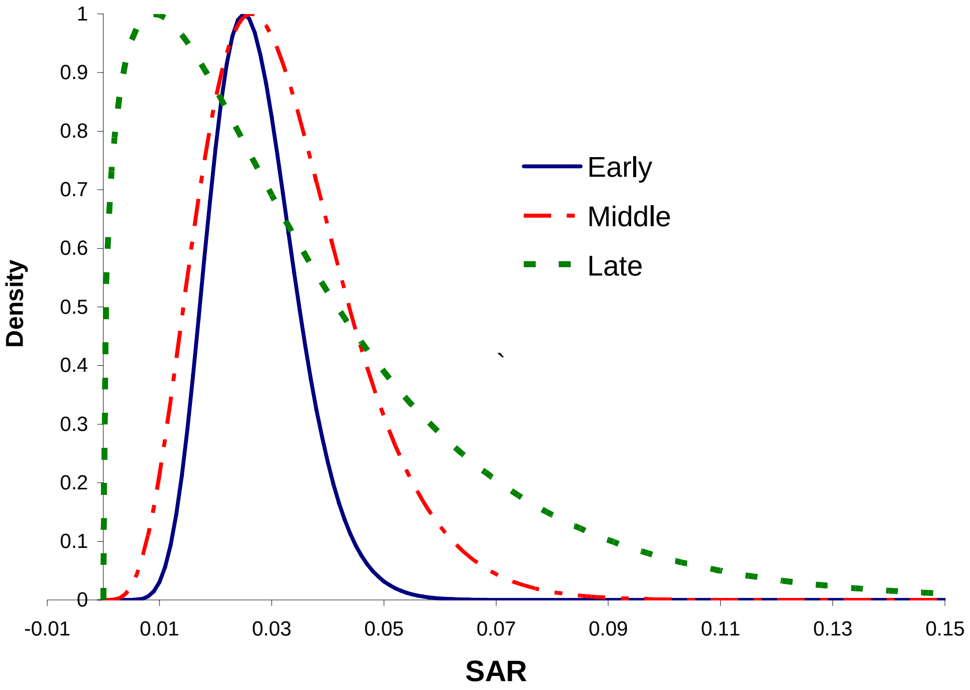


Figure 4.20. PDFs for SAR of wild steelhead transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.

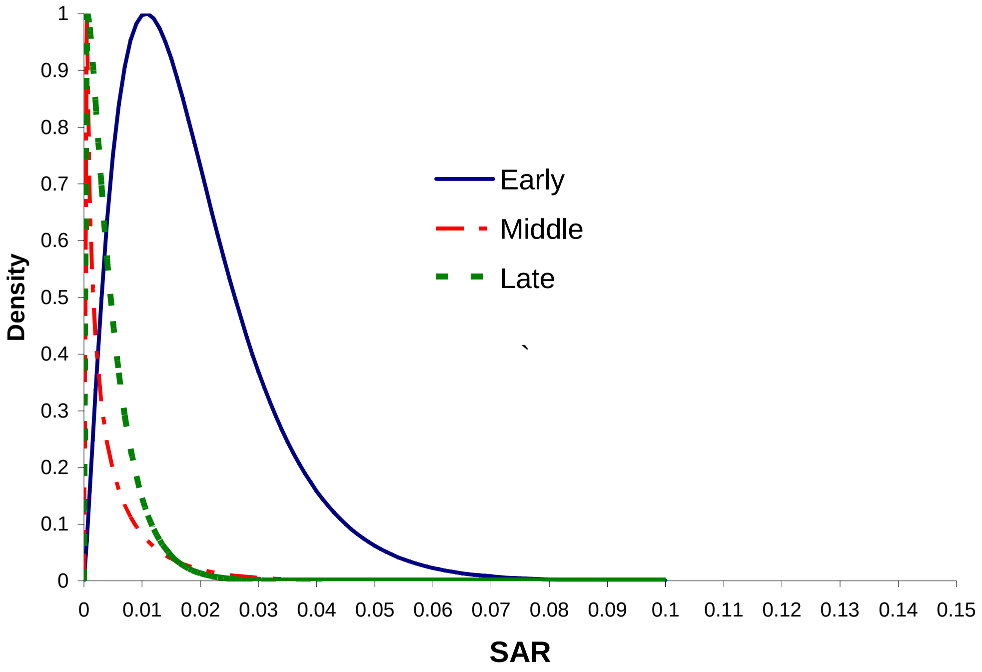


Figure 4.21. PDFs for SAR of wild steelhead migrating in-river (C_1)from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.

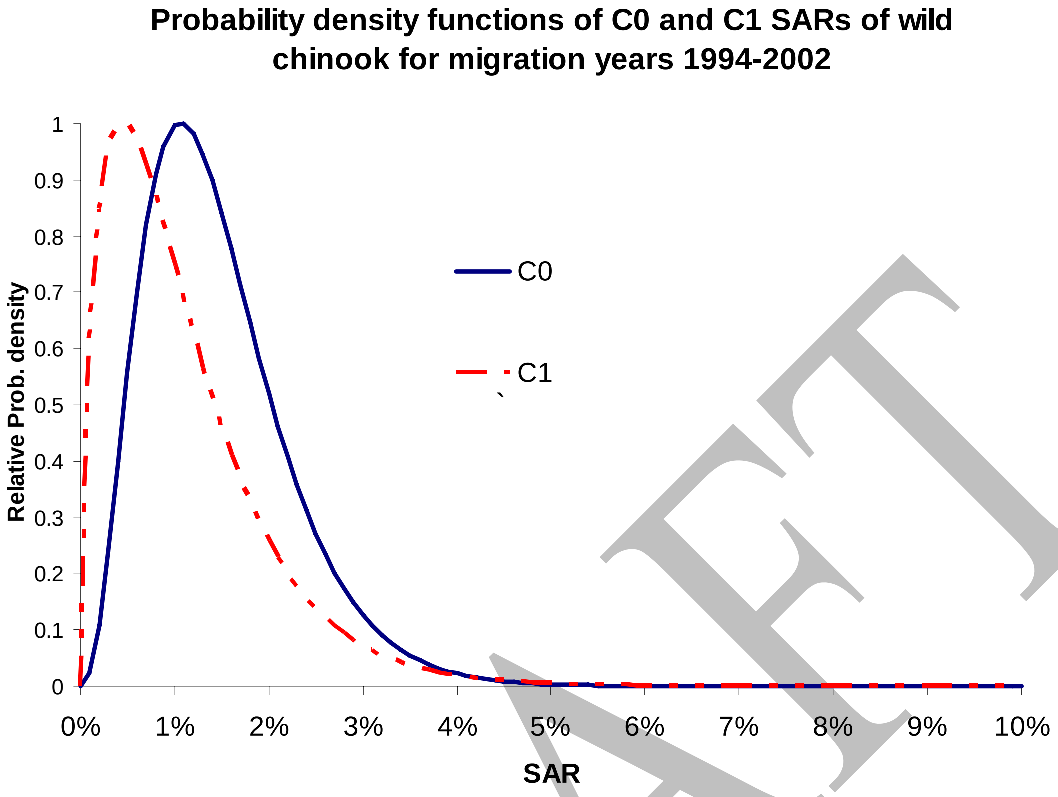


Figure 4.22. Distributions of SAR for true controls (C_0) and smolts detected at Lower Granite and returned to the river (C_1), 1994-2002 migration years.

Seasonal TIRs derived from these seasonal C_1 SARs may contain some positive bias because the true controls(C_0-the way the system is presently managed), which migrate through spill and turbine routes at collector dams, have shown higher SARs than fish bypassed at one or more of the collector dams (Berggren et al. 2005). The SAR distributions for true controls (C_0) and smolts detected and returned to the river at LGR dam (C_1) using the same method are shown in Figure 4.22. If in-river survivals are similar for C1 and C_0 groups, as generally assumed, the differential SAR is evidence of delayed mortality for bypassed fish (see Budy et al. 2002). It is also possible that the trend in increasing TIRs may not be as pronounced for C_0 fish as seen for C_1 fish, particularly in years when the spill program is implemented.

Discussion

The exercise of removing sampling error from SAR estimates shows that inter-annual variation in SARs of transported and in-river migrants is considerable for both wild Chinook and wild steelhead. Since population viability can be expected to be sensitive to the amount of variation in survival rates, management to minimize variation in SARs, in addition to increasing mean SARs, could be valuable in conservation strategies. The transport, in-river, and aggregate distributions suggest realized SARs have been considerably below target levels for recovery for Chinook, and generally below target levels for steelhead.

Taking into account precision of SAR estimates likely results in better estimates of the central tendencies and distributions of TIR than unweighted, multiple-year means. The resultant distributions suggest that on average, transportation as currently implemented is not of benefit for wild Chinook, regardless of transport project, as the bulk of the distributions for all projects is less than 1. Transportation from LMN seems to be particularly ineffective. Mean TIR estimates are considerably lower than estimates from other studies, which did not account for sampling error or covariance between transport and in-river SARs.

For wild steelhead, in contrast, transportation (particularly from LGR) appears to provide a significant benefit to compared to in-river migration under the current system. The benefit of transportation appears to decline lower in the system.

Derived *D* distributions suggest substantial delayed mortality of transported wild Chinook. Mean Chinook *D* values are substantially lower than means estimated using previous methods, which did not account for varying precision of estimates from different migration years, or for covariance between transport and in-river SARs. *D* estimates for steelhead are much higher than for Chinook, suggesting that delayed mortality from transport is much lower, consistent with the relative efficacy of transporting steelhead, compared to transporting Chinook.

The exercise of estimating SAR distributions for wild Chinook and steelhead migrants for three separate periods within the migration period indicates that SARs vary over the migration season, though there is significant overlap between periods. The relatively high C_1 SARs early in the season suggest that current strategies that maximize transportation of collected fish over the entire migration season are not optimizing overall wild Chinook SAR. The results also suggests that previously observed increasing trends in Chinook TIR over the migration season are a result mainly of the dramatic decline in C_1 SARs over the season, rather than increasing survival of transported fish.

Similar patterns in in-river SARs within the season are seen for steelhead; however the relatively high transport SARs seen for steelhead suggest that full season transportation may be optimizing steelhead survival under the current configuration and operation of the hydrosystem. Smolt-to-adult survival of transported steelhead appears to be much more variable later in the season than earlier, however. Under past operations, optimizing survival of both wild Chinook and wild Steelhead at the same time has not occurred.

The decline in SAR of in-river fish of both species as the season progresses is consistent with the hypothesis that the protracted migration and late arrival in the estuary is in part responsible for elevated levels of post-Bonneville mortality as a consequence of the hydrosystem experience. This is consistent with other studies suggesting that delayed estuary arrival timing is a cause of delayed mortality (e.g. Muir et al. 2006) .

The lognormal approximation to the ratio of beta random variables, while good for the range of parameters examined in this report, is less useful when mean survival rates are very close to zero or exhibit extremely high variability. Consequently, the ability to apply this approximation to SAR distributions estimated from smaller datasets, such as from temporal or geographic subsets of the annual Snake River wild migration of either species, may be limited.

The results for steelhead should be qualified in acknowledgement of the short time series and the strong influence of 2002 migration year on steelhead C_0 SARs, TIRs, and *D*s, due to the high number of tagged smolts in that year, compared to other years. Almost all of the tagged smolts were untransported that year, and the estimated in-river SAR was particularly low. The low survival rates may be in part due to the absence of spill at Lower Monumental Dam that year, because of repairs to the stilling basin. Annual steelhead transport and in-river SARs are likely positively correlated, but the sample sizes (tagged smolt numbers) were low compared to Chinook, and consequently point estimates subject to large error. Unlike Chinook, the data therefore didn't reflect this correlation, so the resulting distributions of TIR and D are necessarily wider than for Chinook.

A further avenue of exploration is the effect of estimation uncertainty on the number of C_0 smolts. Since this number isn't observed directly, but must be estimated from other observed and estimated quantities, this number [the denominator of SAR(C_0)] isn't known without error, as usually assumed in inferences about binomial random variables. The error is small as a portion of the seasonal C_0 estimate: coefficients of variation (CVs) are mostly around 2 - 4%, and range from 1 – 10% (highest for steelhead in 2001), with larger CVs corresponding to smaller C_0 point estimates. Since years with the smallest C_0 estimates have the least weight in estimating overall SAR(C_0) mean and variance, the effect is probably minimal. For this report, then, these levels of estimation error were assumed to be unimportant in estimating overall sampling error. However, simulations are planned to examine how sensitive the SAR (and TIR and *D*) distributions are to this level of deviation from a true binomial proportion.

Chapter 5.

Evaluation and Comparison of Overall SARs

Introduction

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 (2003) mainstem amendments to the Fish and Wildlife Program adopted as an interim objective, to "…contribute to achieving smolt-to-adult return rates (SARs) in the 2-6 percent range (minimum 2 percent; average 4 percent) for listed Snake River and upper Columbia salmon and steelhead." The NPCC (2003) also called for evaluation of the scientific soundness and achievability of, and impact of ocean conditions on, these SAR objectives. Analyses in this chapter address the extent to which wild Snake River spring/summer Chinook and steelhead population aggregates may be meeting the NPCC (2003) interim biological objectives, and factors influencing the overall SARs.

The NPCC 2-6% SAR objectives have a scientific basis in analyses by the Plan for Analyzing and Testing Hypotheses (PATH), conducted in support of the 2000 Biological Opinion. 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 100-year interim survival standard required a median SAR of at least 2%. PATH analyses did not identify specific SARs necessary for steelhead survival and recovery, however, historic steelhead SARs before FCRPS completion were somewhat greater than those of spring/summer Chinook (Marmorek et al. 1998). Currently, the Interior Columbia River Technical Recovery Team (IC-TRT) is developing biological recovery criteria based on the Viable Salmonid Population concepts (McElhaney et al. 2001). Additional SAR objectives may be associated with the IC-TRT recovery criteria when adopted or incorporated into a Recovery Plan. Regardless of specific future SAR objectives, the same types of data and analytical methods will be required in the future to evaluate the overall effectiveness of the hydrosystem mitigation strategy. In addition, the ISAB (2006) raised the issue that more attention should be given to whether PIT-tagged fish survive as well as the untagged fish. Differences, and causes of any differences, need to be identified to relate PIT tag SARs to the regional recovery objectives.

SARs reflect the combined influence of hydrosystem seaward migration and ocean/climatic influence. Analyses in this chapter include multiple regression modeling of Snake River spring/summer Chinook SARs (dependent) and management and environmental variables in the migration corridor and ocean (independent). These analyses also address, in part, the NPCC (2003) direction to evaluate the scientific soundness and achievability of (considering the impact of ocean conditions on survival) these SAR objectives.

Background -- Patterns observed in recruits-per-spawner (R/S) and smolt-to-adult survival (SAR) data collected as part of the CSS, as well as studies done by other researchers (e.g., Pyper et al. 2005), indicate that strong covariation in performance exists among anadromous salmon populations in the Pacific Northwest. Such synchronized population behavior is believed to be driven primarily by large-scale climate variables or 'year' effects. Thus, towards a more complete understanding of factors influencing inter-annual patterns in PIT-tag-based SARs and other performance measures used by the CSS (i.e., TIR ratios and *D*), we evaluated relationships between SARs and selected environmental parameters in this chapter. We provide an analysis of wild and hatchery Chinook salmon SAR (Lower Granite-to-Lower Granite) variation due to in-river, estuary/early ocean, and off-shore marine environmental conditions. Further, in order to determine whether or not CSS SAR–environmental variable relationships are consistent with and representative of those existing for wild Snake River spring/summer Chinook salmon historically, we simultaneously analyzed relationships between run-reconstruction-based SARs and environmental factors.

In chapter 5, we also compare SARs for Snake River spring/summer Chinook and SARs from downriver populations which are less influenced by the hydrosystem. The upriver/downriver population comparison was initiated primarily to provide information relevant to the patterns observed in spawner-recruit (SR) patterns between upriver and downriver stream-type Chinook (e.g., Schaller et al. 1999, Deriso et al. 2001, Schaller and Petrosky *in press*). The PATH comparison of SR patterns indicated productivity and survival rates of Snake River populations declined more than those of downriver populations, coincident with development and operation of the FCRPS. The SR comparisons also provided evidence of delayed mortality of in-river migrants from the Snake River, after accounting for direct mortality, differential delayed mortality of transported smolts (D), and the common year effect (Peters and Marmorek 2001; CSS Delayed Mortality Workshop proceedings, Marmorek et al. 2004; Schaller and Petrosky in press). Our specific interest in Chapter 5 is whether upriver/downriver differences in SARs for wild and/or hatchery stream-type Chinook were consistent with the differential mortality estimated from SR models for wild populations. We also compared biological characteristics (smolt FL, migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation.

Populations and population aggregates used in the Chapter 5 analyses from the Snake River include aggregate wild Snake River spring/summer Chinook, and Snake River hatchery spring/summer Chinook from Dworshak, Rapid River, and McCall hatcheries, and the Imnaha and Catherine Creek acclimation ponds. The IC-TRT (2003) has identified 30 extant Snake River spring/summer Chinook populations upriver of Lower Granite Dam, excluding 4 reestablished, unlisted populations in the Clearwater River. We also examined patterns of SARs among subbasins (Clearwater, Grande Ronde, Salmon and Imnaha rivers) within the aggregate wild Snake River spring/summer Chinook. In addition, information for aggregate wild Snake River steelhead, and hatchery aggregate Snake River steelhead is presented in this chapter. The IC-TRT has identified 24 extant steelhead populations upriver of Lower Granite Dam, which are represented in our aggregate wild population.

Populations and population aggregates from the downriver interior Columbia River region used in Chapter 5 include the aggregate wild John Day River spring Chinook and Carson Hatchery spring Chinook. The John Day wild spring Chinook aggregate (downriver) is comprised of three populations, from the North Fork, Middle Fork and upper mainstem.

Methods

Sources of study fish in the CSS are described in detail in Appendix A. PIT-tagged smolts were detected at six Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA), and Bonneville (BON). In addition, PIT-tag detections were obtained at the NOAA Fisheries trawl (TWX) operated in the lower Columbia River half-way between BON and the mouth of the Columbia River. PIT-tagged returning adults were detected in the Lower Granite Dam adult fish ladder (GRA) in each year. Beginning in return year 2002, detectors were installed in all the adult fish ladders at Bonneville (BOA) and McNary (MCA) dams, allowing detection of returning PIT-tagged adults at these additional locations. Details of juvenile and adult detections are also described in Appendix A.

The population of PIT-tagged study fish arriving at LGR is partitioned into three categories of smolts related to the manner of subsequent passage through the hydro system. Fish have the opportunity to either (1) pass inriver through the Snake River collector dams in a non-bypass channel route (spillways or turbines), (2) pass inriver through the dam's bypass channel, or (3) pass in a truck or barge to below BON. These three ways of hydro system passage is used to define the three study categories, C_0, C_1 and T_0, respectively, of the CSS. Typically, study categories T_0 and C_0 are the most representative of the run-at-large untagged population (exception is 1997 when most fish collected, tagged and untagged, in April and May at LGS and LMN were bypassed to the river). See Appendix A for the formulas used to estimate the number of smolts in each study category and Chapter 3 for details of the analysis.

Overall SARs

We estimated overall SARs for the following population groupings (see Chapter 3):

- Wild spring/summer Chinook 1994-2004
  - Subbasin SARs, 1998-2000, 2002
- Hatchery spring/summer Chinook, 1997-2004
- Wild steelhead, 1997-2004
- Hatchery steelhead, 1997-2004

We used two methods to test whether the overall SARs, for wild Snake River spring/summer Chinook and steelhead population groupings, exceeded the minimum 2% SAR and/or the average 4% SAR NPCC objectives. The first method employed a t-test of observed SARs (which included measurement and process error). The second method evaluated the likelihood that the same population groupings exceeded the minimum 2% SAR and/or the average 4% SAR NPCC objectives (see Chapter 4 methods - Akcakaya (2000) method to estimate total variance and remove sampling variance).

To evaluate SARs by Subbasin above LGR, we used the wild PIT-tagged juvenile Chinook from all available marking efforts in the Snake River basin above Lower Granite Dam. Wild Chinook from each subbasin (plus fish tagged at Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years 1994 to 2004 (Table 5.1).

Table 5.1. Number of PIT-tagged wild Chinook parr/smolts from the four subbasins above Lower Granite Dam and Snake River trap used in the CSS analyses for migration years 1994 to 2004.

Migr. Year	Number of PIT-tagged wild Chinook utilized in CSS by location of origin					
	Total PIT Tags	**Clearwater River (Rkm 224)**	**Snake River trap[1] (Rkm 225)**	**Grande Ronde River (Rkm 271)**	**Salmon River (Rkm 303)**	**Imnaha River (Rkm 308)**
1994	49,657	8,292	1,423	8,828	27,725	3,391
1995	74,639	17,605	1,948	12,330	40,609	2,148
1996	21,523	2,246	913	7,079	7,016	4,269
1997	9,781	671	None	3,870	3,543	1,697
1998	33,836	4,681	921	8,644	11,179	8,411
1999	81,493	13,695	3,051	11,240	43,323	10,184
2000	67,841	9,921	1,526	7,706	39,609	9,079
2001	47,775	3,745	29	6,354	23,107	14,540
2002	67,286	14,060	1,077	9,715	36,051	6,428
2003	103,012	15,106	381	14,057	60,261	13,165
2004	99,743	17,214	541	12,104	56,153	13,731
Average % of total		16.3%	1.8%	15.5%	53.1%	13.3%

[1] Snake River trap collects fish originating in Salmon, Imnaha, and Grande Ronde rivers.

In order to evaluate whether there were differences in SARs for PIT-tagged wild Chinook from the four tributaries above LGR, there needs to be adequate numbers of returning adults detected from the PIT-tagged smolts released in each subbasin. Table 5.2 shows the number of returning adults (age 2 ocean and older) for each study category (T_0, C_0, and C_1) for fish from the four tributaries, plus the Snake River trap. Since the latter tagging site includes fish originating from either the Grande Ronde, Salmon, or Imnaha rivers, it will not be included in the analysis of SARs by drainage of origin. A criteria of greater than 15 PIT-tagged returning adults in each of the four tributaries was used in determining which migration years to select for this evaluation. Table 5.2 highlights (values in red) the four years meeting the criteria. Therefore, further analyses of SARs by drainage will be limited to migration years 1998, 1999, 2000, and 2002.

Although Table 5.1 shows the breakdown of the release of PIT-tagged wild Chinook across drainages, it is breakdown of the PIT-tagged smolts surviving to LGR (both detected and undetected fish) that is of more interest. This is because the PIT-tagged fish that make up the aggregate wild Chinook population within each drainage are tagged at different locations and time over a 10-month period and so experience different amounts of mortality before they arrive at the start of the hydrosystem. Figure 5.1 shows that in migration year 1998, the PIT-tagged wild Chinook from the Salmon and Imnaha rivers each accounted for nearly one-third of the overall wild Chinook aggregate population, whereas in migration years 1999, 2000, and 2002, tagged fish from the Salmon River accounted for approximately half of the individuals in the aggregate wild Chinook tagged populations. Excluding the fish released from the Snake River trap, the remaining PIT-tagged fish were fairly evenly split (within an 11- 20% range) across the other drainages.

Table 5.2. Number of PIT-tagged wild Chinook adults (2-ocean and older) detected in Lower Granite Dam adult fish ladder from aggregate of fish tagged in 10-month period between July 25 and May 20 and classified into each of the three study categories from 1994 to 2004. Cells with >15 fish are bolded; cells with >15 fish in each of 4 drainages are highlighted in red.

Migr. Year	Study Category	Total Aggregate	Clearwater River	Grande Ronde River	Salmon River	Imnaha River	Snake River Trap
1994	T_0	9	0	0	5	3	1
	C_0	5	3	1	0	1	0
	C_1	3	2	0	0	1	0
1995	T_0	8	**4**	0	**3**	0	1
	C_0	10	**1**	5	**3**	0	1
	C_1	36	**11**	4	**18**	1	2
1996	T_0	2	0	0	1	1	0
	C_0	5	1	0	1	2	1
	C_1	7	0	2	1	2	2
1997	T_0	4	0	**2**	0	2	0
	C_0	16	1	**9**	2	4	0
	C_1	18	0	**10**	3	5	0
1998	T_0	15	**2**	**4**	**2**	**7**	0
	C_0	42	**4**	**7**	**8**	**20**	3
	C_1	131	**11**	**19**	**35**	**62**	4
1999	T_0	43	**2**	**5**	**20**	**11**	5
	C_0	95	**14**	**15**	**45**	**14**	7
	C_1	495	**40**	**58**	**244**	**107**	46
2000	T_0	12	**0**	**2**	**7**	**3**	0
	C_0	155	**18**	**20**	**82**	**31**	4
	C_1	392	**23**	**54**	**187**	**109**	19
2001	T_0	7	1	0	0	**6**	0
	C_0	1[A]	0	0	1	**0**	0
	C_1	29	1	2	6	**20**	0
2002	T_0	31	**4**	**7**	**18**	**0**	2
	C_0	76	**6**	**20**	**33**	**14**	3
	C_1	125	**18**	**18**	**63**	**21**	5
2003	T_0	30	1	**6**	**17**	**6**	0
	C_0	29	0	**6**	**10**	**13**	0
	C_1	22	1	**5**	**6**	**10**	0
2004[B]	T_0	39	3	9	**13**	**13**	1
	C_0	7	0	0	**3**	**4**	0
	C_1	30	4	5	**11**	**10**	0

[A] One returning adult with no detections may have inadvertently been transported; therefore, inriver SARs are based solely on Category C_1 fish in 2001.

[B] Migration year 2004 is incomplete with 2-ocean adult returns as of 8/9/2006.

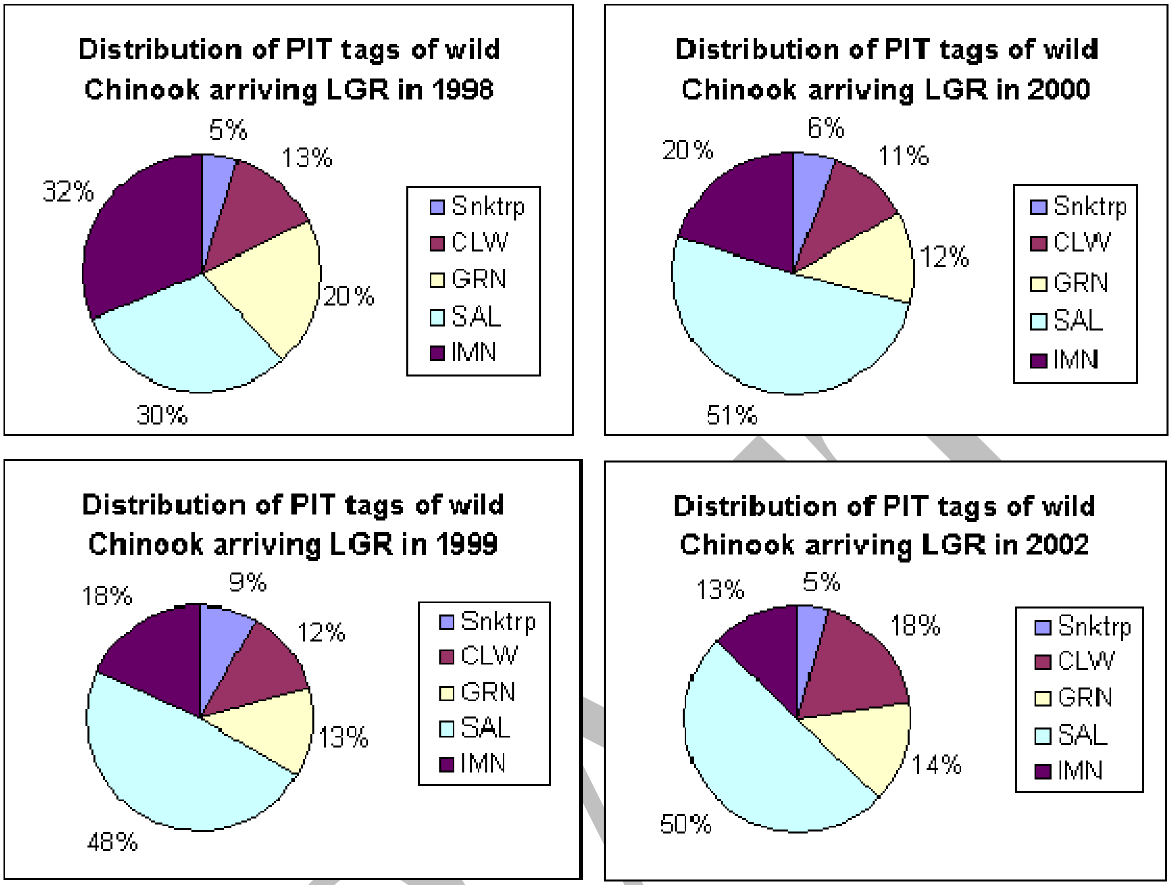


Figure 5.1. Percentage of PIT tags in wild Chinook aggregate from Clearwater (CLW), Grande Ronde (GRN), Salmon (SAL), and Imnaha (IMN) rivers, plus Snake River trap at Lewiston, Idaho, for migration years 1998, 1999, 2000, and 2002.

Relationships between wild and hatchery Chinook SARs and in-river, estuary/early ocean, and off-shore marine environmental variables

SAR estimates - Smolt-to-adult return rate (SAR) provides a measure of overall survival from the out-migrating smolt stage to the returning adult (or recruit) stage. For wild spring/summer Chinook, we quantified relationships between environmental variables and smolt-to-adult survival using annual SAR estimates from the CSS PIT tag estimates for 1994-2004 (11 years). We used annual weighted SAR estimates for both wild and hatchery fish (Appendix C). These values incorporate SARs of both transported (T_0) and inriver (C_0, C_1) study groups, with the contribution of each category to the overall estimate being weighted by its relative abundance in the run at large (during outmigration). We also quantified relationships between environmental variables and a longer SAR time series which pre-dates the completion of the FCRPS. For the longer time series, we combined the CSS estimates with run reconstruction SARs for 1964-1984 and 1992-1993 (34 years). The run reconstruction SARs are calculated as the number of jacks and adults (age 3-5) returning to the Columbia River mouth by brood year, which are then divided by number of smolts (from that brood) arriving at the uppermost dam on the Snake River (Lower Granite dam since 1975). The historical run reconstruction SARs represent pre-harvest adult recruits (adults to upper dam adjusted by harvest rates experienced in the mainstem Columbia tribal and non-tribal fisheries). These SARs were estimated for the aggregate Snake River wild spring and summer Chinook using the methods described in Petrosky et al. (2001) and extended by Williams et al. (2005). We also adjusted the CSS $\mathrm{SAR}_{\mathrm{LGR\text{-}LGR}}$ for harvest rates experienced on wild spring/summer Chinook during the respective return years 1996-2006 (range 4.8% to 14.6%; U.S. v. Oregon Technical Advisory Committee 2006). In contrast to other studies (Scheuerell and Williams 2005; Williams et al. 2005), we excluded years when estimated smolt abundance was based on spawner-recruit model predictions (i.e., MY 1985-1991). A time series plot of SARs for wild spring summer Chinook appears in Figure 5.2.

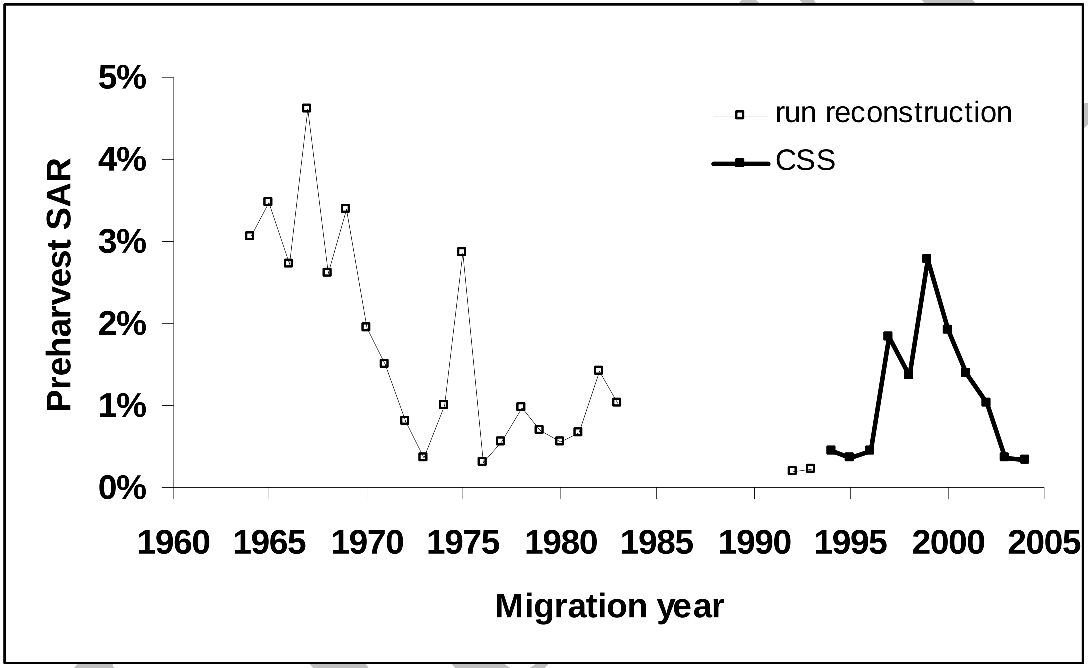


Figure 5.2. Preharvest smolt-to-adult returns for Snake River wild spring/summer Chinook, migration years 1964-2004.

SARs were estimated for hatchery Chinook salmon populations based on PIT-tag releases occurring at Dworshak National Fish Hatchery, Imnaha Hatchery, McCall Hatchery, Rapid River Hatchery and the Catherine Creek Acclimation Pond. Our hatchery Chinook salmon SAR time series extends from MY 1997 to 2004 (8 years), and represented the average SAR across hatcheries (Figure 5.3). The CSS wild PIT SAR estimates were highly correlated (r= 0.94) with the aggregate wild run reconstruction estimates, for migration years 1994-2001. The CSS hatchery PIT SAR estimates were highly correlated (r= 0.87) with the aggregate wild run reconstruction estimates, for migration years 1997-2001. Lastly, the CSS hatchery PIT SAR estimates were also highly correlated (r= 0.86) with the CSS wild PIT SAR estimates. Given the high correlation among SAR estimates, we focused the remainder of the analyses on the contemporary CSS wild PIT estimates and on the longer time series that included the aggregate wild run reconstruction estimates (migration years 1964-1984, 1992-1993) and the CSS wild PIT estimates (migration years 1994-2004) in order to get the largest contrast in survival estimates.

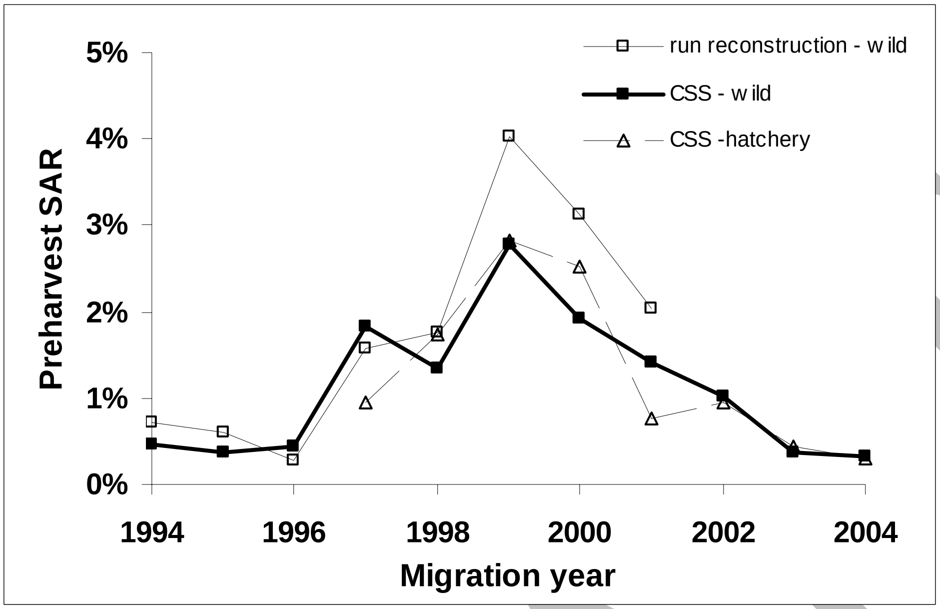


Figure 5.3. Preharvest smolt-to-adult returns for Snake River spring/summer Chinook, migration years 1994-2004 (open squares are run reconstruction wild, solid squares are CSS wild, and open triangles are CSS hatchery)

Environmental variables – Environmental variables used in this analysis included water travel time experienced by Snake River juvenile spring migrants, and ocean environment indices describing coastal upwelling intensity and broad scale measures of sea surface temperature during the first year of ocean residence.

Water travel times (SNWTT), from the confluence of the Snake and Clearwater rivers to Bonneville Dam, were calculated for the period April 15-May 31, the primary spring migration period. Water travel time is a function of reservoir volume and inflow, both of which are partially subject to management control. SNWTT ranged from 5 to 40 days during the 1964-2004 smolt migrations (Figure 5.4).

We included in our analysis two variables describing environmental conditions existing during the early-ocean phase of Chinook salmon. First, we described conditions existing immediately off shore using monthly indices of coastal upwelling intensity (i.e., the Bakun Index, CUI) estimated at 45N and 125W. Upwelling indices have also been linked to ocean survival for Columbia stream-type Chinook salmon (Scheuerell and Williams 2005) and Oregon coastal Coho salmon (Nickelson 1986). Monthly CUI indices were obtained from NOAA Pacific Fisheries Environmental Laboratory website http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html and are displayed in Figure 5.5.

Second, we described conditions existing in the off-shore marine environment using the Pacific Decadal Oscillation index (PDO), given existing knowledge on associations between salmon production and PDO regimes (e.g., Hare et al. 1999). PDO is a large-scale ocean-climatic index. The PDO data were from updated standardized values of the PDO index derived as leading principal component of monthly SST anomalies in the North Pacific Ocean (Mantua et al. 1997). Negative values indicate cold-PDO and positive values indicate warm phases; production of Columbia River salmon is believed to be greatest during cold-PDO phases due to increased primary production encountered by these fish while at sea. Monthly PDO indices were obtained from the University of Washington website http://jisao.washington.edu/pdo/PDO.latest, and are displayed in Figure 5.6.

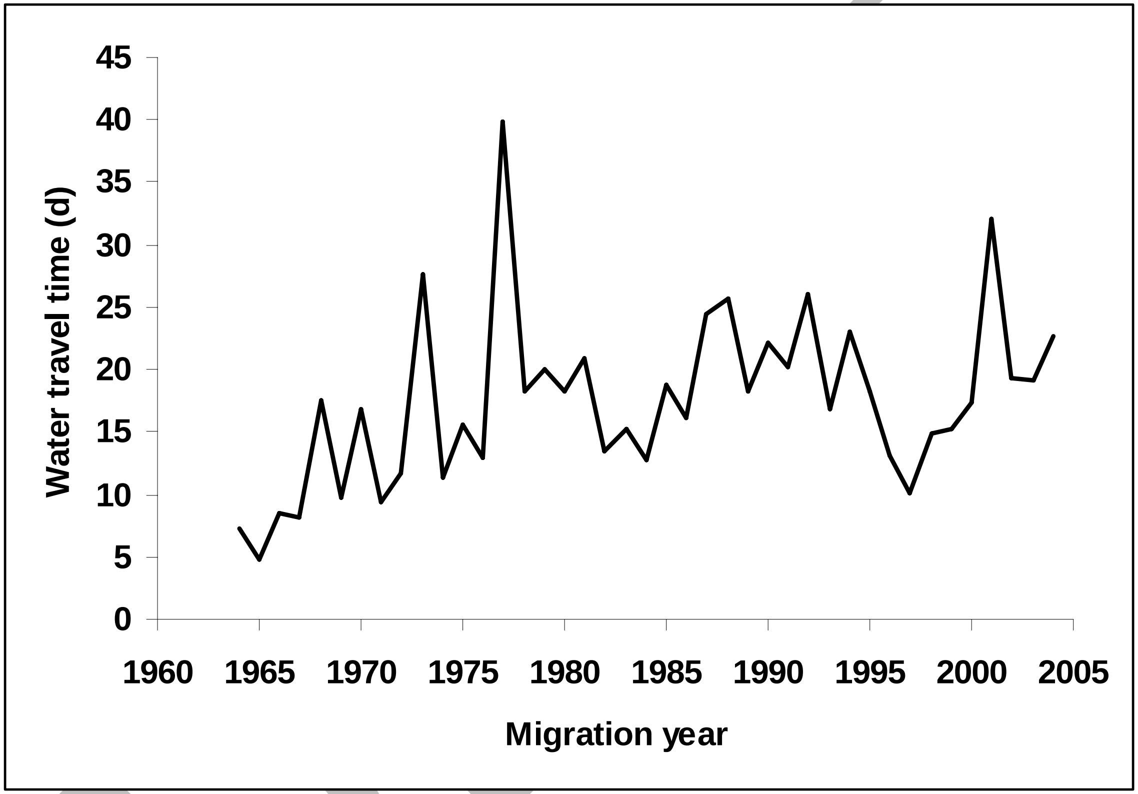


Figure 5.4. Water travel time(d) experienced by juvenile spring Snake River migrants, 1964-2004.

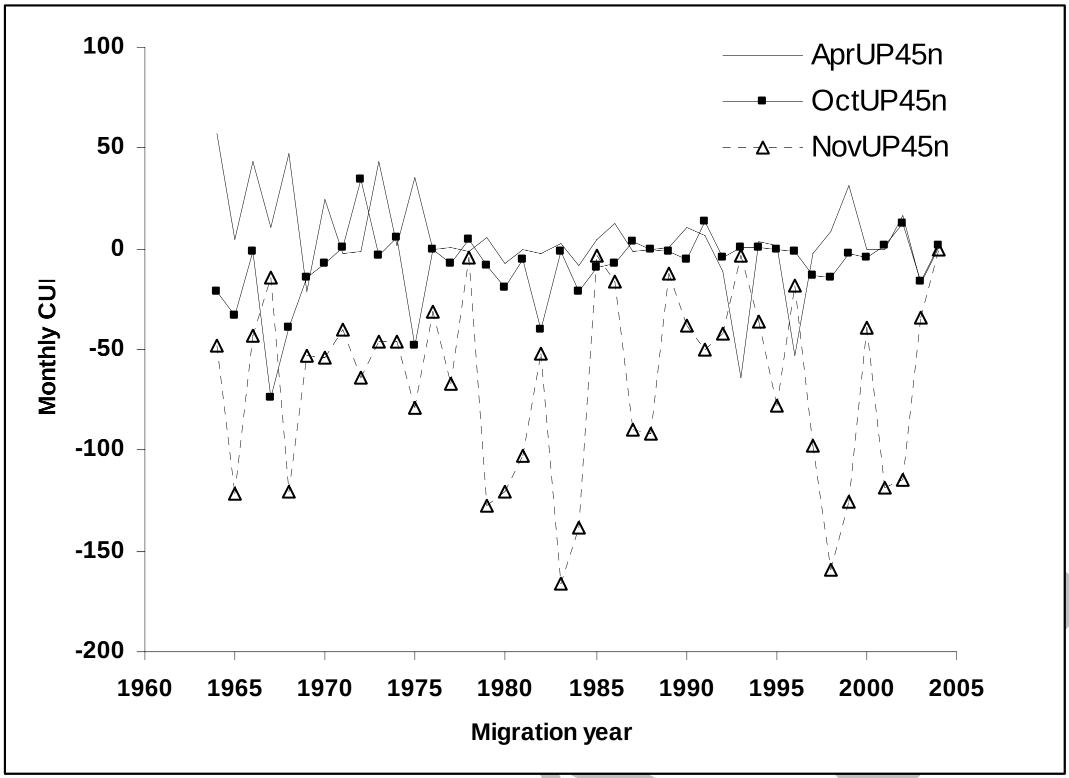


Figure 5.5. Monthly CUI indices (45N 125W) for April, October and November, 1964-2004 migration years. April, October and November indices were frequently incorporated in multiple regression models describing SAR.

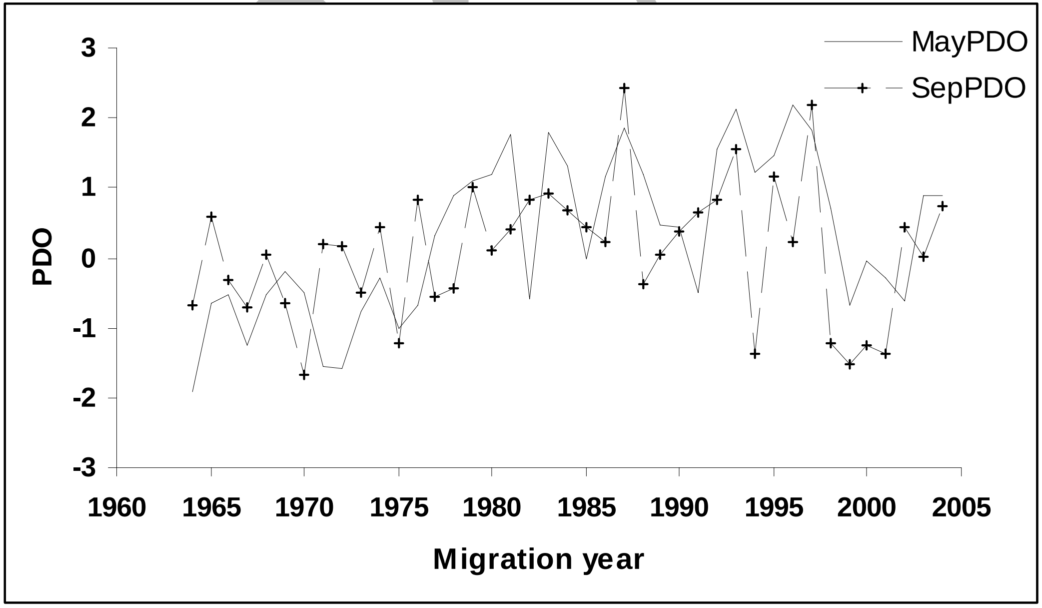


Figure 5.6. Monthly PDO indices for May and September, 1964-2004 migration years. May and September indices were frequently incorporated in multiple regression models describing SAR.

Data analysis -- We explored relationships between SARs (ln-transformed for normalization) and inriver and estuary/early ocean environmental conditions, separately, through a multi-stage linear regression modeling exercise.

<u>Multiple Factor Model</u>

Multiple regression was used to relate the SAR estimates for spring/summer Chinook to environmental variables encountered during early ocean residence (monthly PDO, upwelling indices) and during migration through the hydrosystem as smolts (Water Travel Time, days). For each dataset, we distinguished between candidate models at each stage using the least-squares version of Akaike's Information Criterion (AIC_c; also corrected for small sample size) following the information-theoretic approach advocated by Burnham and Anderson (2002) and using Bayesian Information Criterion (BIC). Although we completed a separate model selection and fitting exercise for both historic (i.e., full time series) and contemporary (i.e., PIT-tag-based) SAR datasets, we ultimately contrasted results between groups in order to understand the generality of patterns existing in each. To do this, we qualitatively compared model selection results, contrasted bivariate slope parameters (i.e., estimates +/- 95% CIs), and examined associated scatter plots.

We started with a set of bivariate single-predictor inriver models and single-predictor ocean environment models (i.e., distinguishing between monthly CUIs, and monthly PDOs) and progressively built towards our most fully parameterized model – one including a single inriver and 2 marine variables (i.e., including the best upwelling variable and PDO). In addition, we screened monthly oceanographic environmental variables to avoid models that contained independent variables that were highly correlated (e.g. use only May, because April and May r=.90, May and June r=.85).

Thus, our multiple regression between *SAR*(*t*)and indices of multiple environmental factors typically took the form of:

$$\begin{aligned} -\ln[SAR(t)] &= \beta 0 + \beta_{WTT} \cdot \mathrm{WTT}(t) + \beta_{SepPDO} \cdot \mathrm{PDO}_{\mathrm{Sep}}(t) \\ &\quad + \beta_{Apr\mathrm{UPWELL}} \cdot \mathrm{UPWELL}_{\mathrm{Apr}}(t) + \varepsilon t \,, \end{aligned} \qquad [5.1]$$

All analyses were completed using SAS version 91.

Snake River and Downriver SAR Comparison

Differential mortality estimates from spawner-recruit data: Deriso et al. (2001) evaluated alternative spawner recruit (SR) models using seven Snake River index populations (Bear Valley Creek, Marsh Creek, Sulphur Creek, Johnson Creek, Poverty Flat, Imnaha River, and Minam River), three John Day River populations (North Fork, Middle Fork and upper mainstem) and three additional downriver populations (Warm Springs, Klickitat and Wind rivers). SR data for the Snake River and John Day River populations began in the 1950s, a decade or more before completion of the FCRPS; SR data for the three additional downriver populations began in 1969, 1966 and 1970, respectively. The best empirical models, evaluated by Deriso et al. (2001), included an estimate of a common year-effect (δ) for Snake River and downriver stream-type Chinook salmon populations. Their primary model (delta model) was:

$$\ln(\mathrm{R}_{t,i} / \mathrm{S}_{t,i}) = (\mathrm{a}_i + \delta_t - \mathrm{m}_{t,i}) - \beta_i \mathrm{S}_{t,i} + \varepsilon_{t,i} \qquad [5.2]$$

where $R_{t,i}$ is the Columbia River recruitment originating from spawning in year t and population i, $S_{t,i}$ is the spawners in year t and population i, a_i is the Ricker a value for population i, δ_t is the common year-effect in year t, $m_{t,i}$ is the total passage mortality (direct plus delayed mortality) for population i in year t, B_i is the regression slope for population i, $\varepsilon_{t,i}$ is the normally distributed process error and sampling error.

The differential mortality (μ_t) experienced by Snake River populations relative to the downriver populations can be indirectly estimated by output from the delta model. Differential mortality is the difference between model estimated total mortality for the Snake River populations ($m_{t,i}$) and juvenile passage mortality ($M_{t,i}$) experienced by the downriver populations (equations 4-6 in Deriso et al. 2001). Schaller and Petrosky (*in press*) used Paulsen and Hinrichsen (2002) ordinary least square (OLS) method to fit the delta model, to all years of SR data updated through brood year 1998. They used the same Snake River populations as Deriso et al. (2001), but for the downriver populations used only the three John Day populations in these analyses because updated estimates for the other downriver populations were not available. Sensitivity analysis indicated the estimate of μ was not greatly influenced by the inclusion or exclusion of the other downriver populations through brood year 1990 (Schaller and Petrosky, *in press*).

Differential mortality estimates from SAR data: We calculated an analogous measure of differential mortality between Snake River and downriver populations based on smolt to adult return rates (SARs) of Snake River and John Day River wild stream-type Chinook salmon. SAR data provide independent information to help identify the life stage that primarily influences the SR model estimates of μ.. This analogue to μ was estimated as:

$$\mu_{SAR,t} \quad = -\ln(SAR_{Snake,t}/SAR_{John\ Day,t}) \qquad [5.3]$$

where SAR_{Snake} = (smolts arriving at first dam encountered, LGR)/(adult return to BOA); $SAR_{John\ Day}$ = (smolts arriving at first dam encountered, JDA)/(adult return to BOA); and t is brood year. Adult recruits for upriver and downriver populations are enumerated at Bonneville Dam, assuming similar lower river harvest rates, for consistency with the SR definition of recruitment employed in equation 1. The estimates of SAR_{Snake} and $SAR_{John\ Day}$ were available from CSS for migration years 2000 to 2004, where the John Day PIT tag studies began in 2000.

Finally, we compared differential mortality estimates based on the SR data for smolt years 1972-2000 (Schaller and Petrosky *in press*; equation 1) with those from SAR ratios of upriver and downriver wild and hatchery populations (equation 2).

Wild upriver/downriver SAR difference: In the lower Columbia River basin, the CSS utilizes the PIT-tagged wild spring Chinook from the aggregate John Day River population (tagged under a separate contract between ODFW and BPA) for the upriver/downriver comparison. ODFW crews PIT-tagged 1,800 to 6,100 juvenile Chinook within the John Day River basin in migration years 2000-2004 (Table 5.7). Methods and locations of this PIT-tagging are found in Carmichael et al. (2002).

Table 5.7. Number of PIT-tagged wild Chinook released in John Day River basin, estimated survival and resulting smolt population arriving John Day Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.

Migration year	Release number	Survival estimate[A]	Survival 90% CI	Smolt est. at JDA	JDA # 90% CI	Adults at BOA
2000	1,851	0.709	0.648 – 0.784	1,312	1,199 – 1,451	140
2001	3,881	0.701	0.674 – 0.730	2,721	2,617 – 2,835	106
2002	3,999	0.639	0.570 – 0.724	2,555	2,279 – 2,894	95
2003	6,122	0.687	0.640 – 0.737	4,203	3,919 – 4,512	123
2004[B]	4,372	0.630	0.540 – 0.756	2,755	2,359 – 3,304	68

[A] Survival of aggregate from release sites to John Day Dam (JDA) tailrace based on Bonneville Dam and trawl sites as downriver PIT-tag detection sites.

[B] Migration year 2004 is incomplete with jacks and Age 2-ocean adult returns through 8/9/2006.

Snake River wild Chinook SARs were estimated according to methods described in Chapter 3 and Appendix A, except that adults were enumerated at BOA (see equation 2). Estimating SAR for John Day River populations from first dam encountered as smolts to BOA as adults requires an estimate of the number of PIT-tagged John Day River wild Chinook smolts passing JDA. This smolt estimate was obtained by multiplying the tag release number by estimated survival from release to JDA tailrace (Table 5.7). In estimating this survival, we did not include the PIT-tag recoveries from the bird colonies on estuary islands, since the detections at BON and the trawl alone provided sufficient precision in the survival estimate to JDA tailrace.

Hatchery upriver/downriver SAR difference: In the lower Columbia River basin, the CSS currently utilizes the PIT-tagged hatchery spring Chinook from Carson Hatchery for the upriver/downriver comparisons. Upriver hatchery populations include DWOR, RAPH, MCCA, IMNA and CATH.

Although the CSS has PIT-tagged a given number of Carson Hatchery production in each year since 1997 (see Appendix C for the number of Carson NFH Chinook PIT-tagged, median length, and percentage of production tagged in each year from 1997 to 2004), an adult PIT-tag system was not fully installed at BON until the 2002 return season. Therefore, we will limit discussion in the annual report of Carson Hatchery PIT-tag releases to migration years 2000 to 2004 for purpose of the upriver and downriver SAR comparison. SAR data from 1997 to 1999 may be seen in the 2005 CSS Annual Report (Berggren *et al*. 2005).

For Carson Hatchery spring Chinook, BON is the primary evaluation site. BON is the only project these fish pass on their way to the ocean, and juvenile survival estimates must rely on a recapture site(s) below the project to estimate survival to Bonneville Dam and thereby the number of PIT-tagged Carson Hatchery Chinook smolts index at that dam. NOAA Fisheries operates a trawl located at River KM 74 near Clatskanie, OR, that is equipped with PIT-tag detection equipment in the cod-end of the net. Only a specific amount of sets can be made during the season, and catch rate will vary based on river flow, velocity of the flow, and debris and other factors that might reduce sampling time during a given year. Since these recapture numbers can be low, we explored in the 2003/04 CSS Annual Report (Berggren *et al*. 2005) the additional use of PIT tags decoded from the tern and cormorant nesting sites at Rice Island (Rkm 34) and East Sand Island (Rkm 8) in the lower Columbia River estuary. We found that the CJS reach survival estimate from Carson Hatchery to BON for migration years 1998 to 2002 were more stable (fluctuating only 10 percentage points over these years) when both the tag detections at the trawl and tag recoveries on the bird colonies as two final recovery sites below BON.

However, along with utilizing the PIT-tags recovered from bird colony comes the unproven assumption that the birds did not capture PIT-tagged fish above Bonneville Dam. Table 5.8 presents the resulting survival estimates to BON.

Table 5.8. Number of PIT-tagged Carson Hatchery Chinook released in the Wind River, estimated survival and resulting smolt population arriving Bonneville Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.

Migration year	Release number	Survival rate [A] Estimate (95% CI)	Smolt est. at BON	Smolts at BON 90% CI	Adults at BOA
2000	14,992	0.863 (0.69 – 1.03)	12,945	11,015 – 15,531	427
2001	14,978	0.835 (0.72 – 0.95)	12,506	11,244 – 14,150	223
2002	14,983	0.824 (0.60 – 1.02)	12,349	10,096 – 15,432	151
2003	14,983	0.848 (0.68 – 1.02)	12,709	10,855 – 15,275	34
2004[B]	14,973	Estimate > 1, so use 0.843 (avg of 2000–2003)	12,622	NA	79

[A] Survival estimates and 95% confidence intervals from hatchery to Bonneville Dam (BON) tailrace based on trawl site and bird colony sites as the downriver PIT-tag detection sites.

[B] Migration year 2004 is incomplete with jacks and Age 2-ocean adult returns through 8/9/2006; including 226 PIT tags found on East Sand Island bird colony, estimated release-to-BON survival >1 was obtained, so average survival rate of prior 4 years is used for 2004.

In determining SARs indexed on adult returns at (BOA), we need an estimate of the number of smolts passing BON and number of PIT-tagged adults passing BOA in the fish ladders. Only 2-ocean and older adult returns are used in the computations of the SARs (the full age composition of the returning jacks and adults for each migration year is shown in Appendix C). Beginning with return year 2002 there was the capability to detect nearly all PIT-tagged adult fish passing the three ladders at BOA. However, since a portion of the fish swim over the weir crests and don’t pass through the orifices where the detection equipment is installed, the detection rate for PIT-tagged adult fish at BON remains less than 100%. To expand the number of adult PIT-tag detections at BON to account for “missed” fish, we computed BOA adult PIT-tag detection efficiency estimates for migration years 2000 (see Table 46 of Berggren *et al.* 2005) and 2001 to 2004 (Table 5.9). The combined hatchery/wild detection efficiency estimates were used for all wild and hatchery Chinook groups in the estimation of SARs.

Table 5.9. PIT-tag detections of returning adult Chinook (ages 2- and 3-ocean) at Bonneville and Lower Granite dams with percentage of fish undetected at Bonneville Dam – returns from smolts that outmigrated in 2001 to 2004.

Smolt Migr. Year	**Dam for adult detections[1]**	**Age 2-and 3-Ocean Returning Adult Chinook**		
		Hatchery Chinook[2]	**Wild Chinook[3]**	**Combined Chinook**
2001	BOA	616	45	631
	GRA, MCA, IHA	626	46	642
	BOA detection efficiency[5]	98.4%	97.8%	**98.3 %**
2002	BOA	1,026	232	1,258
	GRA, MCA, IHA	1,065	240	1,305
	BOA detection efficiency[5]	96.3%	96.7%	**96.4 %**
2003[4]	BOA	514	84	598
	GRA, MCA, IHA/ICH	543	90	633
	BOA detection efficiency[5]	94.7%	93.3%	**94.5 %**
2004[4]	BOA	318	86	404
	GRA, MCA, ICH	326	88	414
	BOA detection efficiency[5]	97.5%	97.7%	**97.6%**

[1] BOA covers Bonneville Dam ladders (detectors BO1, BO2, and BO3), MCA covers McNary Dam ladders (detectors MC1 and MC2), IHA/ICH covers Ice Harbor Dam ladders, and GRA covers the Lower Granite Dam ladder.

[2] Hatchery Chinook contains the combination of PIT-tagged fish from Rapid River, Dworshak, Catherine Creek AP, Imnaha AP, and McCall hatcheries.

[3] Wild Chinook contain the aggregate of PIT-tagged fish originating above LGR used in the CSS.

[4] Migration year 2004 is incomplete with 2-ocean adult returns as of 8/9/2006.

[5] Calculated as p = (N detected at BOA) / (N detected at BOA + N passing BOA undetected that were later detected upriver)

Comparison of biological characteristics of Snake River and downriver smolts

Background -- The use of an upriver-downriver stock-comparison approach towards evaluating the effects of the FCRPS on endangered anadromous salmonids (e.g., Schaller et al. 1999; Deriso et al. 2001; Schaller and Petrosky *In Press*) has been criticized for a number of reasons (Zabel and Williams 2000; Williams et al. 2005). Critics suggest that downriver stocks, which pass through fewer dams than upriver stocks (i.e., 3 vs. 8 projects), are not appropriate controls for evaluating the effects of hydropower development because a number of confounding issues are at play. For instance, downriver smolts may migrate to sea at a different time than upriver stocks and therefore experience different (more favorable) conditions during estuary/early ocean residence (Zabel and Williams 2000; Williams et al. 2005); also, they may be less exposed to ocean fisheries than their upriver counterparts (Zabel and Williams 2000). More recently, it has been suggested that smolts produced by upriver populations may be smaller than those originating from downriver stocks (Williams et al. 2005), thereby suffering greater (size-selective) mortality at sea (Zabel and Williams 2002). Overall, critics argue that the existence of systematic differences in upriver and downriver population life history attributes precludes the ability to ascribe stock viability differences to the FCRPS.

Previous responses to this criticism (Schaller et al. 2000; Deriso et al. 2001; Budy et al. 2002) have stressed that life-history differences would need to explain the systematic change in relative performance existing for upriver and downriver populations coincident with, but unrelated to, the development and operation of the FCRPS. Thus, the relevant issue is not whether or not genetic or life history differences exist between upriver and downriver groups, but rather whether or not differences (if present) were manifested contemporaneously with the completion of the FCRPS. For this reason, upriver-downriver criticisms may be best evaluated using a historic time series comparison approach (i.e., where parameters describing various life history attributes are contrasted between groups as a function of time). Though we are attempting to assemble such a historical dataset, contemporary data (i.e., from the last decade) are all that is available for a quantitative evaluation.

For our present purpose, we explore whether or not there are any observable (present-time) differences between upriver and downriver populations that could explain the observed differential mortality. We focused on life history characteristics associated with the active outmigrant, or smolt, life stage. For both upriver and downriver populations, we quantified and compared outmigration attributes in order to understand the possible confounding effects of smolt life history differences on the results reported in this chapter and elsewhere (Schaller et al. 1999; Schaller and Petrosky *In Press*). To do this, we exploited a six-year time series of outmigrant smolt data collected at juvenile traps affiliated with the wild Chinook salmon tagging component of the CSS. We contrasted size-at-tagging (fork length, in mm), emigration timing (using the trap site as a reference point for emigration), downriver migration rates (in km / day, to Bonneville Dam, BON), and estuary arrival timing (taken as arrival at BON) between wild/natural Chinook salmon smolts captured, tagged, and released at upriver (above Lower Granite Dam, LGR) trap sites and the John Day River mainstem trap site for migration years (MY) 2000 through 2005.

We used five upriver smolt trap sites in our comparison of upriver-downriver life histories: (1) the Snake River trap (SNKTRP); (2) the Salmon River trap (SALTRP); (3) the Clearwater River trap (CLWTRP); (4) the Grande Ronde River trap (GRNTRP);and (5) the Imnaha River trap (IMNTRP). Our primary downriver reference for wild Chinook salmon smolt collection and tagging is the John Day River mainstem site (JDAR1). Our analysis of smolt life history characteristics was based on daily smolt collections for the primary period of juvenile outmigration (March 15th to May 20th; i.e., *our evaluation is inclusive of spring outmigrants only*) during migration years 2000 to 2005 (Note: CLWTRP operations were not initiated until 2002).

Smolt size analysis -- We tested for differences in smolt size across the six release sites under two approaches. First, we tested for differences in size while explicitly accounting for across-site differences in relative abundance (i.e., using per-kilometer redd density as a surrogate measure of abundance to account for density dependent effects; See 2006 annual report for details) using analysis of covariance (ANCOVA). Second, we used an ANOVA approach where we implicitly accounted for inter-annual variation in in-stream conditions relating to juvenile growth and size (i.e., by incorporating MY as a factor). We evaluated ANOVA and ANCOVA model-effect significance based on *F*-tests (Type-III sums-of-squares); we contrasted density- and year-adjusted mean fork length between John Day smolts and those collected at other release sites using Tukey's post-hoc HSD test. To further explore the effects of density on smolt size, we inspected slope parameters and their associated significance tests and examined plots of mean fork length against redd density, for each site. As a final note, because the sample sizes involved were quite large and statistical significance was therefore virtually guaranteed for all tests, we judged biological significance when between-group size differences were greater than 5 mm in magnitude.

Outmigration timing -- Assuming that daily tag releases were proportional across the outmigration period and that collected individuals were actively migrating smolts, we estimated passage distribution statistics for each wild/natural Chinook salmon trap site described above. That is, we plotted cumulative passage distributions for each site and MY, as well as for the 6-year average. Additionally, we computed the median passage date for each trap site and MY.

Downriver migration rate -- We estimated downriver migration rates, in kilometers per day (km / d) for fish tagged and released at upriver and downriver sites. For distance estimation, the upriver reference was the location of release (i.e., the trap site) and the downriver reference was BON (inclusive of all juvenile interrogation sites); migration duration was estimated for each individual as the difference between release date/time and final date/time of detection at BON (if detected). Migration distances used in computations were 512, 564, 603, 405, 694, and 513 for CLWTRP, GRNTRP, IMNTRP, JDAR1, SALTRP, and SNKTRP release sites, respectively. Ultimately, we tested for a difference in migration rates between upriver and downriver populations using ANOVA (as described above for our smolt size evaluation).

Given the different distances traveled by upriver and downriver fish prior to reaching downriver detection sites and the distance–acceleration relationships that have been documented for Snake-origin spring/summer Chinook salmon (i.e., migration speeds increase as fish progress through the hydrosystem; Williams et al. 2005), we also compared migration rates between populations for a comparable (developmentally speaking) segment of their mainstem FCRPS hydrosystem migration corridor, on an exploratory basis. As dictated for downriver detection opportunities for JDAR1 fish, we compared mean first-to-third dam (John Day Dam-Bonneville Dam for downriver, LGR-Lower Monumental Dam for upriver fish) migration durations (in days) between populations. Because different river reaches (of comparable length JDA-BON = 116 km; LGR-LMN = 158 km) had to be used for this analysis by design, we evaluated whether or not populations differed as a function of reach- and/or year-specific water velocities, as measured water travel time values (WTT; the average duration in days it takes water particles to travel from the upriver end of a reservoir to the tailrace of another dam; a function of observed river flow and estimated reservoir volume).

Estuary arrival timing -- Using the same methods as for outmigration timing, we quantified arrival timing distribution statistics for those fish detected at BON, assuming that passage at this site is equivalent to estuary arrival. That is, *for those fish that survived and were detected at BON*, we plotted cumulative passage distributions and estimated dates of 50% passage (i.e., median passage dates) for both upriver and downriver release groups.

As a final note, due to the small number of fish released and subsequently detected at BON in 2001 (*n* = 4), 2004 (*n* = 17), and 2005 (*n* = 8) for the SNKTRP site, we did not estimate migration rate or estuary arrival timing for this site in these years. Additionally, to understand the potential influence of disparate mortality levels imposed upon upriver- relative to downriver-originating smolts prior to BON arrival, we computed the BON detection rate as a proxy for survival (i.e., *n* BON detects / *n* released at trap site).

SARs by Bonneville Arrival Timing

The numbers of Snake River wild spring/summer Chinook PIT-tagged smolts and returning adults from the CSS study groups T_0, C_0, and C_1 were summarized for smolt arrival timing based on their detection at Bonneville Dam, at John Day Dam or trawl samples below Bonneville Dam, 2000-2003 migration years. Bonneville arrival dates for smolts detected only at John Day Dam or in the trawl were corrected for median travel times to or from the Bonneville detector. Numbers of PIT-tagged wild John Day River spring Chinook smolts and adults for the same arrival periods and years were included in the summary. SARs in this case represent smolts from Bonneville dam to adult returns to Bonneville dam. Numbers of smolts and adult returns by group were summarized by biweekly period (before April 16; April 16-30; May 1-15; May 16-31; June 1-15; June 16-30; July 1 and later). Adult returns for 2003 were summarized for 2-ocean returns only in this analysis. We compared SARs and calculated binomial confidence intervals of Snake River CSS groups and John Day River smolts each year for the primary migration period of John Day smolts (April 16-May 31).

Do PIT tag SARs represent SARs of the run at large?

We evaluated whether the PIT tag SARs were representative of the SARs for the run-at-large wild Snake River Chinook population. The methods used for annual run reconstruction SARs only provide point estimates. We compared SAR estimates from run reconstruction techniques reported in Williams et al. (2005) and Petrosky et al. (2001) with the PIT tag SAR estimates and their confidence intervals. We also examined uncertainties associated with the methods for computing the run reconstruction SARs, and identify approaches for addressing potential biases.

Results

Overall SARs

The estimated SARs for Snake River wild spring/summer Chinook were less than the NPCC minimum 2% SAR objective in 10 of 11 years, and the bootstrapped 90% confidence interval included 2% in only 4 of 11 years (Figure 5.10). The geometric mean SAR for 1994-2003 was 0.86%. Annual average SARs ranged from 0.34% to 2.39%. Coefficients of variation on annual estimates ranged from 12% in 2002 to 58% in 1996. The mean SAR was 1.08%, and using a t-distribution, less than 1% of the distribution exceeded a 2% SAR. Using the process error approach (Chapter 4 results), the mean SAR is 0.82% and approximately 5.6% of the distribution is above 2%.

SARs covaried during 1998-2004 for wild spring/summer Chinook from the Clearwater, Grande Ronde, Salmon and Imnaha subbasins (Figure 5.11). With our criteria of at least 15 adults per category, estimates at the subbasin level were achieved in 1998, 1999, 2000 and 2002. Bootstrapped 90% CI generally overlapped within year for SARs from the different subbasins; however, it appears that Imnaha Chinook tended to have higher than average SARs and Clearwater Chinook may have had lower than average SARs.

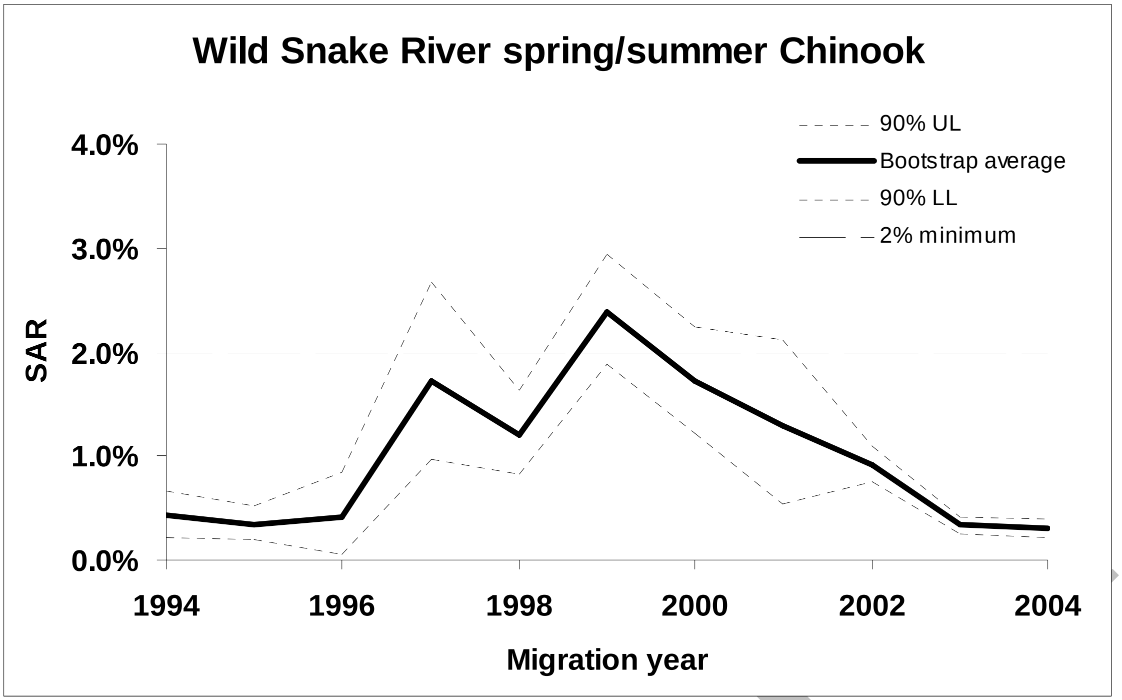


Figure 5.10 Bootstrapped SAR and upper and lower CI for wild aggregate Snake River spring/summer Chinook, migration years 1994-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

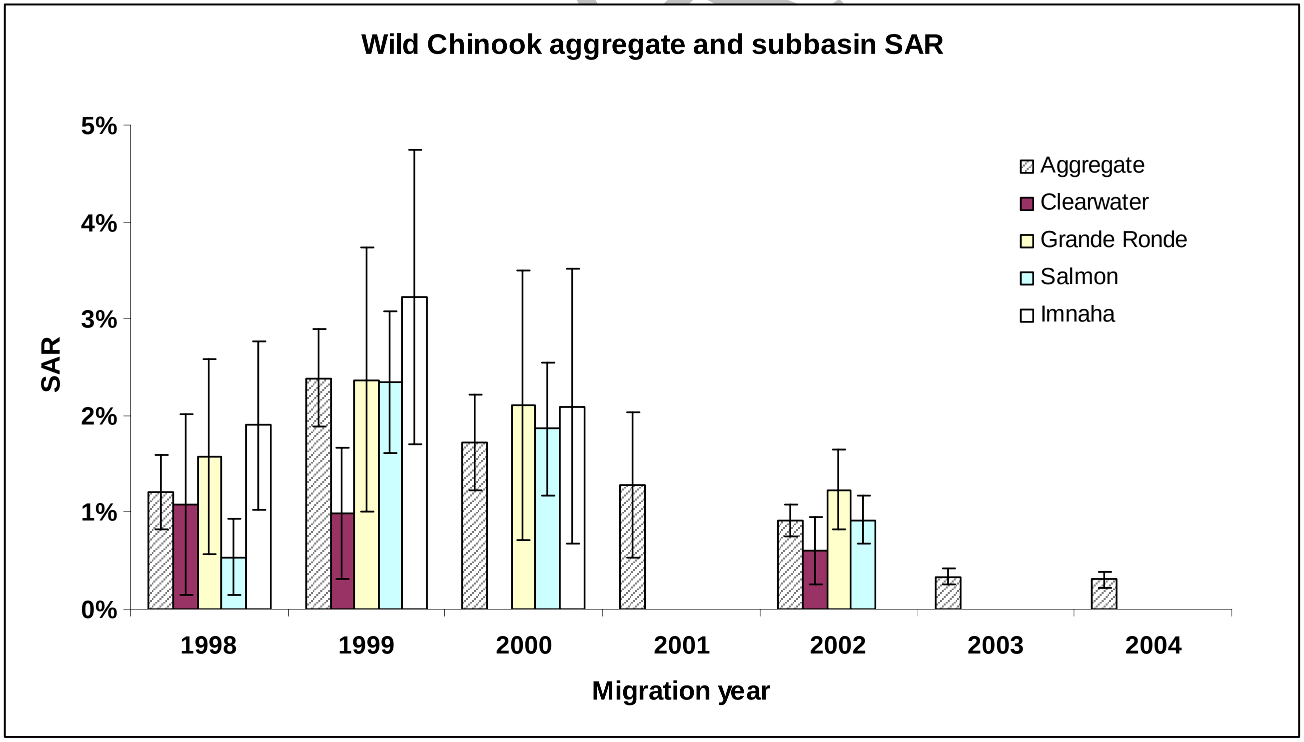


Figure 5.11. SARs and 90% CI for wild aggregate Snake River spring/summer Chinook, and four subbasins above LGR (Clearwater, Grande Ronde, Salmon and Imnaha), 1998-2004.

SARs for the Snake River hatchery spring/summer Chinook tracked closely with wild aggregate SARs during 1997-2004 (Figure 5.12). Correlations among all hatchery and wild groups (excluding Catherine Creek, which had only four years of data) ranged from 0.77 to 0.97. Dworshak Hatchery spring Chinook SARs tended to be less than wild aggregate SARs.

The geometric mean SAR for Dworshak Hatchery spring Chinook during 1997-2003 was 0.62%, and annual estimated SARs ranged from 0.21% to 1.18% (Figure 5.13; Appendix D). Coefficients of variation on annual estimates ranged from 6% to 18%.

The geometric mean SAR for Rapid River Hatchery spring Chinook during 1997-2003 was 1.07%, and annual estimated SARs ranged from 0.24% to 2.91% (Figure 5.13; Appendix D). Coefficients of variation on annual estimates ranged from 4% to 14%.

The geometric mean SAR for McCall Hatchery summer Chinook during 1997-2003 was 1.67%, and annual estimated SARs ranged from 0.68% to 3.26% (Figure 5.13; Appendix D). Coefficients of variation on annual estimates ranged from 4% to 12%.

The geometric mean SAR for Imnaha Hatchery summer Chinook during 1997-2003 was 1.03%, and annual estimated SARs ranged from 0.53% to 2.89% (Figure 5.13; Appendix D). Coefficients of variation on annual estimates ranged from 5% to 20%.

The geometric mean SAR for Catherine Creek Hatchery spring Chinook during 2001-2003 was 0.38%, and annual estimated SARs ranged from 0.22% to 0.77% (Figure 5.13; Appendix D). Coefficients of variation on annual estimates ranged from 18% to 30%.

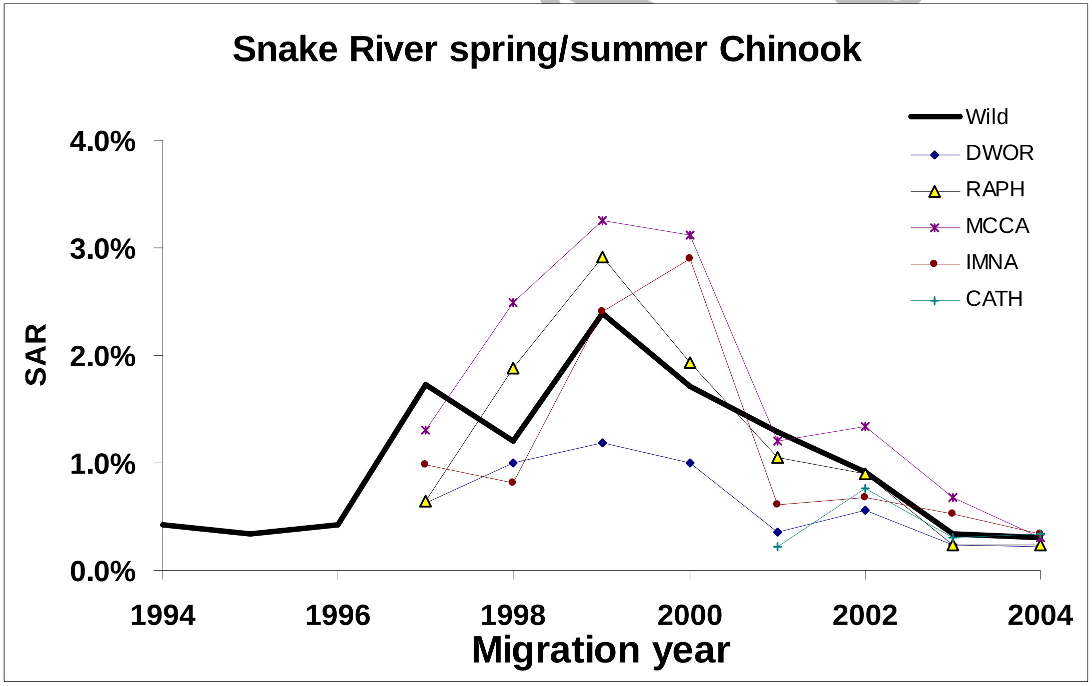


Figure 5.12. Bootstrapped SAR for aggregate wild and five hatchery populations of Snake River spring/summer Chinook, 1994-2004. Migration year 2004 is complete through 2-ocean returns only.

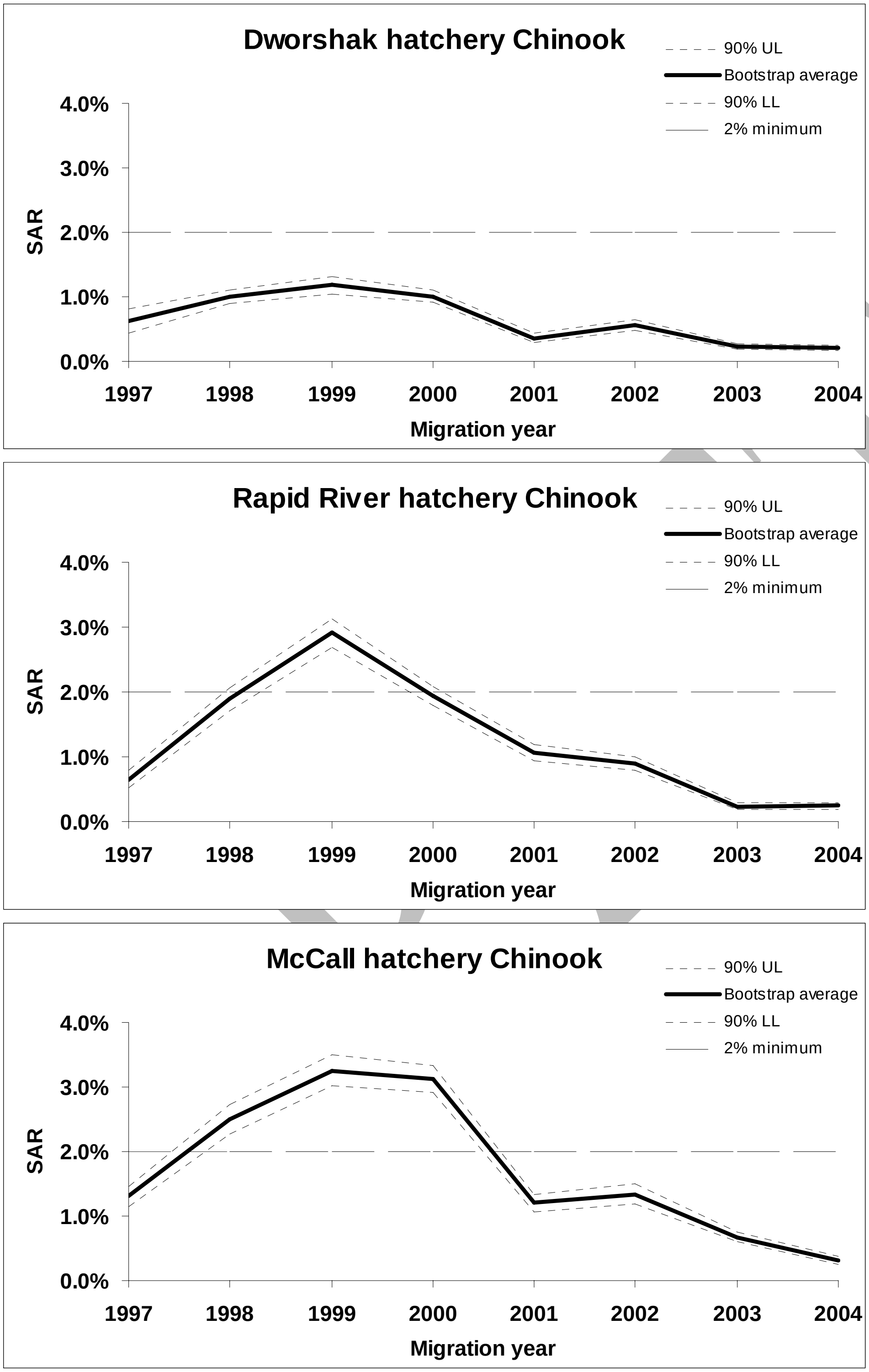


Figure 5.13 Bootstrapped SAR and upper and lower CI for selected hatchery Snake River spring/summer Chinook, migration years 1997-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

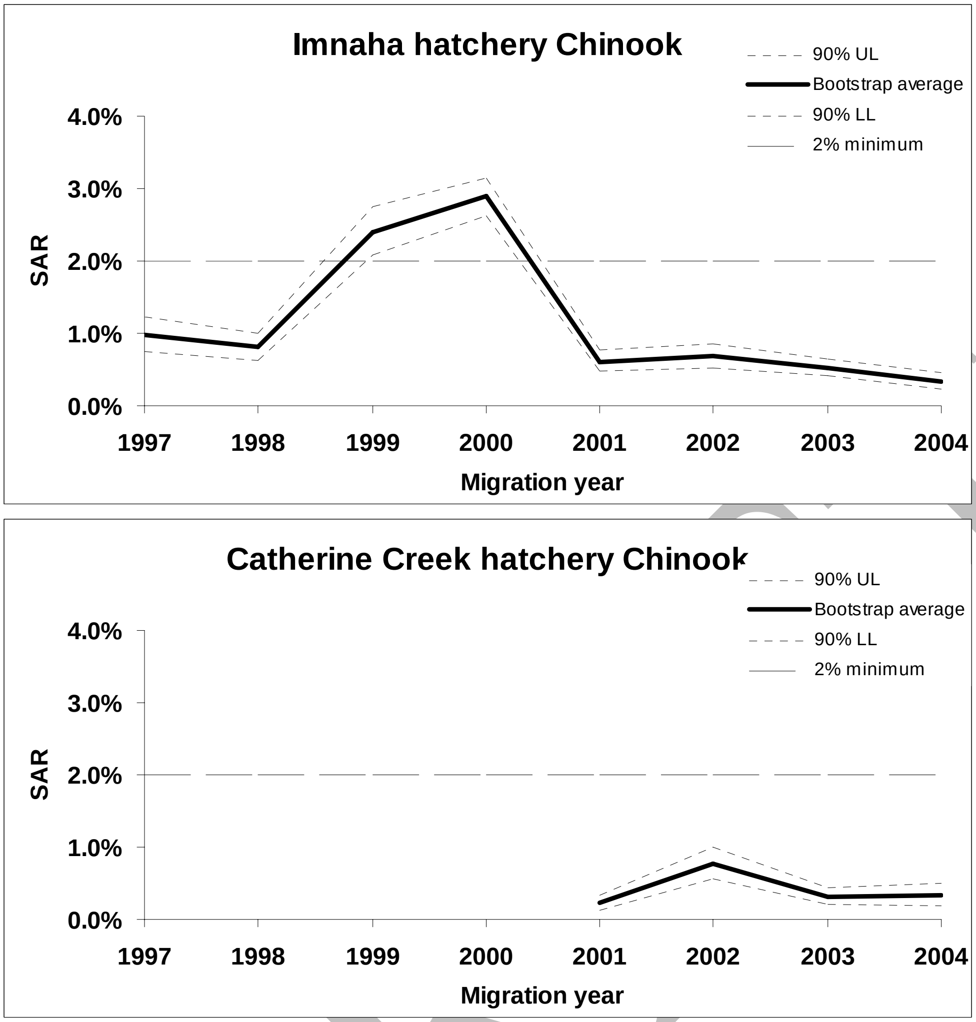


Figure 5.13 continued. Bootstrapped SAR and upper and lower CI for selected hatchery Snake River spring/summer Chinook, migration years 1997-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

SARs for Snake River wild steelhead were closer to the NPCC minimum 2% SAR objective than were those of wild spring summer Chinook, but the geometric mean was only 1.56%. Annual estimated SARs ranged from 0.31% to 2.91% (Figure 5.14). The estimated SARs for Snake River wild steelhead exceeded the NPCC minimum 2% SAR objective in four of seven years, but were consistently less than the NPCC 4% recommended average. The bootstrapped 90% lower CI was consistently less than 2%; the upper confidence interval exceeded 2% in five of seven years (Figure 5.14). Coefficients of variation on annual estimates ranged from 14% in 2003 to 62% in 1998.

The mean SAR was 1.89%, and using a t-distribution, less than 25% of the distribution exceeded a 2% SAR. Using the process error approach (Chapter 4 results), the mean SAR is 1.95% and approximately 42% of the distribution is above 2%.

Hatchery steelhead SARs generally tracked wild steelhead SARs during 1997-2003 (Figure 5.14). The correlation between wild and hatchery SARs was 0.57 for the seven years of estimates. The geometric mean SAR for aggregate hatchery steelhead during 1997-2003 was 0.91%, and annual estimated SARs ranged from 0.40% to 1.88%. Coefficients of variation on annual estimates ranged from 10% to 47%.

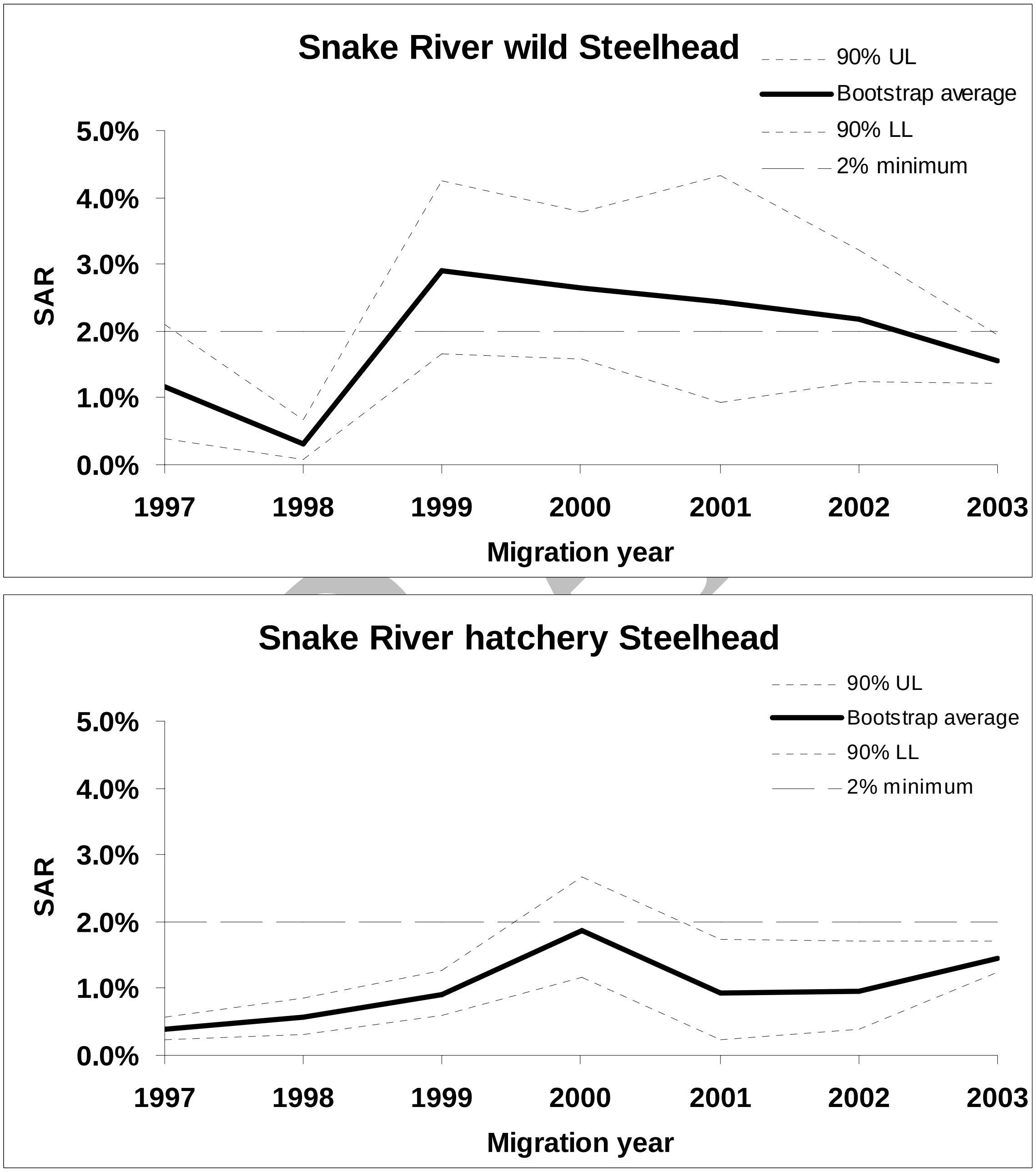


Figure 5.14. Bootstrapped SAR and upper and lower CI for aggregate wild and aggregate hatchery Snake River steelhead, migration years 1997-2003. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

Relationships between Chinook SARs and in-river, estuary/early ocean, and off-shore marine environmental variables

Both *PIT-tag-based current time series* SARs and inriver and marine environmental conditions varied considerably across migration years 1994-2004 (Figures X2, X3, X4 and X5). These SARs spanned a range of over an order of magnitude across observations (min to max: 0.3 to 2.8 %). The long time series of SARS (including run reconstruction and PIT tag estimates) spanned a wider range across observations (min to max: 0.2 to 4.6 %, Figure 5.3).

First we evaluated the correlation amongst monthly PDO indices and monthly CUI 45N indices to select months that were not highly correlated (Table 5.4).

We then used the bi-variate results to guide the suite of PDO and CUI monthly indices to enter into the multiple regression model selection process (Tables 5.5 and 5.6).

Table 5.4. Correlation matrices for monthly environmental variables for the years 1964-2004. A is monthly Pacific Decadal Osscilation Indices. B is monthly Bacun Upwelling Iindices at 45degrees North.

A - Correlation Matrix

	JanPDO	*FebPDO*	*MarPDO*	*AprPDO*	*MayPDO*	*JunPDO*	*JulPDO*	*AugPDO*	*SepPDO*	*OctPDO*	*NovPDO*	*DecPDO*
JanPDO	1											
FebPDO	0.86752	1										
MarPDO	0.770245	0.866838	1									
AprPDO	0.671794	0.785699	0.895626	1								
MayPDO	0.54553	0.652263	0.770738	0.896072	1							
JunPDO	0.492058	0.564511	0.626894	0.741906	0.839395	1						
JulPDO	0.361532	0.397151	0.497439	0.589945	0.722167	0.804676	1					
AugPDO	0.253914	0.215857	0.305576	0.426126	0.561341	0.561405	0.766399	1				
SepPDO	0.066742	0.050667	0.146318	0.328646	0.464429	0.429578	0.65832	0.870705	1			
OctPDO	0.118872	0.152237	0.247703	0.353131	0.465529	0.472259	0.621194	0.755974	0.812647	1		
NovPDO	0.165566	0.209255	0.331116	0.404017	0.447314	0.441342	0.547059	0.665791	0.665777	0.829294	1	
DecPDO	0.180076	0.233523	0.367464	0.419428	0.410038	0.450566	0.560689	0.550964	0.541034	0.699202	0.847112	1

B - Correlation Matrix

	JanUP45n	*FebUP45n*	*MarUP45n*	*AprUP45n*	*MayUP45n*	*JunUP45n*	*JulUP45n*	*AugUP45n*	*SepUP45n*	*OctUP45n*	*NovUP45n*	*DecUP45n*
JanUP45n	1											
FebUP45n	-0.027303	1										
MarUP45n	0.259063	0.198048	1									
AprUP45n	-0.110961	-0.049187	0.012444	1								
MayUP45n	-0.031177	0.07991	0.019866	0.232125	1							
JunUP45n	0.143944	-0.010577	0.270575	-0.03037	0.308022	1						
JulUP45n	0.100807	0.02876	0.280723	-0.143071	0.094671	0.087513	1					
AugUP45n	-0.201506	0.00961	-0.019231	0.045265	0.105317	0.161155	0.037889	1				
SepUP45n	0.103121	-0.270332	-0.020316	0.032238	0.11652	0.280418	0.081022	0.060637	1			
OctUP45n	-0.016028	-0.044359	-0.107451	-0.221746	-0.303045	-0.53835	-0.258851	-0.018204	-0.053168	1		
NovUP45n	0.109577	0.501003	0.11184	-0.215824	0.028289	0.034362	0.047073	0.072198	-0.220774	0.068564	1	
DecUP45n	0.258616	-0.184709	0.003525	-0.046264	-0.040432	0.046526	-0.163375	-0.258795	0.174489	-0.11881	0.023765	1

Table 5.5. Bi-variate selection results for LN(SAR)-environmental variable (PDO) regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).

Long Time Series

Variables	R^2	AIC	BIC
MayPDO	0.32	-20.36	-18.40
AugPDO	0.23	-15.94	-14.49
JulPDO	0.16	-13.13	-12.00
SepPDO	0.15	-12.77	-11.69
OctPDO	0.15	-12.68	-11.60
AprPDO	0.14	-12.34	-11.30
JunPDO	0.11	-10.94	-10.06
NovPDO	0.09	-10.51	-9.68
MarPDO	0.09	-10.35	-9.53
JanPDO	0.08	-10.03	-9.24
DecPDO	0.05	-8.76	-8.11
FebPDO	0.04	-8.64	-8.01

Current Time Series

Variables	R^2	AIC	BIC
MayPDO	0.24	-6.43	-10.43
FebPDO	0.22	-6.18	-10.18
AprPDO	0.19	-5.75	-9.75
JanPDO	0.15	-5.20	-9.20
JulPDO	0.06	-4.14	-8.14
MarPDO	0.06	-4.08	-8.08
OctPDO	0.06	-4.06	-8.06
SepPDO	0.01	-3.54	-7.54
JunPDO	-0.01	-3.25	-7.25
AugPDO	-0.08	-2.54	-6.54
NovPDO	-0.10	-2.39	-6.39
DecPDO	-0.11	-2.26	-6.26

Table 5.6. Bi-variate selection results for LN(SAR)-environmental variable (PDO) regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).

Long Time Series			
Variables	R^2	AIC	BIC
AprUP45n	0.24	-16.34	-14.65
OctUP45n	0.23	-15.85	-14.21
MayUP45n	0.05	-9.08	-8.21
NovUP45n	0.04	-8.72	-7.90
JunUP45n	0.03	-8.16	-7.39
SepUP45n	0.03	-8.05	-7.30
JanUP45n	0.02	-7.85	-7.12
JulUP45n	-0.01	-6.72	-6.11
DecUP45n	-0.02	-6.46	-5.88
MarUP45n	-0.03	-6.17	-5.62
FebUP45n	-0.03	-6.13	-5.58
AugUP45n	-0.03	-6.11	-5.57

Current Time Series			
Variables	R^2	AIC	BIC
NovUP45n	0.41	-9.12	-13.12
AprUP45n	0.18	-5.65	-9.65
JanUP45n	0.14	-5.06	-9.06
FebUP45n	0.13	-4.94	-8.94
MayUP45n	0.03	-3.76	-7.76
SepUP45n	0.03	-3.70	-7.70
DecUP45n	-0.03	-3.10	-7.10
JunUP45n	-0.05	-2.85	-6.85
JulUP45n	-0.08	-2.57	-6.57
OctUP45n	-0.10	-2.37	-6.37
MarUP45n	-0.11	-2.28	-6.28
AugUP45n	-0.11	-2.27	-6.27

The long time series yielded fairly good fit to 2 and 3 parameter models. Parameter values for SNWTT were fairly consistent across models – indicating decrease in survival with increasing WTT (Table 5.7). September PDO is similarly consistent across the models indicting increasing survival with cooler phase ocean conditions. We also observed a consistent inverse relationship in the late fall with the upwelling index – strong downwelling in the fall was associated with improved survival.

Current time series results for multiple regression analysis yielded poorer fits than the long time series (Table 5.7). Parameter values for SNWTT were fairly consistent across models – also indicating decrease in survival with increasing WTT. Parameter values for SNWTT for the current time series were similar to those for the long time series – however SNWTT was less significant for the shorter time series. The model selection identified May PDO as influential, but the parameter values also indicated increasing survival with cooler phase ocean conditions.

Lastly, when upwelling entered into the model for the current time series, the value was similar to the long time series.

Table 5.7. Model selection results for LN(SAR)-environmental variable regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).

Model Fit	Adjusted R^2	AIC	BIC	Variables	Parameter Estimate	Pr > |t|
Long Time Series						
Best	0.71	-46.36	-41.51	Intercept	-4.1500	<.0001
				SNWTT	-0.0540	0.0020
				MayPDO	-0.2060	0.0240
				SepPDO	-0.3210	0.0043
				OctUP45n	-0.0120	0.0127
				NovUP45n	-0.0060	0.0040
Best 3 Parm	0.61	-36.97	-36.29	Intercept	-3.7229	<.0001
				SNWTT	-0.0760	<.0001
				SepPDO	-0.4936	<.0001
				NovUP45n	-0.0056	0.011
Best 2 Parm	0.52	-31.52	-31.68	Intercept	-3.3441	<.0001
				SNWTT	-0.0751	<.0001
				SepPDO	-0.4861	0.0001
Current Time Series						
Best	0.51	-10.09	-0.54	Intercept	-3.9457	0.0033
				SNWTT	-0.0529	0.1644
				MayPDO	-0.4305	0.1048
				NovUP45n	-0.0062	0.1652
Best 2 Parm	0.43	-8.84	-3.11	Intercept	-3.0399	0.0036
				SNWTT	-0.0696	0.0822
				MayPDO	-0.6241	0.0181

Snake River and Downriver SAR Comparison

Wild upriver/downriver SAR difference: The SARs from first-dam encountered as smolts to Bonneville Dam as adults were substantially higher across migration years 2000 to 2004 for the John Day River wild Chinook (downriver group) than aggregate Snake River stocks (upriver group) (Table 5.8; Figure 5.15). The SAR computations used BOA adult numbers expanded by the reciprocal of the PIT-tag detection efficiency estimated for that site. The PIT-tag aggregate of wild Chinook from the John Day River and the PIT-tag aggregate of wild Chinook from the Snake River basin above LGR both had a decreasing trend in SARs from migration year 2000 to 2004. The ratio of the upriver SAR to downriver SAR was significantly higher for migration years 2001 and 2002 compared to 2003 and 2004 based on non-overlapping 90% confidence intervals. The U/D ratio for migration year 2000 was intermediate to the other years.

Table 5.8. Estimates of SAR from first dam encountered[1] as smolts to Bonneville Dam (BOA) as adults[2] for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.

Migr. Year	Upriver Wild Chinook		Downriver Wild Chinook		Ratio Upriver/Downriver	
	Weighted[3] SAR %	SAR$_{LGR\text{-}to\text{-}BOA}$ 90% CI %	Estimated SAR %	SAR$_{JDA\text{-}to\text{-}BOA}$ 90% CI %	Estimated U/D Ratio	U/D Ratio 90% CI
2000	2.70	2.03 – 3.35	11.11	9.27 – 12.98	0.24	0.18 – 0.32
2001	1.84	0.93 – 2.87	3.96	3.29 – 4.58	0.47	0.23 – 0.75
2002	1.19	0.97 – 1.39	3.86	3.12 – 4.60	0.31	0.23 – 0.40
2003	0.36	0.28 – 0.45	3.10	2.61 – 3.62	0.12	0.09 – 0.15
2004[4]	0.39	0.30 – 0.48	2.53	1.87 – 3.20	0.15	0.11 – 0.22

[1] First dam encounter is LGR for upriver wild Chinook and JDA for downriver wild Chinook

[2] Estimated SARs use adults detected at BOA that have been expanded by reciprocal of the PIT-tag detection efficiency estimates of 0.960 for migration year 2000 from Table 46 in Berggren *et al.* 2005, and 0.983, 0.964, 0.945, and 0.976 for migration years 2001 to 2004 from Table 32 in this chapter.

[3] Upriver SAR is weighted average of study-specific SARs when weight is estimated proportion of study group in run-at-large for migration year.

[4] Migration year 2004 is incomplete with 2-ocean adult returns as of 8/9/2006.

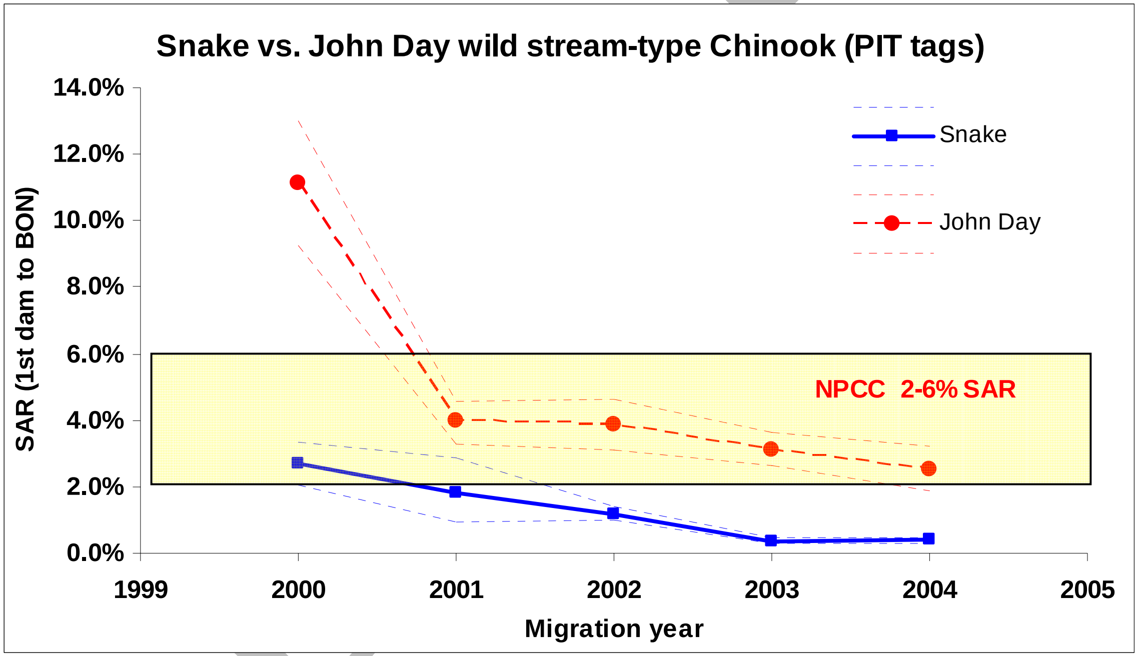


Figure 5.15. SARs (90% CI) for Snake River and John Day River wild stream-type Chinook from smolts at first dam encountered to adult returns to Bonneville Dam. The NPCC interim SAR goal for listed Snake and upper Columbia River salmon and steelhead is shown for reference.

Estimates of differential mortality (equation 2) for the six years of SAR data (smolt migration years 2000 to 2004) from PIT-tagged wild populations (Snake and John Day rivers) are presented in Table 5.9 with associated 95% confidence intervals for comparison with the historic differential mortality estimates from Deriso et al. (2001) and Schaller and Petrosky (*in press*). Wider confidence intervals (95% instead of 90%) are used to match those of the historic data set. In the one year of overlap between the two data series, the PIT-tag wild Chinook SAR-based differential mortality estimate (μSAR) for 2000 agreed well with the differential mortality estimated from the spawner-recruit analysis (Figure 5.16). A benefit of the SAR-based differential mortality estimate appears to be a much narrower confidence interval than obtained from the spawner-recruit analysis – see the trend in confidence interval spread from 2000 to 2004. The ISAB (2006) recommended incorporating additional downriver wild populations in future estimates of differential mortality.

Table 5.9 Conversion of estimated upriver/downriver ratios to differential mortality rates for comparison to differential mortality rates computed by spawner-recruit analyses, 95% confidence intervals shown with each method.

Migr. Year	Ratio Upriver/Downriver		Differential Mortality (μSAR)	
	Estimated U/D Ratio	U/D Ratio 95% CI	Estimated μSAR	μSAR 95% CI
2000	0.243	0.165 – 0.340	1.41	1.08 – 1.80
2001	0.466	0.194 – 0.802	0.76	0.22 – 1.64
2002	0.308	0.224 – 0.424	1.18	0.86 – 1.50
2003	0.117	0.083 – 0.161	2.15	1.83 – 2.49
2004[4]	0.153	0.104 – 0.241	1.88	1.42 – 2.26

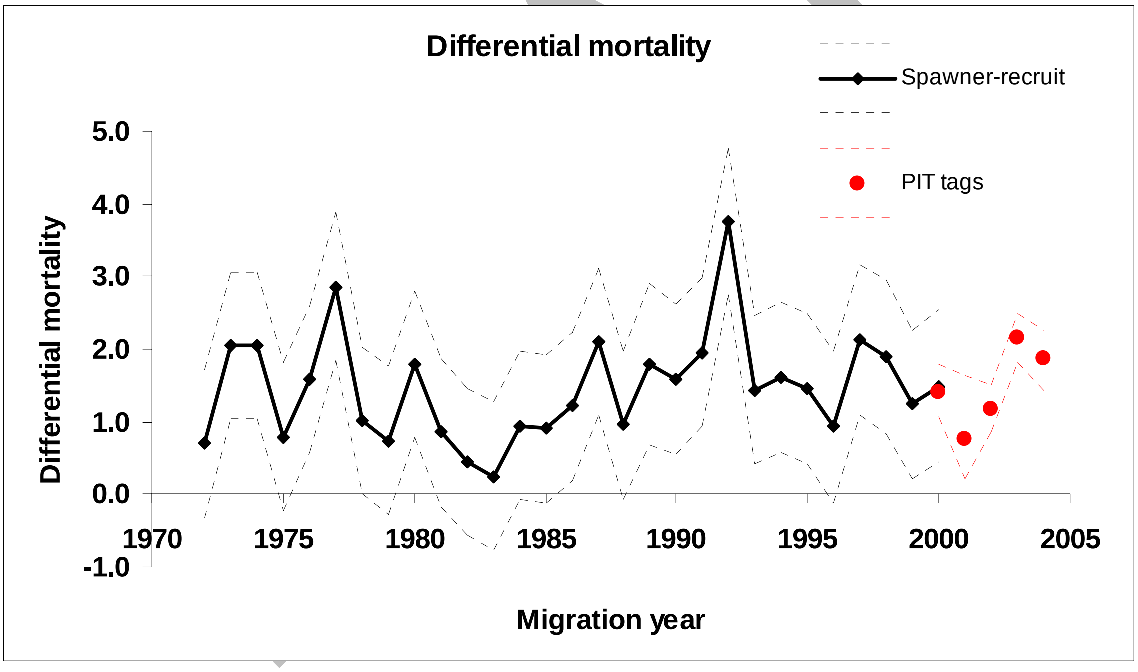


Figure 5.16 Differential mortality from SR data through migration year 2000 (Schaller and Petrosky in press) compared to estimates based on SARs of wild Snake River and John Day River stream-type Chinook, smolt migration years 2000-2004.

Hatchery upriver/downriver SAR difference: Differential mortality estimates between SARs from upriver and downriver hatcheries were less than differential mortality estimates for wild spring/summer Chinook based on SARs and S-R data (Figure 5.16). Differential mortality estimates also varied according to which Snake River hatchery was included in the comparison (Table 5.10; Figure 5.16). The SARs from first-dam encountered as smolts to Bonneville Dam as adults was higher across migration years 2000 to 2004 for Carson NFH Chinook (downriver group) than for the upriver spring Chinook hatchery releases, but not always higher for the upriver summer Chinook (Table 5.9). The SAR computations used BOA adult numbers expanded by the reciprocal of the PIT-tag detection efficiency estimated for that site. The PIT-tag hatchery Chinook from the upriver Snake River hatcheries and the downriver hatchery both had a decreasing trend in SARs from migration year 2000 to 2004. The ratio of the upriver SAR to downriver SAR ranged was highest among all five upriver hatcheries in migration year 2003, and lowest in 2001 for Dworshak, Catherine Creek, and Imnaha hatcheries and lowest in 2004 for Rapid River and McCall hatcheries (Table 5.10). The upriver/downriver ratios in 2003 were significant higher than prior years based on non-overlapping 90% confidence intervals for the two summer stocks (McCall and Imnaha hatcheries). Confidence intervals were not available for migration year 2004 data, because the estimation of the population of PIT-tagged smolts at BON for that year could only be indirectly estimated using the average survival rate from release to BON tailrace of the prior four years.

Based on CSS results to date, differential mortality estimated from SARs of upriver and downriver hatchery spring/summer Chinook do not appear to be a good surrogate for differential mortality of wild populations. It is currently difficult to generalize this result however, because estimates are based on a single downriver hatchery. In addition, differences in hatchery practices, rearing conditions and overall fitness among hatchery stocks within and between regions may confound differences due to hydrosystem experience among the hatchery stocks. The ISAB (2006) recommended additional downriver hatchery populations be incorporated in future estimates of differential mortality.

Table 5.10. Estimates of SAR from first dam encountered[1] as smolts to Bonneville Dam (BOA) as adults[2] for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.

Hatchery Run Type	Migr. Year	Upriver Hat. Chinook [3] $SAR_{LGR\text{-}to\text{-}BOA}$		Carson NFH Chinook $SAR_{BON\text{-}to\text{-}BOA}$		Upriver/Downriver Ratio	
		Est. %	90% CI %	Est. %	90% CI %	Est.	90% CI
RAPH Sp Ch	2000	2.71	2.53 – 2.87	3.44	2.82 – 4.07	0.79	0.65 – 0.96
	2001	1.38	1.24 – 1.52	1.81	1.53 – 2.09	0.76	0.63 – 0.93
	2002	1.06	0.94 – 1.18	1.27	0.97 – 1.60	0.83	0.65 – 1.12
	2003	0.34	0.28 – 0.41	0.28	0.20 – 0.38	1.21	0.86 – 1.79
	2004 [4]	0.32	0.26 – 0.39	0.64	N/A	0.50	N/A
DWOR Sp Ch	2000	1.58	1.45 – 1.70	3.44	2.82 – 4.07	0.46	0.38 – 0.57
	2001	0.44	0.37 – 0.51	1.81	1.53 – 2.09	0.24	0.19 – 0.30
	2002	0.75	0.66 – 0.85	1.27	0.97 – 1.60	0.59	0.45 – 0.78
	2003	0.31	0.26 – 0.37	0.28	0.20 – 0.38	1.11	0.77 – 1.67
	2004 [4]	0.40	0.34 – 0.46	0.64	N/A	0.63	N/A
CATH Sp Ch	2001	0.37	0.23 – 0.51	1.81	1.53 – 2.09	0.20	0.19 – 0.30
	2002	1.11	0.83 – 1.41	1.27	0.97 – 1.60	0.87	0.60 – 1.22
	2003	0.35	0.22 – 0.50	0.28	0.20 – 0.38	1.25	0.72 – 2.03
	2004 [4]	0.42	0.25 – 0.62	0.64	N/A	0.66	N/A
MCCA Su Ch	2000	3.76	3.53 – 3.99	3.44	2.82 – 4.07	1.09	0.91 – 1.34
	2001	1.46	1.30 – 1.62	1.81	1.53 – 2.09	0.81	0.67 – 0.99
	2002	1.72	1.54 – 1.91	1.27	0.97 – 1.60	1.35	1.05 – 1.81
	2003	0.81	0.72 – 0.89	0.28	0.20 – 0.38	2.85	2.08 – 4.15
	2004 [4]	0.44	0.37 – 0.51	0.64	N/A	0.69	N/A
IMNA Su Ch	2000	3.61	3.29 – 3.93	3.44	2.82 – 4.07	1.05	0.87 – 1.30
	2001	0.81	0.66 – 0.99	1.81	1.53 – 2.09	0.45	0.34 – 0.59
	2002	0.92	0.73 – 1.13	1.27	0.97 – 1.60	0.73	0.52 – 0.99
	2003	0.71	0.58 – 0.84	0.28	0.20 – 0.38	2.50	1.76 – 3.77
	2004 [4]	0.50	0.38 – 0.63	0.64	N/A	0.78	N/A

[1] First dam encounter is LGR for upriver wild Chinook and JDA for downriver wild Chinook

[2] Estimated SARs use adults detected at BOA that have been expanded by reciprocal of the PIT-tag detection efficiency estimates of 0.960 for migration year 2000 from Table 46 in Berggren *et al*. 2005, and 0.983, 0.964, 0.945, and 0.976 for migration years 2001 to 2004 from Table 32 in this chapter.

[3] Upriver SAR is weighted average of study-specific SARs when weight is estimated proportion of study group in run-at-large for migration year.

[4] Migration year 2004 is incomplete with 2-ocean adult returns as of 8/9/2006.

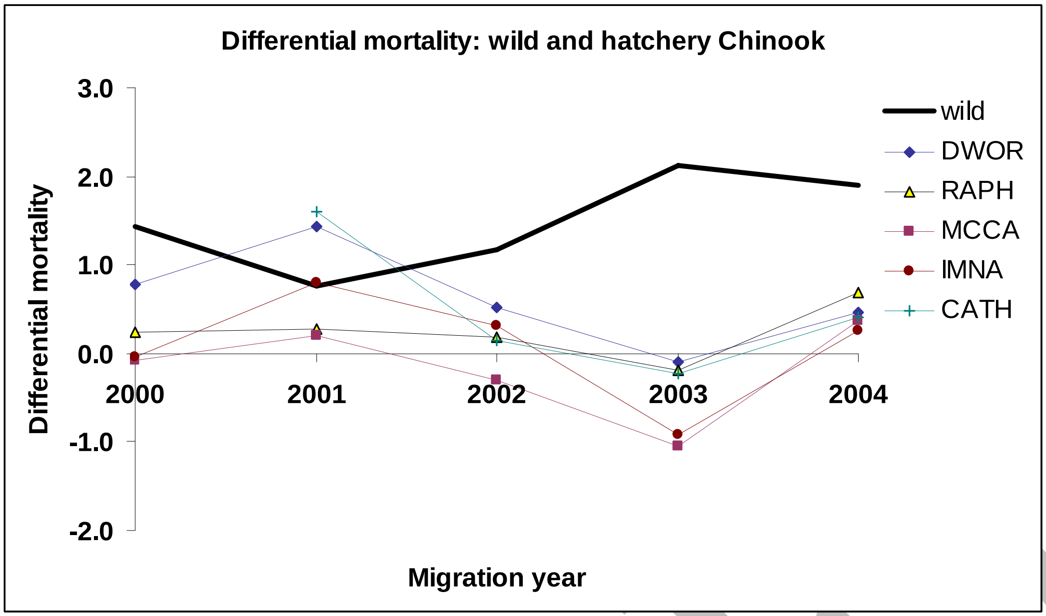


Figure 5.16. Differential mortality of Snake River wild and hatchery populations of spring/summer Chinook 2000-2004 migration years.

Comparison of biological characteristics of Snake River and downriver smolts

Summary -- In total, we evaluated differences between upriver and downriver smolt life histories based on a sample of over 100,000 individual fish collected across the 6-year time series. Based on these data, we observed that smolt size and outmigration timing were generally similar across upriver and downriver sites. We also observed that upriver-originating smolts that survived to and were detected at BON migrated downriver at a similar rate but arrived in the estuary at a later time later than downriver-origin smolts. Of JDAR1 fish tagged and released, 13% were detected at BON; 7% of upriver-origin smolts were detected at BON.

Smolt size analysis -- Our analysis demonstrates that smolt size varies considerably across migration years, both within and across sites (Table 5.11; Figure 5.17). Within these data, however, there was no clear indication of a systematic size difference between the John Day fish relative to those captured at upriver trap sites. During some years, JDAR1 smolts were larger than those captured at upriver sites whereas in other years they were considerably smaller. The only clear and consistent trend indicated that those fish captured at the GRNTRP site were generally the largest whereas those captured at the CLWTRP site were the smallest of all sites in question. More importantly, with the exception of GRNTRP and CLWTRP sites, JDAR1 fish were generally within 5 mm of upriver sites.

Table 5.11. Summary statistics for wild Chinook salmon smolts captured, tagged, and released at CSS trap sites between March 15th and May 20th during migration years 2000-2005.

Release site	**MY**	**Trap releases (*n*)**	**Mean fork length, mm (SD)**	**BON detections (*n*)**
JDAR1	2000	1,599	113 (9)	280
	2001	3,374	104 (8)	694
	2002	3,278	99 (9)	256
	2003	5,838	104 (10)	722
	2004	2,893	109 (10)	167
	2005	2,363	105 (9)	307
SNKTRP	2000	1,520	107 (10)	216
	2001	29	120 (16)	4
	2002	1,076	105 (10)	105
	2003	383	102 (11)	34
	2004	541	104 (11)	17
	2005	339	103 (9)	8
SALTRP	2000	2,022	105 (11)	298
	2001	1,768	111 (13)	130
	2002	5,429	95 (10)	462
	2003	9,133	100 (11)	716
	2004	7,216	97 (10)	177
	2005	8,974	103 (9)	203
CLWTRP	2000	0	NA	NA
	2001	0	NA	NA
	2002	260	99 (9)	21
	2003	990	91 (9)	59
	2004	1,224	99 (10)	35
	2005	1,880	104 (10)	22
IMNTRP	2000	3,450	110 (9)	430
	2001	9,315	109 (10)	742
	2002	2,142	104 (11)	227
	2003	4,832	104 (10)	522
	2004	8,549	101 (10)	151
	2005	2,572	98 (9)	72
GRNTRP	2000	1,235	118 (10)	158
	2001	718	121 (11)	50
	2002	1,178	113 (9)	99
	2003	2,254	111 (12)	166
	2004	2,861	112 (11)	98
	2005	1,783	113 (12)	43

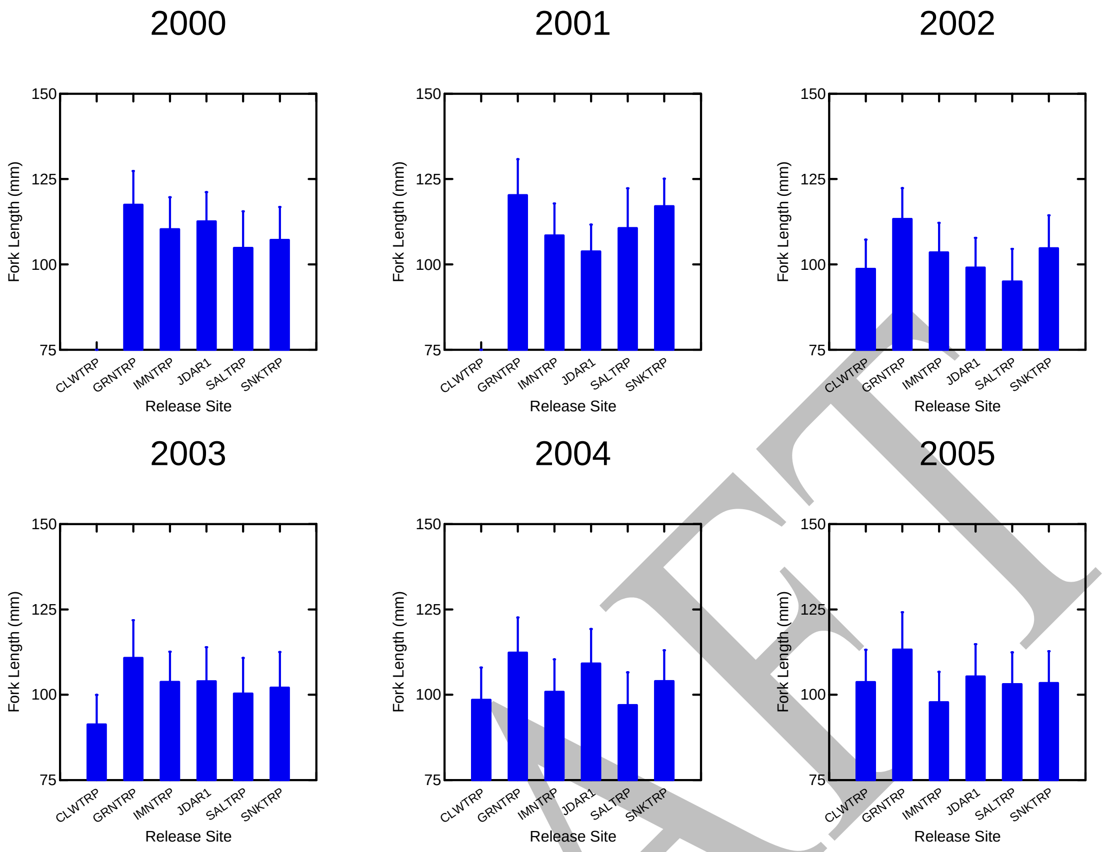


Figure 5.17. Wild Chinook salmon smolt size (mean fork length +/- 1 SD) for fish tagged and released during migration years 2000-2005 (between 15 March and 20 May). From left to right, trap sites are: CLWTRP = Clearwater R., GRNTRP = Grande Ronde R., IMNTRP = Imnaha R., JDAR1 = John Day R., SALTRP = Salmon R., SNKTRP = Snake R. *Note*: there were no wild Chinook smolt size data available for CLWTRP prior to 2002.

Table 5.12. Results from an ANCOVA-based comparison of smolt size across upriver and downriver release sites, using redd density as a covariate.

Effect	Sum-of-squares	df	MSS	F	*P*
Rel_site	311,305	5	62,260.9	561.703	< 0.001
Redds	48,801	1	48,801.3	440.273	< 0.001
Rel_site*Redds	137,368	5	27,473.6	247.86	< 0.001
Error	11,417,500	103,006	110.843		

Analysis of Covariance (ANCOVA) results indicate that fork length varies across sites, but as a site-specific function of redd density (Table 5.12). With the exception of GRNTRP, smolt size—redd density regressions all had negative, non-zero ($P < 0.001$ for all parameter significance tests) slopes (Figure 5.18). Given that the density effect was site specific, we contrasted least-squares adjusted mean fork length between release sites at both the average density and at 4 redds per km – a level of abundance common to all sites (i.e., to avoid extrapolating for low-escapement sites). At an average level of density (8.9 redds per km), density-adjusted mean fork lengths differed significantly between all release sites (P < 0.001 for all pairwise contrasts); values were 74, 121, 106, 106, 100, and 100 mm for CLWTRP, GRNTRP, IMNTRP, JDAR1, SALTRP, and SNKTRP fish. At 4 redds per km, density-adjusted sizes for the same release groups (respectively) were 90, 117, 108, 107, 100, and 104 mm. Thus, though there is evidence for statistically significant differences between fish across release sites, the magnitude of departure may not be biologically profound. However, it should be noted that this model accounted for only a minor proportion of fork length variation and that the majority was due to the release site effect (not redd density).

In addition to explicitly incorporating density effects, we also contrasted fork lengths between release sites using ANOVA with MY as a factor. This approach accounted for a greater proportion of overall fork length variation than the density-specific model (i.e., Table 5.13 vs. Table 5.12). Similar to the ANCOVA results, ANOVA results indicate that significant differences exist among release sites, but that the general pattern varies depending on the migration year in question (Tables 5.12 and 5.13; Figure 5.17). Post-hoc pair-wise comparisons indicate the rank of JDAR1 fish size relative to upriver sites varied across years (*P* < 0.001 for all contrasts): 1) in 2000, JDAR1 fish were between 2 and 8 mm larger than those collected at upriver sites; 2) in 2001, they were between 5 and 17 mm smaller than those captured at all other sites; 3) JDAR1 smolts were smaller than all but SALTRP and CLWTRP fish in 2002; 4) excluding CLWTRP and GRNTRP in 2004 and GRNTRP and IMNTRP in 2005, JDAR1 fish were within 5 mm of those collected at upriver sites in both of these years.

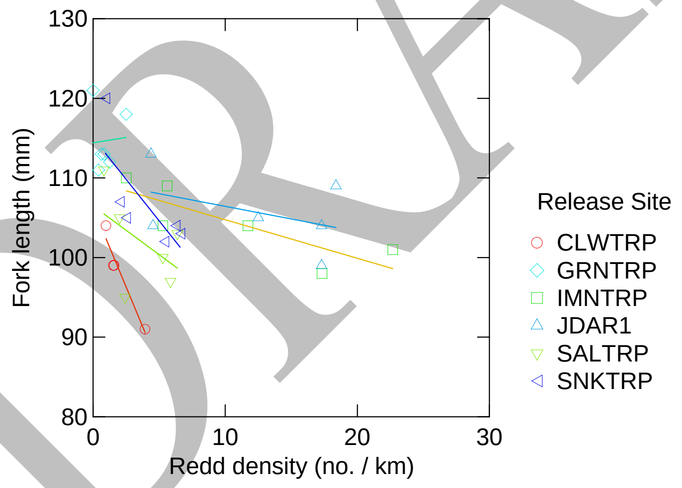


Figure 5.18. Scatter plot of mean fork length (mm) against redd density (redds / km) for wild Chinook salmon smolts collected, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 36 caption for release site abbreviation definitions.

Table 5.13. Results from an ANOVA evaluating smolt size variation across release sites and migration years.

Effect	Sum-of-squares	df	MSS	F	*P*
Rel_site	1,145,889	5	229,177.8	2,266.934	<0.001
my	93,338	5	18,667.6	184.652	<0.001
Rel_site*my	704,810	23	30,643.9	303.117	<0.001
Error	10,411,300	102,984	101.1		

Outmigration timing -- Outmigration timing varied considerably across sites and migration years, particularly so for upriver-origin smolts. In most years, the 50% passage date occurred in mid April, but was as early as March 27th (SALTRP, MY 2004) and as late as May 17th (SNKTRP, MY 2005). Variability in JDAR1 outmigration timing was considerably less than that observed for upriver release groups. Table 5.14 details median passage dates for each site and migration year. Despite the wide range of variability in outmigration timing, there was no evidence for any systematic difference between upriver and downriver populations – that is, in some years downriver populations emigrated earlier than upriver populations whereas in other years they emigrated later. Despite the variability within sites across years, it appears that upriver and downriver populations initiate emigration from subbasin streams within a similar time window, on average (Figure 5.19); both the upriver aggregate (i.e., all traps together) and the JDAR1 6-year average date of 50% passage was April 13th (across 2000-2005). Thus, in terms of trap catch data, we found no evidence for a disparity in outmigration timing for upriver and downriver groups.

Table 5.14. Dates of 50% passage (i.e., median emigration date) for Chinook salmon captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.

	Median emigration date						
Site	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**6-y mean**
JDAR1	18-Apr	11-Apr	14-Apr	11-Apr	13-Apr	15-Apr	13-Apr
SNKTRP	20-Apr	27-Apr	16-Apr	17-Apr	28-Apr	17-May	25-Apr
SALTRP	12-Apr	25-Apr	9-Apr	4-Apr	27-Mar	12-Apr	9-Apr
CLWTRP	NA	NA	2-May	31-Mar	29-Mar	3-Apr	8-Apr
IMNTRP	1-Apr	28-Mar	19-Apr	4-Apr	12-Apr	10-Apr	7-Apr
GRNTRP	20-Apr	19-Apr	17-Apr	3-Apr	12-Apr	29-Apr	16-Apr

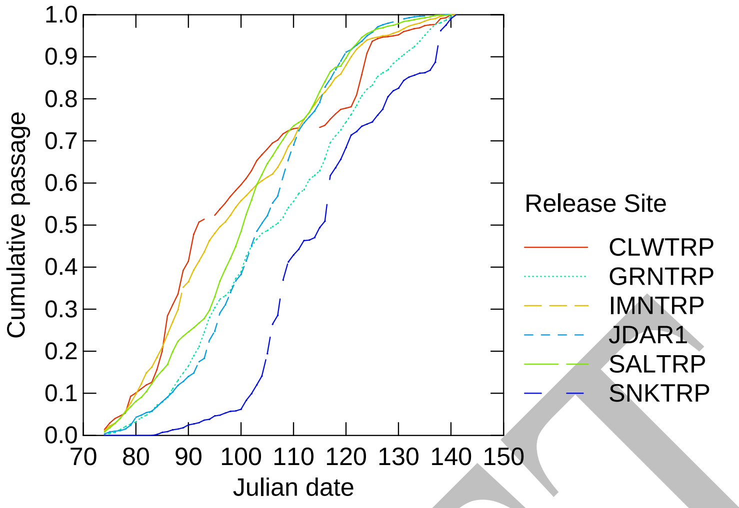


Figure 5.19 6-year mean trap passage (i.e., emigration) distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. Note: Julian date 75 is March 16th, 100 is April 10th, 125 is May 5th, and 150 is May 30th. See Figure 36 caption for release site abbreviation definitions.

Downriver migration rates -- Based on those fish tagged, released, and later detected at BON, we also estimated total downriver migration rates (km / d) and compared them between upriver and downriver populations. This comparison demonstrates that smolts from upriver populations and downriver-origin smolts migrated at a similar rate, once their differing migration distances were accounted for. As illustrated in Figure 5.20, JDAR1 fish migrated to the estuary at a rate of approximately 15-24 km / d whereas upriver fish migrated at a rate of 11-23 km / d. In the 2006 annual report, we concluded John Day smolts were migrating at a slower rate than Snake River smolts, however this conclusion was a result of using an incorrect distance between Bonneville Dam and the JDAR1 collection site (170 km). When we used the correct distance (405 km), this apparent difference between groups diminished greatly.

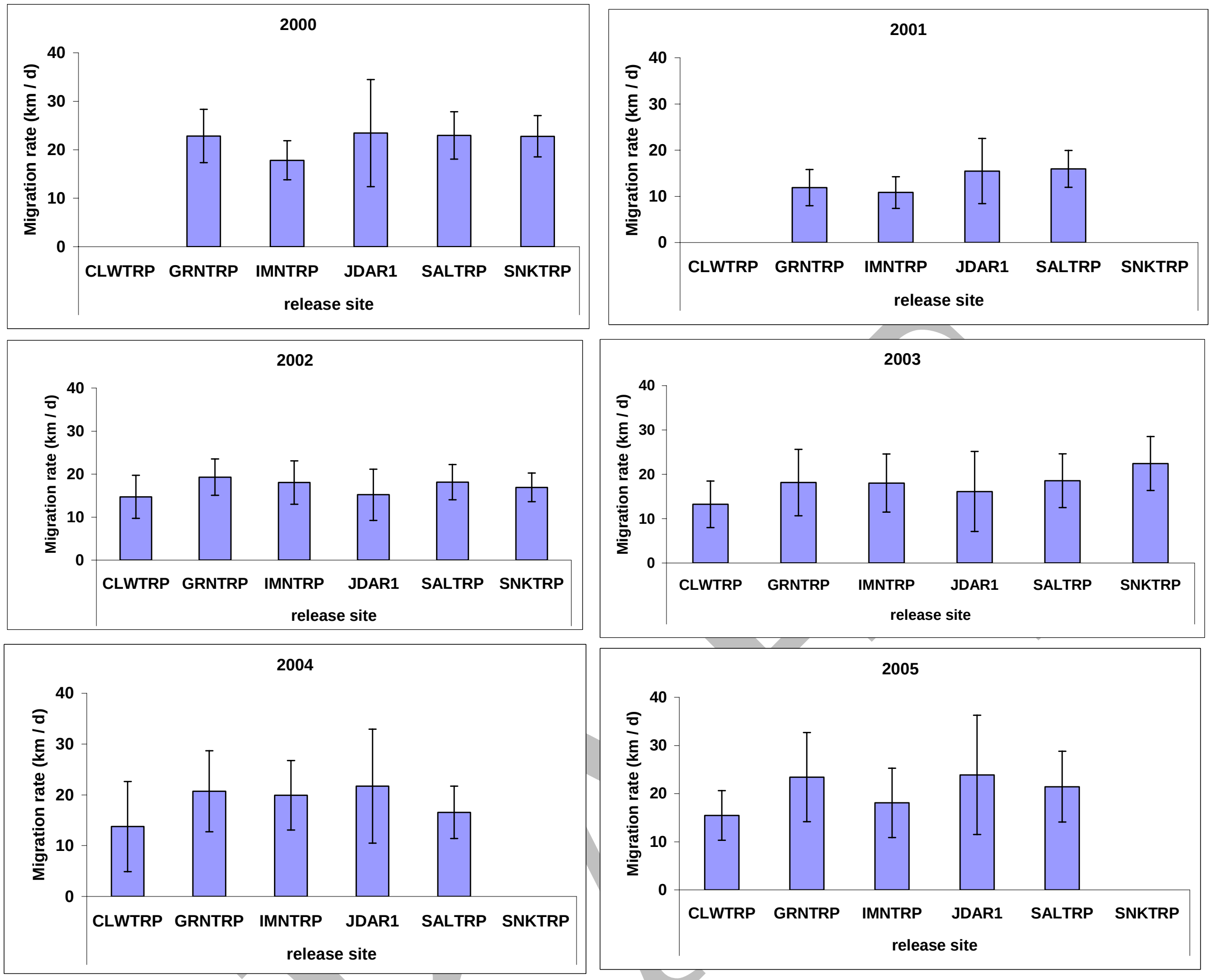


Figure 5.20. Wild Chinook salmon smolt downriver migration rates (km / d, +/- 1 SD) for those fish captured, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 36 caption for release site abbreviation definitions. Note, CLWTRP operations did not begin until 2002; also, too few tags were available for SNKTRP estimation in 2001, 2004-2005.

We also found evidence of similar and WTT-influenced first-to-third dam migration lengths (in days) for both upriver and downriver populations (Figure 5.21). In particular, analysis of covariance (with site and WTT effects) suggests a strong positive influence of WTT ($F_{1,27} = 71.3$, $P < 0.001$) but no effect of release site on migration duration, once upriver-downriver WTT differences are considered ($F_{5,27} = 0.9$, $P = 0.485$). The mean (WTT-adjusted) first-to-third dam migration duration (± 2*SE*) for JDAR1 was 12±2 days; for upriver populations, durations averaged 10±2 days.

Estuary arrival timing – Despite the contemporaneous natal stream departure schedule and the similar downriver migration rates, upriver-origin smolts generally reached the estuary later than downriver fish (Table 5.15; Figure 5.22). That is, while upriver release groups reached BON within roughly a day of each other on average (based on 6-year average of 50% passage date), they arrived 9-10 days after the downriver release group. On average, downriver fish arrived at the estuary on May 9th whereas upriver fish arrived on May 18th. Further, this pattern of delayed arrival was consistent across years.

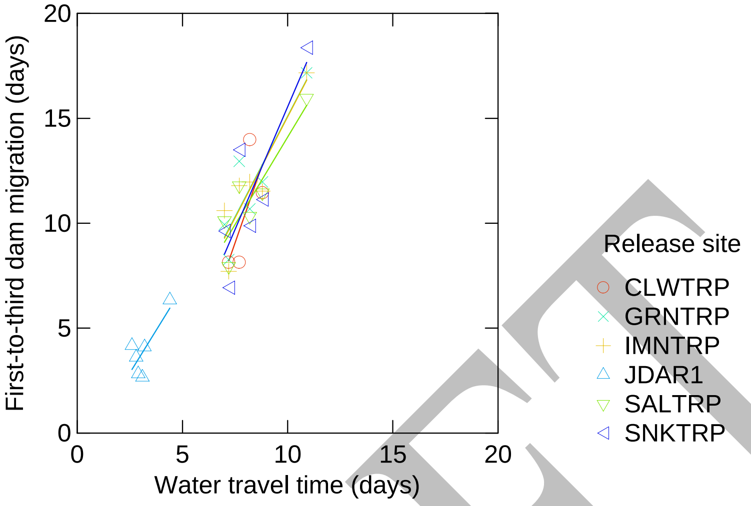


Figure 5.21. Scatter plot of first-to-third dam migration duration as a function of water travel time. Each dot reflects the mean value for a year-site combination. See Figure 36 caption for release site abbreviation definitions.

Table 5.15. Median estuary arrival (i.e., BON detection) dates for Chinook salmon smolts captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.

	Median estuary arrival date						
Site	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**6-y mean**
JDAR1	8-May	10-May	11-May	14-May	7-May	5-May	9-May
SNKTRP	12-May	NA	18-May	16-May	NA	NA	15-May
SALTRP	12-May	5-Jun	19-May	15-May	15-May	18-May	19-May
CLWTRP	NA	NA	28-May	22-May	18-May	17-May	21-May
IMNTRP	8-May	2-Jun	22-May	18-May	17-May	18-May	19-May
GRNTRP	14-May	4-Jun	19-May	9-May	16-May	23-May	19-May

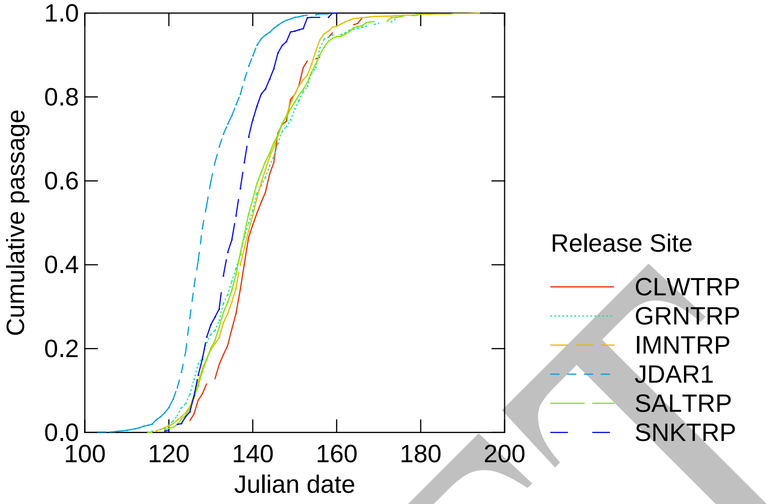


Figure 5.22. 6-year mean estuary arrival (measured at BON) timing distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. Note: Julian date 100 is April 10th, 125 is May 5th, 150 is May 30th, and 175 is June 24th. See Figure 36 caption for release site abbreviation definitions.

SARs by Bonneville Arrival Timing

The arrival timing of John Day wild smolts was primarily late April through May all years (similar to Snake River wild smolt timing at Lower Granite Dam) (Table 5.16). A combination of delayed migration of in-river smolts and transportation has altered the arrival timing of Snake River migrants to the lower Columbia River estuary. Less than 1% of John Day smolts arrived outside the April 16-May 31 window whereas 27.5% of Snake River smolts arrived outside this window (Table 5.16). All groups of Snake River wild Chinook significantly experienced lower SARs (Bonneville to Bonneville) than John Day wild Chinook within the same arrival time period and for the season (Figure 5.23).

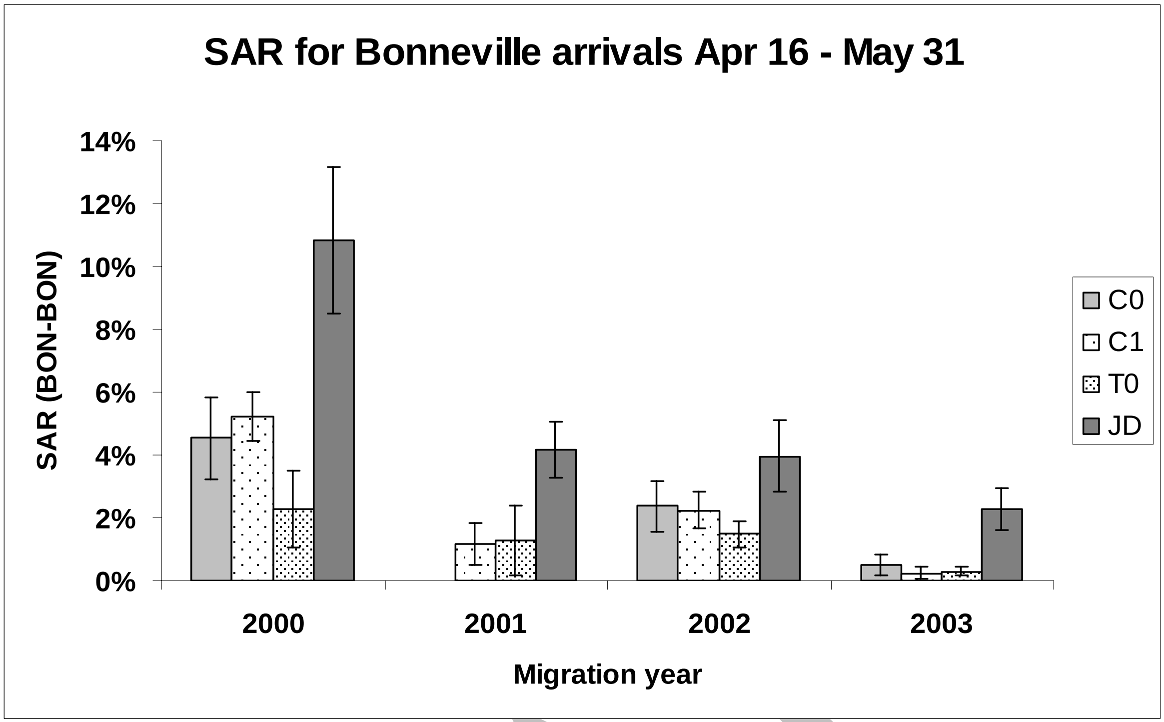


Figure 5.23. SAR and 95% binomial confidence intervals for Snake River wild spring/summer Chinook by group (C_0, C_1, T0) and for John Day River wild spring Chinook (JD) for smolts passing Bonneville Dam during the period April 16 – May 31, migration years 2000-2003..

Table 5.16 Number of smolts and adult returns for Snake River wild spring/summer Chinook by group (C_0, C_1, T_0) and for John day River wild spring Chinook for smolts passing Bonneville Dam during biweekly periods migration years 2000-2003.

		Bonneville Dam Arrival Time							
Migration year	**Group**	**to Apr 15**	**Apr 16-30**	**May 1-15**	**May 16-31**	**Jun 1-15**	**Jun 16-31**	**Jul 1 to end**	**Total year**
2000	C_0 adults		3	24	18	6			51
2000	C_0smolts		66	516	411	161	34	2	1190
2000	C_1 adults		13	112	38	8	1		172
2000	C_1 smolts	1	277	2124	716	248	19	5	3390
2000	T_0 adults	5	4	8	1	3	1		22
2000	T_0 smolts	52	271	225	77	71	37	25	758
2000	JDA adults		14	57	3				74
2000	JDA smolts	9	162	467	54				692
2001	C_0 adults								0
2001	C_0smolts			2	10	24	6	4	46
2001	C_1 adults				11	5			16
2001	C_1 smolts			11	938	1662	466	163	3240
2001	T_0 adults	6	3	2					11
2001	T_0 smolts	63	203	119	68	48	25	11	537
2001	JDA adults		4	66	12	1			83
2001	JDA smolts	2	23	1485	464	32	12		2018
2002	C_0 adults			12	22	5	1		40
2002	C_0smolts		1	560	877	260	72	6	1776
2002	C_1 adults			16	41	15	2		74
2002	C_1 smolts			650	1889	715	239	42	3535
2002	T_0 adults		4	18	21	2	2	1	48
2002	T_0 smolts	68	878	1248	790	361	278	40	3663
2002	JDA adults		3	30	10				43
2002	JDA smolts	1	131	710	242	4	2		1090
2003	C_0 adults			7	3				10
2003	C_0smolts		27	932	1007	425	42	1	2434
2003	C_1 adults			3	2	2			7
2003	C1 smolts		23	1078	1098	1359	127	11	3696
2003	T_0 adults	1	9	2	8	3			23
2003	T_0 smolts	661	3108	1583	1777	904	153	59	8245
2003	JDA adults		3	23	19				45
2003	JDA smolts	1	92	932	934	1			1960

<u>Do PIT tag SARs represent SARs of the run at large?</u>

The run reconstruction SARs of natural-origin spring summer Chinook point estimates (Williams et al. 2005) tend to be larger than SAR point estimates of the CSS PIT tag group (Figure 5.24). The geometric mean ratio of run reconstruction SAR to PIT tag SAR was 1.26 (range 0.65 to 1.63). Run reconstruction SAR point estimates exceeded PIT tag point estimate in all but two years during 1996-2001, but fell within the CSS 90% confidence intervals in four of eight years (Figure 5.24). Origin of salmon passing the viewing window at LGR has been classified by the U.S. v. Oregon Technical Advisory Committee since the late 1990s based on the presence/absence of an adipose fin. However, the 'natural' category included unclipped hatchery fish, partially clipped fish with regenerated fins, and supplementation fish, which deliberately were not marked with an adipose clip (Copeland et al. 2005). Several assumptions are currently necessary to estimate the proportion of hatchery-origin unclipped adults that can influence the run reconstruction estimates of recruits. Until more reliable estimates of the hatchery proportion of adipose-intact adults at LGR are available, it is difficult to determine whether the CSS PIT tag SARs are negatively biased, the run reconstruction SARs are positively biased, or both (Berggren et al. 2006; Marmorek et al. 2004). The primary concern of negative bias from PIT tag SARs would be in evaluating whether SARs are meeting NPCC biological objectives (2% minimum, 4% average).

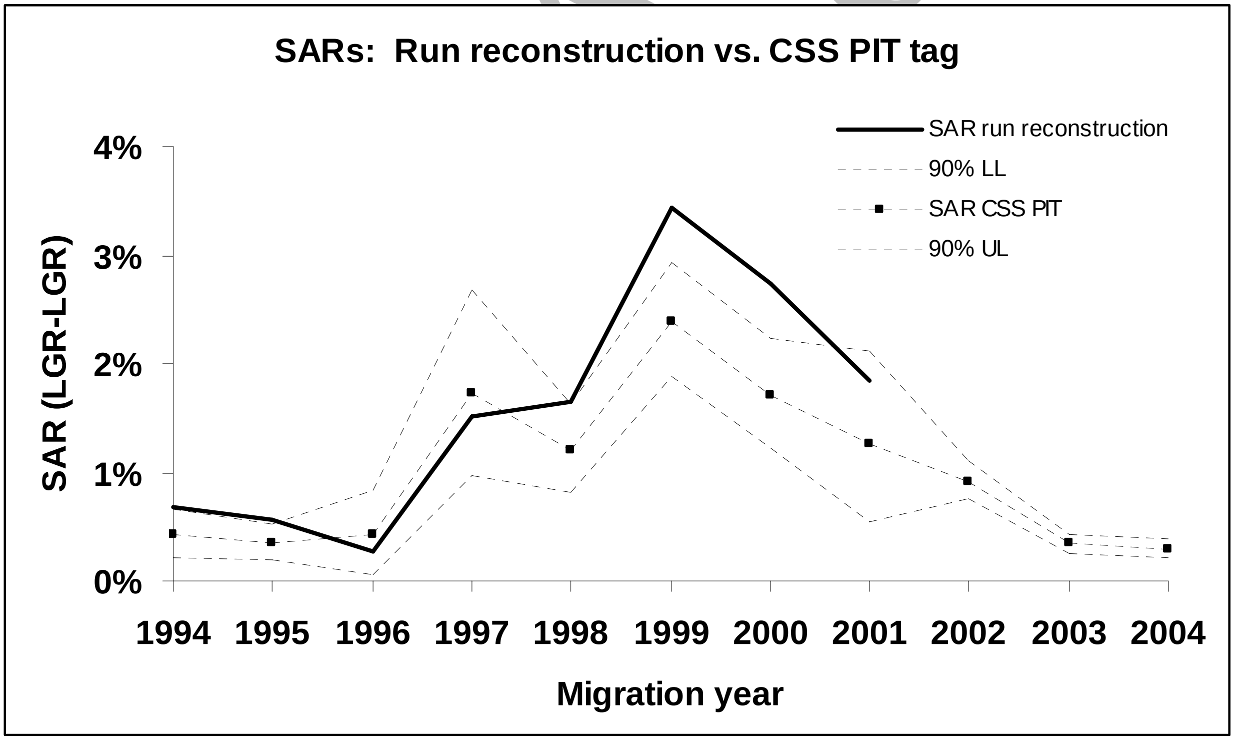


Figure 5.24. SARs from Lower Granite Dam smolts and adults based on run reconstruction (Williams et al. 2005) and SARs and 90% confidence limits from CSS PIT tags.

Discussion and Conclusions

SARs of Snake River wild spring/summer Chinook were less than NPCC interim objectives (2% minimum, 4% average) in most years, achieving the minimum in only 1 of 11 years during 1994-2004. Snake River wild steelhead SARs averaged less than NPCC the minimum of 2%, but met the minimum in 4 of 7 years during 1997-2003.

SARs of hatchery spring/summer Chinook tracked closely with those of the aggregate Snake River wild population during 1997-2004, indicating similar factors were influencing survival during the smolt migration and in the estuary and ocean life stage. Although the hatchery populations generally responded differently to transportation than wild populations, the patterns observed in overall hatchery SARs appear useful for augmenting wild SAR data, as well as providing important management information for these specific hatcheries. We observed within year SAR differences among the different hatcheries, with Dworshak NFH showing generally poorer SARs than Rapid River, McCall and Imnaha. Similar diversity in SARs may exist among wild spring/summer Chinook populations. We had sufficient adult returns to estimate SARs and CI at a subbasin scale in four years (1998-2000, 2002). Although CI were wide and generally overlapped within years of comparison, Clearwater SARs appeared to be lower than the average, and Imnaha appeared somewhat higher than average. Future monitoring should address these SAR patterns on finer scales (Major Population Group or population) to better address viability criteria for Snake River wild spring/summer Chinook and steelhead. Multi-year methods such as developed in Chapter 4 may be useful for dealing with relatively small sample sizes when comparing group performance. In addition, the method of forming the cohort upon release ("NPT method") rather than at the dams will facilitate SAR estimation at these finer scales. CSS adopted this method beginning with the 2006 release (Appendix A).

We believe that evaluation of steelhead hatchery SAR performance would be valuable in assessing hydro impacts on steelhead populations. CSS has proposed steelhead hatchery groups for marking (consistent with ISAB/ISRP review recommendations), but the activity has not been funded to date.

Multiple linear regression analysis indicated that SARs of Snake River wild spring/summer Chinook were best described by water travel time experienced during the smolt migration and certain ocean/climatic variables. These general results were consistent for both the recent SAR time series based on CSS PIT tag estimates (1994-2004), and for a longer time series based on a combination of run reconstruction and PIT tag estimates (1964-2004). Water travel time is a measure of the number of days it takes for water to move between the Snake and Clearwater River confluence and Bonneville Dam. As a result of federal dam construction, water travel time has increased from about 2 -3 days in a free-flowing river to an average 19 days with the current FCRPS (range, 10 – 40 days depending on inflow). Water travel time influences the smolt migration rate, and is indirectly related to spill and other hydrosystem factors. The ocean/climatic variables that we found influential and beneficial to survival were cool phases of the PDO index, primarily in May or September, and down-welling in the fall (November) during the first year of ocean residence.

SARs of downriver wild spring Chinook from the John Day River averaged about four times as high as those from the Snake River during migration years 2000-2004. The difference in SARs between upriver and downriver wild Chinook is consistent with previous findings of differential mortality between upriver and downriver population groups based on spawner and recruit data before and after FCRPS completion (Schaller et al. 1999, 2000, Deriso et al. 2001;

Schaller and Petrosky *In Press*). The recent John Day SARs ranged from 2.5% to 11.1%, whereas Snake River SARs ranged from 0.4% to 2.7%. In this contrast, SARs represent smolts at the first dam encountered to adult return to Bonneville Dam for consistency with spawner-recruit based estimates of differential mortality. One benefit of the SAR-based differential mortality estimate is a much narrower confidence interval than obtained from the spawner-recruit analysis. CSS currently has the ability to compare downriver SARs from the John Day River (3 populations) with those from the Snake River (over 30 populations), and has proposed (but not received funding for) PIT tagging wild spring Chinook smolts in the Warm Springs River (Deschutes Subbasin). Additional candidate populations relevant to these SAR comparisons from downriver areas of the Interior Columbia include Klickitat, and Yakima rivers. Future monitoring should also consider incorporating PIT tag SARs from the upper Columbia region to expand these regional comparisons.

Upriver and downriver hatchery spring/summer Chinook SARs did not show the same level of differential mortality as was apparent from the wild populations. Survival of hatchery fish is subject to additional fitness and rearing factors that may not affect wild populations. CSS currently has the ability to compare SARs from a single downriver hatchery (Carson NFH) with those from five Snake River hatcheries. Additional candidate populations relevant to these SAR comparisons from downriver hatcheries of the Interior Columbia include Klickitat, Warm Springs, and Round Butte (depending on fish health constraints). Future monitoring should also consider incorporating PIT tag SARs from the upper Columbia region to expand these regional comparisons.

Our comparison of upriver and downriver Chinook salmon population-specific life history attributes yielded several important results. We found no evidence for a consistent and/or systematic difference in size-at-migration existing between upriver and downriver populations. That is, both upriver and downriver production areas yielded smolts of similar, but variable (on an inter-annual basis) size. We also demonstrated that a portion of fork length variation could be attributed to density-dependent effects. Our analysis of trap-passage timing distributions illustrates that both upriver and downriver populations depart from natal streams within a similar timeframe. We also found evidence for greater variation in outmigration timing for upriver relative to downriver populations. This finding is consistent with that of Williams et al. (2005), who reported greater variation in passage timing (at BON) for unmarked, upriver-origin yearling Chinook salmon.

Across all years in question, we found that upriver-origin smolts migrated to the estuary at similar rates as those emigrating from the John Day system. These results may be explained because most smolts were trapped in tributaries and that smoltification status increases and travel times decrease as an increasing function of time spent in migration (e.g., Berggren and Filardo 1993; Williams et al. 2005). Based on a comparison of migration rates between upriver and downriver populations for similar sections of their respective mainstem migration corridors (i.e., between the first and third dams encountered by each group), we found that hydrosystem migration rates did not differ between groups but were strongly influenced by water travel time. Despite their similar size, similar emigration timing, and downriver migration rate, upriver-origin smolts arrived at the estuary later (~7-10 days) than John Day River Chinook salmon smolts. Given the above conclusions and the historical increase in water travel times due to hydropower dam development, however, the observed discrepancy in arrival timing at BON is most likely a result of the FCRPS than some innate life history difference existing between upriver and downriver Chinook populations.

In summary, our analysis illustrates that although subtle differences occur within and across Chinook salmon populations, there is no indication that a systematic smolt life history difference exists between upriver and downriver production areas. Thus, while our use of an upriver-downriver comparison relies on a 'natural experiment' approach and therefore has some design limitation, the analysis we present here illustrates that the potential confounding effects due to life history differences are probably negligible.

Altered arrival timing due to the FCRPS presence and operation has been hypothesized as one factor which may reduce survival of juvenile spring/summer Chinook salmon in the ocean (Budy et al. 2002, Williams et al. 2005; Muir et al. 2006). The CSS results clearly demonstrate delayed estuary entry of in-river smolts due to the presence and operation of the FCRPS. Nonetheless, estuary entry of Snake River spring/summer Chinook overlaps with that of downriver spring Chinook from the John Day River, which are less affected by the hydrosystem. Enough PIT tag data exist to compare SARs from smolts detected at Bonneville or the lower river to compare SARs between Snake and John Day River populations during the primary migration period (April 16 - May 31). The disparity between SARs for Snake River wild Chinook, when they arrive to the lower Columbia River in the same time window (April 16 - May 31) as the John Day River smolts, provides additional support for mechanisms of delayed hydrosystem mortality in addition to the simple alteration of estuary entry timing.

The ISAB (2006) concluded that more attention should be given by the CSS and the Region as a whole to the apparent documentation that PIT-tagged fish do not survive as well as untagged fish. This question is currently difficult to address because of issues with estimating the number of natural-origin spring/summer Chinook adults at LGR for run reconstructions. Copeland et al. (2005) estimated the age composition for the aggregate Snake River natural adult run passing LGR using video sampling estimates of length frequency of adipose-intact adults, and analysis of fin-ray sections from salmon carcasses on spawning grounds to determine length-at-age for each return year. Origin of salmon passing the viewing window at LGR has been classified by the U.S. v. Oregon Technical Advisory Committee since the late 1990s based on the presence/absence of an adipose fin. However, the 'natural' category included unclipped hatchery fish, partially clipped fish with regenerated fins, and supplementation fish, which deliberately were not marked with an adipose clip (Copeland et al. 2005). Misclassification of hatchery adults could introduce a positive bias in run reconstruction SAR estimates for natural fish because the hatchery returns numbers were much larger than the natural escapement. A fairly small misclassification rate in a large hatchery run could seriously inflate the estimates of natural adult run-size. Copeland et al. (2005) recommended that precision and bias of the run reconstruction SAR estimates be examined. A primary data need is to determine the proportion of adipose intact adults of hatchery origin, through Genetic Stock Identification (GSI) techniques and/or scale pattern analysis. A Lower Snake River Compensation Plan project to assess the feasibility of estimating numbers of adults by origin through GSI techniques began collecting scales at LGR in 2006 (J. White, IDFG. pers. comm.). The CSS project plans to continue to examine the question as results of this study become available.

Implications of bias (if present) would be negligible for relative comparisons of the CSS PIT tag SAR data, such as between Snake River migrants with different hydrosystem experiences, or between Snake River and downriver populations. We would expect any (negative) bias due to PIT tagging to affect groups similarly. Note that SARs of the John Day wild spring Chinook populations exceeded 11% in migration year 2000 (1st dam smolts to BON adults); if Snake River SARs were underestimated that year due to PIT tagging, a similar underestimate of SAR would be expected for the downriver populations since the same tagging protocols were used.

Chapter 6

Partitioning Survival Rates – Hatchery Release to Return

Introduction

In the early 1990s, Mundy et al. (1994) concluded that research results to date were not conclusive regarding the ability of transportation to improve returns to the spawning grounds (or hatcheries) due to problems associated with experimental design. Even if transportation provides an apparent survival improvement relative to juvenile migration through the hydrosystem (as measured by adult return to the dams), the benefit may not carry through to natal areas if transported fish were more likely to stray or die before spawning. One of several advantages of the CSS experimental design of tagging fish at hatcheries or in tributaries before release (rather than at the dams as in previous studies) is that it allows for partitioning survival rates by treatment of known-origin fish between locations along their juvenile and adult migrations.

An objective of CSS has been to develop a long-term index of survival rates from release of yearling Chinook smolts at hatcheries to return of adults to hatcheries. This objective includes partitioning survival rates from (i) hatchery (smolts) to LGR (smolts), (ii) LGR (smolts) to back to LGR (adults), and (iii) LGR (adults) to the hatchery (adults).

Hatchery Chinook SARs from smolts at LGR to adults at LGR (task ii) are a primary focus of CSS and are addressed in detail in Chapter 3. CSS has also estimated survival of hatchery smolts from release to LGR (task i). The third task of partitioning survival rates from LGR adults to the hatchery has proven more difficult. However, we have assessed the relative return rates from LGR to hatcheries for adults that were either transported or migrated through the hydrosystem as juveniles, a primary concern of the Mundy et al. review (1994). In addition, the CSS PIT tag data allows for evaluation of the relative upriver passage success of returning adults (BON-LGR) from transport and in-river groups to further partition the LGR-LGR SARs (task ii) and assess the extent to which transportation may contribute to straying or poor upstream passage conversion. The capability of estimating the relative adult passage success between Bon-LGR became possible in 2002 because adult PIT tag detection devices were completed in the adult ladders at BON and LGR.

In this chapter we summarize findings from previous annual reports (Berggren et al. 2003; 2005; 2006) regarding survival from release to LGR, detections of PIT tagged adults returning to hatchery racks for transported and in-river groups, expansions for harvest rates in areas upstream of LGR, and estimates of adult survival rates between LGR and the hatcheries of origin. We quantified adult migration (BON-LGR) survival for both transport and in-river study categories and tested for differences in migration survival, timing and duration between groups. Additionally, we evaluated the role of environmental factors (flow, spill and temperature) on the upstream survival of salmon.

Methods

Tagging methods, releases and assignment of hatchery Chinook smolts into study categories are described in Appendix A. Survival from release to LGR estimated from CJS methods described in Appendix A.

Smolt survival from hatchery release to LGR

Survival from release to LGR estimated from CJS methods is described in Appendix A.

Adult survival from LGR to hatchery

Adults and jacks returning from McCall, Imnaha, Catherine Creek, Dworshak and Rapid River hatcheries were scanned for PIT tags at the hatchery racks. Details of PIT tag recovery activities at the hatcheries are in the CSS 2002 and 2005 annual reports (Berggren et al. 2003, 2005). PIT tagged hatchery Chinook adults and jacks are detected at the LGR adult ladder as described in Appendix A.

In the 2002 annual report (Berggren et al. 2003), we compared the detection probabilities by route of passage (in-river or transported) and smolt migration year (MY 1997-2000). Detection probabilities were simply the number of adults and jacks detected at a hatchery rack divided by the number detected at LGR for each MY. We then tested the effect of passage route on detection probability using χ^2-tests.

In the 2005 annual report (Berggren et al. 2005), we estimated survival of returning adults from LGR to the hatchery racks, MY 1997-2004. Survival estimates from LGR to hatcheries (or vicinity of release location) require an estimate of the detection probabilities at the hatchery racks expanded by the harvest rates estimated by individual agencies each return year. The Imnaha PIT tag data were excluded from this analysis because adults typically pass the weir site before installation.

Associations between smolt outmigration experience and survival rates for adult Chinook salmon between Bonneville and Lower Granite Dams

Associations between smolt outmigration experience and apparent survival rates for adult Chinook salmon between Bonneville and Lower Granite Dams were evaluated in the 2006 Annual Report (Berggren et al. 2006). Using data collected at PIT-tag interrogation systems on adult fishways, the latter quantity can be directly estimated and compared between CSS's transport (T_0 and T_1) and in-river (C_0 and C_1) study categories. By quantifying upstream survival rates, it may be possible to more precisely identify mechanisms responsible for a portion of the observed study-category SAR differential.

Approach -- We tested for an effect of juvenile transportation on upstream adult migration timing, duration, and success for Chinook salmon through three separate analyses: 1) we tested whether or not BON-LGR migration success was independent of juvenile outmigration history using χ^2-tests (Note: given the ~100% detection probability at LGR, we take detection at LGR [i.e., BON-LGR migration success] to be synonymous with upstream-migration survival [i.e., *inclusive of both mortality and straying*]); 2) we modeled individual survival, a binary response, using logistic regression; within this analysis, we tested for transportation and environmental variables effects using an Akaike's Information Criterion (AIC)-based model-selection exercise and based on significance tests for fitted model parameters and associated odds ratios; 3) we contrasted adult return timing (i.e., arrival at BON) and BON-LGR upstream travel time (i.e., passage duration, in days) across outmigration histories using analysis of variance.

Dataset description -- We evaluated relationships between outmigration experience and upstream survival and migration characteristics for hatchery and wild Chinook salmon, separately. For hatchery Chinook salmon, we used available adult PIT-tag detections for fish released from Catherine Creek (CATH), Dworshak (DWOR), Imnaha (IMNA), McCall (MCCA), and Rapid River (RAPH) hatcheries; for wild salmon, we relied on PIT-tag releases from CSS-affiliated smolt traps and from tagging efforts occurring in natal streams throughout the Snake River Basin. We included in our analysis ≥1-ocean adults (i.e., we excluded jacks) from MYs 2001-2004 that were detected as adults at BON, McNary (MCN), Ice Harbor (IHR), and LGR PIT-tag interrogation sites in RYs 2002-2006. Also, we excluded those adult that were not initially detected at BON during their respective upstream migration. We determined each adult's juvenile outmigration experience based its smolt capture history and grouped individuals in a manner similar to Marsh et al. (2005). Thus, we included categories for the following juvenile outmigration histories: 1) in-river outmigrants (i.e., undetected or detected but bypassed = 'in-river' group hereafter); 2) transported individuals that were collected at and transported from LGR ('LGR' group hereafter); and 3) transported individuals that were collected at and transported from LGS or another downstream project ('LGSdown' group hereafter). Sample sizes, by migration year, transport history, and BON-LGR passage success are provided in Table 6.1 (hatchery; aggregate *n* = 3,649) and **Table 6.2** (wild; aggregate *n* = 539).

Table 6.1. Counts of hatchery Chinook salmon adults that failed ('F') or were successful ('S') in surviving their BON-LGR migration in return years 2002-2006, grouped by migration year and outmigration experience (see Methods for group definitions). There was evidence for a significant association between transport history and migration success where sufficient observations-per-cell were available (see Table 26 for details).

Outmigration history	MY2001 F	MY2001 S	MY2002 F	MY2002 S	MY2003 F	MY2003 S	MY2004 F	MY2004 S	Combined F	Combined S
In-river	12	43	146	789	62	395	40	113	260	1340
LGR	140	560	66	226	53	174	76	142	335	1102
LGSdown	22	89	46	214	20	119	31	71	119	493

Table 6.2. Counts of wild Chinook salmon adults that failed ('F') or were successful ('S') in surviving their BON-LGR migration in return years 2002-2006. There was evidence for a significant association between transport history and migration success where sufficient observations-per-cell were available (i.e., ≥ 5; MY2002: χ^2 = 8.74, df = 2, *P* = 0.013; Combined: χ^2 = 7.94, df = 2, *P* = 0.019; MY2001, MY2003-4, not applicable).

Outmigration History	MY2001 F	MY2001 S	MY2002 F	MY2002 S	MY2003 F	MY2003 S	MY2004 F	MY2004 S	Combined F	Combined S
In-river	4	34	30	210	8	53	8	36	50	333
LGR	3	7	7	12	2	15	8	28	20	62
LGSdown	0	5	6	26	0	16	2	19	8	66

Environmental variables -- Within the context of our logistic regression-based assessment of transportation effects, we also wished to account for variation in BON-LGR survival that could be attributed to in-river migration conditions. Specifically, given the results from the University of Idaho's radio telemetry work (Keefer et al. 2005; Naughton et al. 2006), we quantified the influence of discharge, spill (%), and water temperature on adult passage success. We summarized these variables using records from the Fish Passage Center and USACE's websites. Discharge and temperature data were summarized for Lower Granite (i.e., used as a proxy for Snake River hydrological and thermal conditions) and Bonneville dam (i.e., as a proxy for Columbia River conditions) sites and averaged across 2-week time blocks in each RY. Similarly, spill was summarized as an average Lower Columbia (BON, TDA, JDA, and MCN, averaged) and Lower Snake (IHR, LMN, LGS, and LGR, averaged) value for the same time blocks. Environmental variables were matched with individual fish records based on their Bonneville arrival date. However, given that the majority (hatchery: 570/714 or 80%; wild: 64/78 or 82%) of adults that failed to arrive at LGR dropped out before McNary Dam and that variables are correlated across sites, we used only Lower Columbia environmental variables in our final analysis.

Statistical analysis -- For both wild and hatchery Chinook salmon, we analyzed relationships between outmigration experience and adult migration success according to the following steps. First, we ran a separate χ^2-test (2 × 3 table; success/failure × in-river/LGR/LGSdown categories) for each migration year (MY) and RY, when sufficient observations per cell were available (i.e., ≥ 5); we also performed a single χ^2-test, pooling individuals across years. We additionally performed hatchery-specific tests for hatchery Chinook.

Second, we evaluated the effects of both transportation history and environmental conditions (i.e., Lower Columbia flow, spill, and temperature) on the upstream migration survival of individual fish using logistic regression. Thus, we fit 11 *a priori* models (Tables 6.4 and 6.6) describing an individual's survival response (0 = unsuccessful; 1 = successful) as a function of a combination of transportation (i.e., dummy variables for LGR and LGSdown histories; intercept = in-river) and/or environmental predictor variables. Thus, we evaluated the possibilities that individual upstream passage success was determined by transportation history or environmental conditions alone, or in combination. We used an AIC-based model selection approach to determine the level of support for different models (i.e., hypotheses) and subsequently assessed slope parameter sign (+/-) and significance (using a *t*-test), as well as success odds ratio estimates (i.e., $O_{\mathrm{LGR}}/O_{\text{in-river}}$ and $O_{\mathrm{LGSdown}}/O_{\text{in-river}}$, where $O_i = p_{\mathrm{success}}/p_{\mathrm{fail}}$ for group *i*) and associated 95% CIs from our top model.

For the final component of our analysis, we contrasted BON arrival timing (i.e., date of adult return, measured as the Julian calendar date) and BON-LGR upstream travel times (in days, $\log_{10}$-transformed for normality purposes) between in-river, LGR, and LGSdown groups. To do this, we performed ANOVAs on both hatchery and wild Chinook salmon data sets, separately. Factors included in both arrival timing and travel time analyses were transport history (i.e., in-river, LGR, LGSdown groups), RY (i.e., as a blocking factor), and their interaction. We evaluated model-effect significance based on *F*-tests (Type-III sums-of-squares) and subsequently contrasted responses between categories using Tukey's HSD test.

All statistical analyses were performed using SYSTAT v. 9 (SPSS 1998). We evaluated statistical significance at $\alpha = 0.05$.

Table 6.3. Summary of MY-, RY-, and hatchery-specific χ^2-tests for hatchery Chinook salmon. The *P*-values listed are not corrected for multiple tests. The success rate ranking corresponds to the ordering of % successful upstream migrants by juvenile outmigration history. The entry 'NA' corresponds to table values that are not applicable because either a test was not performed due to low cell counts (i.e., RY2002) or the resulting test statistic was not significant ($\alpha = 0.05$). df = 2 for all tests.

Table	*P*-value	Success Rate Ranking
Aggregate	**<0.001**	In-river > LGSdown > LGR
MY2001	0.946	NA
MY2002	**0.022**	In-river > LGSdown > LGR
MY2003	**0.004**	In-river > LGSdown > LGR
MY2004	0.200	NA
RY2002	NA	NA
RY2003	**0.009**	In-river > LGSdown > LGR
RY2004	**0.005**	In-river > LGSdown > LGR
RY2005	**0.029**	In-river > LGSdown > LGR
RY2006	0.126	NA
CATH	**0.015**	In-river > LGR > LGSdown
DWOR	**<0.001**	LGSdown > In-river > LGR
IMNA	0.092	NA
MCCA	0.383	NA
RAPH	**0.009**	In-river > LGSdown > LGR

Results

Smolt survival from hatchery release to LGR

Survival from hatchery release to LGR averaged about 65% from CSS hatcheries during 1997-2004 (Fig. 6.1; Appendix C). Survival from Dworshak Hatchery was generally higher than other CSS hatcheries; survival from Catherine Creek AP was notably lower than the others.

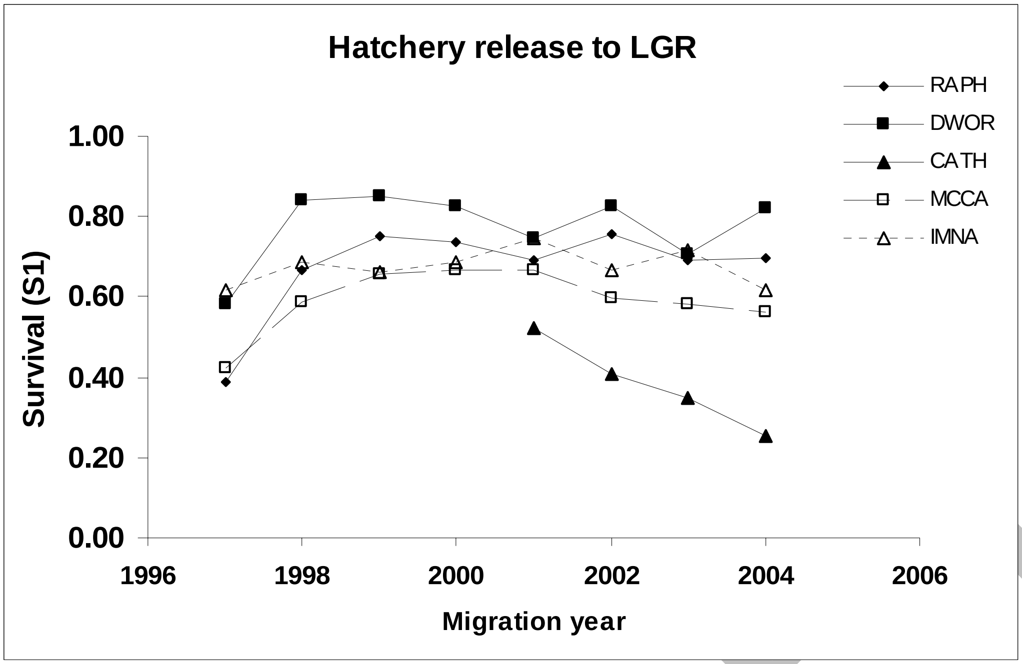


Figure 6.1. Survival from hatchery release to Lower Granite Dam for Rapid River Hatchery, Dworshak Hatchery, Catherine Creek AP, McCall hatchery, and Imnaha AP, migration years 1997 – 2004.

Adult Survival from LGR to Hatcheries

The proportions of adults and jacks detected at LGR that were subsequently detected at the hatchery of origin were summarized in the CSS 2002 Annual Report (Berggren et al. 2003) by route of juvenile passage (in-river or transport) for smolt migration years 1997 – 2000. Detection proportions reflect harvest in Snake River tributaries, targeted on these hatcheries, and the combined effects of straying, spawning below the hatchery weir, escaping upstream of a hatchery weir undetected, tag loss or incomplete detection efficiency and pre-spawning mortality. The overall data, pooled for all hatcheries, are shown in Figure 6.2. There was no significant difference in detection probabilities between transport or in-river groups for any of the hatcheries (Berggren et al. 2003). These results suggest that whatever straying or survival impairment may occur due to the juvenile transportation experience has already occurred by the time the adults have migrated through the hydrosystem.

We attempted in the CSS 2005 Annual Report to estimate survival of PIT-tagged adults from LGR to the hatchery racks by expanding proportion detected at the racks by the harvest rates estimated by individual agencies each return year (Berggren et al. 2005). The Imnaha PIT tag data were excluded from this analysis because adults typically pass the weir site before installation. The average detection proportion accounted for by this approach, across hatcheries and migration years, was 59% (Figure 6.3). Berggren et al. (2005) concluded that multiple factors could explain this apparent low detection proportion: (1) unaccounted adults spawning below the weirs and trapping sites; (2) adults overshooting the trapping sites during periods when weirs are not installed; (3) straying into other streams; (4) missed detections of PIT-tagged adults or shed tags at the hatchery; (5) under-reporting of harvest; (6) delayed mortality from hooking and handling these fish during fisheries; and (7) high natural mortality of adults after passing upstream through the hydrosystem. Future monitoring, in coordination with CSS, may be able to estimate the magnitude of factors 1, 2 and 3 for hatchery weirs in locations with intensive spawning ground and carcass surveys, such as upper the Grande Ronde River and Catherine Creek, Imnaha River, and South Fork Salmon Rivers (McCall Hatchery). An evaluation specifically directed at tag loss or detection efficiency (factor 4) would also be useful.

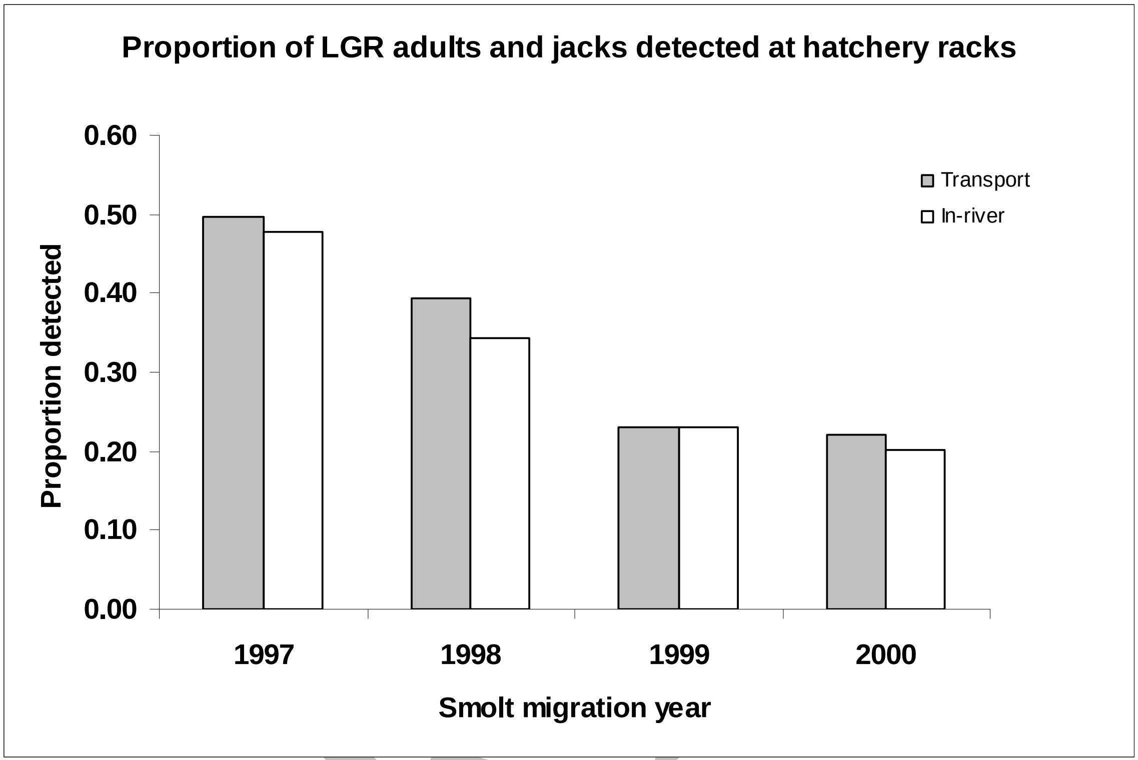


Figure 6.2. Proportion of PIT tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks (pooled across hatcheries), by juvenile passage route (in-river or transport) and smolt migration year (1997-2000).

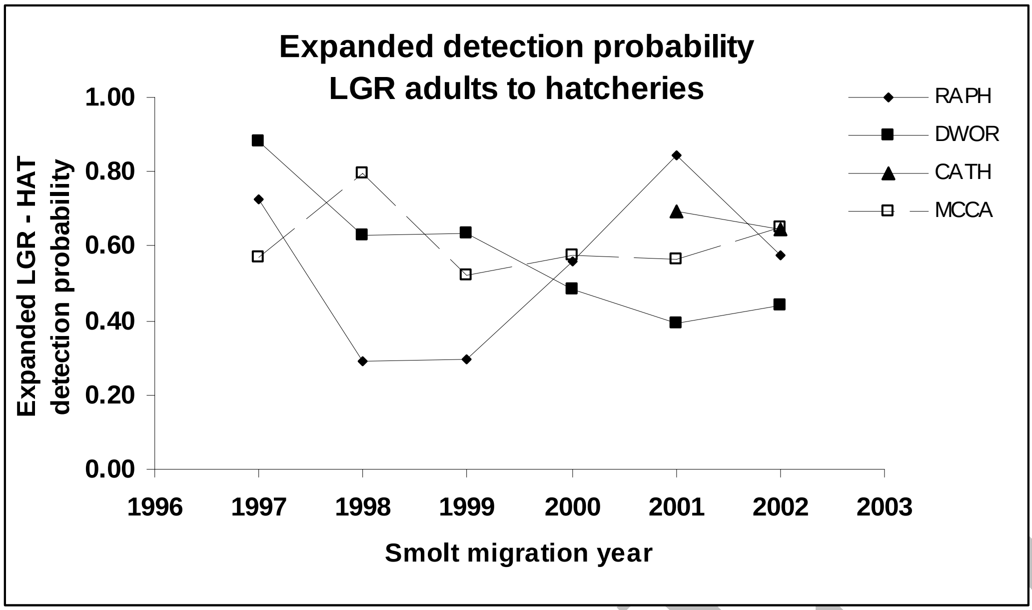


Figure 6.3. Proportion of PIT tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks, expanded for estimated harvest rate, smolt migration year (1997-2002).

Associations between smolt outmigration experience and survival rates for adult Chinook salmon between Bonneville and Lower Granite Dams

Hatchery Chinook χ^2 *tests* -- The results from the aggregate, MY-, RY-, and hatchery-specific χ^2-tests are summarized in Table 6.3. Though there was some variability in which of these tests indicated a significant departure from the null expectation (i.e., that migration success was independent of outmigration experience), on average 77% of LGR adults passed from BON to LGR; in contrast, 81% and 84% of all LGSdown and in-river outmigrants, respectively, made a successful BON-LGR migration (Figure 6.4). This pattern was generally consistent across χ^2-tests conducted on a MY, RY, or aggregate basis. Hatchery-specific χ^2-tests also suggest a transportation effect. However, there appeared to be a distance-to-LGR effect on the results for the different hatcheries. That is, the disparity in migration success between in-river and LGR adults was generally less for those individuals originating from hatcheries that were further upstream (Pearson *R* = -0.61, correlation between the LGR vs. in-river success-rate difference and distance from release to LGR). Also worth noting is the possible role of race type in survival patterns. χ^2-tests for IMNA and MCCA hatcheries – the only two releasing summer-run Chinook smolts – were not significant. The association between outmigration experience and adult migration success for spring-run Chinook hatcheries, in contrast, was statistically significant across all sites.

Wild Chinook χ^2 *tests* -- Given the small sample size for wild CSS Chinook salmon adults, we focused primarily on the pooled χ^2-test for inferential purposes (i.e., MY2002 was the only year with $\geq$5 observations per cell for all MY- and RY-specific analyses). Consistent with our findings for hatchery salmon, this analysis suggests that wild adult Chinook salmon BON-LGR migration success is influenced by outmigration experience. Specifically, adults that were transported from LGR as smolts were consistently less successful at returning to their upstream tributaries than those that emigrated as in-river or LGSdown smolts ($P = 0.019$). Whereas only about 10% of in-river and LGSdown smolts did not survive (inclusive of mortality and straying) from BON and LGR, approximately 25% of those collected and transported from LGR as smolts did not reach LGR (Figure 6.4).

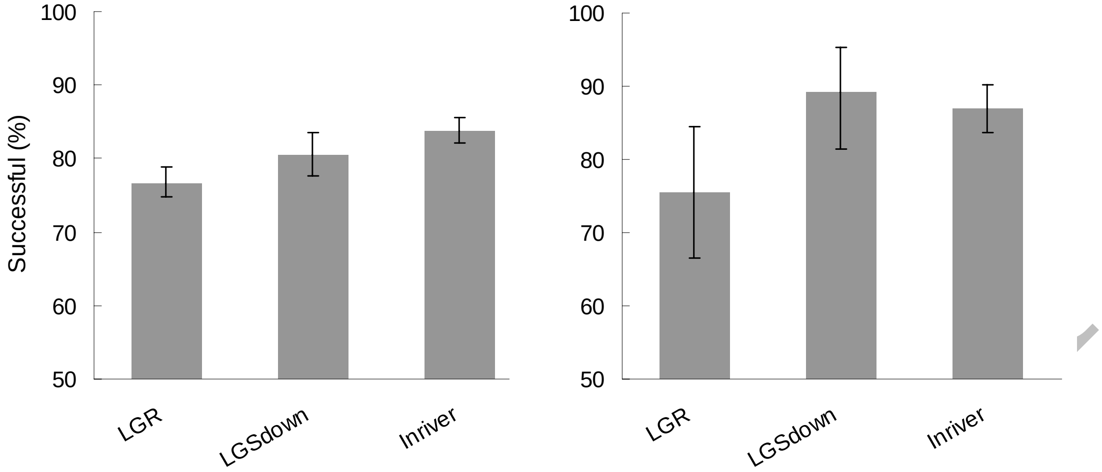


Figure 6.4. Bar chart of the percent of hatchery (left) and wild (right) Chinook salmon that were successful in migrating from BON to LGR for in-river, LGR, and LGS-down outmigration histories across return years 2002-2006 (i.e., combined counts). Error bars correspond 95% confidence intervals.

Hatchery Chinook logistic regression analysis -- Consistent with hatchery χ^2 findings, our AIC-based model-selection exercise also demonstrates an effect of transportation history on upstream adult migration success. The best model describing individual migration success included transport, temperature, and spill effects (Table 6.5). Model evidence ratios (i.e., w_i-best overall model / w_i-best environmental variables-only model; Table 6.4) indicate that the top model, which contained a combination of transportation and environmental effects, was > 6,000 times more likely than the best environmental variables-only model. Thus, based on these data and candidate models evaluated, there is clear evidence suggesting that patterns in individual survival are due to a combination of transportation history and environmental conditions.

Considering the top logistic regression model in greater detail (i.e., the transport + temperature + spill model), all parameters differed significantly from zero, except for the dummy variable identifying an LGSdown-group effect ($P = 0.085$; Table 6.5). Parameter estimates indicate that the probability of an individual fish migrating successfully from BON to LGR was less for LGR individuals than for either in-river outmigrants and LGSdown individuals. Additionally, parameter estimates suggest that upstream migration success was lessened during periods characterized by high spill and cold temperatures in the Lower Columbia River. Further, the odds ratio estimate for the LGR group (estimate: 0.64; 95% CI: 0.53-0.77) indicates that these adults had significantly lower odds of surviving their BON-LGR migration than in-river outmigrants (i.e., the 95% CI did not include 1). The odds ratio for the LGSdown parameter did not differ from 1 (estimate: 0.81; 95% CI: 0.64-1.03), suggesting that these individuals had a similar likelihood of making it to LGR as in-river-outmigrant adults.

Table 6.4. Logistic regression model-selection results for CSS hatchery Chinook salmon. Note, Y = *P*(Success | X), where X is the variable in question. The bold-faced model was the one most supported by the data, however those with a ΔAIC < 2 can be considered nearly equivalent. K is the number of estimated parameters (inclusive of variance).

Model	K	AIC	ΔAIC	w_i
Y = Spill	3	3612.9	24.3	0.00
Y = Flow	3	3612.3	23.7	0.00
Y = Temperature	3	3608.7	20.2	0.00
Y = Spill + Temperature	4	3606.2	17.6	0.00
Y = Flow + Temperature	4	3606.7	18.1	0.00
Y = Transport	5	3593.7	5.2	0.04
Y = Transport + Spill	6	3595.0	6.4	0.02
Y = Transport + Flow	6	3595.4	6.9	0.02
Y = Transport + Temperature	6	3590.9	2.3	0.18
Y = Transport + Spill + Temperature	**7**	**3588.6**	**0.0**	**0.57**
Y = Transport + Flow + Temperature	7	3591.1	2.5	0.16

Table 6.5. Parameter estimates for the top logistic regression model describing BON-LGR migration success for CSS hatchery Chinook salmon returning in 2002-2006.

Parameter	Estimate	SE	T	*P*-value
Intercept	1.410	0.285	4.95	<0.001
LGR	-0.446	0.092	-4.84	<0.001
LGSdown	-0.212	0.123	-1.73	0.085
Spill	-0.016	0.008	-2.04	0.041
Temperature	0.057	0.020	2.87	0.004

Wild Chinook logistic regression analysis -- Our wild Chinook logistic regression analysis also demonstrates an effect of transportation history on upstream adult migration success. The best model describing individual migration success included transport effects alone (Table 6.6); every one of the closest competing models (i.e., those models with ΔAIC < 2) also included transportation effects. Model evidence ratios (i.e., w_i-best model / w_i-best environmental variable-only model; Table 6.6) indicate that a transport-effects-only model is 4 times more likely than the best environmental variables-only model. Thus, based on these data and candidate models, there is stronger support for a transportation-legacy hypothesis than any environmental conditions-only hypotheses. Of parameters estimated for our top model, only the LGR parameter differed significantly from zero ($P = 0.003$; Table 6.7). As expected, the probability of an individual fish migrating successfully from BON to LGR was lower for LGR individuals than for either in-river outmigrants or LGSdown individuals. At 0.46 (95% CI: 0.26-0.84), the odds ratio estimate for this group indicates that LGR salmon were about half as likely to survive their migration from BON to LGR than in-river outmigrants. Similar to hatchery models logistic regression results, the odds ratio for LGSdown adults did not differ from 1 (estimate: 1.24; 95% CI: 0.56-2.73).

Table 6.6. Logistic regression model-selection results for CSS wild Chinook salmon. Note, Y = *P*(Success | X), where X is the variable in question. The bold-faced model was the one most supported by the data, however those with a ΔAIC ≤ 2 were viewed as equivalent. K is the number of estimated parameters (inclusive of variance).

Model	K	AIC	ΔAIC	w_i
Y = Spill	3	451.6	3.1	0.07
Y = Flow	3	451.1	2.5	0.09
Y = Temperature	3	451.4	2.8	0.08
Y = Spill + Temperature	4	453.2	4.7	0.03
Y = Flow + Temperature	4	452.9	4.4	0.03
Y = Transport	**5**	**448.6**	**0.0**	**0.31**
Y = Transport + Spill	6	450.4	1.8	0.13
Y = Transport + Flow	6	450.4	1.9	0.12
Y = Transport + Temperature	6	450.2	1.6	0.14
Y = Transport + Spill + Temperature	7	451.7	3.1	0.06
Y = Transport + Flow + Temperature	7	452.1	3.5	0.05

Table 6.7. Parameter estimates for the top logistic regression model describing BON-LGR migration success for CSS wild Chinook salmon returning from 2002-2006.

Parameter	Estimate	SE	t	*P*-value
Intercept	1.896	0.152	12.5	<0.001
LGR	-0.765	0.299	-2.6	0.010
LGSdown	0.214	0.404	0.5	0.596

Hatchery Chinook arrival and travel time ANOVAs -- Analysis of variance results for hatchery Chinook salmon suggest that no consistent trend exists in either BON arrival date or BON-LGR travel time across the three outmigration histories, though there was considerable variation in both responses across RYs. Significant effects in the arrival date ANOVA include RY ($F = 35.1$, $P < 0.001$) and its interaction with outmigration history ($F = 6.2$, $P < 0.001$). The model effect outmigration by itself did not account for a significant portion of arrival date variation ($F = 2.2$, $P = 0.12$). Given the significant RY × outmigration history interaction effect, we evaluated differences between groups within years using Tukeys' HSD test. Of all within-year, across-group comparisons, the only significant difference observed was between LGR and in-river fish during 2003 ($P < 0.001$); in this case, LGR fish arrived at BON 10 days earlier than in-river adults. Across years, however, all groups returned to BON within a 3-day window of each other, with in-river, LGR, and LGSdown mean arrival dates being 21-May, 23-May, and 19-May, respectively.

Similar to BON arrival timing, travel times varied significantly across years (RY *F*-test, $F = 71.7$, $P < 0.001$) and there were some differences between study categories that varied by year (RY × outmigration history *F*-test, $F = 3.3$, $P = 0.001$). However, the outmigration effect by itself was not significant ($F = 0.4$, $P = 0.662$). As with arrival timing, the only significant within-year difference was between LGR and in-river fish in 2003; in-river migrants passed from BON to LGR 2 days faster than LGR study fish. All other year-group comparisons indicate negligible differences occur in upstream travel times due to outmigration history, though LGR fish tended towards a more skewed distribution (i.e., at the slow end of travel times; Figure 6.5). On average, all groups passed from BON to LGR in 14 days.

Wild Chinook arrival and travel time ANOVAs -- Similar to the hatchery Chinook BON arrival timing and BON-LGR travel time analysis, there was considerable variability in both responses across RYs but not groups. For the BON arrival timing ANOVA, the only significant model effect was RY ($F = 7.1$, $P < 0.001$), with arrival dates tending to be earlier in 2004-6 than 2002-3. Arrival dates averaged later than those for hatchery Chinook, with in-river, LGS, and LGSdown adults groups averaging 30-May, 27-May, and 28-May across the 5-year record, respectively. Thus, return timing did not differ as a function of outmigration experience. Similarly, BON-LGR travel times varied considerably (and slightly increasing in time) across years (RY *F*-test, $F = 8.0$, $P < 0.001$), but not as a function of outmigration experience, either across or within years (outmigration history *F*-test, $F = 0.5$, $P = 0.623$; RY*outmigration history *F*-test, $F = 1.3$, $P = 0.247$). All study groups migrated upstream at a similar rate (i.e., in 14.8, 14.0, and 13.3 days, aggregate means for LGR, LGSdown, and in-river groups, respectively); however, as with hatchery Chinook, there was a tendency towards a more skewed and slower travel time distribution for LGR adults (**Figure 6.5**).

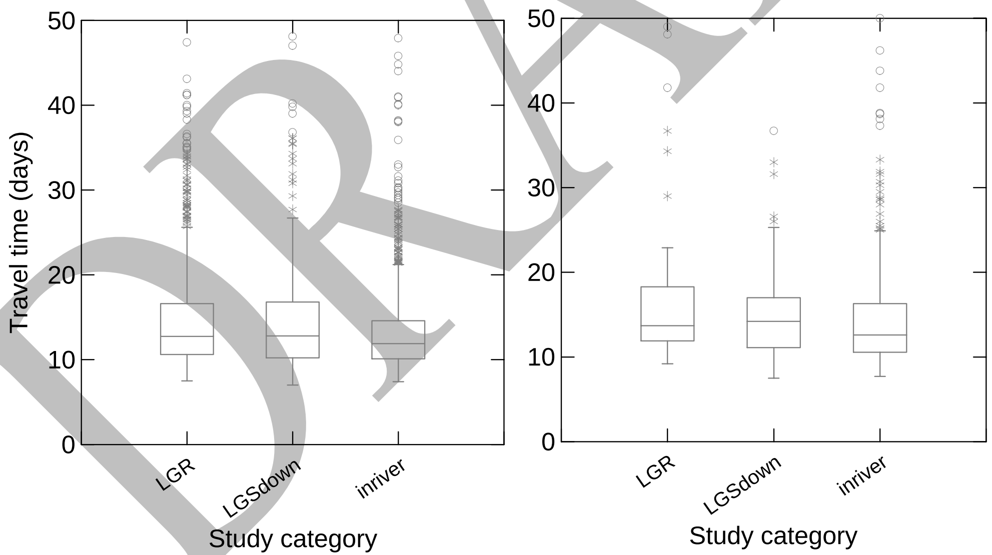


Figure 6.5. Box-and-whisker plot of BON-LGR travel times for hatchery (left) and wild (right) Chinook salmon, by outmigration experience (pooled across RYs 2002-2006). Lower and upper box bounds correspond to 25th and 75th percentiles, respectively; the mid line represents the median; the upper and lower whiskers encompass 1.5 times the inter-quartile range (IQR); values beyond 3 times the IQR appear as circles, those within as asterisks.

Discussion

The CSS project has routinely estimated survival of hatchery smolts from release to LGR for each hatchery and year. Dworshak Hatchery smolts have generally survived better to this location than those from other Snake River hatcheries, due in part to closer proximity to the dam. However, Dworshak overall SARs and relative response to transportation generally have been less than other Snake River hatcheries (see Chapter 3). Hatchery evaluations are not a primary focus of CSS, the project's survival data nevertheless provide a rich source of data for hypothesis testing.

A portion of the SAR survival difference observed between Chinook salmon with different juvenile outmigration histories (transportation or in-river) is manifested during the adult upstream migration. For both wild and hatchery Chinook salmon, our analysis demonstrates a significant effect of outmigration experience on the upstream migration success or survival of returning adults. However, our analysis also illustrates that this effect was most pronounced for fish that were transported from LGR as smolts, with these individuals surviving at an approximately 10% lower rate than those with either an in-river or LGS-down smolt history. Further, our results suggest that outmigration experience does not affect the timing of adult return (based on all BON detections) or the upstream travel times of those salmon surviving to LGR.

Previous research suggests that transportation can affect adult survival rates in the direction we observed in several ways. First, it has been suggested that smolt transportation can disrupt the imprinting process, which typically occurs during smoltification (e.g., Quinn 2005), and thus lead to increased straying of spawners upon return (e.g., Pascual et al. 1995; Bugert et al. 1997; Chapman et al. 1997). In the case where successful migration is defined by an individual's arrival at LGR, inter-dam straying is equivalent to mortality. Additionally, elevated fallback rates and extensive downstream forays by adult salmon have been attributed to juvenile transportation (Keefer et al. 2006). Given that mortality can increase with the number of fallback events and reascension attempts that are made by individuals (Keefer et al. 2005), transport-related fallback may also explain a portion of the observed disparity between study categories. Though less clear, other possible mechanisms may account for the mortality differential we observed. For instance, if increased fallback and impaired homing increase an individual's residence time between BON and MCN dams, transported fish may be more vulnerable to the zone-6 tribal fishery. This possibility, however, has not been evaluated to any great extent.

Regardless of the precise mechanisms involved, our results have important implications worth noting:

1) A portion of deviation in both TIR and *D* from their null expectations may be attributed to survival differences occurring in the mainstem Columbia and Snake Rivers after adults return to the freshwater environment to spawn.

2) The effect of outmigration experience on upstream adult survival appears to be tempered by a distance-from-release effect. Although we provide only a preliminary analysis of this issue in the present report, we observed two results supporting this conclusion: a) in contrast to LGR-transported fish, the differential between transported and in-river outmigrants was considerably less for those fish collected and transported from LGS or sites even further downstream (i.e.,

LMN, MCN); and b) the survival discrepancy between LGR and in-river outmigrants tended to be less for hatcheries existing higher in the watershed. This finding is consistent with the results Solazzi et al. (1991), who documented an increase in the straying rates of adult coho salmon that were transported and released as smolts at differing distances from their hatchery rearing site. Further, the lack of a transportation effect on homing for adults transported from IHR as smolts (Ebel et al. 1973) prior to the completion of LGR suggests that sufficient distance for imprinting may exist between LGR and IHR.

3) Finally, using project-specific PIT-tag detections has become the standard for estimating inter-dam conversion rates for use in in-season fisheries management. While a PIT-tag approach has permitted managers to avoid some of the pitfalls associated with traditional count-based approaches towards conversion rate estimation (Dauble and Mueller 2000), our data suggest that such estimates may be biased (relative to the run at large) if transportation history is not considered in the estimation process. This is because a smaller proportion of PIT tagged fish were actually transported than that for the run-at-large.

We document a clear in-river, upstream-migrant mortality effect resulting from different juvenile outmigration experiences. We intend to further explore these results, their implications, as well as perform additional supporting analyses for future reports. The consequences of increased straying or mortality due to transportation may also extend beyond the Snake River hatchery and wild populations in these analyses. For instance, the high proportion of out-of ESU steelhead spawners (including Snake River) has been identified as a constraint to viability of Mid-Columbia steelhead (OR recovery planning documents). The CSS data and evaluations can be used to evaluate the extent to which transportation management contributes to straying for out-of-basin ESU fish.

This difference in upstream migrant mortality between different juvenile outmigration routes was not apparent upstream of the hydrosystem, based on relative proportions of detected adults at the hatcheries. Obtaining absolute survival estimates from LGR to the hatcheries has been problematic, due in part to difficulties in accounting for fish which may stray or spawn below the hatchery racks, uncertainties in harvest accounting, and possible issues with tag loss or detection inefficiencies at the hatchery racks. These accounting issues are beyond the present scope of the CSS, but may be addressed in the future in locations with intensive spawning ground surveys and with future directed studies.

The CSS transportation evaluations based on LGR smolts and LGR adults appear to reasonably describe the relative performance of transported and in-river migrants, based on our finding of no apparent survival difference upstream of the hydrosystem. This result should continue to be tested in future CSS evaluations.

Chapter 7

Simulation Studies to Evaluate Adequacy of Coverage of Bootstrap Confidence Intervals used with SARs, TIRs, and Ds and Assess Impacts on these Parameters of Assumption Violations in CJS Estimation of Survival Rate and Collection Probability.

Introduction

Through a series of simulations, we will investigate the impact that violations of key assumptions of the Cormack-Jolly-Seber (CJS) may have on our ability to obtain accurate estimates of reach survival rates and other study parameters. In particular, the simulations will directly address the assumptions that “all fish in a release group have equal detection and survival probabilities” (within the same river reach or at the same dam) and “previous detections have no influence on subsequent survival or detection probabilities” (*i.e.*, no downstream difference due to whether fish was collected and bypassed as opposed to passed undetected in spill or turbines). These are assumptions #2 and #5, respectively, presented in Appendix C. The computational formulas and their expectations for each parameter of interest will be compared with the simulated “true” values of those parameters.

In the first set of simulations (SIM-1), the emphasis was on the population characteristics of survival rates and collection probabilities that could change over time at the dams where transportation was taking place, thus violating the mark-recapture Assumption #2 above. These are parameters that will affect how many smolts are estimated within each of the CSS’s three study categories (detected and transported, detected and bypassed, or undetected at the Snake River collector dams) and thus affect the SARs, TIR, and *D* estimation.

A new capability completed in early 2007 allows multiple simulated datasets (*i.e.*, replicates) to be created from the characteristics of a single population. For each of the SIM-1 scenarios (twelve in total) investigated, there were 1000 independent datasets created (*i.e.*, 1000 replicates) to produce the distribution of “true” parameter values possible for that specific underlying population. Four of these independent datasets (run #’s 100, 200, 900, and 1000) were then inputted to the bootstrap program and another 1000 bootstrap estimates of study parameters were computed. For each parameter of interest, the width of the 90% confidence intervals obtained from the bootstrap program was compared to the width of the middle 90% of the distribution of “true” parameter estimates. The allowed us to determine whether the confidence intervals created by the bootstrapping program for the various survival rate parameters and combinations of these parameters presented in the CSS closely approximate the nominal coverage around the point estimate of interest.

In the second set of simulations (SIM-2), the effects of detection history-dependent survival rates are explored. An additional outcome of this set of simulations will be an assessment of how best to estimate the numbers of smolts in each of the CSS’s three study categories when applying the NPT approach of splitting releases into two pre-assigned groups – one to reflected the experience of the untagged run-at-large, and the other to provide reach survival estimates. The NPT approach was adopted in 2006 for the CSS, whereas in all prior years, the assignment to in-river and transported fish has occurred following arrival and disposition at the Snake River collector dams.

Methods

Simulator program overview

The simulator program described in Chapter 10 of the 2006 CSS Annual Report is used to generate data sets of fish capture history that could originate from an underlying population of fish migrating through the hydrosystem. The migrational characteristics of the fish populations are set for each simulation run – these cover survival rate to LGR, LGR arrival distribution timing and shape, survival rates and travel time distributions through successive dams, probabilities for collection efficiency and removal of collected fish for transportation, and SARs by study group. In the simulations completed for this report, survival rates to LGR and from MCN to TWX followed the default inputs from the 2006 CSS Annual Report, as did the collection probabilities at JDA, BON, and TWX and all travel time distributions.

Each run of the simulator program creates a single population of tagged fish that moves through the hydrosystem experiencing “user defined” changing patterns of survivability and collectability over the migration season. The simulator program accounts for travel time and temporal spread of the passage distributions of migrating fish as they move thorough the hydrosystem in order to reflect how real fish pass the monitored dams. Capture history codes are created as these fish are split between undetected, detected and bypassed, or detected and transported routes of passage at these dams. The resulting simulated population of fish with associated capture history codes may then be run through the bootstrap program to obtain the CJS reach survival estimates. Estimates of reach survival rates between LGR and LMN are used in expanding study category smolt numbers to LGR-equivalents. Estimates of in-river survival rates between LGR and BON are used in calculating the S_R term in the computation of D.

There are seven input screens to the simulator program to establish the migrational characteristics to be modeled for a particular population. Initially, the screens contain a default set of input parameter values that were calibrated to reflect conditions seen with real data of past years (particularly smolt migration year 2000). The input screens and default values are illustrated in figures 43 to 49 of Chapter 6 in the 2006 CSS Annual Report.

In the second input screen, there are parameters that define the midpoint and breadth of the Gaussian Distributed (*Normal*) arrival population of smolts in LGR forebay. This spreads the population of smolts over a span of time similar to that observed historically for wild Chinook at LGR. On this screen and the subsequent six screens, there are parameters to describe the travel time for smolts to migrate between successive dams where PIT-tag detectors are present. At these dams, there are parameters to describe an expected daily collection efficiency that may (or may not) change over time as defined by the analyst. In the river reaches between dams where PIT-tag detectors are located, there are parameters to describe an expected daily survival rate that may (or may not) change over time also. Smolt travel time, collection efficiency, and reach survival all may change across the days of the migration season to reflect “real-life” situations where smolt travel time decreases as the season progress (e.g., fish may migrate faster as their physiological smoltification development advances over time), collection efficiency decreases as flows and spill levels increase during the peak of the annual freshet, and reach survival rates decrease as one moves further from the peak of the migration distribution. The simulator program allows the analyst to vary the amount of change by adjusting slopes of the linear and quadratic terms in each relation. The resulting values for travel time estimates are then fed into a gamma distribution while the collection efficiency and reach survival rates are fed into a binomial distribution.

Additional day-to-day variability (natural noise) may be added by allowing the probability term of the binomial distribution to vary as a beta distributed term. Therefore, the analyst has the option to use beta-binomial or simple binomial distributed probabilities of collection efficiency or survival rates (this is also true of the removal probabilities at each dam). The set of daily varying parameters is applied to the pool of smolts that have arrived in the forebay of a specific dam on a specific day. The smolts arriving on a specific day at an upstream site and continuing in-river to the next site will have their passage timing at the next downstream site spread out based on their travel times, but up to a maximum width of 10 days (analyst may specify a lower width). For the fish arriving in the forebay of a particular dam on a specific day, random draws based on the outcome from the collection efficiency curve on that day will determine which fish are collected at that site and which fish pass undetected. For this dam's collected fish on that given day, random draws based of the outcome of the removal probability determination for that day will determine which smolts are removed for transportation or bypassed back-to-river.

As fish are moving downstream through the hydrosystem, they are assigned a capture-history code based on their outcome at each dam. Once they pass the trawl site, they have all the required digits in their capture-history code to define how they passed through the system, or died in route. The total number of fish released, each with their associated capture-history code, become the input dataset for the bootstrap program for evaluation of questions regarding the robustness of the CJS survival rate estimates under conditions of changing survivability and collect-ability.

Input for Simulation-1

The default input values for creating the simulated dataset of SIM-1 are presented next, followed by the changes made in input values for the 12 scenarios being evaluated.

Inputs with default values that will not changed throughout Simulation 1:

Simulated migration year = 2000
Release number = 32,000
Survival to LGR (S_1) = 0.95
Migration state date = 03/22/2000 and stop date = 06/30/2000 at LGR
Expected midpoint of distribution of smolts arriving LGR = 50 reflecting 05/10/2000 and std dev = 1.1
Expected Std Dev of distribution of smolts arriving LGR=8.8 and stochastic draw Std Dev factor =100
Beta parameter for Gamma distribution describing all travel times = 0.85
Std Dev for all stochastic daily travel time from random normal draw = 0.10
Width of date range for all travel time distributions =10
Expected travel time from LGR to LGS (parabolic) = $3.5 – 0.070*day + 0.00069*day^2$
Expected travel time from LGS to LMN (parabolic) = $5.0 – 0.095*day + 0.00094*day^2$
Expected travel time from LMN to MCN (parabolic)= $6.5 – 0.120*day + 0.00119*day^2$
Expected travel time from MCN to JDA (parabolic) = $8.0 – 0.145*day + 0.00144*day^2$
Expected travel time from JDA to BON (parabolic) = $8.0 – 0.145*day + 0.00144*day^2$
Expected travel time from BON to TWX (parabolic)= $8.0 – 0.150*day + 0.00015*day^2$
Adult Parameters SAR(C_1) = SAR(C_0) = SAR(T_0) = 0.03 and Std Dev =0

Expected juvenile detection probability Coef of Var = 0.20 at all dams
Expected survival Std Dev = 0.05 at all inter-dam reaches
Expected detection probability parameters at JDA (parabolic)
$P6 = 0.50 - 0.0100*(day) + 0.000100*day^2$
Expected detection probability parameters at BON (parabolic)
$P7 = 0.35 - 0.0045*(day) + 0.000045*day^2$
Expected survival from JDA to BON (parabolic)
$S6 = 0.65 + 0.0100*(day) - 0.0000990*day^2$
Collection at the trawler (includes survival BON to TWX) = 0.10 and Coef of Var=0
Std Dev for all mean removal probabilities = 0
Mean removal probabilities all dams except X1 (LGR), X01 (LGS), X001 (LMN) = 0
Mean removal probabilities collector dams X1 = X01 = X001 = 0.667

Inputs with default values that will change in various scenarios of Simulation 1:

Expected detection probability parameters at LGR (parabolic)
$P2 = 0.70 - 0.0120*(day) + 0.0001188*day^2$
Expected detection probability parameters at LGS (parabolic)
$P3 = 0.70 - 0.0120*(day) + 0.0001188*day^2$
Expected detection probability parameters at LMN (parabolic)
$P4 = 0.60 - 0.0075*(day) + 0.0000740*day^2$
Expected detection probability parameters at MCN (parabolic)
$P5 = 0.70 - 0.0140*(day) + 0.0001380*day^2$
Expected survival from LGR to LGS (parabolic)
$S2 = 0.80 + 0.0057*(day) - 0.0000564*day^2$
Expected survival from LGS to LMN (parabolic)
$S3 = 0.80 + 0.0057*(day) - 0.0000560*day^2$
Expected survival from LMN to MCN (parabolic)
$S4 = 0.65 + 0.0100*(day) - 0.0000990*day^2$
Expected survival from MCN to JDA (parabolic)
$S5 = 0.65 + 0.0100*(day) - 0.0000990*day^2$

Different set of input values used in each of the 12 scenarios of Simulation 1:

#1: Scenario Run-13mar: Uses default P2 to P5 and S2 to S5

#2: Scenario Run-19mar: Uses a constant "true" resulting from default runs
$P2= 0.406$ $S2= 0.934$
$P3= 0.402$ $S3= 0.913$
$P4= 0.414$ $S4= 0.900$
$P5= 0.353$ $S5= 0.889$

#3: Scenario Run-20mar: collection prob. decreasing linearly
$P2= 0.6514 - 0.006*(day)$ S2= default
$P3= 0.6514 - 0.006*(day)$ S3= default
$P4= 0.6514 - 0.006*(day)$ S4= default
$P5= 0.6053 - 0.006*(day)$ S5= default

#4: Scenario Run-21mar: collection prob. decreasing linearly & survival rate increasing linearly

P2= 0.650 – 0.006*(day) S2= 0.55 + 0.005*(day)
P3= 0.650 – 0.006*(day) S3= 0.55 + 0.005*(day)
P4= 0.650 – 0.006*(day) S4= 0.50 + 0.005*(day)
P5= 0.605 – 0.006*(day) S5= default

#5: Scenario Run-23mar: collection prob. & survival rate both decreasing linearly

P2= 0.650 – 0.006*(day) S2= 1.10 – 0.005*(day)
P3= 0.650 – 0.006*(day) S3= 1.10 – 0.005*(day)
P4= 0.650 – 0.006*(day) S4= 1.05 – 0.005*(day)
P5= 0.605 – 0.006*(day) S5= default

#6: Scenario Run-22mar: survival rate increasing linearly

P2= default S2= 0.55 + 0.005*(day)
P3= default S3= 0.55 + 0.005*(day)
P4= default S4= 0.50 + 0.005*(day)
P5= default S5= default

#7: Scenario Run-25mar: survival rate decreasing linearly

P2= default S2= 1.10 – 0.005*(day)
P3= default S3= 1.10 – 0.005*(day)
P4= default S4= 1.05 – 0.005*(day)
P5= default S5= default

#8: Scenario Run-27mar: collection prob. increasing linearly

P2= 0.065 + 0.006*(day) S2= default
P3= 0.065 + 0.006*(day) S3= default
P4= 0.065 + 0.006*(day) S4= default
P5= 0.050 + 0.006*(day) S5= default

#9: Scenario Run-24mar: collection prob & survival rate both increasing linearly

P2= 0.065 + 0.006*(day) S2= 0.55 + 0.005*(day)
P3= 0.065 + 0.006*(day) S3= 0.55 + 0.005*(day)
P4= 0.065 + 0.006*(day) S4= 0.50 + 0.005*(day)
P5= 0.050 + 0.006*(day) S5= default

#10: Scenario Run-26mar: collection prob. increasing linearly & survival rate decreasing linearly

P2= 0.065 + 0.006*(day) S2= 1.10 – 0.005*(day)
P3= 0.065 + 0.006*(day) S3= 1.10 – 0.005*(day)
P4= 0.065 + 0.006*(day) S4= 1.05 – 0.005*(day)
P5= 0.050 + 0.006*(day) S5= default

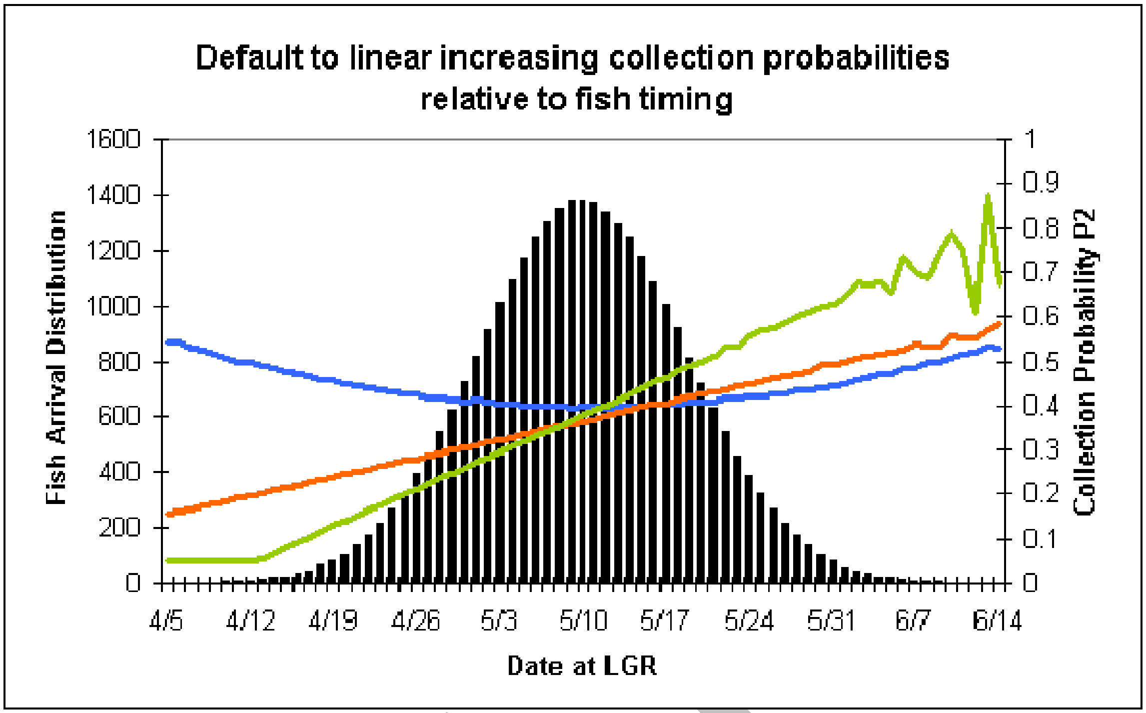
#11: Scenario Run-01aprr: collection prob. & survival rate both increasing steeper linearly
P2= –0.220 + 0.006*(day) S2= 0.33 + 0.005*(day)
P3= –0.220 + 0.006*(day) S3= 0.33 + 0.005*(day)
P4= –0.220 + 0.006*(day) S4= 0.28 + 0.005*(day)
P5= –0.270 + 0.006*(day) S5= default

#12: Scenario Run-31mar: collection prob. & survival rate both decreasing steeper linearly
P2= 0.980 – 0.012*(day) S2= 1.33 – 0.010*(day)
P3= 0.980 – 0.012*(day) S3= 1.33 – 0.010*(day)
P4= 0.980 – 0.012*(day) S4= 1.28 – 0.010*(day)
P5= 0.930 – 0.012*(day) S5=default

In scenarios #3 to #12, any changes from the default in collection probability and/or survival rates are to a linear trend. Early in these simulations, it was observed that the use of a parabola limited the user's ability to make any substantial changes over time due to its symmetrical nature. Effectively the default parabola inputs produce relatively flat parameter values over the range of dates in the middle 80% of each dams simulated passage distribution. Figures 7.1 to 7.2 (***in prep***) show the default parabolas and linear increasing and decreasing trends in survival rates and collection probabilities over time simulated at LGR with population distribution of fish arriving there. These figures illustrate the level of changes being covered in the 12 simulation scenarios.

Input for Simulation-2

For the SIM-2 scenarios, we shift from evaluating impacts caused when collection probabilities and/or survival rates change over time in the reaches between LGR and MCN to evaluating impacts on reach survival rates caused by how the fish passed the Snake River collector dams (LGR, LGS, and LMN). Although the simulator program was not designed to directly evaluate this situation, it is possible to indirectly investigate the impacts caused when fish detected and bypassed at the three Snake River collector dams have different subsequent reach survival rates than those fish passing these dams undetected through a combination of spill and turbine routes passage. In this simulation, we are creating two populations with different survival rates in S_2 (LGR to LGS), S_3 (LGS to LMN) and S_4 (LMN to MCN) caused by differences in the passage experience of their fish. By combining these two populations together as if they were a single population satisfying Assumption #2 that "all fish in a release group have equal detection and survival probabilities" and Assumption #5 that "previous detections have no influence on subsequent survival or detection probabilities," we investigate impacts of violations of these assumptions on the CJS survival rate estimation and subsequent CSS parameters.



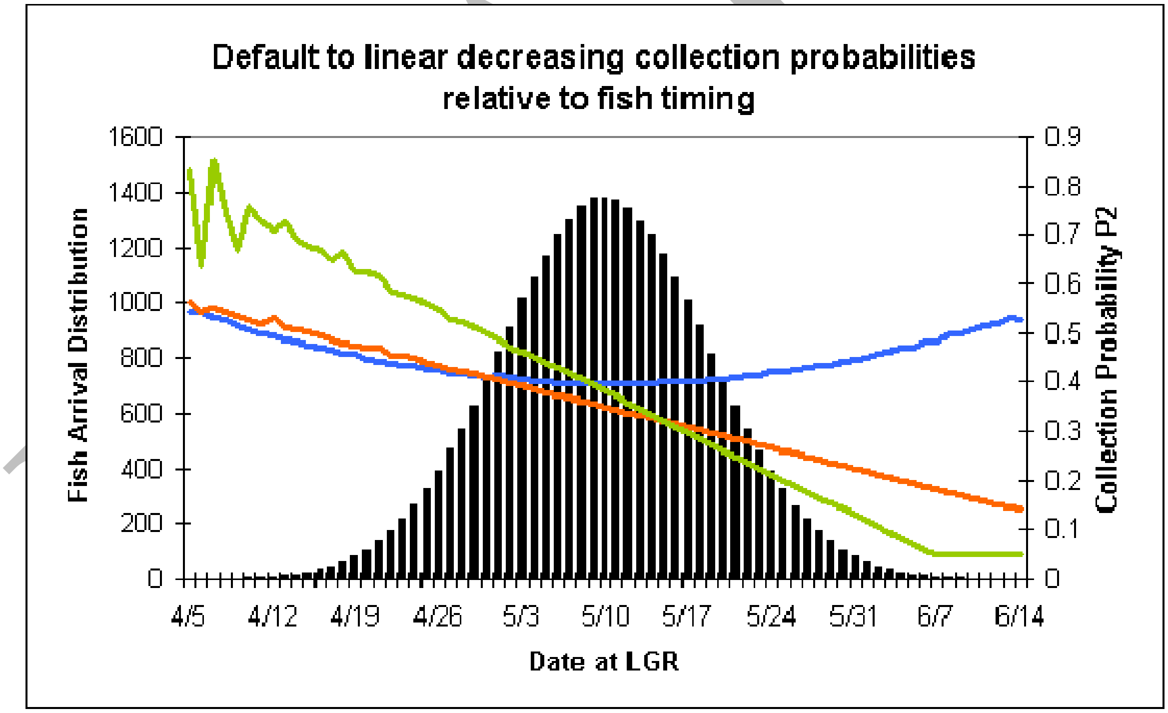
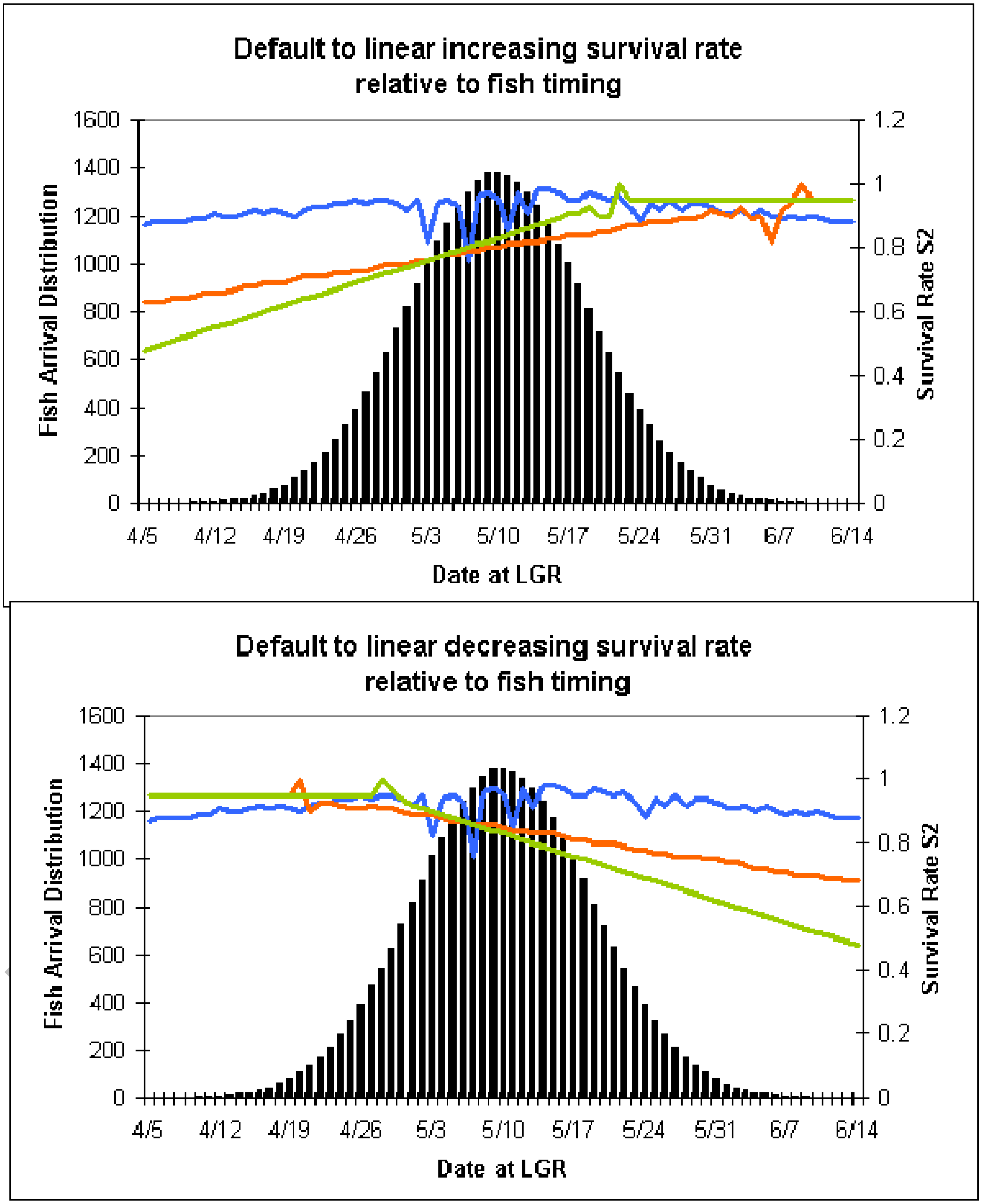


Figure 7.1. Default collection probability parabola compared to linear trend of increasing (top plot) and decreasing (bottom plot) collection probabilities used in Simulation-1 scenarios. These plots show fish timing at LGR and collection probability at that dam; however, the linear trend lines are similar at LGS and LMN and shifted slightly lower at MCN. The corresponding fish timing distributions will shift later at these downstream dams as a function of fish travel time.


Default to linear increasing survival rate relative to fish timing

Default to linear decreasing survival rate relative to fish timing

Figure 7-2. Default survival rate parabola compared to linear trend of increasing (top plot) and decreasing (bottom plot) survival rates used in Simulation-1 scenarios. These plots show fish timing at LGR and survival rates from LGR to LGS; however, the linear trend lines are similar for the LGS to LMN reach and shifted slightly lower for the LMN to MCN reach. The corresponding fish timing distributions will shift later at these downstream dams as a function of fish travel time.

Our approach utilizes the concept of pre-assigning tagged fish to two groups whereby one group (called Group T) is 100% transported if collected and the other (called Group R) is 100% bypassed if collected. The Group R's migrants include fish passing through bypasses, spill, and/or turbines and Group T's in-river migrants include only fish passing through spill and/or turbines. If we assume that fish spilled have a higher survival in the next reach than fish bypassed and those passing through turbines have the lowest survival in the next reach, then we have two conditions to evaluate in terms of impact due to violation of CJS model assumptions when Groups R and T are combined to create a single population. The first condition is when most undetected fish are passing through spill, resulting in Group T's in-river survival rates S_2, S_3 and S_4 being higher than those of Group R (run "R-lower"). The second condition is when most undetected fish are passing through turbines, resulting in Group T's in-river survival rates S_2, S_3 and S_4 being lower than those of Group R (run "R-higher").

Most inputs for SIM-2 are the same default inputs shown earlier for SIM-1 (including the "not change" and "will change" lists) with inputs having a change being limited to release numbers, SARs by study category, removal probabilities for X1, X01, and X001, and reach survival rates S_2, S_3 and S_4 (the expected survival Std Dev = 0 in cases with asterisks). The SARs were set at 0.03 for T_0, 0.02 for C_0, and 0.01 for C_1 in all Simulator-2 runs. Inputs for the removal probabilities and reach survival rates by group:

Inputs	Group T	Group R-lower	Group R-higher
Release #	32,000	16,000	16,000
S_2	0.900	0.850	0.950^*
S_3	0.950	0.925	0.975^*
S_4	0.800	0.700	0.900
Rem_X1	1	0	0
Rem_X01	1	0	0
Rem_X001	1	0	0

The "true" values for the parameters of reach survival rates and collection probabilities are obtained by running the simulator program separately for each group, and then combining components to obtain the "true" parameter values for the combined group. Estimating reach survivals with the CJS method is possible with the R groups and combined groups, but not with Group T. Of interest when using the NPT approach of pre-assigned groups is knowledge of the extent to which violations of assumptions #2 and #5 could impact the partitioning of a combined group of R and T fish into components of T_0 and C_0 smolt numbers, which are needed in the TIR and *D* parameter estimations.

Results and Discussion

Simulation-1

Investigating potential bias in CJS-based estimates due to across-season aggregation

The primary parameters of interest in the CSS are smolt-to-adult survival rates (SARs) for fish migrating through the hydrosystem under different conditions, as well as ratios of these SARs (termed TIR) and a measure of delayed differential mortality between transported and in-river migrants (termed *D*). Key to obtaining valid estimates of SARs, TIRs and *D* is having available reliable estimates of survival rates and collection probabilities, which are integral components in the estimation of the above parameters. Survival rates and collection probabilities are estimated using the CJS model, which has a set of assumptions necessary for obtaining valid estimates. In Simulation-1, we are investigating the impacts of time-varying survival rates and collection probabilities. When either survival rates or collection probabilities or both are changing over time, and a single population parameter is to be estimated within reaches and at dams of interest, then Assumption #2 (equality of survival rates and collection probabilities for the group of tagged individuals) of the CJS model is violated. But it is not clear how estimation of the three parameters list above is affected.

In this first series of simulations (Simulation-1), we will be causing temporal changes. Based on tallies of smolts in the forebays, tallies of collected fish removed for transportation, and remaining fish in the tailraces of each dam, we will obtain the average "true" value for survival rates and collection probabilities for each reach and dam between time of release and passage at Bonneville Dam for the population as a whole, given the simulated variation in underlying survival rates and collection probabilities. We assume all fish are distributed with identical probabilities of survival and collection on a given day at a given location, but that these probabilities may vary in a controlled manner across each day of passage. A total of twelve scenarios are run including two base-case scenarios with no or minimal change allowed over time, four scenarios with either survival rates or collection probabilities allowed to change separately, and six scenarios with both survival rates and collection probabilities allowed to change together.

Integral to each of the three parameters (SARs, TIRs, and *D*) are estimates of the number of tagged smolts in each of the categories the CSS creates to reflect the migrational characteristics of the population. These categories are: 1) fish transported (Group T_0); 2) fish migrating in-river with at least one detection in a bypass at a Snake River collector dam (Group C_1); and 3) fish migrating in-river with no detections at any of the three Snake River collector dams (Group C_0). From the tallies of smolts in the tailrace of LMN with particular capture histories, we obtain "true" counts of smolts reaching the tailrace of LMN that belong to each of groups C_0 and C_1. Dividing the survivors of each group by the "true" reach survival rates, S_2S_3, from LGR to LMN, we convert these counts to their respective "true" smolt number in LGR-equivalents. Likewise, the sum of expanded capture histories $X_{12}+X_{102}/S_2+X_{1002}/(S_2S_3)$ will give the "true" number of transported smolts in LGR-equivalents. In most years covered in the CSS, the tagged fish in groups T_0 and C_0 closely reflect the experience of the untagged run-at-large. Incorporating the "true" smolt numbers for these two groups into their respective SARs, TIR (ratio of $sarT_0/sarC_0$) and *D* (computed as $TIR \cdot [S_R/S_T]$) provide "true" values for these parameters also.

As shown in Appendix B, the estimates of number of smolts in each study category may be computed by one of two equations. The first equations are considered the standard computational formulas; they use the observational data from the first row of the reduced M-matrix (the m_{12}, m_{13}, and m_{14}) for inriver migrants and the specific capture histories X_{12}, X_{102}, and X_{1002} for transported migrants in order to compute estimated numbers of smolts in each study category in LGR-equivalents. The second equations are considered the expectations to these computation equations since they apply the parameter estimates of survival rates and collection probabilities to arrive at the expected numbers of $E(m_{12})$, $E(m_{13})$, $E(m_{14})$, $E(X_{12})$, $E(X_{102})$, and $E(X_{1002})$, which in turn are used to estimated the expected number of smolts in each study category. In the simulations, we allowed removals at LGR, LGS, and LMN for purposes of transportation only, and no removals at any other sites. Therefore, the d_0 and d_0 components in Appendix B equations 15 and 16 were both zero. The survival rates and collection probabilities were estimated with the CJS equations as illustrated in Appendix B Figure 1. In order not to confuse the "true" survival rates and CJS estimated survival rates, we will reserve an upper case italic "S_J" for "true" values and use a lower case (non-italic) "s_J" for CJS estimated values. The following collection probabilities "p_J" are also CJS estimated values. The formulas used in the simulations for the respective numbers of smolts estimated in each study category are:

$$\text{Group } C_0 = R_1s_1 - (m_{12} + m_{13}/s_2 + m_{14}/s_2s_3) \qquad [7.1]$$

$$C_0 = R_1s_1 \cdot (1-p_2) \cdot (1-p_3) \cdot (1-p_4)$$

$$\text{Group } T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2s_3 \qquad [7.2]$$

$$T_0 = R_1s_1 \cdot p_2 \cdot (X_{12}/m_{12}) + R_1s_1 \cdot (1-p_2) \cdot p_3 \cdot (X_{13}/m_{13}) + R_1s_1 \cdot (1-p_2) \cdot (1-p_3) \cdot p_4 \cdot (X_{14}/m_{14})$$

$$\text{Group } C_1 = (m_{12} - X_{12}) + (m_{13} - X_{102})/s_2 + (m_{14} - X_{1002})/s_2s_3 \qquad [7.3]$$

$$C_1 = R_1s_1 \cdot p_2 \cdot (1-X_{12}/m_{12}) + R_1s_1 \cdot (1-p_2) \cdot p_3 \cdot (1-X_{12}/m_{12}) + R_1s_1 \cdot (1-p_2) \cdot (1-p_3) \cdot p_4 \cdot (1-X_{12}/m_{12})$$

Table 7.1 shows that in all but the most severely changing smolt survival rate and collection conditions simulated, the differences between the average smolt number estimates based on the computational formulas and the averages based on the expectation formula were ½ of 1% or less. The values present in Table 7.1 to 7.4 for each simulation scenario are averages of the distribution of 1000 data points that were simulated from a specific population condition. In simulation runs with either seasonally decreasing or increasing collection probabilities, Table 7.1 shows CJS-based estimates of smolt numbers are slightly higher for Group C_0 and slightly lower for groups C_1 and T_0 when using computational formulas instead of their expectations. These differences were greater for Group C_0. These patterns had also been observed with the "real" data for wild and hatchery Chinook and steelhead and may be indicative of the effect of changing collection efficiencies that occur in the hydrosystem (Figure ___ [*in prep*] illustrates these patterns at LGR). Because only minor differences exist between the CJS-based estimates of smolt numbers obtained with the computational and expectation formulas, the remaining tables will concentrate on smolt numbers obtained with the computational formulas for reasons that will become apparent in the next paragraph.

Table 7.1. Comparing smolt numbers estimated for each study category with the computational and expectation formulas under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. Smolt numbers are averages from the distribution of 1000 simulated data sets.

Run #	Test Condition[1]	C_0 (CJS)	EC_0 (CJS)	Relative Diff. [2]	C_1 (CJS)	EC_1 (CJS)	Relative Diff. [2]	T_0 (CJS)	ET_0 (CJS)	Relative Diff. [2]
13mar	default_PS	6,309	6,310	-0.02 %	8,021	8,021	0.00 %	16,078	16,078	0.00 %
19mar	constant_PS	6,356	6,363	-0.11 %	7,998	7,996	0.03 %	16,031	16,027	0.02 %
25mar	default_P+decr_S	6,294	6,299	-0.08 %	8,029	8,028	0.01 %	16,079	16,076	0.02 %
26mar	incr_P+decr_S	7,988	7,935	0.67 %	7,507	7,524	-0.23 %	15,032	15,067	-0.23 %
27mar	incr_P+default_S	7,657	7,616	0.54 %	7,495	7,509	-0.19 %	15,014	15,041	-0.18 %
24mar	incr_P+incr_S	7,189	7,171	0.25 %	7,482	7,488	-0.08 %	14,997	15,008	-0.07 %
01apr	incr_PS_steep	5,719	5,618	1.80 %	7,504	7,537	-0.44 %	15,041	15,108	-0.44 %
22mar	default_P+incr_S	6,257	6,263	-0.10 %	8,024	8,022	0.02 %	16,071	16,067	0.02 %
21mar	decr_P+ incr_S	8,824	8,779	0.51 %	7,212	7,227	-0.21 %	14,464	14,494	-0.21 %
20mar	decr_P+default_S	8,391	8,352	0.47 %	7,242	7,255	-0.18 %	14,516	14,542	-0.18 %
23mar	decr_P+decr_S	8,037	8,013	0.30 %	7,223	7,231	-0.11 %	14,473	14,489	-0.11 %
31mar	decr_PS_steep	6,036	5,945	1.53 %	7,383	7,413	-0.40 %	14,777	14,838	-0.41 %

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Difference between computation formula value and expected value divided by expected value.

The CJS estimated smolt numbers for Group C_0 differ more from the "true" values than do those for groups C_1 and T_0 (Table 7.2). The direction of these differences when collection probabilities are increasing or decreasing over time is toward a CJS-based estimate of smolts numbers in Group C_0 that is lower than the "true" value. As previously shown in Table 7.1, the smolt number estimates for Group C_0 were higher using the computation formula than expectation formula. Therefore, under the conditions covered in Simulation-1, using the computational formulas produce closer agreement of Group C_0 smolt numbers to the "true" values than would occurred if using the expectation formulas. Since both the computational and expectation formulas give close estimates of smolt numbers for either Group C_1 or Group T_0, the overall use of the computational formulas for all study groups is preferred.

Two interesting patterns are illustrated in Table 7.2. First, estimated smolt numbers appear to diverge more from "true" values when collection probability changes over time than when survival rate changes. When a default collection probability case is combined with survival rates that are either linearly increasing or decreasing, the absolute differences between the CJS-based estimates of smolt numbers and the "true" values were negligible (0.3% or less). But when a default survival rate case is combined with collection probabilities that are either linearly increasing or decreasing, the absolute differences between the CJS-based estimates of smolt numbers and the "true" values increased from 0.1% to 0.3% for groups C_1 and T_0 and from 0.3% to 2.1-2.6% for Group C_0 (2.1-2.6%).

Second, when the linear changes in collection efficiency and survival rates are in opposite directions, there appears to be a dampening effect on the difference between the CJS-based estimates and "true" smolt numbers for Group C_0, resulting in less of a difference than occurred when even the default survival rate case was used. When both collection probabilities and survival rates changed in the same linear direction, the CJS-based estimates were 5.5 to 6.3% lower than the "true" smolt numbers for Group C_0. When the steepness of the slopes was doubled and maintained in the same direction for collection probabilities and survival rates, the impact was greatly increased to around a 20% difference in the CJS-based estimates of smolt numbers from "true" values. Under these extreme conditions, CJS-based estimates of smolt numbers for both groups C_1 and T_0 were also reduced from the "true" values, but to a less extent (decreasing to around 6% for Group C_1 and less than 2% for Group T_0). In real situations, we do not expect linear trends as extreme as modeled here, and so this latter conditions may be viewed as a maximum boundary for assessing impacts of differences in estimated smolt numbers from "true" values on the key parameters of SARs, TIR, and *D*.

Table 7.2. Comparing estimated smolt numbers (computational equations) for each study category with the "true" simulated values under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. Smolt numbers are averages from distribution of 1000 simulated data sets.

Run #	Test Condition[1]	True C_0	C_0 (CJS)	Relative diff. frm "true" [2]	True C_1	C_1 (CJS)	Relative diff. frm "true" [2]	True T_0	T_0 (CJS)	Relative diff. frm "true" [2]
13mar	default_PS	6,280	6,309	0.5 %	8,028	8,021	-0.1 %	16,089	16,078	-0.1 %
19mar	constant_PS	6,334	6,356	0.4 %	8,013	7,998	-0.2 %	16,051	16,031	-0.1 %
25mar	default_P+decr_S	6,275	6,294	0.3 %	8,036	8,029	-0.1 %	16,087	16,079	-0.1 %
26mar	incr_P+decr_S	7,969	7,988	0.2 %	7,413	7,507	1.3 %	15,022	15,032	0.1 %
27mar	incr_P+default_S	7,823	7,657	-2.1%	7,519	7,495	-0.3 %	15,057	15,014	-0.3 %
24mar	incr_P+incr_S	7,669	7,189	-6.3%	7,638	7,482	-2.0 %	15,092	14,997	-0.6 %
01apr	incr_PS_steep	7,080	5,719	-19.2%	7,992	7,504	-6.1 %	15,325	15,041	-1.9 %
22mar	default_P+incr_S	6,275	6,257	-0.3 %	8,036	8,024	-0.2 %	16,084	16,071	-0.1 %
21mar	decr_P+ incr_S	8,839	8,824	-0.2 %	7,110	7,212	1.4 %	14,445	14,464	0.1 %
20mar	decr_P+default_S	8,611	8,391	-2.6 %	7,254	7,242	-0.2 %	14,533	14,516	-0.1 %
23mar	decr_P+decr_S	8,506	8,037	-5.5 %	7,353	7,223	-1.8 %	14,540	14,473	-0.5 %
31mar	decr_PS_steep	7,555	6,036	-20.1 %	7,853	7,383	-6.0 %	14,993	14,777	-1.4 %

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Difference between computation formula value and "true" value divided by "true" value.

Table 7.3 shows the average SAR of 1000 datasets for each study group for each simulation condition. In each simulation run, the number of adults for a study group was obtained by a binomial draw with binomial probability of $SAR_{LGR-LGR}$ set to 3% and n equal to the simulated "raw" number of smolts in each respective group. When smolt numbers are expanded to LGR-equivalents, the resulting SAR will vary across study groups and among the twelve simulation conditions due to that expansion. The SARs for Group C_0 will be lower than that of groups C_1 and T_0 because all undetected fish surviving to LMN tailrace need to be expanded to LGR-equivalents for Group C_0 while only first-time detected fish at LGS and LMN need this expansion (LGR detected fish are already there) for groups C_1 and T_0. Therefore, the comparisons of interest in Table 7.3 (and again later in Table 7.4) is limited to differences between the CJS-based estimate of SARs and the "true" value for each study group, and how these differences change across the 12 simulation scenarios.

Table 7.3. Comparing estimated SARs for each study category with the "true" simulated values under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. The SAR values are averages from the distribution of 1000 simulated data sets. Differences <= ± 0.0001 are considered trivial, and denoted with "=".

Run #	Test Condition[1]	True sar-C_0	sar-C_0 (CJS)	Relative diff. frm "true" [2]	True sar-C_1	sar-C_1 (CJS)	Relative diff. frm "true" [2]	True sar-T_0	sar-T_0 (CJS)	Relative diff. frm "true" [2]
13mar	default_PS	0.0260	0.0259	=	0.0287	0.0287	=	0.0286	0.0286	=
19mar	constant_PS	0.0254	0.0253	=	0.0285	0.0285	=	0.0285	0.0285	=
25mar	default_P+decr_S	0.0217	0.0216	=	0.0271	0.0272	=	0.0271	0.0272	=
26mar	incr_P+decr_S	0.0216	0.0215	=	0.0273	0.0269	-1.5%	0.0270	0.0269	=
27mar	incr_P+default_S	0.0259	0.0264	1.9%	0.0285	0.0286	=	0.0286	0.0286	=
24mar	incr_P+incr_S	0.0194	0.0207	6.7%	0.0257	0.0262	1.9%	0.0261	0.0262	=
01apr	incr_PS_steep	0.0206	0.0255	23.8%	0.0254	0.0270	6.3%	0.0266	0.0271	1.9%
22mar	default_P+incr_S	0.0196	0.0197	=	0.0262	0.0262	=	0.0262	0.0262	=
21mar	decr_P+ incr_S	0.0196	0.0197	=	0.0266	0.0262	-1.5%	0.0261	0.0261	=
20mar	decr_P+default_S	0.0260	0.0266	2.3%	0.0285	0.0286	=	0.0285	0.0286	=
23mar	decr_P+decr_S	0.0214	0.0227	6.1%	0.0266	0.0271	1.9%	0.0269	0.0270	=
31mar	decr_PS_steep	0.0199	0.0249	25.1%	0.0254	0.0270	6.3%	0.0265	0.0269	1.5%

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Difference between computation formula value and "true" value divided by "true" value.

Table 7.4 shows the average parameter values from the distribution of 1000 data points simulated for the parameters of TIR, S_R, and D under the conditions of each simulation run. The relative difference between CJS-based estimated TIR and "true" TIR followed a similar pattern over the 12 simulation scenarios as was observed previously for the SAR of Group C_0 alone. With TIR computed as SAR(T_0)/SAR(C_0) and little difference between CJS-based estimates of SAR(T_0) and the "true" values, it is not unexpected that the TIR parameter would track the pattern of SAR(C_0). Since the S_T fluctuate only over a small range (typically between 0.88 and 0.98), most of the influence upon the magnitude of the parameter D arises from its component parts TIR and S_R (*i.e.*, inriver survival rate within hydrosystem). Parameter S_R tends to follow a pattern different from parameter TIR across the 12 simulation runs. When CJS-based estimates of TIR showed little differences from "true" values, there were greater differences for S_R. When the estimated TIR showed larger differences from "true" values, then the estimated S_R also showed larger differences from the "true" values, but in the opposite directions. The resulting effect is CJS-based estimates of D that are closer to the "true" values than was observed for parameter TIR.

Table 7.4. Comparing estimated TIR (i.e., sarT$_0$/sarC$_0$), S_R (formerly V_C), and D values with the "true" simulated values under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. Parameter values shown are averages from the distribution of 1000 simulated data sets.

Run #	Test Condition[1]	True TIR	TIR (CJS)	Relative diff. frm "true" [2]	True S_R	S_R (CJS)	Relative diff. frm "true" [2]	True *D*	*D* (CJS)	Relative diff. frm "true" [2]
13mar	default_PS	1.109	1.115	0.5%	0.606	0.597	-1.5%	0.718	0.710	-1.1%
19mar	constant_PS	1.129	1.134	0.4%	0.597	0.589	-1.3%	0.724	0.716	-1.1%
25mar	default_P+decr_S	1.262	1.267	0.4%	0.445	0.441	-0.9%	0.634	0.632	-0.3%
26mar	incr_P+decr_S	1.256	1.258	0.2%	0.450	0.443	-1.6%	0.642	0.633	-1.4%
27mar	incr_P+default_S	1.110	1.090	-1.8%	0.608	0.607	-0.2%	0.723	0.706	-2.4%
24mar	incr_P+incr_S	1.352	1.275	-5.7%	0.391	0.402	2.8%	0.623	0.599	-3.9%
01apr	incr_PS_steep	1.298	1.069	-17.6%	0.441	0.494	12.0%	0.660	0.597	-9.5%
22mar	default_P+incr_S	1.349	1.347	-0.1%	0.395	0.392	-0.8%	0.621	0.615	-1.0%
21mar	decr_P+ incr_S	1.338	1.334	-0.3%	0.398	0.392	-1.5%	0.624	0.613	-1.8%
20mar	decr_P+default_S	1.105	1.078	-2.4%	0.603	0.606	0.5%	0.714	0.698	-2.2%
23mar	decr_P+decr_S	1.260	1.196	-5.1%	0.438	0.451	3.0%	0.629	0.611	-2.9%
31mar	decr_PS_steep	1.342	1.087	-19.0%	0.385	0.441	14.5%	0.596	0.546	-8.4%

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Difference between computation formula value and "true" value divided by "true" value.

Tables 7.1 to 7.4 have illustrated that under the range of changing survival rates and collection probabilities over time covered in Simulation-1, only under a condition more severe than expected in nature, would there exist major concerns of bias in CJS-based estimates of SARs for each study group and in estimates of the TIR, S_R, and *D* parameters. Under the simulated negative and positive linear slopes of 0.005 per day for survival rates and 0.006 per day for collection probabilities, the differences between CJS-based estimates of key parameters and their "true" values remain close with few simulated scenarios exceeding a 5% difference. These levels of changes are within the range of "real" yearling Chinook data as shown in Figures 7.4 and 7.5. The inter-relation between how these changes occur over time appears to influence how much bias in CJS-based estimated parameters may occur, with greater impact when both survival rates and collection probabilities change in the same direction over time. There appears to be a stronger impact caused by changes in collection probabilities than by changes in survival rates over time. Overall, the results of Simulation-1 provides evidence of the robustness of CJS estimates of survival rates and collection probabilities even when these parameters are changing over time, and thus robustness in estimates of SAR for each study group, TIR, S_R, and *D*, which utilize these CJS estimates in their derivation.

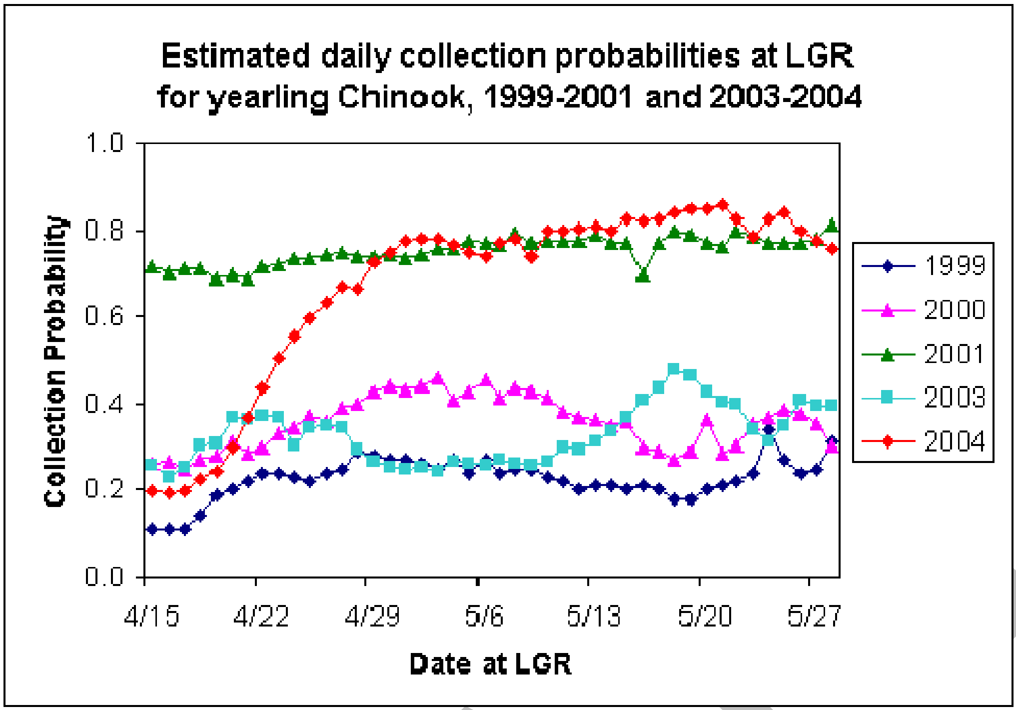


Figure 7.4. Estimated daily collection probabilities at LGR for combined PIT-tagged hatchery and wild Chinook originating above LGR based on detected fish at LGS for 5 migration years.

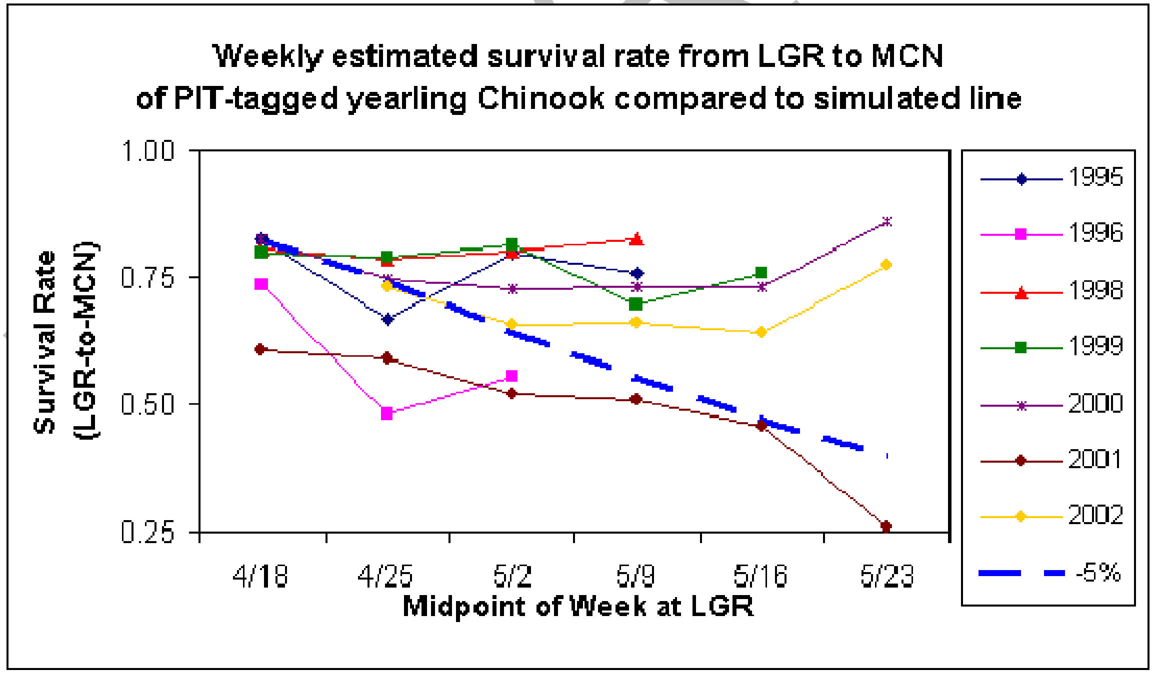


Figure 7.5. Estimated survival rates from LGR tailrace to MCN tailrace for combined PIT-tagged hatchery and wild Chinook originating above LGR or tagged and released at LGR during weekly intervals for 7 migration years. The blue dash line is the simulated linear 5% decrease for the LGR to LGS reach that has been expanded on a per mile basis to MCN.

Investigating the adequacy of coverage of bootstrapped non-parametric confidence intervals

Table 7.5 shows the non-parametric 90% confidence intervals around the actual “true” and CJS-based estimated population distributions of 1000 SARs computed for each study group. The averages of these distributions were previously shown in Table 7.3. The values of the lower and upper boundaries of the confidence intervals and the width between them remained nearly identical for the simulation runs where little change had been observed in the averages of CJS-based estimates of SARs and the “true” values. As these difference increased, there was a shifting to higher values of the lower and upper boundaries of the confidence intervals in Table 7.5 to correspond to the shift to higher averages observed in Table 7.3. Plus there was a widening of the 90% confidence interval as the differences in averages become greater.

Table 7.5. Comparing width of non-parametric 90% confidence intervals about the actual “true” and CJS estimated SARs for each study category from the distribution of 1000 simulated data sets for 12 runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized.

Run #	Test Condition[1]	S_J[2]	sar-C_0 90% CI			sar-C_1 90% CI			sar-T_0 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
13-mar	default_PS	True	0.0228	0.0293	0.0065	0.0259	0.0318	0.0059	0.0265	0.0308	0.0043
		Est.	0.0227	0.0293	0.0066	0.0258	0.0317	0.0059	0.0266	0.0308	0.0042
19-mar	constant_PS	True	0.0223	0.0285	0.0062	0.0255	0.0316	0.0061	0.0263	0.0307	0.0044
		Est.	0.0222	0.0285	0.0063	0.0255	0.0316	0.0061	0.0263	0.0308	0.0045
25-mar	default_P +decr_S	True	0.0188	0.0248	0.0060	0.0241	0.0301	0.0060	0.0250	0.0292	0.0042
		Est.	0.0185	0.0247	0.0062	0.0241	0.0301	0.0060	0.0250	0.0292	0.0042
26-mar	incr_P +decr_S	True	0.0190	0.0243	0.0053	0.0241	0.0304	0.0063	0.0248	0.0292	0.0044
		Est.	0.0189	0.0243	0.0054	0.0238	0.0301	0.0063	0.0248	0.0291	0.0043
27-mar	incr_P +default_S	True	0.0230	0.0288	0.0058	0.0254	0.0317	0.0063	0.0263	0.0310	0.0047
		Est.	0.0233	0.0296	0.0063	0.0254	0.0319	0.0065	0.0264	0.0311	0.0047
24-mar	incr_P +incr_S	True	0.0168	0.0221	0.0053	0.0227	0.0286	0.0059	0.0241	0.0283	0.0042
		Est.	0.0179	0.0237	0.0058	0.0231	0.0292	0.0061	0.0242	0.0285	0.0043
01-apr	incr_PS _steep	True	0.0180	0.0234	0.0054	0.0226	0.0282	0.0057	0.0246	0.0287	0.0041
		Est.	0.0221	0.0290	0.0069	0.0241	0.0300	0.0059	0.0250	0.0292	0.0042
22-mar	default_P +incr_S	True	0.0167	0.0227	0.0060	0.0234	0.0292	0.0058	0.0243	0.0283	0.0040
		Est.	0.0167	0.0227	0.0060	0.0234	0.0291	0.0057	0.0243	0.0284	0.0041
21-mar	decr_P + incr_S	True	0.0172	0.0221	0.0049	0.0235	0.0297	0.0062	0.0240	0.0283	0.0043
		Est.	0.0172	0.0222	0.0050	0.0232	0.0294	0.0062	0.0240	0.0282	0.0042
20-mar	decr_P +default_S	True	0.0232	0.0287	0.0056	0.0253	0.0319	0.0066	0.0262	0.0307	0.0045
		Est.	0.0236	0.0296	0.0060	0.0252	0.0319	0.0067	0.0262	0.0308	0.0046
23-mar	decr_P +decr_S	True	0.0188	0.0240	0.0052	0.0235	0.0297	0.0062	0.0246	0.0292	0.0046
		Est.	0.0199	0.0255	0.0056	0.0239	0.0302	0.0063	0.0247	0.0294	0.0047
31-mar	decr_PS _steep	True	0.0174	0.0227	0.0052	0.0225	0.0283	0.0058	0.0244	0.0287	0.0043
		Est.	0.0216	0.0285	0.0069	0.0239	0.0302	0.0063	0.0248	0.0291	0.0043

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] True denotes actual “true” average survival rates and Est. denotes CJS estimated “true” average survival rates were used when computing smolt numbers in LGR-equivalents for the respective SARs.

Table 7.6 shows the non-parametric 90% confidence intervals around the actual "true" and CJS-based estimated population distributions of 1000 TIRs, S_R's, and *D*s. The averages of these distributions were previously shown in Table 7.4. For parameter TIR, the values of the lower and upper boundaries of the confidence intervals and the width between them remained nearly identical for the simulation runs where little change had been observed in the averages of CJS-based estimates of TIRs and the "true" values. As these difference increased, then we see a shift to lower values of the lower and upper boundaries of the confidence intervals in Table 7.6 to correspond to the shift to lower averages observed in Table 7.4. Also we see a narrowing of the 90% confidence interval as the differences in averages become greater.

The parameter S_R differs from the other parameters in tables 7.5 and 7.6 in one important way. Its "true" value contains no sampling error as does the "true" values of the SAR, TIR, and *D* parameters. The sampling error for these later three parameters arises from the binomial random draws for number of adults to be used in each of the 1000 simulated data sets. Each data point in the distribution of 1000 simulated S_R values is simply the product of five reach survival rates. Each rate is determined by the tally of smolts in the tailrace of the upstream dam divided by the tally for fish in the tailrace of the downstream dam (including in the tally any transportation removals at the downstream site if present). In Table 7.6, we see that the "true" S_R confidence interval widths are 1/8th to 1/4th of the widths of the CJS estimated S_R confidence intervals. In all but the two simulation scenarios with the steepest slopes for changing survival rates and collection probabilities, the width of the CJS estimated S_R confidence intervals were large enough to allow coverage over both the lower and upper limits of the "true" S_R confidence interval. In two cases of steepest slopes, the lower limit of the CJS estimated S_R confidence interval failed to cover the "true" lower limit, but only by 0.015 percentage points or less.

As for parameter *D*, those impacts on the coverage of the "true" lower and upper boundaries of the 90% confidence interval for TIR and S_R carried over onto the coverage of its "true" confidence interval boundaries. The width of the CJS-based confidence intervals for parameter *D* was between 12 and 20 percent greater than that of the "true" width in the twelve simulation scenarios, and as in the case of TIRs, a narrowing of the 90% confidence interval occurred as the differences in averages become greater. In four of the twelve simulation scenarios, the CJS-based estimate of *Ds* upper limit failed to cover the upper limit of the "true" D, and again the impact was greatest in the two cases of steepest slopes, as was the case with the S_R parameter.

The bottom line of this comparison of the 90% confidence boundary of a population distribution created with CJS-based estimates of parameters and one that was created with the "true" values for parameters SARs, TIRs, S_R's, and *D*s is that the 90% confidence intervals of CJS-based parameter estimates will at least cover the boundaries of the "true" 90% confidence intervals in all but the most extreme (temporally changing survival rates and collection probabilities with steepest slopes) simulation runs. When using bootstrap subsampling to obtain non-parametric confidence intervals around each parameter of interest to the CSS, we are directly working with estimated survival rates and collection probabilities in the process of obtaining parameter estimates of SARs, TIR, S_R, and *D*. When the bootstrap 90% confidence intervals provide the same width of coverage as was observed in the 90% confidence intervals of CJS-based parameter estimates for a given population, then bootstrapping will be a reliable method of estimating 90% confidence intervals for the parameter of interest in that population.

Table 7.6. Comparing width of non-parametric 90% confidence intervals about the “true” TIR, S_R, and *D* values and CJS-based estimates of these parameters from the distribution of 1000 simulated data sets for 12 runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized.

Run #	Test Condition[1]	S_J [2]	TIR 90% CI			S_R 90% CI			*D* 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
13-		True	0.957	1.276	0.319	0.591	0.621	0.030	0.620	0.825	0.205
mar	default_PS	Est.	0.961	1.290	0.329	0.544	0.659	0.115	0.599	0.842	0.243
19-		True	0.981	1.309	0.328	0.589	0.606	0.017	0.628	0.840	0.212
mar	constant_PS	Est.	0.980	1.315	0.335	0.536	0.648	0.112	0.599	0.849	0.250
25-	default_P	True	1.067	1.465	0.398	0.438	0.451	0.013	0.537	0.737	0.200
mar	+decr_S	Est.	1.073	1.475	0.402	0.396	0.496	0.100	0.516	0.762	0.246
26-	incr_P	True	1.080	1.453	0.373	0.444	0.457	0.013	0.554	0.743	0.189
mar	+decr_S	Est.	1.083	1.458	0.375	0.399	0.495	0.096	0.527	0.758	0.231
27-	incr_P	True	0.957	1.273	0.316	0.593	0.622	0.029	0.624	0.830	0.206
mar	+default_S	Est.	0.934	1.253	0.319	0.547	0.665	0.118	0.592	0.829	0.237
24-	incr_P	True	1.153	1.592	0.439	0.385	0.398	0.013	0.529	0.737	0.208
mar	+incr_S	Est.	1.085	1.504	0.419	0.357	0.452	0.095	0.494	0.730	0.236
01-	incr_PS	True	1.110	1.500	0.390	0.434	0.447	0.013	0.564	0.763	0.199
apr	_steep	Est.	0.910	1.246	0.336	0.446	0.549	0.103	0.493	0.717	0.224
22-	default_P	True	1.132	1.600	0.468	0.389	0.401	0.012	0.522	0.740	0.218
mar	+incr_S	Est.	1.129	1.596	0.467	0.350	0.441	0.091	0.493	0.754	0.261
21-	decr_P	True	1.154	1.554	0.400	0.392	0.403	0.011	0.538	0.728	0.190
mar	+ incr_S	Est.	1.142	1.561	0.419	0.352	0.437	0.085	0.510	0.730	0.220
20-	decr_P	True	0.968	1.267	0.299	0.590	0.617	0.027	0.624	0.820	0.196
mar	+default_S	Est.	0.942	1.236	0.294	0.552	0.663	0.111	0.593	0.820	0.227
23-	decr_P	True	1.090	1.450	0.360	0.432	0.444	0.012	0.545	0.724	0.179
mar	+decr_S	Est.	1.033	1.387	0.354	0.405	0.501	0.096	0.511	0.728	0.217
31-	decr_PS	True	1.139	1.561	0.422	0.379	0.391	0.012	0.503	0.696	0.193
mar	_steep	Est.	0.921	1.279	0.358	0.394	0.500	0.106	0.442	0.661	0.219

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] True denotes actual “true” average survival rates and Est. denotes CJS estimated “true” average survival rates were used when computing smolt numbers in LGR-equivalents for the respective SARs.

Table 7.7 shows a comparison of the widths of non-parametric 90% confidence intervals obtained by bootstrapping 1000 subsamples from a series of independent datasets extracted from the population of 1000 datasets that characterized SAR distributions for a particular level of model assumption violations. A total of twelve simulation scenarios with varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized are presented. For each simulation scenario, the CJS-based estimated confidence boundaries about the “true” population parameter are shown in the first row under the designation “Est-true.” The next four rows provide the corresponding confidence intervals obtained by bootstrapping a particular dataset from the population of 1000. Since the dataset are randomly created, the systematic selection of the 100th, 200th, 900th, and 1000th datasets will provide a random selection from the parent population. The initial value of each parameter of interest within the selected dataset is simply one point on the distribution of 1000 in the parent population. These four dataset may have widely different initial values and respective bootstrapped confidence intervals, but all should share a common property with regard to their confidence interval width. The bootstrap confidence interval width should match that of the 90% confidence intervals of CJS-based parameter estimates of its parent population.

The average confidence interval width of the four datasets for Group T_0's SAR was within ±0.0001 in ten of twelve scenarios (Table 7.7). Only the "constant" and "steeply increasing" scenarios deviated more. Group C_1 SAR confidence interval widths differences were up to ±0.0004, but with no directional pattern. The average confidence interval widths of the bootstrapped datasets for Group C_0 SARs ranged from no difference to 0.0006 higher, with the largest changes occurring in directly polar scenarios (*i.e.*, constant/default and steep-slope scenarios).

Table 7.8 continues the comparison of the widths of non-parametric 90% confidence intervals obtained by bootstrapping 1000 subsamples with that of its parent population for the additional parameters TIR, S_R, and *D*. For parameter TIR, seven of the twelve scenarios had a smaller width of the average bootstrap confidence interval widths, two scenarios approximately the same width, and the remaining three had a larger width. There does not appear to be a pattern with regard to severity (from default to severe) of assumption violations affecting parameter TIR. Parameter S_R had average bootstrap confidence interval widths that were larger than the parent population in two-thirds of the simulation scenarios. But like parameter TIR, there does not appear to be a pattern with regard to severity (from default to severe) of assumption violations affecting parameter S_R. Finally, parameter D was spilt 50-50 between average bootstrap confidence interval widths being either smaller or larger than the parent population, with no pattern apparent with regard to severity (from default to severe) of assumption violations affecting parameter *D*.

Tables 7.7 and 7.8 have illustrated that under the range of changing survival rates and collection probabilities over time covered in Simulation-1, the bootstrap confidence intervals appear to adequately capture the width of the parent population for CJS-based estimates of SARs for each study group and the TIR, S_R, and *D* parameters. The bootstrap derived confidence intervals around SAR(C_0) may be wider than that of the parent population in some situations, while those for groups C_1 and T_0 tend to be closer to that of the parent population in all situations simulated. An increase in the number of datasets utilized in the computing the average bootstrap confidence interval width would be beneficial in determination if that pattern continues.

Table 7.7. Comparing widths of non-parametric 90% confidence intervals obtained by bootstrapping 1000 samples from each of four independent datasets of the population of 1000 dataset used in establishing population variability characteristics for the SAR distributions of each study category under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. The estimated "true" confidence interval width and average of the confidence interval widths obtained with the four bootstrap samples are shown in bold.

Run #	Test Condition[1]	S_J [2]	sar-C_0 90% CI			sar-C_1 90% CI			sar-T_0 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
13-mar	default_PS	Est-true	0.0227	0.0293	**0.0066**	0.0258	0.0317	**0.0059**	0.0266	0.0308	**0.0042**
		Bs100	0.0262	0.0338	0.0076	0.0229	0.0286	0.0067	0.0260	0.0305	0.0045
		Bs200	0.0244	0.0317	0.0073	0.0256	0.0318	0.0062	0.0259	0.0300	0.0041
		Bs900	0.0233	0.0301	0.0068	0.0254	0.0317	0.0063	0.0237	0.0279	0.0042
		Bs1000	0.0249	0.0317	0.0068	0.0250	0.0305	0.0055	0.0272	0.0314	0.0042
		Av.4 Bs			**0.0071**			**0.0062**			**0.0043**
19-mar	constant_PS	Est-true	0.0222	0.0285	**0.0063**	0.0255	0.0316	**0.0061**	0.0263	0.0308	**0.0045**
		Bs100	0.0242	0.0313	0.0071	0.0253	0.0314	0.0061	0.0265	0.0308	0.0043
		Bs200	0.0204	0.0269	0.0065	0.0284	0.0351	0.0067	0.0255	0.0299	0.0044
		Bs900	0.0229	0.0297	0.0068	0.0250	0.0313	0.0063	0.0238	0.0278	0.0040
		Bs1000	0.0234	0.0302	0.0068	0.0247	0.0307	0.0060	0.0263	0.0307	0.0044
		Av.4 Bs			**0.0068**			**0.0063**			**0.0043**
25-mar	default_P +decr_S	Est-true	0.0185	0.0247	**0.0062**	0.0241	0.0301	**0.0060**	0.0250	0.0292	**0.0042**
		Bs100	0.0180	0.0241	0.0061	0.0265	0.0324	0.0059	0.0255	0.0300	0.0045
		Bs200	0.0206	0.0272	0.0066	0.0259	0.0323	0.0064	0.0252	0.0296	0.0044
		Bs900	0.0196	0.0263	0.0067	0.0225	0.0285	0.0060	0.0245	0.0286	0.0041
		Bs1000	0.0202	0.0269	0.0067	0.0252	0.0314	0.0062	0.0254	0.0296	0.0042
		Av.4 Bs			**0.0065**			**0.0061**			**0.0043**
26-mar	incr_P +decr_S	Est-true	0.0189	0.0243	**0.0054**	0.0238	0.0301	**0.0063**	0.0248	0.0291	**0.0043**
		Bs100	0.0183	0.0236	0.0053	0.0246	0.0310	0.0064	0.0238	0.0283	0.0045
		Bs200	0.0170	0.0221	0.0051	0.0242	0.0304	0.0062	0.0249	0.0292	0.0043
		Bs900	0.0183	0.0240	0.0057	0.0212	0.0269	0.0057	0.0257	0.0302	0.0045
		Bs1000	0.0192	0.0248	0.0056	0.0254	0.0318	0.0064	0.0254	0.0298	0.0044
		Av.4 Bs			**0.0054**			**0.0062**			**0.0044**
27-mar	incr_P default_S	Est-true	0.0233	0.0296	**0.0063**	0.0254	0.0319	**0.0065**	0.0264	0.0311	**0.0047**
		Bs100	0.0263	0.0327	0.0064	0.0283	0.0353	0.0070	0.0262	0.0308	0.0046
		Bs200	0.0222	0.0280	0.0058	0.0258	0.0323	0.0065	0.0255	0.0301	0.0046
		Bs900	0.0245	0.0309	0.0064	0.0235	0.0295	0.0060	0.0260	0.0305	0.0045
		Bs1000	0.0244	0.0308	0.0064	0.0220	0.0280	0.0060	0.0256	0.0301	0.0045
		Av.4 Bs			**0.0063**			**0.0064**			**0.0046**
24-mar	incr_P +incr_S	Est-true	0.0179	0.0237	**0.0058**	0.0231	0.0292	**0.0061**	0.0242	0.0285	**0.0043**
		Bs100	0.0166	0.0222	0.0056	0.0208	0.0267	0.0059	0.0245	0.0289	0.0044
		Bs200	0.0187	0.0244	0.0057	0.0276	0.0343	0.0067	0.0235	0.0278	0.0043
		Bs900	0.0178	0.0237	0.0059	0.0219	0.0280	0.0061	0.0262	0.0307	0.0045
		Bs1000	0.0182	0.0240	0.0058	0.0203	0.0259	0.0056	0.0237	0.0278	0.0041
		Av.4 Bs			**0.0058**			**0.0061**			**0.0043**
01-apr	incr_PS _steep	Est-true	0.0221	0.0290	**0.0069**	0.0241	0.0300	**0.0059**	0.0250	0.0292	**0.0042**
		Bs100	0.0254	0.0331	0.0077	0.0240	0.0299	0.0059	0.0249	0.0294	0.0045
		Bs200	0.0252	0.0330	0.0078	0.0229	0.0293	0.0064	0.0248	0.0292	0.0044
		Bs900	0.0225	0.0295	0.0070	0.0236	0.0297	0.0061	0.0269	0.0315	0.0046
		Bs1000	0.0243	0.0316	0.0073	0.0227	0.0288	0.0061	0.0238	0.0281	0.0043
		Av.4 Bs			**0.0075**			**0.0061**			**0.0045**

(Table continued on next page)

Table 7.7. Continued.

Run #	Test Condition[1]	S_J [2]	sar-C_0 90% CI			sar-C_1 90% CI			sar-T_0 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
22-mar	default_P +incr_S	Est-true	0.0167	0.0227	**0.0060**	0.0234	0.0291	**0.0057**	0.0243	0.0284	**0.0041**
		Bs100	0.0145	0.0200	0.0055	0.0244	0.0304	0.0060	0.0243	0.0286	0.0043
		Bs200	0.0166	0.0227	0.0061	0.0256	0.0319	0.0063	0.0232	0.0272	0.0040
		Bs900	0.0176	0.0235	0.0059	0.0234	0.0296	0.0062	0.0247	0.0290	0.0043
		Bs1000	0.0226	0.0295	0.0069	0.0215	0.0273	0.0058	0.0243	0.0284	0.0041
		Av.4 Bs			**0.0061**			**0.0061**			**0.0042**
21-mar	decr_P + incr_S	Est-true	0.0172	0.0222	**0.0050**	0.0232	0.0294	**0.0062**	0.0240	0.0282	**0.0042**
		Bs100	0.0140	0.0184	0.0044	0.0224	0.0284	0.0060	0.0236	0.0280	0.0044
		Bs200	0.0181	0.0232	0.0051	0.0237	0.0297	0.0060	0.0240	0.0284	0.0044
		Bs900	0.0168	0.0219	0.0051	0.0225	0.0287	0.0062	0.0235	0.0279	0.0044
		Bs1000	0.0190	0.0242	0.0052	0.0242	0.0306	0.0064	0.0260	0.0306	0.0046
		Av.4 Bs			**0.0050**			**0.0062**			**0.0045**
20-mar	decr_P default_S	Est-true	0.0236	0.0296	**0.0060**	0.0252	0.0319	**0.0067**	0.0262	0.0308	**0.0046**
		Bs100	0.0253	0.0315	0.0062	0.0266	0.0333	0.0067	0.0244	0.0289	0.0045
		Bs200	0.0199	0.0255	0.0056	0.0227	0.0289	0.0062	0.0239	0.0282	0.0043
		Bs900	0.0245	0.0310	0.0065	0.0256	0.0318	0.0062	0.0270	0.0316	0.0046
		Bs1000	0.0231	0.0289	0.0058	0.0228	0.0289	0.0061	0.0238	0.0282	0.0044
		Av.4 Bs			**0.0060**			**0.0063**			**0.0045**
23-mar	decr_P +decr_S	Est-true	0.0199	0.0255	**0.0056**	0.0239	0.0302	**0.0063**	0.0247	0.0294	**0.0047**
		Bs100	0.0207	0.0262	0.0055	0.0247	0.0313	0.0066	0.0264	0.0309	0.0045
		Bs200	0.0198	0.0256	0.0058	0.0242	0.0306	0.0064	0.0244	0.0288	0.0044
		Bs900	0.0202	0.0259	0.0057	0.0191	0.0248	0.0057	0.0253	0.0302	0.0049
		Bs1000	0.0204	0.0262	0.0058	0.0233	0.0294	0.0061	0.0232	0.0277	0.0045
		Av.4 Bs			**0.0057**			**0.0062**			**0.0046**
31-mar	decr_PS _steep	Est-true	0.0216	0.0285	**0.0069**	0.0239	0.0302	**0.0063**	0.0248	0.0291	**0.0043**
		Bs100	0.0238	0.0309	0.0071	0.0257	0.0321	0.0064	0.0255	0.0303	0.0048
		Bs200	0.0243	0.0320	0.0077	0.0240	0.0305	0.0065	0.0242	0.0285	0.0043
		Bs900	0.0246	0.0320	0.0074	0.0233	0.0296	0.0063	0.0230	0.0272	0.0042
		Bs1000	0.0223	0.0290	0.0067	0.0259	0.0325	0.0066	0.0238	0.0282	0.0044
		Av.4 Bs			**0.0072**			**0.0065**			**0.0044**

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Est. denotes CJS estimated "true" average survival rates were used in computing variability in population parameter distributions and Bs# denotes variability estimated by bootstrapping four datasets from the population of 1000. The # following the Bs indicates the particular population dataset being utilized.

Table 7.8. Comparing widths of non-parametric 90% confidence intervals obtained by bootstrapping 1000 samples from each of four independent datasets of the population of 1000 dataset used in establishing population variability characteristics for the TIR, S_R, and *D* distributions under runs of varying degrees of assumption violation in the CJS survival rates and collection probabilities utilized. The estimated "true" confidence interval width and average of the confidence interval widths obtained with the four bootstrap samples are shown in bold.

Run #	Test Condition[1]	S_J [2]	TIR 90% CI			S_R 90% CI			*D* 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
13-mar	default_PS	Est-true	0.961	1.290	**0.329**	0.544	0.659	**0.115**	0.599	0.842	**0.243**
		Bs100	0.821	1.110	0.289	0.544	0.650	0.106	0.511	0.714	0.203
		Bs200	0.860	1.164	0.304	0.516	0.635	0.119	0.513	0.739	0.226
		Bs900	0.838	1.133	0.295	0.554	0.670	0.116	0.532	0.758	0.226
		Bs1000	0.909	1.207	0.298	0.530	0.642	0.112	0.543	0.763	0.220
		Av.4 Bs			**0.297**			**0.113**			**0.219**
19-mar	constant_PS	Est-true	0.980	1.315	**0.335**	0.536	0.648	**0.112**	0.599	0.849	**0.250**
		Bs100	0.898	1.201	0.303	0.481	0.581	0.100	0.494	0.694	0.200
		Bs200	1.000	1.392	0.392	0.589	0.722	0.133	0.677	0.998	0.321
		Bs900	0.849	1.154	0.305	0.528	0.641	0.113	0.507	0.725	0.218
		Bs1000	0.927	1.251	0.324	0.523	0.637	0.114	0.557	0.802	0.245
		Av.4 Bs			**0.331**			**0.115**			**0.246**
25-mar	default_P +decr_S	Est-true	1.073	1.475	**0.402**	0.396	0.496	**0.100**	0.516	0.762	**0.246**
		Bs100	1.125	1.581	0.456	0.372	0.458	0.086	0.508	0.754	0.246
		Bs200	0.982	1.363	0.381	0.371	0.467	0.096	0.447	0.657	0.210
		Bs900	0.983	1.379	0.396	0.374	0.468	0.094	0.449	0.666	0.217
		Bs1000	0.993	1.389	0.396	0.409	0.512	0.103	0.497	0.735	0.238
		Av.4 Bs			**0.407**			**0.095**			**0.228**
26-mar	incr_P +decr_S	Est-true	1.083	1.458	**0.375**	0.399	0.495	**0.096**	0.527	0.758	**0.231**
		Bs100	1.076	1.449	0.373	0.395	0.494	0.099	0.529	0.771	0.242
		Bs200	1.199	1.626	0.427	0.434	0.550	0.116	0.631	0.931	0.300
		Bs900	1.151	1.555	0.404	0.400	0.498	0.098	0.559	0.807	0.248
		Bs1000	1.078	1.461	0.383	0.470	0.590	0.120	0.608	0.891	0.283
		Av.4 Bs			**0.397**			**0.108**			**0.268**
27-mar	incr_P default_S	Est-true	0.934	1.253	**0.319**	0.547	0.665	**0.118**	0.592	0.829	**0.237**
		Bs100	0.848	1.105	0.257	0.559	0.674	0.115	0.539	0.753	0.214
		Bs200	0.970	1.291	0.321	0.523	0.628	0.105	0.579	0.815	0.236
		Bs900	0.889	1.182	0.293	0.597	0.727	0.130	0.617	0.868	0.251
		Bs1000	0.881	1.174	0.293	0.630	0.766	0.136	0.632	0.896	0.264
		Av.4 Bs			**0.291**			**0.122**			**0.241**
24-mar	incr_P +incr_S	Est-true	1.085	1.504	**0.419**	0.357	0.452	**0.095**	0.494	0.730	**0.236**
		Bs100	1.175	1.643	0.468	0.390	0.503	0.113	0.576	0.874	0.298
		Bs200	1.020	1.402	0.382	0.339	0.424	0.085	0.433	0.641	0.208
		Bs900	1.173	1.622	0.449	0.339	0.426	0.087	0.503	0.752	0.249
		Bs1000	1.047	1.428	0.381	0.394	0.505	0.111	0.529	0.782	0.253
		Av.4 Bs			**0.420**			**0.099**			**0.252**
01-apr	incr_PS _steep	Est-true	0.910	1.246	**0.336**	0.446	0.549	**0.103**	0.493	0.717	**0.224**
		Bs100	0.802	1.088	0.286	0.511	0.659	0.148	0.502	0.750	0.248
		Bs200	0.797	1.091	0.294	0.417	0.516	0.099	0.407	0.595	0.188
		Bs900	0.968	1.322	0.354	0.477	0.600	0.123	0.557	0.814	0.257
		Bs1000	0.793	1.090	0.297	0.474	0.589	0.115	0.454	0.671	0.217
		Av.4 Bs			**0.308**			**0.121**			**0.228**

(Table continued on next page)

Table 7.8. Continued.

Run #	Test Condition[1]	S_J[2]	TIR 90% CI			S_R 90% CI			*D* 90% CI		
			LL	UL	Width	LL	UL	Width	LL	UL	Width
22-mar	Default_P +incr_S	Est-true	1.129	1.596	**0.467**	0.350	0.441	**0.091**	0.493	0.754	**0.261**
		Bs100	1.294	1.840	0.546	0.366	0.466	0.100	0.609	0.908	0.299
		Bs200	1.094	1.544	0.450	0.328	0.408	0.080	0.444	0.669	0.225
		Bs900	1.108	1.548	0.440	0.375	0.485	0.110	0.536	0.806	0.270
		Bs1000	0.878	1.179	0.301	0.368	0.466	0.098	0.402	0.597	0.195
		Av.4 Bs			**0.434**			**0.097**			**0.247**
21-mar	decr_P + incr_S	Est-true	1.142	1.561	**0.419**	0.352	0.437	**0.085**	0.510	0.730	**0.220**
		Bs100	1.369	1.906	0.537	0.296	0.365	0.069	0.515	0.761	0.246
		Bs200	1.098	1.482	0.384	0.338	0.423	0.085	0.476	0.687	0.211
		Bs900	1.145	1.568	0.423	0.359	0.456	0.097	0.524	0.763	0.239
		Bs1000	1.141	1.527	0.386	0.328	0.403	0.075	0.463	0.659	0.196
		Av.4 Bs			**0.433**			**0.082**			**0.223**
20-mar	decr_P default_S	Est-true	0.942	1.236	**0.294**	0.552	0.663	**0.111**	0.593	0.820	**0.227**
		Bs100	0.818	1.079	0.261	0.582	0.708	0.126	0.545	0.765	0.220
		Bs200	0.998	1.335	0.337	0.584	0.715	0.131	0.679	0.953	0.274
		Bs900	0.922	1.216	0.294	0.578	0.695	0.117	0.610	0.846	0.236
		Bs1000	0.870	1.150	0.280	0.538	0.648	0.110	0.540	0.747	0.207
		Av.4 Bs			**0.293**			**0.121**			**0.234**
23-mar	decr_P +decr_S	Est-true	1.033	1.387	**0.354**	0.405	0.501	**0.096**	0.511	0.728	**0.217**
		Bs100	1.070	1.426	0.356	0.352	0.426	0.074	0.455	0.638	0.183
		Bs200	1.020	1.362	0.342	0.405	0.495	0.090	0.500	0.702	0.202
		Bs900	1.030	1.401	0.371	0.376	0.461	0.085	0.470	0.675	0.205
		Bs1000	0.942	1.265	0.323	0.392	0.480	0.088	0.455	0.644	0.189
		Av.4 Bs			**0.348**			**0.084**			**0.195**
31-mar	decr_PS _steep	Est-true	0.921	1.279	**0.358**	0.394	0.500	**0.106**	0.442	0.661	**0.219**
		Bs100	0.880	1.191	0.311	0.440	0.575	0.135	0.473	0.708	0.235
		Bs200	0.809	1.104	0.295	0.427	0.542	0.115	0.426	0.629	0.203
		Bs900	0.758	1.043	0.285	0.396	0.517	0.121	0.376	0.565	0.189
		Bs1000	0.868	1.200	0.332	0.401	0.507	0.106	0.426	0.620	0.194
		Av.4 Bs			**0.306**			**0.119**			**0.205**

[1] See methods section for collection probabilities (P) and survival rates (S) utilized in test conditions.

[2] Est. denotes CJS estimated "true" average survival rates were used in computing variability in population parameter distributions and Bs# denotes variability estimated by bootstrapping four datasets from the population of 1000. The # following the Bs indicates the particular population dataset being utilized.

Simulation-2

Investigating potential bias in CJS-based estimates due to capture-history-dependent survival

As was shown in Simulation-1, having reliable estimates of survival rates and collection probabilities was key to obtaining valid estimates of SARs, TIRs and *D*. When estimating survival rates and collection probabilities using the CJS model, there are assumptions that need to be met in order to ensure these estimates are reliable. In Simulation-1, we investigated the impacts of conditions were survival rates and collection probabilities were varying over time. In Simulation-2 the goal is to assess the impacts on reach survival rates caused by how segments of a population of fish pass the Snake River collector dams (LGR, LGS, and LMN). If prior passage experience through spill, turbines, or bypasses causes any change in survival rates in subsequent downstream reaches, then Assumption #5 (“previous detections have no influence on subsequent survival or detection probabilities”) will be violated in addition to Assumption #2 (equality of survival rates and collection probabilities for the group of tagged individuals). When passing the Snake River collector dams, some PIT-tagged fish will enter the dam’s bypass system, where they get detected and then either transported or returned back to the river. Other PIT-tagged fish will pass undetected through either spill or turbines. As stated earlier when describing the methods of SIM-2, these different passage experiences for members of a common population could impact our CJS model estimates of survival rates.

Two simulation scenarios are created for these evaluations, which differed only in the survival rates S_2, S_3, and S_4 for reaches LGR-LGS, LGS-LMN, and LMN-MCN, respectively. The default collection probabilities of SIM-1 were used at each dam in both scenarios of SIM-2. With the same default collection probabilities and transportation probabilities, we obtained “true” numbers of smolts (average of 500 simulated datasets) in study categories T_0, C_0, and C_1 (expanded to LGR-equivalents) that only differed slightly (due to beta-binomial variability in collection probabilities) across the two scenarios. The breakdown of average “true” smolt numbers in T_0, C_0, and C_1 by pre-assigned groups T and R for the two scenarios is as follows (note: the same 500 simulated datasets for Group T are used in both scenarios):

	Scenario 1 “R higher S_J than T”				**Scenario 2 “R lower S_J than T”**		
	Grp-T	Grp-R	T&R		Grp-T	Grp-R	T&R
Rel.	32,000	16,000	48,000	Rel.	32,000	16,000	48,000
T_0	24,121		24,121	T_0	24,121		24,121
C_0	**6,274**	**3,142**	**9,415**	**C_0**	**6,274**	**3,144**	**9,418**
C_1		12,054	12,054	C_1		12,053	12,053

The differences in survival rates between the two scenarios are shown in tables 7.9 and 7.10. The average “true” survival rates are shown for Group T, Group R, and the combination of these two groups into Group T&R. In addition, CJS-model estimates of the survival rates for Group T&R are shown from each of five datasets selected from the parent population of 500 datasets. For the combined Group T&R, the relative absolute difference between the CJS-model estimates and the average “true” values [$(s_J - S_J)/S_J$ for the Jth reach) was > ± 2% for the release to LGR reach (S_1), LGR to LGS reach (S_2), and JDA to BON reach (S_6) for both scenarios, plus for the LMN to MCN reach (S_4) for Scenario 2. It is apparent from the computational formulas used to estimate the number of smolts (in LGR equivalents) in study categories C_0, $T_{0,}$ and C_1 that when CJS-model estimates of survival rates s_1 and s_2 (bolded for emphasis in formulas below) differ from the “true” values, the study category most impacted will be C_0:

$$\text{Group } C_0 = R_1 s_1 - (m_{12} + m_{13}/s_2 + m_{14}/s_2 s_3) \qquad [7.1]$$

$$\text{Group } T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2 s_3 \qquad [7.2]$$

$$\text{Group } C_1 = (m_{12} - X_{12}) + (m_{13} - X_{102})/s_2 + (m_{14} - X_{1002})/s_2 s_3 \qquad [7.3]$$

Table 7.9. Average "true" survival rates for all survival rates S_1 to S_6 for groups T, R, and the combined T&R with a comparison to the CJS-model estimates of s_1 to s_6 for Group T&R under the condition when Group R had HIGHER survival rates than Group T for S_2, S_3, and S_4 (reaches LGR-LGS, LGS-LMN, and LMN-MCN, respectively).

True S_J	S_1	S_2	S_3	S_4	S_5	S_6
Group T	0.950	0.900	0.967	0.801	0.890	0.883
Group R	0.950	0.950	0.980	0.901	0.888	0.881
Group T&R	**0.950**	**0.923**	**0.975**	**0.873**	**0.889**	**0.881**
Estimated s_J	s_1	s_2	s_3	s_4	s_5	s_6
T&R-run100	0.914	0.952	0.978	0.876	0.908	0.911
T&R-run200	0.921	0.940	0.997	0.875	0.857	0.991
T&R-run300	0.915	0.951	0.968	0.894	0.895	0.872
T&R-run400	0.915	0.943	0.990	0.882	0.888	0.935
T&R-run500	0.922	0.938	0.998	0.892	0.865	0.859
Avg of 5 runs	**0.917**	**0.945**	**0.986**	**0.884**	**0.883**	**0.914**
Relative difference from "True"	-3.4%	2.4%	1.1%	1.2%	-0.7%	3.7%

Table 7.10. Average "true" survival rates for all survival rates S_1 to S_6 for groups T, R, and the combined T&R with a comparison to the CJS-model estimates of s_1 to s_6 for Group T&R under the condition when Group R had LOWER survival rates than Group T for S_2, S_3, and S_4 (reaches LGR-LGS, LGS-LMN, and LMN-MCN, respectively).

True S_J	S_1	S_2	S_3	S_4	S_5	S_6
Group T	0.950	0.900	0.967	0.801	0.890	0.883
Group R	0.950	0.850	0.928	0.701	0.889	0.880
Group T&R	**0.950**	**0.877**	**0.945**	**0.732**	**0.889**	**0.881**
Estimated s_J	s_1	s_2	s_3	s_4	s_5	s_6
T&R-run100	0.979	0.854	0.966	0.677	0.887	0.949
T&R-run200	1.000	0.850	0.916	0.702	0.904	0.880
T&R-run300	0.987	0.855	0.931	0.701	0.857	0.887
T&R-run400	0.980	0.860	0.951	0.706	0.851	0.972
T&R-run500	0.990	0.850	0.962	0.686	0.901	0.881
Avg of 5 runs	**0.987**	**0.854**	**0.945**	**0.695**	**0.880**	**0.914**
Relative difference from "True"	3.9%	-2.7%	0.0%	-5.1%	-1.0%	3.8%

Table 7.11 shows the CJS-based estimates of number of smolts in Category C_0 was approximately 9.5 % too low in Scenario 1 (when Group R has higher S_J than Group T) and approximately 12.9% too high in Scenario 2 (when Group R has lower S_J than Group T). Fortunately, the s_1 and s_2 differ in opposite directions from the "true" values (i.e., $s_1 < S_1$ and $s_2 > S_2$ as in Scenario 1; $s_1 < S_1$ and $s_2 > S_2$ as in Scenario 2) as seen in tables 7.9 and 7.10, otherwise, if s_1 and s_2 had differed in the same direction from the "true" values, the impact on estimation of number of smolts in Category C_0 would be greater than obtained in this simulation. However, because of the existence of negative correlation between survival rates of adjacent reaches when using the CJS-model, we wound not expect the latter "worse" condition to actually occur when using the CJS-model on real data. For the two scenarios, the CJS-based estimates of number of

smolts in Category C_1 were within ± 1% of the “true” value; it was approximately ± 3% of the “true” value for Category T_0.

Table 7.11. Comparing CJS-based estimates of smolt numbers for each study category with the “true” simulated values for two test scenarios where combined groups T and R differ in reach survival rates to assess impact of assumption violations in the CJS estimation of survival rates and collection probabilities utilized.

		Smolt number in Group C_0			Smolt number in Group C_1			Smolt number in Group T_0		
Study scenario	Data source[1]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]
T base & R with higher Sj	av-true	9,415	n/a		12,054	n/a		24,121	n/a	
	ds100	9,343	8,338	-10.8%	12,153	12,164	0.1%	24,083	23,345	-3.1%
	ds200	9,226	8,429	-8.6%	12,099	12,092	-0.1%	24,264	23,673	-2.4%
	ds300	9,473	8,500	-10.3%	12,044	12,104	0.5%	24,043	23,324	-3.0%
	ds400	9,407	8,455	-10.1%	12,027	12,036	0.1%	24,123	23,415	-2.9%
	ds500	9,239	8,516	-7.8%	12,138	12,159	0.2%	24,158	23,568	-2.4%
	Avg.			**-9.5%**			**0.2%**			**-2.8%**
T base & R with lower Sj	av-true	9,418	n/a		12,053	n/a		24,121	n/a	
	ds100	9,569	10,580	10.6%	11,871	11,754	-1.0%	24,083	24,672	2.4%
	ds200	9,252	10,673	15.4%	12,039	12,063	0.2%	24,264	25,269	4.1%
	ds300	9,355	10,571	13.0%	12,071	12,027	-0.4%	24,043	24,768	3.0%
	ds400	9,505	10,507	10.5%	11,963	11,853	-0.9%	24,123	24,663	2.2%
	ds500	9,321	10,703	14.8%	12,006	11,901	-0.9%	24,158	24,898	3.1%
	Avg.			**12.9%**			**-0.6%**			**3.0%**

[1] Lines “av-true” show the average “true” values of the respective parent population (distribution of 500 simulated datasets) characterized by the reach survival rates of each test scenario. The designation ds# is for the 100th, 200th, 300th, 400th, and 500th dataset from the parent population, with actual “true” values being compared to the CJS-based estimates of that parameter.

[2] Difference between computation formula value and “true” value divided by “true” value.

The CJS-based estimates of the SARs for fish in study categories C_0, C_1, and T_0 differ from their “true” values in similar magnitude, but in the opposite direction (Table 7.12). This is exactly what is expected, since only the denominator in the SAR formula utilizes the CJS-model survival rate estimates. As the ratio of two SARs that are showing a relative difference in the same direction from their respective “true” values, we see as smaller relative difference in the opposite direction for the TIR parameter from the “true” values of the parent population in each scenario (Table 7.13). For the LGR to BON reach survival rates, S_R, the relative difference of CJS-based estimates from “true” values were in the opposite direction from that of the TIR, so that when parameter D was computed, a further reduction in the relative difference occurs between its CJS-based estimate and the “true” values of the parent populations in each scenario. Although the relative difference seen with parameter D was lower in Scenario 1 than it was in Scenario 2, it is very likely that with more datasets selected from the parent population distribution, the absolute value of this result will become more similar. This will be verified by looking at more than 5 sampled datasets in SIM-2 prior to submission of this chapter to the ISAB review.

Table 7.12. Comparing CJS-based estimates of SARs for each study category with the "true" simulated values for two test scenarios where combined groups T and R differ in reach survival rates to assess impact of assumption violations in the CJS estimation of survival rates and collection probabilities utilized.

		sar-C_0			sar-C_1			sar-T_0		
Study scenario	Data source[1]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]
T base & R with higher Sj	av-true	0.0178	n/a		0.0098	n/a		0.0284	n/a	
	ds100	0.0146	0.0163	11.6%	0.0113	0.0113	0.0%	0.0286	0.0295	3.1%
	ds200	0.0172	0.0189	9.9%	0.0089	0.0089	0.0%	0.0271	0.0278	2.6%
	ds300	0.0204	0.0227	11.3%	0.0098	0.0098	0.0%	0.0277	0.0286	3.2%
	ds400	0.0196	0.0218	11.2%	0.0101	0.0101	0.0%	0.0288	0.0297	3.1%
	ds500	0.0186	0.0202	8.6%	0.0101	0.0100	-1.0%	0.0292	0.0300	2.7%
	Avg.			**10.5%**			**-0.2%**			**3.0%**
T base & R with lower Sj	av-true	0.0169	n/a		0.0091	n/a		0.0284	n/a	
	ds100	0.0145	0.0131	-9.7%	0.0096	0.0097	1.0%	0.0286	0.0279	-2.4%
	ds200	0.0152	0.0132	-13.2%	0.0088	0.0088	0.0%	0.0271	0.0260	-4.1%
	ds300	0.0195	0.0172	-11.8%	0.0095	0.0096	1.1%	0.0277	0.0269	-2.9%
	ds400	0.0177	0.0160	-9.6%	0.0087	0.0088	1.1%	0.0288	0.0282	-2.1%
	ds500	0.0193	0.0168	-13.0%	0.0093	0.0093	0.0%	0.0292	0.0284	-2.7%
	Avg.			**-11.4%**			**0.7%**			**-2.8%**

[1] Lines "av-true" show the average "true" values of the respective parent population (distribution of 500 simulated datasets) characterized by the reach survival rates of each test scenario. The designation ds# is for the 100th, 200th, 300th, 400th, and 500th dataset from the parent population, with actual "true" values being compared to the CJS-based estimates of that parameter.

[2] Difference between computation formula value and "true" value divided by "true" value.

Although SIM-2 was conducted with only two scenarios being evaluated, its results suggest that survival rates differences between segments of the same population based on prior detection history may cause more impacts to estimation of smolts numbers in Category C_0 than occurs by temporal changes in survival rates and collection probabilities as evaluated in SIM-1. The differences between the reach survival rates of groups T and R could be viewed as relatively moderate, and yet the impact observed was of the level obtained under the most extreme conditions of temporally changing reach survival rates and collection probabilities. In SIM-1, the changes in collection probabilities were more problematic than changes in survival rates, while in SIM-2 the collection probabilities were set at the default levels (*i.e.*, negligible change over time). In SIM-2, the survival rate difference alone were the causative factor in creating the potential bias in CJS-based estimates of smolt numbers in Category C_0.

Table 7.13. Comparing CJS-based estimates of TIR, S_R, and D parameters with the "true" simulated values for two test scenarios where combined groups T and R differ in reach survival rates to assess impact of assumption violations in the CJS estimation of survival rates and collection probabilities utilized.

		TIR			S_R			**D**		
Study scenario	Data source[1]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]	actual "true"	estimate (CJS)	relative diff frm "true"[2]
T base & R with higher Sj	av-true	1.606	n/a		0.615	n/a		1.052	n/a	
	ds100	1.963	1.807	-7.9%	0.611	0.674	10.3%	1.276	1.277	0.1%
	ds200	1.571	1.471	-6.4%	0.619	0.696	12.4%	1.032	1.077	4.4%
	ds300	1.362	1.259	-7.6%	0.612	0.643	5.1%	0.888	0.850	-4.3%
	ds400	1.473	1.364	-7.4%	0.608	0.683	12.3%	0.957	0.979	2.3%
	ds500	1.570	1.483	-5.5%	0.614	0.620	1.0%	1.025	0.967	-5.7%
	Avg.			**-7.0%**	**0.613**	**0.663**	**8.2%**			**-0.6%**
T base & R with lower Sj	av-true	1.690	n/a		0.475	n/a		0.881	n/a	
	ds100	1.967	2.123	7.9%	0.468	0.470	0.4%	1.005	1.105	10.0%
	ds200	1.777	1.968	10.7%	0.477	0.435	-8.8%	0.930	0.960	3.2%
	ds300	1.426	1.564	9.7%	0.470	0.424	-9.8%	0.736	0.739	0.4%
	ds400	1.630	1.762	8.1%	0.474	0.478	0.8%	0.848	0.932	9.9%
	ds500	1.513	1.686	11.4%	0.476	0.445	-6.5%	0.786	0.835	6.2%
	Avg.			**9.6%**	**0.473**	**0.450**	**-4.8%**			**5.9%**

[1] Lines "av-true" show the average "true" values of the respective parent population (distribution of 500 simulated datasets) characterized by the reach survival rates of each test scenario. The designation ds# is for the 100th, 200th, 300th, 400th, and 500th dataset from the parent population, with actual "true" values being compared to the CJS-based estimates of that parameter.

[2] Difference between computation formula value and "true" value divided by "true" value.

Key to these results is the CSS move toward utilizing the NPT approach of pre-assigning part of one's tag population to Group T to reflect the untagged population and the remainder to Group R to obtain the reach survival rates and collection probabilities. It will be important to assess the potential of differences between these two groups with regard to their in-river survival rates in through the hydrosystem with TEST 3 from Program MARK (White *et al*. 1999). A successful outcome of TEST 3 would provide evidence supporting the assumption of no impact due to prior capture history on subsequent survival rates, and allow a valid combining of groups T and R into a single common population from which the estimation of smolts in study categories C_0, C_1, and T_0 may be directly obtained utilizing the existing CSS Bootstrap Computer Program without any modifications. Additional benefits of utilizing the combined Group T&R is (1) the availability of more in-river fish for estimating survival rates s_5 and s_6 in the lower reaches (MCN to JDA and JDA to BON) of the hydrosystem and (2) a larger number of smolts for Study Category C_0.

Conclusions

In this chapter we investigated the impact that violations of key assumptions of the Cormack-Jolly-Seber (CJS) have on our ability to obtain accurate estimates of reach survival rates and other study parameters through two sets of simulations. Our first set of simulations found that:

a. CJS-based estimation of parameters of SARs by study group (sarC_0, sarC_1, and sarT_0), TIRs (sarT_0/sarC_0), S_R (inriver survival from LGR to BON), and D (delayed differential mortality between T_0 and C_0 groups) are robust to population changes in survival rates and collection probabilities over time.
b. for the range of changing simulated survival rates and collection probabilities over time, the bootstrap confidence intervals appear to adequately capture the width of the 'true' simulated population for CJS-based estimates of SARs for each study group and the TIR, S_R, and D parameters.

The second set of simulation results showed that:

a. for the range of simulated survival rates and collection probabilities changing over time, the bootstrap confidence intervals appear to adequately capture the width of the 'true' simulated population for CJS-based estimates of SARs for each study group and the TIR, S_R, and D parameters.
c. CJS-based estimation of parameters of SARs by study group (sarC_0, sarC_1, and sarT_0), TIRs (sarT_0/sarC_0), S_R (inriver survival from LGR to BON), and D (delayed differential mortality between T_0 and C_0 groups) are not as robust to population changes in survival rates between segments of a common population (based on prior passage experience) as was observed when changes were strictly temporal in nature. However, the differences between simulated and true values of TIRs, Srs, and Ds were generally less than 10%.
d. the impacts of violating the assumption that prior detection history has no effect on the survival rates, appears to more strongly influence the CJS-based estimates for the number of smolts used in the Study Category C_0 ('true inriver control').

Chapter 8

Conclusions and Future Direction

The CSS has now been implemented for ten years. We have summarized the conclusion from our retrospective analyses, and provide recommendations to guide future study designs to address critical uncertainties and improve the reliability of CSS survival estimates for informing decisions regarding hydrosystem management actions. Below is a discussion of the key findings of the ten years of study are described, summarization of how the original study goals and objectives were met, and guidance for future study design.

I- The CSS represents a successful implementation of large scale PIT tag marking program over multi-jurisdictions and wide geographic area (Figures 1.2 and 1.3). We were consistently able to achieve PIT tag marking levels for the various hatcheries and wild population groupings for Spring/summer Chinook that we identified in our study plans. These mark groups were spread over a wide geographic range and we coordinated the marking that was implemented by various agencies. We were also able to get sufficient sample sizes for the various treatment groups by reaching target mark levels and using the PIT tag separation-by-code equipment and software.

II- The CSS is a field study that addresses important and technically complex issues regarding the survival of spring/summer Chinook and Steelhead through the Columbia River hydrosystem from migrating juveniles to returning adults. One focus of the CSS is on relative survival of fish that traveled downstream as juveniles by alternative routes (e.g., in-river, transported, different routes of dam passage, and different numbers of dams passed). The results have important implications for operation of the hydrosystem to ensure protection, restoration, and mitigation for anadromous salmonids. This study successfully generated reach survivals, transport SARs, in-river SARs, overall annual SARs for hatchery and wild Chinook for each of the study years and their corresponding confidence intervals. In addition, we used the CSS methods to estimate the same set of parameters for hatchery and wild steelhead, taking advantage of PIT tags from other marking programs. These annual CSS parameter estimates have been widely used in the region to inform managers about fish population performance.

III- The CSS PIT tag data provides extensive data set for other groups to use and has been incorporated in studies by numerous scientific investigators. The CSS long-term study approach maintains consistent and continuous mark groups throughout the Columbia River Basin. Every effort is made to avoid duplication of mark groups with other studies and gain the maximum efficiency from mark groups from other research studies. The actual mark proposals for CSS have been dependent on year-to-year coordination with other research studies. The CSS PIT-tagging goals have been coordinated with those of Lower Snake River Compensation Program (LSRCP).

IV- Summary of release PIT tag marking information for the CSS.

a. Approximately 2,010,000 spring/summer Chinook have been PIT-tagged and released from hatcheries above LGR and approximately 143,300 at Carson NFH above BON specifically for the CSS, from 1997 through 2007. Since 2002, the CSS has provided 145,000 PIT tags to augment ongoing wild Chinook tagging activities at mainstem Snake River traps and various tributary traps, as well as the Clearwater River trap. The upriver wild fish stocks comprise six Major Population Groups (MPG) in the Snake River. The CSS compares the differential survival rates to adult of these fish with John Day River wild spring Chinook, a Mid-Columbia ESU. Among these seven wild Chinook mark groups, five are listed under the ESA.

b. Despite never receiving funding to PIT tag steelhead, the CSS has evaluated steelhead survival parameters using tagged fish from other studies. Beginning in 2003 the CSS coordinated with state and tribal researchers to route a portion of their PIT-tagged fish to transportation, and received funding to PIT tag 2,000 wild steelhead per year at the Clearwater River trap. These wild fish comprise four Major Population Groups (MPG) in the Snake River. All of these wild steelhead mark groups are listed under the ESA. The marking levels for steelhead hatchery and wild populations have not been funded to fully implement CSS objectives and ISAB/ISRP recommendations.

V- Summary of recapture PIT tag marking information for juveniles (at LGR) and adults (at LGR)

a. Over 976,000 PIT tagged juvenile hatchery spring/summer Chinook CSS study fish have been estimated to arrive at LGR, from 1997 through 2004. In addition, the CSS has used 231,720 PIT tagged juvenile wild spring/summer Chinook that have been estimated to arrive at LGR, from 1994 through 2004.

b. From the CSS aggregate of PIT-tagged wild Chinook that outmigrated as smolts from 1994 to 2004, there have been 2,013 PIT-tagged returning adults detected at LGR through return year 2006. In the four hatcheries where Chinook have been PIT-tagged for the CSS, a total of 8,695 PIT-tagged returning adults were detected at LGR.

c. The adult detection system at Bonneville Dam was completed in 2002; we are now able to use these detections to estimate SARs back to Bonneville Dam..

d. Over 162,000 PIT tagged juvenile hatchery steelhead have been estimated to arrive at LGR, from 1997 through 2003. In addition, the CSS has used 72,000 PIT tagged juvenile wild spring/summer Chinook that have been estimated to arrive at LGR, from 1994 through 2004.

e. From the CSS aggregate of PIT-tagged wild steelhead that outmigrated as smolts from 1997 to 2003, there have been 632 PIT-tagged returning adults detected at LGR through return year 2005. From the CSS hatchery aggregate 903 PIT-tagged hatchery steelhead that outmigrated during this same time, were detected as adults at LGR.

VI- Chapter 2

a. Developed estimates of within-season reach fish travel times, survivals, and instantaneous mortality rates for Snake River hatchery and wild Chinook groups, and a composite steelhead group

b. Simple models incorporating WTT, average percent spill, and Julian day explained 81-95% of the variation in median FTT.
c. Variation in instantaneous mortality (Z) in the LGR-MCN reach was explained by average spill, WTT and Julian day. Variation in the MCN-BON reach was explained by temperature and Julian day. However, there was substantial uncertainty in the lower reach due to reduced numbers of PIT-tagged fish available, which may have affected the ability to identify the important factors.
d. Models that integrated predictions of median FTT and instantaneous mortality (Z) explained most of the variation in survival rates of yearling Chinook and steelhead. This two-step approach outperformed modeling survival rates directly as functions of the same environmental variables.

VII- Chapter 3

a. The annual SARs (LGR smolts-to-LGR adults) for wild Snake River sp/su Chinook has been highly variable, and far below the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003).
b. Transportation provided little or no benefit (over fish that migrated inriver) to wild sp/su Chinook during the conditions experienced in most years during 1994-2004, except during the severe drought year 2001.
c. Delayed mortality of transported wild spring/summer Chinook smolts was substantial most years relative to that of inriver migrants, based on a 10-yr geometric mean *D* estimate (excluding 2001) of 0.49, indicating transported smolts died at twice the rate as inriver migrants once they passed BON tailrace.
d. SARs (LGR-to-LGR) for hatchery Snake River spring/summer Chinook have shown similar patterns as wild Chinook during 1997-2004, although the actual survival rates have differed among hatcheries and between spring and summer runs. SARs of most hatchery Chinook (except Dworshak) have equaled or exceeded the SARs of wild Chinook in migration years 1997-2004.
e. In general, transportation provided benefits (over fish that migrated inriver) most years to Snake River hatchery spring/summer Chinook 1997-2004, however benefits varied among hatcheries.
f. Delayed mortality of transported hatchery spring and summer Chinook smolts was evident most years relative to that of inriver migrants, based on estimated values of *D* less than 1.
g. While wild and hatchery spring and summer Chinook populations demonstrated differences in magnitude for some parameters (TIR, *D* and SARs), the annual patterns of these parameters for wild and hatchery populations were highly correlated.
h. Wild steelhead from the Snake River basin had higher estimated annual SARs (indexed LGR to LGR) than hatchery steelhead in 6 of the 7 migration years (1997 to 2003). Wild steelhead had four years with annual SARs > the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003).
i. Transportation seems to provide benefit (over fish that migrated inriver) to wild and hatchery Snake River steelhead; the geometric mean TIR (1997-2000, 2002-2003) was 1.72 wild stocks and 1.46 for hatchery stocks. Migration year 2001

had very high, but imprecise TIRs, for both wild and hatchery steelhead.

j. Delayed mortality was evident with transported wild and hatchery steelhead relative to inriver migrants as the geometric mean *D* for 1997-2003 (excluding 2001) was 0.80 for wild stocks and 0.64 for hatchery stocks. Confidence intervals were wide due to small sample size.

k. Given small sample sizes and wide confidence intervals for both wild and hatchery steelhead, it is premature to conclude whether hatchery steelhead can serve as surrogates for wild steelhead. However, trends in S_R and TIRs were similar between wild and hatchery steelhead.

VIII- Chapter 4

a. Distributions of SAR of transported and in-river (C_0) migrants suggest that inter-annual variation in SAR is large for both Chinook and steelhead.

b. The transport, in-river (C_0), and aggregate distributions suggest realized SARs have been considerably below the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003) for Chinook, and generally below this level for steelhead.

c. TIR distributions suggest that on average, transportation as currently implemented is not of benefit (over fish that migrated in-river (C_0)) for wild Chinook, regardless of transport project, as the bulk of the distributions for all projects is less than 1.

d. Transportation, particularly from LGR, appears to provide a benefit to wild steelhead compared to in-river (C_0) migration under the current system. The benefits of transportation appears to decline lower in the system.

e. Derived *D* distributions suggest substantial delayed mortality of transported wild Chinook. *D* estimates for steelhead are higher than for Chinook, suggesting that delayed mortality from transport is lower, compared to transporting Chinook.

f. The analysis for wild spring/summer Chinook demonstrated relatively high SARs early in the season, and severe declines later in the season in SARs of in-river (C_1) fish. Similar patterns in in-river SARs within the season are seen for wild steelhead.

g. The decline in SAR of in-river (C_1) fish of both species as the season progresses is consistent with the hypothesis that the protracted migration and late arrival in the estuary is in part responsible for elevated levels of post-Bonneville mortality as a consequence of the hydrosystem experience.

IX- Chapter 5

a. SARs of Snake River wild spring/summer Chinook were less than NPCC interim objectives (2% minimum, 4% average) in most years, achieving the minimum in only 1 of 11 years during 1994-2004. Snake River wild steelhead SARs averaged less than NPCC the minimum of 2%, but met the minimum in 4 of 7 years during 1997-2003.

b. SARs of hatchery spring/summer Chinook tracked closely with those of the aggregate Snake River wild population during 1997-2004, indicating similar factors were influencing survival during the smolt migration and in the estuary and ocean life stage. The patterns observed in overall hatchery SARs appear useful for augmenting wild SAR data, as well as providing important management information for these specific hatcheries.

c. Multiple linear regression analysis indicated that SARs of Snake River wild spring/summer Chinook were positively correlated with faster water travel time experienced during the smolt migration, cooler phases of the PDO index (primarily in May or September) and stronger down-welling in the fall (November) during the first year of ocean residence.
d. SARs of downriver wild spring Chinook from the John Day River (migrate through 5 fewer dams) averaged about four times greater than those from the Snake River during migration years 2000-2004. The difference in SARs between upriver and downriver wild Chinook is consistent with previous findings of differential mortality between upriver and downriver population groups based on spawner and recruit data before and after FCRPS completion (Schaller et al. 1999, 2000, Deriso et al. 2001; Schaller and Petrosky *In Press*).
e. Upriver and downriver hatchery spring/summer Chinook SARs did not show the same level of differential mortality as was apparent from the wild populations.
f. Our comparison of upriver and downriver wild Chinook salmon population-specific life history attributes found no evidence for a consistent and/or systematic difference in size-at-migration, timing distributions, and migration rates in the hydrosystem. Thus, while our use of an upriver-downriver comparison relies on a 'natural experiment' approach and therefore has some design limitations, the analysis we present here illustrates that the potential confounding effects due to life history differences are probably negligible.
g. The CSS PIT tag results clearly demonstrate delayed estuary entry of Snake River in-river smolts due to the presence and operation of the FCRPS.
h. When Snake River wild Chinook arrive to the lower Columbia River in the same time window (April 16 - May 31) as the John Day River smolts, the disparity between SARs for Snake River wild Chinook provides additional support for mechanisms of delayed hydrosystem mortality beyond the simple alteration of estuary entry timing.

X- Chapter 6

a. The CSS project has routinely estimated survival of hatchery Chinook smolts from release to LGR for each hatchery and year. Dworshak Hatchery has typically had the highest survival through this life stage, but lowest overall SARs and poorest response to transportation compared to other hatcheries in the study.
b. A portion of the SAR survival difference observed in the TIR estimates between Chinook salmon with different juvenile outmigration histories (transportation or in-river) is manifested through mortality and/or straying during the adult upstream migration. Adults that were transported from LGR as smolts survived the upstream migration at a 10% lower rate than those with either an in-river smolt history or those that were transported from LGS or LMO. Use of project specific PIT-tag detections has become the standard for estimating inter-dam conversion rates for use in in-season fisheries management; the CSS findings suggest such estimates may be positively biased if transportation history is not considered in the estimation process. The consequences of increased straying due to

transportation may also extend beyond the Snake River populations in these analyses, for instance by creating situations with undesirably high of-of-basin strays in mid-Columbia steelhead (listed) and spring Chinook (unlisted) populations.

c. This difference in upstream migrant mortality between different juvenile outmigration routes was not apparent upstream of the hydrosystem, based on relative proportions of detected adults at the hatcheries. Obtaining absolute survival estimates from LGR to the hatcheries has been problematic, due in part to difficulties in accounting for fish which may stray or spawn below the hatchery racks, uncertainties in harvest accounting, and possible issues with tag loss or detection inefficiencies at the hatchery racks. These accounting issues are beyond the present scope of CSS, but may be addressed with future directed studies.

d. The CSS transportation evaluations based on LGR smolts and LGR adults appear to reasonably describe the relative performance of transported and in-river migrants, based on our finding of no apparent survival difference upstream of the hydrosystem. This result should be tested in future CSS evaluations.

XI- Chapter 7

a. We developed a simulation model to evaluate the influence of violating key assumptions for the Cormack-Jolly-Seber (CJS) on CSS parameters of interest.

b. Specifically, we investigated the impact that violations of key assumptions of the Cormack-Jolly-Seber (CJS) have on our ability to obtain accurate estimates of reach survival rates and other study parameters through two sets of simulations.

c. The first set of simulation results showed that :

    i. CJS-based estimation of parameters of SARs by study group (sarC$_0$, sarC$_1$, and sarT$_0$), TIRs (sarT$_0$/sarC$_0$), S_R (inriver survival from LGR to BON), and *D* (delayed differential mortality between T$_0$ and C$_0$ groups) are robust to population changes in survival rates and collection probabilities over time.

    ii. for the range of changing simulated survival rates and collection probabilities over time, the bootstrap confidence intervals appear to adequately capture the width of the 'true' simulated population for CJS-based estimates of SARs for each study group and the TIR, S_R, and *D* parameters.

d. The second set of simulation results showed that:

    i. CJS-based estimation of parameters of SARs by study group (sarC$_0$, sarC$_1$, and sarT$_0$), TIRs (sarT$_0$/sarC$_0$), S_R (inriver survival from LGR to BON), and *D* (delayed differential mortality between T$_0$ and C$_0$ groups) are not as robust to population changes in survival rates between segments of a common population (based on prior passage experience) as was observed when changes were strictly temporal in nature. However, the differences between simulated and true values of TIRs, Srs, and Ds were generally less than 10%.

    ii. the impacts of violating the assumption that prior detection history has no effect on the survival rates, appears to more strongly influence the CJS-based estimates for the number of smolts used in the Study Category C$_0$

('true inriver control').

XII- We conclude that the CSS study successfully met the four primary objectives: 1) develop long term index of transport to inriver SARs for Snake River hatchery and wild Spring/summer Chinook and Steelhead; 2) develop long term index of survival rates from release of yearling Chinook smolts at hatcheries to return of adults at hatchery; 3) compute and compare overall SARs for selected upriver and downriver spring/summer Chinook hatchery and wild stocks; and 4) begin a time series of SARs for use in regional long term monitoring and evaluation.

XIII- The above CSS study objectives specifically focused the overall question of whether collecting juvenile fish and transporting them downstream in barges and trucks and releasing them below Bonneville Dam was compensating for the effects of the Federal Columbia River Power System (FCRPS) on survival of Snake Basin spring/summer Chinook and steelhead migrating through the hydrosystem (Mundy et al. 1994).

The CSS results indicated that the survival of transported fish relative to in-river groups varied across species and between wild and hatchery groups. Wild spring/summer Chinook showed little relative benefit from transportation most years (TIR ~ 1.0), except in severe drought years. Wild spring/summer Chinook exhibited substantial differential delayed transport mortality (D <1.0). Responses of hatchery spring/summer Chinook to transportation were more positive (TIR averages across hatcheries ~ 1.1-1.5) than those of wild, but hatchery Chinook still exhibited substantial differential delayed mortality relative to in-river migrants (D < 1.0). Wild and hatchery steelhead responded more positively to transportation (TIR wild mean of 1.7, TIR hatchery mean of 1.5) than wild spring/summer Chinook, however, considerable differential delayed mortality of transported steelhead was also evident (D < 1.0).

Overall SARs for wild spring/summer Chinook (geometric mean 0.9%, range 0.3% - 2.4%) fell short of the NPCC SAR objectives (2% minimum, 4% average for recovery), and were only 1/4 that of similar downriver populations which migrated through fewer dams. Overall SARs of wild steelhead (geometric mean 1.6%, range 0.3%-2.9%) also fell short of NPCC SAR objectives, although they exceeded those of wild Chinook. Based on these CSS SAR results relative to NPPC SAR objectives, it appears that collecting juvenile fish at dams and transporting them downstream in barges and trucks and releasing them downstream of Bonneville Dam did not compensate for the effect of the FCRPS on survival of wild Snake Basin spring/summer Chinook and steelhead migrating through the hydrosystem. Compared to regional broad sense recovery goals which include providing harvestable surplus (future target levels e.g. CBFWA goals and subbasin plans) for wild Snake Basin spring/summer Chinook and steelhead; the estimated CSS SARs are insufficient to also meet these goals.

The CSS project evaluated hydrosystem management actions as they occurred during the past decade, with primary emphasis on juvenile transportation operations. The FCRPS configuration and operations changed during the study period. Hydrosystem management and system configuration will undoubtedly continue to evolve into the future, which will require a long-term monitoring and evaluation program such as CSS to track its effectiveness.

We have demonstrated that the implementation of the CSS study and the accompanying analyses have provided the region with long term indices of survival rates to assess the performance of inriver and transport groups of spring/summer Chinook and steelhead. In addition, we performed assessments that evaluated the relationship of these various survival rates to hydrosystem operational conditions while considering the influence of varying environmental conditions. These findings appear to have important implications for operation of the hydrosystem and provide the building blocks needed to develop tools to evaluate various hydrosystem operational alternatives to ensure protection, restoration and mitigation of anadromous salmonids. Specifically, the CSS study results provide information on past hydrosystem conditions that have optimized survival of fish migrating inriver.

An important management question during the migration season is when to initiate transportation. The Biological Opinion operations are presently designed to change with the anticipated environmental conditions to meet the competing uses of the hydrosystem. The CSS results provide information on seasonal effects of transportation in comparison to in-river (C_1) fish. It should be noted that seasonal TIRs derived from seasonal C_1 SARs may contain some positive bias because the true controls (C_0-the way the system is presently managed), which migrate through spill and turbine routes at collector dams, have shown higher SARs than fish bypassed at one or more of the collector dams. The integration of the reach survival estimates (Chapter 2) and seasonal transport SARs from the CSS results have the potential to inform decisions on when to initiate transportation.

The CSS design and future results will provide the information to assess the response of the populations to any implemented set of management actions. A key element of the CSS design is marking fish above the hydrosystem so we have known origin fish, minimize handling effects on the study fish, and better represent the run at large. Given the long-term nature of the CSS (consistent marking levels and study approach), there will be the ability to gauge population response to future management actions to the historical population performance of past actions.

XIV- CSS SAR estimates provide a time series for status and trend monitoring and these time series of SAR estimates and reach survival estimates provide key information to assess action effectiveness for some the hydrosystem management actions. In addition these time series of CSS survival estimates provide a base line to assess future management actions. Given these conclusions, the following is a list of recommended activities for the continuation of the CSS and to guide the future direction:

a. Maintain the time series of PIT tag information at the levels necessary to provide reach survivals, annual and seasonal transport SARs, inriver SARs, and overall SARs for hatchery and wild Snake River spring/summer Chinook and steelhead. Maintain the time series of PIT tag information at the levels necessary to provide overall SARs for John Day spring Chinook and steelhead and Carson hatchery spring Chinook..
b. Identify additional downriver wild and hatchery populations to PIT tag and provide additional downriver overall SARs.
c. Identify additional Snake River hatchery steelhead populations to PIT tag at levels necessary to provide reach survivals, annual and seasonal transport SARs, inriver SARs, and overall SARs.
d. Augment existing PIT tag groups of Snake River wild steelhead populations to levels necessary to provide reach survivals, annual and seasonal transport SARs, inriver SARs, and overall SARs.
e. Investigate how to improve adult LGR to hatchery rack return estimates.
f. Continue to evaluate the key assumptions of the CJS model in relation to constraints placed on the experimental design given limitations for hydrosystem operations, with continued diligence to minimize bias.
g. Continue to evaluate the relationship between reach survivals and environmental conditions within hydrosystem.
h. Continue to evaluate the relationships between population overall SARs and environmental conditions within and outside the hydrosystem.
i. Evaluate the relationships between population seasonal SARs and environmental conditions within and outside the hydrosystem.
j. Develop techniques and evaluate the relationship between population overall SARs and recruit/spawner information.
k. Continue to coordinate the CSS with other research and monitoring programs in the Columbia Basin to provide and improve efficiencies for PIT tagging, tag detections, data management, and data accessibility.

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Appendix A
Logistical Methods

Introduction

The chronology of the logistical development for conducting the CSS is presented in Table A-1. This progression is organized by CSS Annual Report and shows the sources of PIT-tagged fish available to the CSS across the years, changes in the proportions of PIT-tagged smolts being routed to transportation, and changes to the capabilities to detect returning PIT-tagged adults as more dams were fitted with adult PIT-tag monitors in their fish ladders.

Sources of Study Fish

Fish utilized in the CSS are marked with a unique-coded passive integrated transponder (PIT) tag, which was evaluated for use on salmonids by NOAA (Prentice *et al.* 1986). The computer chips are encapsulated in glass with a 12-mm length and 0.05-mm width. PIT tags are cylindrical in shape and impermeable to water. Individual PIT tags are implanted into the fish's underbelly using a hand-held syringe with a 12-gauge veterinary needle (PTOC 1999 PIT-Tag Marking Procedures Manual). Tag loss and mortality of PIT-tagged fish are monitored, and the tagging files are transferred to Pacific State Marine Fisheries Commission's regional PTAGIS database in Portland, OR.

In each year of the CSS, there have been yearling spring/summer Chinook specifically PIT tagged at key hatcheries for this program. In the Snake River, the hatcheries were selected from each of the four tributary drainages (Clearwater, Salmon, Imnaha, and Grande Ronde rivers) above Lower Granite Dam. Both spring and summer stocks were included. Hatchery programs were selected which accounted for a major portion of the Chinook production in their respective drainage in order to have sufficient numbers of smolts and returning adults for computing statistically rigorous smolt-to-adult survival rates. Since study inception, hatchery fish consistently used in the CSS include Chinook tagged at McCall, Rapid River, Dworshak, and Lookingglass hatcheries. Chinook tagged at Lookingglass Hatchery included the Imnaha River stock that continues to be released at the Imnaha River weir and the Rapid River stock that was released on-site through 1999 and discontinued thereafter in favor of Grande Ronde River basin endemic stocks. Throughout this report, we classify the Imnaha River Chinook as a summer stock (contrary to ODFW classification) due to its high return rate of jacks and later timing of its returning adults, which coincides with the summer stock from McCall Hatchery stock.

In the lower Columbia River, the CSS has PIT tagged Chinook at Carson Hatchery since 1997 for the upstream/downsteam comparisons. There was the attempt to include two additional hatchery stocks for the lower Columbia River when the CSS was initiated. Cowlitz Hatchery spring Chinook were tagged for two years, but dropped due to the outmigration characteristics of this stock being more ocean type than stream type. Round Butte Hatchery spring Chinook were tagged for three years, but dropped to due to high BKD levels occurring during the tagging period, which for logistical constraints had to take place at or near the time fish were leaving the facility.

Table A-1. Progression of study design logistics changes through the series of annual reports prepared by the CSS in 2000 to 2006.

CSS Document	PIT-tagging and fish disposition for CSS	Source Fish	Adult Detections
Annual Report 2000 Published Oct. 2000 DOE/BP-00006203-1 Report covers 1996-1998 sp/su hatchery Chinook (HC) mark/recapture activities (adult returns to 2000)	Tagging was proportional to hatchery production levels in 1996 and 1997, but changed to a fixed tagging quota per hatchery in 1998 in order to allow a more similar release across hatcheries with widely differing production levels. In 1996, fish were tagged only for inriver migration data. Starting 1997, fish are tagged for both transportation and inriver migration data. In 1997, separation-by-code (SbyC) routed 80% of CSS PIT-tag HC detected at LGR to raceways (transportation); min goal of 43K transported and 64.5 K in-river tags (total of all CSS hatcheries) was missed for transport fish. So in 1998, SbyC routed 75% of CSS PIT-tag HC at LGR (all season) and first-time detected at LGS (thru May 9) to raceways (transportation); min targets were reached.	1996 - Upriver HC Dworshak, Kooskia, Clearwater (Powell, Crooked R, Red R AP), McCall, Rapid R., and Lookingglass (onsite and Imnaha AP) 1996 - Downriver HC Cowlitz & Round Butte 1997 - Upriver HC Replace Clearwater H with Sawtooth H (release at Pahsimeroi) Others the same 1997 - Downriver HC Add Carson NFH 1998 - Upriver HC Drop Kooskia & Pahsimeroi H Others unchanged. 1998 - Downriver HC Drop Cowlitz H	Upriver HC Detections at LGR adult trap for all PIT-tagged Fish Upriver return to hatchery 1. McCall H returns to SF Salmon Weir 2. Lookingglass H Imnaha stock returns to Imnaha Weir 3. Lookingglass H (on-site released fish) were 100% CWT and collected at LGR adult trap and trucked to hatchery. 4. Rapid River H returns to adult trapping facility 5. Dwoshak H returns to hatchery fish ladder 6. Kooskia H returns to facility Downriver HC Only detection available is at hatchery facility for Carson, Round Butte, and Cowlitz H returns
Annual Report 2001 Published Feb. 2002 DOE/BP-00006203-2 Report covers 1997-2000 sp/su HC mark/recapture activities with SARs thru 1999 (adult returns to 2001) This report adds 1994 to 1999 wild Chinook (WC) with adult returns to 2001.	In 1999, SbyC routed 67% of CSS PIT-tag HC at LGR (all season) and first-time detected at LGS (beginning May 10) to raceways (transportation); min targets were reached. Following analysis of data from the early years of the CSS, it was determined that routing the same proportion (67%) of first-time detected PIT-tagged fish to transport at each collector dam will be the preferred approach in future years (see discussion in Appendix B); this preferred approach was implement starting in 2000 for HC.	1999 – Upriver HC Dworshak, McCall, Rapid R., and Lookingglass (onsite and Imnaha stock releases) 1999 - Downriver HC Carson NFH (drop Round Butte) 1994 to 1999 – Upriver WC Annual aggregate PIT-tag groups are created using all available tagged wild sp/su Chinook released above LGR for each year's outmigration. Limited to timing, reach survivals, smolt #s – no SARs: 2000 – Upriver HC Lookingglass(on-site) stopped 2000 - Downriver HC Carson NFH	Upriver HC Detections at LGR adult trap for all PIT-tagged Fish The CSS adults had lengths taken, sex and injury noted, and scales obtained. Upriver WC Detections at LGR adult trap, but not sampled for additional data Upriver return to hatchery (data collected for hatcheries listed above, but not presented in report) Downriver HC (release information presented only)

CSS Document	**PIT-tagging and fish disposition for CSS**	**Source Fish**	**Adult Detections**
Annual Report 2002 Published Nov. 2003[A] DOE/BP-00006203-4 Report covers 1997-2000 sp/su HC & 1994-2000 sp/su WC (adult returns to 2002)	(Same as described above for migration years 1997 to 2000) Conditioned WC aggregate PIT-tag population on fish released between July 25 of year preceding outmigration and May 20 of year of migration in order to nearly eliminate tagged fish that outmigrate in a year later than migration year of interest. These tagged fish followed the default return-to-river routing except during SMP timed samples or unplanned operational events.	Report produces SARs for: <u>1997 to 2000 – Upriver HC</u> Dworshak, McCall, Rapid R., and Lookingglass (onsite to 1999 and Imnaha stock releases) <u>1994 to 2000 – Upriver WC</u> Annual aggregate PIT-tag groups are created using all available tagged wild sp/su Chinook released above LGR for each year's outmigration. <u>1997 to 2000 - Downriver HC</u> Carson NFH	<u>Upriver HC</u> (unchanged) <u>Upriver WC</u> (unchanged) <u>Upriver return to hatchery</u> First report to present SARs (hatchery-to-hatchery) for 1997-2000 releases from hatcheries listed at left. <u>Downriver HC</u> First report to present SARs (hatchery-to-hatchery) for 1997-2000 releases from Carson NFH
Annual Report 2003/04 Published Apr. 2005[B] DOE/BP-00006203-5 Report covers 1997-2002 sp/su HC & 1994-2002 sp/su WC (adult returns to 2004)	In drought year 2001, in-river migrants in C_1 are used to estimate annual SAR, TIR, and *D* due to negligible C_0 fish present since no spill at Snake River collector dams. In 2002, due to non-standard operations planned at LMN, the CSS did not directly route PIT-tagged fish to transport at that site. Beginning 2002, coordination with state and tribal tagging programs allowed 50% of their first-time detected PIT-tagged wild Chinook smolts to be routed to transport.	<u>2001 to 2002– Upriver HC</u> Add Catherine Ck AP starting 2001 to replace the discontinued on-site release from Lookingglass H; others same as above. <u>2001 to 2002 – Upriver WC</u> (unchanged) <u>2001 to 2002 – Downriver HC</u> Carson NFH <u>2000 to 2002 – Downriver WC</u> Add PIT-tagged John Day River wild Chinook starting 2000	<u>Upriver HC and WC</u> (unchanged) <u>Upriver return to hatchery</u> New adult detection site is the adult trapping facility on Catherine Ck. SARs from hatchery-to-hatchery presented for 1997-2001 for other hatcheries. <u>Downriver HC and WC</u> Addition of detections from the new BON adult ladder PIT-tag detectors.
Annual Report 2005 Published Dec. 2005 DOE/BP-00025634-1 Report covers sp/su HC and WC thru 2003 (adult returns to 2005) Report adds 1997-2002 wild steelhead (WS) & hatchery steelhead (HS) (adult returns to 2004)	Beginning with this annual report, existing PIT-tagged wild and hatchery steelhead are analyzed in two aggregate populations based on rearing type. These PIT-tagged fish followed the default return-to-river routing except during SMP timed samples or unplanned operational events.	<u>2003 – Upriver HC and WC</u> (unchanged) <u>1997 to 2002 – Upriver HS, HW</u> Annual aggregate PIT-tag group of wild steelhead (>130mm) tagged July 1 of prior year thru June 30 of migration year, plus another for hatchery steelhead, is created with all available tagged steelhead released above LGR. <u>2003 – Downriver HC and WC</u> (unchanged)	<u>Upriver HC, WC, HS, WS</u> Detection of PIT-tagged returning adults is possible at MCN and Ice Harbor beginning return years 2003 and 2004, respectively. <u>Upriver return to hatchery</u> SARs (hatchery-to-hatchery) for 1997-2002 <u>Downriver HC and WC</u> (unchanged)

CSS Document	PIT-tagging and fish disposition for CSS	Source Fish	Adult Detections
Annual Report 2006[C] Published Nov. 2006 DOE/BP-00025634-2 Report covers sp/su HC and WC thru 2004 (adult returns to 2006) Report covers HS and WS thru 2003 (adult returns to 2005)	Beginning 2003, coordination with state and tribal tagging programs allowed 50% of their first-time detected PIT-tagged wild steelhead smolts to be routed to transport at Snake R. collector dams. This matches the routing rate for PIT tagged wild Chinook, while that of PIT-tagged hatchery Chinook remains at 67% at these collector dams.	2004 – Upriver HC and WC (unchanged) 2003 – Upriver HS and WS (unchanged) 2004 – Downriver HC and WC (unchanged)	Upriver HC, WC, HS, WS (unchanged) Upriver return to hatchery (Not analyzed in report) Downriver HC and WC (unchanged)
Items pertinent to future CSS annual reports covering migration years 2005 to 2007 for HC/WC and 2004 to 2007 for HS/WS	1. In 2005, the rate of routing first-time detected PIT-tagged wild and hatchery steelhead and wild Chinook to transport is raised to 67% (matching that of hatchery Chinook) at the Snake R. collector dams. In this year, the routing rate for wild steelhead is also raised to 67%. 2. In 2006, the CSS adopted the NPT approach of pre-assigning a portion of the tagged fish to reflect the experience of untagged fish (which typically is transportation if collected at one of the Snake River transport site) and the remaining portion to the default return-to-river routing if collected at a Snake River dam. PIT-tagged fish in these pre-assigned groups are from state and tribal tagging activities that are cooperatively participating with the CSS.		

[A] BPA cover page to CSS Report erroneously shows April 2005 as publish date instead of November 2003.
[B] BPA cover page to CSS Report erroneously shows November 2003 as publish date instead of April 2005.
[C] BPA cover page to CSS Report erroneously shows 2005-2006 for Annual Report # instead of just 2006.

With the exception of the additional PIT tags provided by the CSS for use on wild Chinook tagging at Smolt Monitoring Program traps and numerous traps operated by IDFG in upper tributaries of the Clearwater and Salmon rivers, most PIT tagged wild Chinook were obtained from all available marking efforts in the Snake River basin above Lower Granite Dam. The wild stocks included Chinook PIT tagged as parr (late July-August) in Idaho streams, pre-smolts (September-December) in Idaho and Oregon streams, and smolts (March-May) in Idaho and Oregon streams. These wild and hatchery steelhead used in the CSS are also from other existing tagging efforts in Idaho and Oregon streams. Since 2003 an additional 2,000 PIT-tags has been budgeted specifically for CSS tagging purposes at the IDFG trap located near the mouth of the Clearwater River.

Although the individual hatchery populations are analyzed separately, this is not the case for the wild Chinook, wild steelhead, and hatchery steelhead tag groups. Aggregate of available PIT tags for these two species by rearing type are created to obtain larger tagged populations for determinations of SARs. Ideally, the PIT-tagged wild steelhead, hatchery steelhead, and wild Chinook used to create these aggregate marked populations should be as representative of the untagged population as possible. For wild fish, the collection and tagging occurs over lengthy time periods from parr stages to smolt stages in each sub-basin located above Lower Granite Dam including the Clearwater, Grande Ronde, Salmon, and Imnaha rivers. These wild fish were PIT-tagged by various organizations over a 10 to 12-month period with varied sampling gear including incline-plane (scoop) traps, screw traps, electrofishing, hook and line, and beach seining. At the hatcheries, fish were obtained across as wide a set of ponds and raceways as possible to allow effective representation of production. Most hatchery steelhead releases have a small number of PIT-tagged fish, typically between 200 and 1000 fish per individual hatchery. The aggregate of these PIT-tag releases provided a fairly good cross-section of the hatchery production in each year, although it was not proportional to the magnitude of each hatchery production. Likewise, the number of wild fish PIT-tagged in each tributary is not expected to be proportional to the total population present; however, with PIT tagging occurring across a wide range of the total population, the resulting SARs of this aggregate PIT-tag population should be adequately reflective of the total population.

The PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead used in the CSS were initially PIT-tagged to satisfy the goals of several different research studies. At certain times of the year, multiple age classes of fish were being PIT-tagged. To ensure that smolts in our annual aggregate groups were actually migrating out in the respective year of interest, fish detected entirely outside the migratory year of interest were excluded. This was necessary since estimates of collection efficiency and survival must reflect a single year. For wild Chinook, we found that limiting the tagging season to a 10-month period from July 25 to May 20 each year reduced the instances of overlapping age classes. In this 10-month period, few additional fish were excluded due to being detected at the dams or trawl in a year outside the migration year; this was less than 0.1% in all years except 1994 when it was 0.18%. For wild steelhead, we 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). Excluding wild steelhead below 130 mm and above 299 mm reduced the instances of multiple age classes and allowed the tagging season to be a full 12-months from July 1 to June 30 each year.

Detection of study fish

PIT-tagged smolts were detected at six Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA), and Bonneville (BON). In addition, PIT-tag detections were obtained at the NOAA Fisheries trawl (TWX) operated in the lower Columbia River half-way between BON and the mouth of the Columbia River.

When PIT-tagged smolts enter the bypass/collection facility of a dam from which transportation occurs, there are four potential outcomes. The tagged fish may (1) be returned-to-river under the default routing option, (2) be routed to the raceways for transportation if requested by the researcher, (3) be routed to the sample room for anesthetization and handling prior to being routed to transportation, and (4) be seen only on the separator detector coils and therefore have an unknown disposition at that site. For PIT-tagged wild steelhead, hatchery steelhead, and wild Chinook originating above LGR, the number of tagged fish specifically routed to transportation has been very small in most prior years prior to 2002 (wild Chinook) and 2003 (wild steelhead and some hatchery steelhead releases). Since the default operation has been to return PIT-tagged fish to the river at collector dams, the only reason some PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead were transported in the early years was because (1) the daily timed subsampling intervals of the Smolt Monitoring Program over-rides the default return-to-river operation for PIT-tagged fish (sampled fish are usually transported) and (2) the occurrence of periods when equipment malfunctions caused the collected PIT-tagged fish to go to the raceways. Based on the detection history of PIT-tagged smolts at the collector dams, we are able to determine into which CSS study category (defined below) to assign these PIT-tagged fish.

PIT-tagged returning adults were detected in the Lower Granite Dam adult fish ladder (GRA) in each year. The adult fish passage facilities at LGR incorporate an adult fish trap located just off the main fish ladder. When trapping occurs, adult fish are diverted from the main fish ladder into a pool area where two false weirs, a metal flume, coded wire detectors, and PIT detectors are in line leading to the adult holding trap. Unmarked fish or fish not required to be diverted will drop back into the fish ladder, and continue up to the main fish ladder where they can exit to the forebay of the dam. In return years through 2001, the tag identification files for CSS PIT tagged chinook were installed in the separation-by-code program that allows the PIT tag detector to selectively trip a gate and shunt these fish to the holding trap. This was done in order to obtain data on fish length, sex, condition (injury), and age (scale sample). Beginning in return year 2002, these data were no longer collected at LGR. Fish length, sex, and condition data will be obtained from the hatcheries. Thereafter, returning adults reaching LGR have continued upstream without any handling at that site. Adults detected at LGR are assigned to a particular study category based on the study category they belonged to as a smolt and fish with no previous detections at any dam are automatically assigned to the category of fish passing the three Snake River collector dams undetected.

Beginning in return year 2002, detectors were installed in all the adult fish ladders at Bonneville (BOA) and McNary (MCA) dams, allowing detection of returning PIT-tagged adults at these additional locations. The addition of PIT-tag detection capabilities at BOA was imperative to the upstream/downstream comparisons of the CSS. In 2003, Ice Harbor Dam (IHA to 4/1/2005 and ICH thereafter) was fitted with a PIT tag detection system in its fish ladder. Lower Granite Dam has PIT tag detection coils located near the adult trapping facility and at the exit section of the adult fish ladder. As noted last year, the LGR adult PIT-tag detection efficiency is ≥ 98% (Berggren *et al.* 2005), so no adjustments to the number of detected adult PIT-tagged fish at LGR are necessary.

All SARs for wild and hatchery Chinook are computed with only returning adults, age 2-salt and older. In the total return, the average percent returning as jacks is higher for summer Chinook stocks than it is for the spring Chinook stocks. This highly variable jack return rate among races in hatchery Chinook and the extremely low proportion of jacks observed within the wild Chinook returns is one reason that SARs computed in the CSS report do not include jacks. All SARs for wild and hatchery steelhead are computed with returning age 1-salt and older adults. Mini's for either species returning in the same year of they outmigrated are not used in any computations.

Defining study groups and study area for SARs

A major objective of the CSS was to compute and compare overall smolt-to-adult survival rates for smolts transported through the hydro system versus smolts migrating in-river. Since 1995, the standard hydro system operation was to transport all smolts collected at LGR, LGS, and LMN throughout the spring and summer seasons, and at MCN only when the subyearling chinook migration predominates the collections in the summer. An exception to this rule occurred in 1997 when large portions of the collections at LGS and LMN were returned to the river in a fishery agencies/tribal effort to equalize the numbers of smolts being transported and remaining in-river that year. The last year of springtime transportation at MCN occurred in

1994. Although all collected smolts were transported in 1994, there were only 42 PIT tagged wild chinook with first detection at MCN that were transported. With so few PIT tagged smolts and no adult PIT tag detections, it was not possible to estimate a SAR for yearling chinook transported from MCN in 1994. Since then there have been too few late-migrating PIT tagged wild yearling chinook smolts collected and transported as first-time detections from MCN to assess SARs from there. Therefore, all CSS status report include the transported smolts from the three Snake River collector dams.

In order to make valid comparisons between groups of smolts with different hydrosystem experiences, we must have common starting and end points for each study group. The most common life stage of study in the CSS has been from LGR as smolts and back to LGR as adults for transportation evaluations and from first-dam detected (LGR for the Snake River stocks, JDA or BON for downstream stocks) as smolts to BON as adults for the upstream/downstream comparisons. Since fish are being transported from three different dams, there is mortality in migrating in-river from LGR to the lower transportation facilities that must be taken into account. It takes a larger count of smolts starting at LGR to provide the final number being transported from LGS or LMN. This is the concept behind the term smolts "destined" for transport. Therefore, an estimated survival rate is needed to convert the actual transport numbers at LGS and LMN into what their LGR starting number would have been (*i.e.*, LGR equivalents). We define transportation at LGR, LGS, and LMN in terms of LGR equivalents, because we are in effect making our allocation into transportation at each dam from the starting number of fish at LGR. Ryding (2006) documented in an actuarial approach the necessity of accounting for the losses between dams for both the transported and inriver migrating smolts when computing SAR and ratios of SAR.

Although transportation occurs at three dams in the Snake River, the CSS did not purposely divert CSS tagged hatchery Chinook smolts into transportation at each dam until 2000. In 2000, the CSS established the protocol of routing the same proportion of the collection of first-time detected smolts at each of the three Snake River collector dams. Whereas in 1997 to 1999, the goal was to attain a fixed quota of smolts transported per hatchery group, with priority of meeting that quota with transportation from LGR first, followed by adding LGS and LMN if more fish were required. With this approach, nearly all CSS transported hatchery Chinook in the transportation group were from LGR, while in 1998 and 1999 there was sizeable numbers of smolts from LGS in the transportation study group. At LGS the CSS PIT-tagged hatchery Chinook were routed to transport for part of the seasons of 1998 and 1999 (routing PIT-tagged fish to transportation ended on May 9 in 1998 and commenced on May 10 in 1999). But this did not occur at LMN until 2000.

It was decided not to route CSS PIT-tagged hatchery Chinook to transportation at LMN in 2002 because of the non-standard operations implemented there to reduce the numbers of fish collected and transported in the absence of spill at that site. This change in project operations from other years was due to repairs being made to the stilling basin below the project. Those repairs required the curtailment of spill at LMN for the season, except for several days around May 22 when spill in excess of hydraulic capacity occurred due to a unit outage (FPC 2002 Annual Report). Spill was increased at LGR and LGS to offset the no spill operations at LMN. With larger than usual numbers of migrating salmonids expected to be collected at LMN under this no spill operation, the facility operations were modified to 2 days collection and transportation followed by a day of direct bypass (no PIT-tag detections possible) for every 3-day interval between April 30 and mid-June when subyearling Chinook began to predominate.

In addition, direct bypass occurred during most of April. All PIT-tagged fish passing the dam through the primary bypass would be undetected and would inappropriately be included in the study category on non-bypassed fish. The remaining undetected PIT-tagged fish would have passed through the turbines in the absence of spill. Under this operation, it was not possible to accurately separate bypassed and non-bypassed tagged fish at LMN during most of the 2002 migration season. Even with this change in operation, LMN still transported a higher number of fish than occurred at either LGR or LGS in 2002.

The numbers of PIT-tagged wild Chinook actually transported in migration years prior to 2002 has been relatively small due to the fact that the standard protocol in those years was to bypass PIT-tagged smolts back to the river. In these years, PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead were only incidentally routed to transportation during the daily timed subsampling intervals (typically 2-6 subsamples per hour of varying duration for 24-hrs) of the Smolt Monitoring Program or when equipment malfunctions caused all collected PIT-tagged fish to be routed to the raceways. All fish collected in the sample room were subject to anesthetization and hands-on processing before being transported, whereas fish routed directly to the raceways or barges did not have this added handling affect. Beginning in 2002, the CSS coordinated with state and tribal research programs (IDFG, ODFW, and CTRUIR) to purposely route 50% of the first-time detected PIT-tagged wild Chinook smolts at Snake River transportation facilities to the raceways for transportation. This proportion was increased to 67% in 2003, and in that year the routing of PIT-tagged wild steelhead to transportation was added. This action has provided more PIT-tagged wild Chinook and wild steelhead smolts in the transportation category in recent years.

Since the PIT-tagged study groups should be representative of their non-tagged counterparts, PIT-tagged fish passing through the hydro system should mimic the experience of non-tagged fish. In the years 1997 to 2005, the CSS used separation-by-code (SbyC) capabilities at the collector dam to route a fixed ratio (1:2 or 2:3) of the collected (and detected) PIT-tagged study fish to the raceways for transportation. Since untagged smolts are nearly always transported when they enter a bypass/collector facility at the Snake River dam, it was desirable to include only the first-time detected smolts at these dams when determining numbers of PIT-tagged smolts transported. Most smolts with prior detection that are again detected downstream at another collector dam had simply followed the default return-to-river routing established for PIT-tagged fish at the upriver dam, and were not representative of the experience of the untagged fish. However, there are special instances, such as when raceways are full and no barge is available for transport, when both the untagged and PIT-tagged fish held in the raceways of an upriver dam will be returned to the river and could downriver be collected and transported from another dam. In this special case, the constraint of having to be a first-time detected PIT-tagged fish does not mimic the untagged fish affected. For this and other reasons to cover later, the CSS adopted the approach pioneered by the Nez Perce Tribe (NPT) in which one pre-assigns a proportion of their tags to a PIT-tag group that directly reflects the experience of the untagged fish. The SbyC operations at the collector dams is set so that this group of tags is routed exactly the same as the untagged fish. The remaining proportion of the tags is then pre-assigned to a PIT-tag group that will follow the default return-to-river routing at the collector dams. This second group is used in the estimation of the reach survival rates to and through the hydrosystem. In the 2006 review of the CSS by the ISAB, a recommendation for the CSS to adopt the NPT approach was made. It was successfully initiated in time for migration year 2006.

Holdovers within the hydrosystem below Lower Granite Dam

In the estimation of inriver survival rates with the Cormack(1964) – Jolly (1965) – Seber (1965) method (hereafter termed CJS), it is assumed that all PIT-tagged smolts in a group are outmigrating together in a single migration year. Any PIT-tagged fish detected as a smolt only in a year later than the expected migration year was excluded from the release group. This exclusionary clause was necessary particularly for wild Chinook and wild steelhead, because at times when multiple age classes were being PIT tagged, our constraints of size on steelhead and tagging dates on Chinook were not enough to remove non-migratory fish for the year of interest. However, PIT-tagged fish detected at an upper dam and then holding over within the hydrosystem with subsequent detections occurring the following year, were handled as follows. The capture history code for these fish showed detections at dams only during the year they initiated their outmigration. The detections in the following year were excluded during the estimation of CJS reach survivals and project collection efficiencies. Fortunately, few yearling Chinook and steelhead delayed in the hydrosystem until the following year except for steelhead that began their migration in 2001 (Berggren *et al*. 2005). No additional holdovers were observed for migration years 2003 (steelhead) and 2004 (Chinook).

Special handling of the 2001 inriver migrants

Obtaining a valid estimate of the number of PIT-tagged wild and hatchery steelhead passing the three Snake River collector dams undetected in 2001 is problematic due to apparent large amount of residualism that year. This is based on the finding that most inriver migrants that returned as an adult were hold-overs. Six of the eight adult returns of PIT-tagged wild steelhead and one of three adult returns of PIT-tagged hatchery steelhead that were bypassed as a smolt at a collector dam in 2001 were actually detected in the lower river in 2002. For the three PIT-tagged wild steelhead adult returns and two PIT-tagged hatchery steelhead adults returns that had no detection anywhere in 2001, it was more likely these fish either completed their smolt migration undetected in 2002 or passed undetected into the raceways during a computer outage in mid-May at LGR than traversed the entire hydrosystem undetected in 2001. Based on estimated collection efficiencies at the Snake River collector dams with no spill in 2001, less than one percent of the wild and hatchery steelhead tagged and untagged run-at-large was estimated to pass all three Snake River collector dams through turbines. Because of the uncertainty in passage route and timing of the undetected PIT-tagged wild and hatchery steelhead smolts in 2001, the in-river SAR for comparisons with transported smolts utilized PIT-tagged smolts that had some detections (bypassed) at the collector dams. In other years, the PIT-tagged smolts undetected at the collector dams (reflective of the untagged run-at-large) formed the inriver group for comparisons with transported smolts.

Although wild and hatchery Chinook were not as affected by residualism in 2001 as their steelhead counterparts, they too had a very small proportion (1.1% for wild Chinook and 2.2-3.6% for hatchery Chinook) of smolts estimated to potentially migrate through turbines at all three consecutive Snake River collector dams in 2001. There were PIT-tagged Chinook adult returns (one wild Chinook and six hatchery Chinook from three of the five CSS hatcheries) from PIT-tagged smolts undetected anywhere (typically about half of the fish undetected at the three collector dams would still have some detections downsteam at MCN, JDA, BON, or TWX). It is very unlikely that these seven adults where from smolts that actually outmigrated inriver in 2001.

It is more likely that because of the large numbers of PIT-tagged fish passing through the PIT-tag detectors during the peak of the run some of these were undetected at LGR and thereby passed to the raceways along with the untagged fish. There was a short period (18 minutes) on May 21 when a computer malfunction at Lower Granite Dam may have resulted in all PIT-tagged fish passing directly to the raceways undetected (PTAGIS site log for GRJ). This added uncertainty as to how fish with no detections at any site actually passed through the hydrosystem. Therefore, just as we did with steelhead, the PIT-tagged wild and hatchery Chinook smolts that had detections (bypassed) at the collector dams in 2001 were used in the comparisons with transported smolts that year.

Appendix B

Analytical Methods: Statistical Framework and Equations of Study Parameters

Statistical Framework Introduction

The parameters generated in the CSS fall into three key areas of interest for fishery managers. These are the annual smolt-to-adult survival rates (SAR) for key salmonid populations, comparisons of SARs relative to how fish experienced passage through the hydrosystem, and assessment of delayed differential survival between the fish with different hydrosystem passage experiences. In order to compute estimates for these parameters, we must have valid estimates of inriver smolt survival rates through reaches of the hydrosystem with corresponding collection probabilities at the dams bordering these reaches. The Cormack-Jolly-Seber (CJS) method is used to estimate these reach survival and collection probabilities. This appendix will present a description of how the estimates of the various study parameters of the CSS are computed and the underlying assumptions inherent in these estimations. It covers the formulas used to estimate the parameters of reach survivals, numbers of smolts in study categories T_0, C_0, and C_1, SAR(C_0), SAR(C_1), $SAR_1(T_0)$, $SAR_2(T_0)$, T/C and U/D ratios, and D, plus the annual SARs. Both the computation formulas and their expectations are presented for each parameter listed above. These are the basic parameters generated in the CSS. The chronology of the development of these formulas across the series of CSS annual reports and technical documents prepared through 2006 is presented in Table B-1.

Additional statistical methods used in hypothesis testing, regression analyses, and removal of sampling error from process error will be covered directly in the chapters where these methods are being used.

Estimation of survival rates and collection probabilities

In Ryding (2006) a list and discussion of twelve assumptions that are key to tag-recapture methods of survival rate estimation and the use of T/C ratios. Eight of the twelve assumptions are directly related to the tag release-recapture methodology for reach survival estimation (assumption number corresponds to Ryding document listing):

#1 – Tagged fish in the study are representative of the population.
#2 – All fish in a release group have equal detection and survival probabilities.
#3 – All fish in a release group have equal probabilities of a particular capture history.
#4 – Fates of individual fish are independent.
#5 – Previous detections have no influence on subsequent survival or detection probabilities.
#6 – Release numbers, capture histories, and PIT tag codes are accurately recorded and known.
#8 – Tagged fish removed [for any purpose, including transportation or for use in other studies] are known and accurately recorded.
#9 – All tagged fish in a cohort release migrate through the Snake and Columbia Rivers within the same season and while the bypass facility and transport systems are operational, *i.e.*, there is no delayed migration of tagged fish.

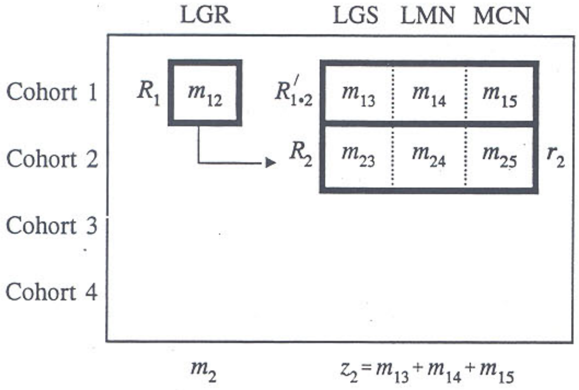
In the simulation chapter of this report, we investigated the impact that violations of assumptions #2 and #5 may have on the resulting reach survival rates and other study parameter estimates. Assumption #3 should be met whenever assumptions #2, #6, and #8 are satisfactorily satisfied. In Appendix A, we discuss how holdover fish were handled in order to minimize effect of violation of assumption #9. Also, we discussed the inability to estimate a valid C_0 study group for 2001 due to likelihood that some non-detected fish may have been transported that year, thus violating assumption #8. Assumption #1 is necessary to infer beyond the subsample of the population being tagged to the entire population. Although easier to accomplish with the hatchery Chinook tagging effort, it is felt that the cross-section of wild Chinook and steelhead, and hatchery steelhead populations included in tagging efforts will adequately reflect the overall population at the species/rear type level of resolution.

When the assumptions above are satisfied, then the theory of tag release/recapture models allows estimation of valid inriver reach survival rates and collection probabilities, which are necessary for expanding estimated PIT-tagged smolt numbers to LGR-equivalents, as noted in the Appendix A, and in the component of in-river survival rate through the hydrosystem, which is used in estimating delayed differential mortality between transported and inriver study groups.

PIT-tagged smolts can be detected in the bypass/collection facilities at Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA) and Bonneville (BON) dams, and in trawls equipped with PIT tag detectors deployed near Jones Beach (TWX). This array of detection sites is analogous to multiple recaptures of tagged individuals allowing for standard multiple mark-recapture survival estimates over several reaches of the hydro system. The Cormack-Jolly-Seber (CJS) (Cormack 1964; Jolly 1965; and Seber 1965) methodology was used to obtain point estimates of survival with corresponding standard errors from release to Lower Granite Dam tailrace and up to five reaches between Lower Granite Dam tailrace and Bonneville Dam tailrace.

The CJS methodology for estimation of in-river reach survival rates and collection efficiency at monitored dams uses reduced M-matrix as partially illustrated in Appendix B Figure 1 (shown to MCN, but same logic continues for remaining downstream detection sites). The first row of the reduce M-matrix gives the number of first-time detected fish at LGR (m_{12}), LGS (m_{13}), LMN (m_{14}), MCN (m_{15}), JDA (m_{16}), BON (m_{17}), and TWX (m_{18}). The notation for the complete reduced M-matrix is m_{jk}, where the j^{th} subscript refers to cohort number and the k^{th} subscript refers to site, where 1 is reserved for release site, and 2 to 8 are used to designate each subsequent downstream detection locations). Cohort 1 is the initial release and provides the tallies by site of all possible capture histories first-detected at that site; the sum across these tallies equating to the total number of tagged fish detected from a given initial release. Cohort 2 is made up of the fish returned-to-river at LGR and m_{2k} gives the summary tallies of these prior detected fishes' subsequent first-detection at a downstream dam. This process is continued through Cohort 7, which is made up of the fish returned-to-river at BON and

Survival from Primary Release to Lower Granite Tailrace

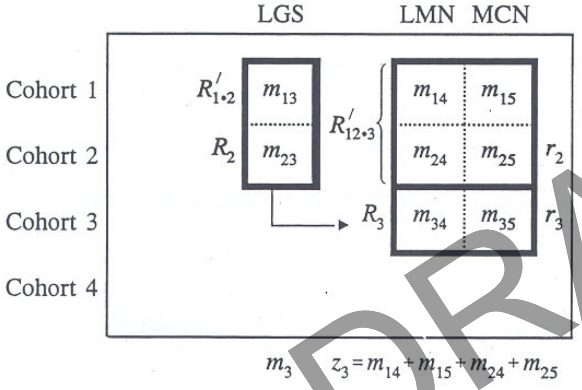


$$\phi_1 = \frac{m_2 + R'_{1\bullet 2}}{R_1}$$

$$\text{where } R'_{1\bullet 2} = z_2\frac{R_2}{r_2}, \quad \text{since } \frac{z_2}{R'_{1\bullet 2}} = \frac{r_2}{R_2}$$

$$\therefore\ \phi_1 = \frac{m_2 + z_2\dfrac{R_2}{r_2}}{R_1}$$

Survival from Lower Granite Tailrace to Little Goose Tailrace

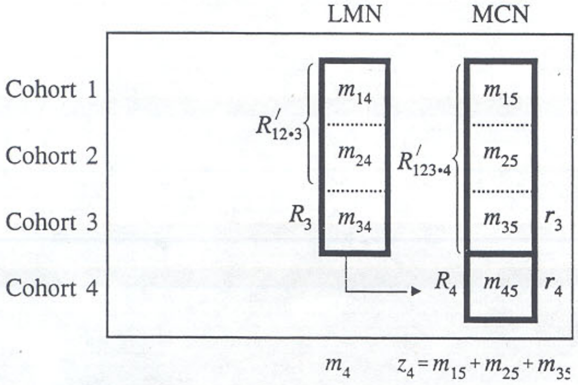


$$\phi_2 = \frac{m_3 + R'_{12\bullet 3}}{R_2 + R'_{1\bullet 2}}$$

$$\text{where } R'_{12\bullet 3} = z_3\frac{R_3}{r_3}, \quad \text{since } \frac{z_3}{R'_{12\bullet 3}} = \frac{r_3}{R_3}$$

$$\therefore\ \phi_2 = \frac{m_3 + z_3\dfrac{R_3}{r_3}}{R_2 + z_2\dfrac{R_2}{r_2}}$$

Survival from Little Goose Tailrace to Lower Monumental Tailrace



$$\phi_3 = \frac{m_4 + R'_{123\bullet 4}}{R_3 + R'_{12\bullet 3}}$$

$$\text{where } R'_{123\bullet 4} = z_4\frac{R_4}{r_4}, \quad \text{since } \frac{z_4}{R'_{123\bullet 4}} = \frac{r_4}{R_4}$$

$$\therefore\ \phi_3 = \frac{m_4 + z_4\dfrac{R_4}{r_4}}{R_3 + z_3\dfrac{R_3}{r_3}}$$

Appendix B Figure 1. Schematic of key part of reduced M-matrix used in estimation of CJS survival rates and CSS study category smolt numbers – complete reduced M-matrix of CSS includes three more sites (JDA, BON, and TWX) and three more cohorts (# 5, 6, and 7).

the tally of its fish subsequently detected at TWX is given by m_{78}. Ratios of various sums across different cohorts provide the ingredients for the CJS survival estimates as depicted in Figure 1 (note: this figure is only a partial depiction of all sites and cohorts, so the various m_j column tallies, z_k tallies and r_j row tallies will span more cohorts and sites than shown here: *e.g.*, $z_2 = m_{13} + m_{14} + m_{15} + m_{16} + m_{17} + m_{18}$ and $r_2 = m_{23} + m_{24} + m_{25} + m_{26} + m_{27} + m_{28}$). The estimate of collection efficiency for the k^{th} site is obtained by dividing the numerator from the Φ_{k-1} survival estimate in Figure 1 into the m_k tally. This methodology produces maximum likelihood estimates of the survival rate and collection efficiency parameters from the reduced M-matrix.

The computer program computed the in-river survival and associated bootstrapped confidence intervals with two methodologies. The first methodology used the CJS directly on the total PIT tagged release group of interest, producing survival estimates for up to six reaches between release site and tailrace of Bonneville Dam (survival estimates S_1 through S_6). The total number of reaches to estimate was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was only limited PIT tag detection capability at John Day Dam and the NMFS trawl. Therefore, reliable survival estimates in those years were possible only to the tailrace of Lower Monumental Dam or McNary Dam. An estimate of survival was considered unreliable when its coefficient of variation exceeded 25%. From 1998 onwards, it has been possible to obtain reliable survival estimates to at least the tailraces of John Day Dam or Bonneville Dam. Estimates of individual reach survival (e.g. LGR-LGS) can exceed 100%; however, this is often associated with an underestimate of survival in preceding or subsequent reaches. Therefore, when computing an overall multi-reach survival estimate (the product of individual reach estimates), we allow individual reach survival estimates to exceed 100%.

The second method applies the CJS method to a subset of the PIT tagged data based on dates of detection at Lower Granite Dam. The PIT tagged passage distribution is stratified into a series of similarly-sized smolt subcohorts, and reach survival estimates S_2 to S_6 were obtained for each separate subcohort using the CJS from Lower Granite Dam tailrace to the tailrace of the lowest dam determined when applying the first method above. For the j^{th} individual reach ($j = 2, 3, \ldots, 6$), a weighted average of the survival estimates S_j across the set of subcohorts was computed, where the weight was the product of inverse relative variance and proportion of the total wild Chinook passage index that occurred during the same timeframe as the subcohort's passage dates at Lower Granite Dam. Weighting by the inverse relative variance gives cohorts with more precise survival estimates greater representation (Sandford and Smith 2002). Weighting by the passage index gives greater representation to cohorts migrating during periods when the largest proportion of the non-tagged smolts are migrating (Bouwes et al. 2002). With specific hatchery releases, the weight used with subcohorts is simply the inverse relative variance. The weighted estimates of S_2 to S_6 were then multiplied together to create the overall reach survival estimate for a given year and group of smolts.

In the computation of the total Lower Granite Dam tailrace to Bonneville Dam tailrace reach survival, an expansion was necessary whenever less than the full set of survivals S_2 to S_6 was available. The method was to take the survival estimated over the upstream portion of the overall reach, convert this survival to a "per mile" survival rate, and then apply this survival rate to the remaining miles of the overall reach. This approach has a drawback in that the per mile survival rates generated in the Snake River are generally lower than the per mile survival rates observed in the lower Columbia River based on data from migration years when survival components in the lower Columbia River are directly computable. Therefore, direct estimates of in-river survival over the longest reach possible are preferable.

Over the years of study it was found that the potential benefits from using the "subcohort" approach were outweighed by limitations on the number of estimable reaches due small number of fish in each cohort surviving to the lower projects. Therefore, in recent CSS annual reports, only the full sample CJS reach survival rates were used in all computations of study parameters.

Estimation of PIT-tagged smolts in study categories

The population of PIT-tagged study fish arriving at LGR is partitioned into three categories of smolts related to the manner of subsequent passage through the hydro system. Fish may either (1) pass inriver through the Snake River collector dams in a non-bypass channel route (spillways or turbines), (2) pass inriver through the dam's bypass channel, or (3) pass in a truck or barge to below BON. Since nearly all collected untagged smolts are transported from the Snake River collector dams, we utilize only first-time detected PIT-tagged fish that are transported in order to be most reflective of the untagged smolts. These three ways of hydrosystem passage define the study categories C_0, C_1 and T_0, respectively, of the CSS. How the inriver fish surviving to the tailrace of LMN (last Snake River collector dam) pass through the dams below LMN does not affect whether they belong to Category C_0 or C_1. In most years, fish in categories T_0 and C_0 mimic the untagged population, although in 1997 a portion of the inriver migrants were of Category C_1 due to bypass protocols implemented on collected fish during April and May at LGS and LMN in that year. Estimation of the number of smolts in each study category is presented below.

In the reduced M-matrix as stated previously, the m_{jk}'s are tallies of capture histories reflecting whether the tagged fish are detected. An eight-digit binary code represents the status of detection (1) or non-detection (0) at each recovery site following initial release (1 in code's first position), so that code 10010001 would show detections at LMN (4th digit) and TWX (8th digit). If a detected fish is not returned-to-river, it will instead receive a digit 2 if transported (e.g., 10020000 if first-time detected fish is transported from LMN) or 3 if "other" removal types such as taken for use in other studies (e.g., sacrificed for physiological research [Congleton 1999 to 2003] or inadvertently collected during NOAA tagging activities at LMN or JDA and re-released elsewhere with those fish in some years). The notation $X_{10020000}$ is used to represent the tally of fish with the capture history shown in the subscript.

The sums of PIT-tagged fish across capture histories for first-time detected fish detected at LGR, LGS, and LMN are m_{12}, m_{13}, and m_{14}, respectively. The sums of PIT-tagged fish that are first-time detected and transported are $X_{12000000}$, $X_{10200000}$, and $X_{10020000}$ for LGR, LGS, and LMN, respectively. Ryding's (2006) assumption #7 stating "only detected fish are subject to transport" applies here. PIT-tagged fish that are first-time detected and returned-to-river at the k^{th} site are tallied as "m_{1k} - d_k", where d_k is the sum of fish removed at the k^{th} site (substitute k=2 for LGR, 3=LGS, and 4 for LMN). The removal sum d_k includes transported (at collector dams) and "other" removal fish. The key tallies for each dam with associated expectations are summarized here:

1. Observed first-time detection tally at Lower Granite Dam (LGR) is m_{12} and expectation of $E(m_{12}) = R_1 \cdot \mathbf{S_1} \cdot \mathbf{p_2}$

2. Observed first-time detection tally at Little Goose Dam (LGS) is m_{13} and expectation of $E(m_{13}) = R_1 \cdot \mathbf{S_1} \cdot (1- \mathbf{p_2}) \cdot \mathbf{S_2} \cdot \mathbf{p_3}$

3. Observed first-time detection tally at Lower Monumental Dam (LMN) is m_{14} and expectation of $E(m_{14}) = R_1 \cdot \mathbf{S_1} \cdot (1- \mathbf{p_2}) \cdot \mathbf{S_2} \cdot (1- \mathbf{p_3}) \cdot \mathbf{S_3} \cdot \mathbf{p_4}$

4. Observed transportation tally of PIT-tag smolts at LGR is $n_2 = X_{12000000}$ and expectation of $E(n_2) = E(m_{12}) \cdot P_{n2}$ where P_{n2} is the proportion of collected PIT-tagged smolts transported at LGR

5. Observed transportation estimate of run-at-large smolts at LGR is t_2 = (LGR run-at-large transported/LGR run-at-large collected) m_{12} and expectation of $E(t_2) = E(m_{12})\ P_{t2}$ where P_{t2} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LGR

6. Observed transportation tally of PIT-tag smolts at LGS is $n_3 = X_{10200000}$ and expectation of $E(n_3) = E(m_{13}) \cdot P_{n3}$ where P_{n3} is the proportion of collected PIT-tagged smolts transported at LGS

7. Observed transportation estimate of run-at-large smolts at LGS is t_3 = (LGS run-at-large transported/LGS run-at-large collected) m_{13} and expectation of $E(t_3) = E(m_{13}) \cdot P_{t3}$ where P_{t3} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LGS

8. Observed transportation tally of PIT-tag smolts at LMN is $n_4 = X_{10020000}$ and expectation of $E(n_4) = E(m_{14}) \cdot P_{n4}$ where P_{n4} is the proportion of collected PIT-tagged smolts transported at LMN

9. Observed transportation estimate of run-at-large smolts at LMN is t_4 = (LMN run-at-large transported/LMN run-at-large collected) m_{14} and expectation of $E(t_4) = E(m_{14})\ P_{t4}$ where P_{t4} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LMN

10. Observed return-to-river tally of PIT-tag smolts at LGR is $m_{12}\text{-}d_2 = m_{12} \cdot (1-P_{d2})$ and expectation of $E(m_{12}\text{-}d_2) = E(m_{12}) \cdot (1-P_{d2})$ where P_{d2} is proportion of collected PIT-tagged smolts not returned-to-river at LGR

11. Observed return-to-river tally of PIT-tag smolts at LGS is $m_{13}\text{-}d_3 = m_{13} \cdot (1-P_{d3})$ and expectation of $E(m_{13}\text{-}d_3) = E(m_{13}) \cdot (1-P_{d3})$ where P_{d3} is proportion of collected PIT-tagged smolts not returned-to-river at LGS

12. Observed return-to-river tally of PIT-tag smolts at LMN is $m_{14}-d_4 = m_{14}\cdot(1-P_{d4})$ and expectation of $E(m_{14}-d_4) = E(m_{14})\cdot(1-P_{d4})$ where P_{d4} is proportion of collected PIT-tagged smolts not returned-to-river at LMN

In order to have a common starting point such as LGR for estimating the numbers of PIT-tagged smolts in each study category, it is necessary to expand the tallies of detected fish at the downstream sites of LGS and LMN into their LGR-equivalents. Simulating known probabilities of survival, collection efficiency, and transportation when collected, Ryding (2006) illustrates the need for accounting for in-river mortality during the migration to LGS and LMN for smolts detected and transported at those sites. This also true for the first-time detected fish bypassed at those sites. The resulting estimated number of PIT-tagged smolts (in LGR-equivalents) for each CSS study category (plus a projection of number transported if the PIT-tagged fish had been transported at the same rate as the untagged run-at-large) with associated expectation is:

13. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are transported from the three Snake River collector dams

$T_0 = X_{12000000} + X_{10200000}/\mathbf{S_2} + X_{10020000}/\mathbf{S_2S_3}$ and expectation of
$E(T_0) = E(n_2) + E(n_3)/\mathbf{S_2} + E(n_4)/\mathbf{S_2S_3}$

14. Estimated number of PIT-tag smolts expanded to LGR-equivalents that would have been transported if the PIT-tag smolts had been transported at the same proportion as the run-at-large from the three Snake River collector dams

$T_0^* = t_2 + t_3/\mathbf{S_2} + t_4/\mathbf{S_2S_3}$ and expectation of
$E(T_0^*) = E(t_2) + E(t_3)/\mathbf{S_2} + E(t_4)/\mathbf{S_2S_3}$

15. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are return-to-river at each collector dam and remain in-river to below LMN

$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/\mathbf{S_2} + (m_{14} - d_4)/\mathbf{S_2S_3} - 2\cdot d_1$ and expectation of
$E(C_1) = E(m_{12})\cdot(1-P_{d2}) + [E(m_{13})\cdot(1-P_{d3})]/\mathbf{S_2} + [E(m_{14})\cdot(1-P_{d4})]/\mathbf{S_2S_3} - 2\cdot d_1$

The subtraction of $2\cdot d_1$ fish from the estimate of Category C_1 smolts was to account for fish from this category being removed below LMN. The numbers removed were expanded to LGR-equivalents with a fixed 50% survival rate.

16. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are not detected at any of the three Snake River collector dams

$C_0 = R_1\mathbf{S_1} - (m_{12} + m_{13}/\mathbf{S_2} + m_{14}/\mathbf{S_2S_3}) - 2\cdot d_0$ and expectation of
$E(C_0) = R_1\mathbf{S_1} - [E(m_{12}) + E(m_{13})/\mathbf{S_2} + E(m_{14})/\mathbf{S_2S_3}] - 2\cdot d_0$
$E(C_0) = R_1\cdot\mathbf{S_1}\cdot(1-\mathbf{p_2})\cdot(1-\mathbf{p_3})\cdot(1-\mathbf{p_4}) - 2\cdot d_0$

The subtraction of $2 \cdot d_0$ fish from the estimate of Category C_0 smolts was to account for fish from this category being removed below LMN. The numbers removed were expanded to LGR-equivalents with a fixed 50% survival rate.
Note that being detected at lower Columbia River dams or the estuary trawl does not preclude fish from Category C_0.

Lastly, there is a small adjustment made to the estimated numbers of smolts in C_0 and C_1 categories to reflect known removals occurring at monitoring sites downstream of Lower Monumental Dam. Fish were considered removed (not returned-to-river) at McNary Dam when detected on raceway or sample room monitors or only on the separator monitor during the summer transportation season, or when collected and removed at John Day or Bonneville Dam for other research purposes. For example, samples of CSS hatchery Chinook from Rapid River, McCall, and Dworshak hatcheries were collected and sacrificed at John Day and/or Bonneville dams during migration years 1999 to 2003 for physiological (blood chemistry) evaluation (Dr. Congleton, University of Idaho Fish and Wildlife Unit). Because most removals occurred at John Day and Bonneville dams for other research purposes, we settled on a fixed 50% Lower Granite to Bonneville Dam survival rate for each removed fish in order to subtract these fish in LGR-equivalents from the estimated number of smolts in Categories C_0 and C_1. Most survival rates from Lower Granite Dam to Bonneville Dam from 1995 to 2004 (excluding 2001 when extremely low in-river reach survival rates and few returning adults occurred on in-river migrants) have been averaging around 50%. In 1994, the wild Chinook in-river survival rate from Lower Granite Dam to McNary Dam was estimated at 47%, with most removals occurring at McNary Dam due to no operational return-to-river diversion route present that year.

Estimation of SARs for study categories

As stated earlier, we only used first-time detections for transported smolts in order to represent the non-tagged smolts. Since springtime transportation occurs at three Snake River collector projects, we needed to have the number of PIT-tagged smolts transported at each dam be reflective of the proportion of the untagged smolt population likewise being transported from each facility. But since most PIT-tagged wild Chinook were returned to river at the collector dams in year prior to 2002 and the fact that the CSS was transporting a higher proportion of its PIT-tagged hatchery Chinook at LGR in the early years of this study, the number of PIT-tagged smolts transported at some projects did not adequately reflect the untagged run-at-large. Therefore, the first formula used in the CSS to estimate the overall transportation SAR weighted the dam-specific SAR estimates (times any in-river survival to reach a transportation site below LGR) by the estimated number of PIT-tags (expanded to LGR-equivalents) that would have been transported at each dam if the PIT tags had been transported in the same proportion as the untagged run-at-large (details in Berggren *et al*. 2002).

However, hatchery Chinook PIT-tagged for the CSS in 1997 were routed to transport only at LGR, whereas in 1998, 1999, and 2002 the CSS hatchery tagged fish were routed to transport at both LGR and LGS, but not LMN. Likewise, from 1995 to 2001, of the collection of PIT-tagged wild Chinook at LGS or LMN less than 10% transported, resulting in few (none to 2) adults returning from which to estimate a dam-specific SAR. Under those conditions using the $SAR_1(T_0)$ estimator was less desirable than using the more simple estimator $SAR_2(T_0)$ introduced in the 2003/04 CSS Annual Report (Berggren *et al*. 2005). In order to take advantage of self-weighting across the three Snake River collector dams, we now use a common annual routing rate to the raceways for transportation at each collector dam. With a common routing rate, the two estimators are basically identical (producing only slight differences due to rounding). This approach was started with hatchery Chinook in 2000 (except 2002 at LMN), wild Chinook in 2002, and wild steelhead in 2003.

In the 2005 and 2006 CSS annual report (Berggren *et al*. 2006a, 2006b), the estimate of $SAR_2(T_0)$ was presented for each year, while the $SAR_1(T_0)$ estimate was presented only for those years when non-zero dam-specific SAR estimates were available for comparison purposes of the two methods. Because the estimator $SAR_2(T_0)$ does not rely on site-specific SARs, it has been more reliable method to use over the full 1994 to 2004 time frame. Likewise, subsequent ratios of SARs and *D* computation have utilized only $SAR_2(T_0)$ in recent CSS reports.

The SARs for Category C_0 and C_1 smolts do not require the same type of adjustment as was needed for Category T_0 smolts. The SAR formula is simply the number of adults divided by number of smolts (in LGR equivalents) for each respective study category. In this report, the adult count is the sum of 2-salt and older returning wild and hatchery Chinook and 1-salt and older returning wild and hatchery steelhead for each study category.

The formulas for SARs for each study category are summarized here:

17. Numbers of returning adults used in SAR estimates are tallies of PIT-tag adults (age 2-salt and older for Chinook; age 1-salt and older for steelhead) detected at Lower Granite Dam adult monitors (GRA), which have near 100% detection efficiency. Some analyses use Bonneville Dam adult detections (BOA), which have been expanded by estimated detection efficiency at that site.

    AT_{LGR} = tally of adults of smolts transported at LGR, capture history “12000000”

    AT_{LGS} = tally of adults of smolts transported at LGS, capture history “10200000”

    AT_{LGR} = tally of adults of smolts transported at LGR, capture history “10020000”

    AC_0 = tally of adults of smolts that passed the three Snake River collector dams undetected (capture histories “1000AAAA” where A=0 signifies not being detected and A=1 signifies detection and return-to-river at a downstream site.

    AC_1 = tally of adults of smolts that passed the three Snake River collector dams with at least one detection (capture histories “11AAAAAA” or “101AAAAA” or “1001AAAA” where the A=0 signifies not being detected and A=1 signifies detection and return-to-river at a downstream site.

18. Site-specific transportation SAR (n_k is observed number smolts at k^{th} dam that is not expanded to LGR-equivalents):

    $SAR(T_{LGR}) = AT_{LGR} / n_2$
    $SAR(T_{LGS}) = AT_{LGS} / n_3$
    $SAR(T_{LMN}) = AT_{LMN} / n_4$

19. Overall transportation SAR where site-specific SARs are weighed by the proportion of PIT-tag smolts that would have been transported from each site (expanded in LGR-equivalents) if the PIT-tag smolts had been transported in the same proportion as the run-at-large at each collector dam

$$SAR_1(T_0) = \{t_2 \bullet SAR(T_{LGR}) + (t_3/\mathbf{S_2}) \bullet [\mathbf{S_2}\bullet SAR(T_{LGS})] \\ + t_4/\mathbf{S_2S_3}) \bullet [\mathbf{S_2S_2}\bullet SAR(T_{LMN})]\}/ \{t_2 + (t_3/\mathbf{S_2}) + (t_4/\mathbf{S_2S_3})\}$$

$$SAR_1(T_0) = \{t_2\bullet SAR(T_{LGR}) + t_3\bullet SAR(T_{LGS}) \\ + t_4\bullet SAR(T_{LMN})\}/\{t_2 + (t_3/\mathbf{S_2}) + (t_4/\mathbf{S_2S_3})\}$$

20. Overall transportation SAR where site-specific SARs are weighed by actual proportion of PIT-tag smolts transported at each collector dam (expanded in LGR-equivalents)

$$SAR_2(T_0) = \{n_2 \bullet SAR(T_{LGR}) + (n_3/\mathbf{S_2}) \bullet [\mathbf{S_2}\bullet SAR(T_{LGS})] \\ + n_4/\mathbf{S_2S_3}) \bullet [\mathbf{S_2S_2}\bullet SAR(T_{LMN})]\}/ \{n_2 + (n_3/\mathbf{S_2}) + (n_4/\mathbf{S_2S_3})\}$$

$$SAR_2(T_0) = \{n_2 \bullet (AT_{LGR} / n2) + (n_3 \bullet (AT_{LGS})/n_3) \\ + n_4 \bullet (AT_{LMN} / n_4)\}/ \{n_2 + (n_3/\mathbf{S_2}) + (n_4/\mathbf{S_2S_3})\}$$

$$SAR_2(T_0) = \{AT_{LGR} + AT_{LGS} + AT_{LMN}\}/ \{n_2 + (n_3/\mathbf{S_2}) + (n_4/\mathbf{S_2S_3})\}$$

21. In-river SAR for smolts not detected at the Snake River collector dams

$$SAR(C_0) = AC_0 / C_0$$

22. In-river SAR for smolts detected at one or more Snake River collector dam

$$SAR(C_1) = AC_1 / C_1$$

Estimation of overall annual SARs

Annual estimates of $SAR_{LGR\text{-}to\text{-}LGR}$ reflective of the run-at-large for wild steelhead, hatchery steelhead, wild Chinook, and hatchery Chinook that outmigrated in 1997 to 2003 are computed 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 inriver. 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, we estimated 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. This estimation uses run-at-large collection and transportation data for these dams from the FPC Smolt Monitoring Program. The total estimated number transported across the three Snake River collector dams in LGR equivalents equals $T^* = t_2+t_3/S_2+t_4/(S_2S_3)$. 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 simply 0. When run-at-large bypassing occurs, $C^*_1 = (T_0 + C_1) - T^*$. The sum of estimated smolts in categories C_0, T^*, 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 $SAR_2(T_0)$, and summed to produce an annual overall weighted $SAR_{LGR\text{-}to\text{-}LGR}$ for each migration year except 2001 as follows:

23. Estimate of annual SARs computed by weighting each study category SAR by the estimated proportion of the run-at-large (in LGR-equivalents) each represents

$$SAR_{ANNUAL} = w(T_0^*) \bullet SAR_2(T_0) + w(C_0) \bullet SAR(C_0) + w(C_1^*) \bullet SAR(C_1)$$

where

$T_0^* = t_2 + (t_3/\mathbf{S_2}) + (t_4/\mathbf{S_2 S_3})$ 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 had been routed to transportation in the same proportion as the run-at-large

$w(T_0^*) = T_0^* / (T_0^* + C_0 + C_1^*)$ is transported smolt proportion
$w(C_0) = C_0 / (T_0^* + C_0 + C_1^*)$ is non-detected (LGR, LGS, LMN) smolt proportion
$w(C1^*) = 1 - [w(T_0^*) + w(C_0)]$ is bypass (LGR, LGS, LMN) smolt proportion

Estimation of the TIR (denoted T/C in prior CSS reports), S_R and S_T (denoted V_C and V_T in prior CSS reports) and D

The TIR ratio is a common parameter used to illustrate differences between the SARs of transported and in-river migrating smolts. It is simply measured as:

24. $TIR = SAR_2(T_0) / SAR(C_0)$

Assessments that these differences are the result of the collection and transportation of the PIT-tagged smolts relative to the baseline effects of migrating inriver through the hydrosystem relies on the following assumptions from Ryding (2006):

#10 – Transported fish and in-river migrants experience the same estuary and ocean conditions.
#11 – Harvest survival [rate] is the same for transported and in-river categories.
#12 – River conditions for same-age returns of a cohort are the same for the T_0 and C categories.

Assumption #10 from Ryding (2006) should be limited to the ocean conditions, since it is expected that arrival timing in the estuary of the of transported PIT-tagged smolts will be on average one to two weeks earlier than that of the smolts completing their migration inriver through the hydrosystem. When the smolts enter the estuary may have a real influence on the subsequent SARs. Evidence to date if of higher levels of straying of adult returns from the transported smolts (particularly for steelhead). Delays and greater levels of straying into other lower Columbia River tributaries may make returning adults of transported smolts more available for tributary harvest, but the rate of harvest is assumed independent of whether fish had been transported as a smolt. These assumptions and comments apply to both TIR and *D*.

Parameter *D* is the ratio of post-BON survival rate of transported fish to that of in-river migrating fish. It is computed as:

25. $D = [\mathrm{SAR}_2(\mathrm{T}_0) \,/\, S_\mathrm{T}] \,/\, [\mathrm{SAR}(\mathrm{C}_0) \,/\, S_\mathrm{R}\,]$

where

$S_\mathrm{T} = V_\mathrm{T} = 0.98 * [\mathrm{t}_2 + \mathrm{t}_3 + \mathrm{t}_4] \,/\, [\mathrm{t}_2 + (\mathrm{t}_3/\mathbf{S_2}) + (\mathrm{t}_4/\mathbf{S_2 S_3})]$
$S_\mathrm{R} = V_\mathrm{C} = \mathbf{S_2 \bullet S_3 \bullet S_4 \bullet S_5 \bullet S_6}$

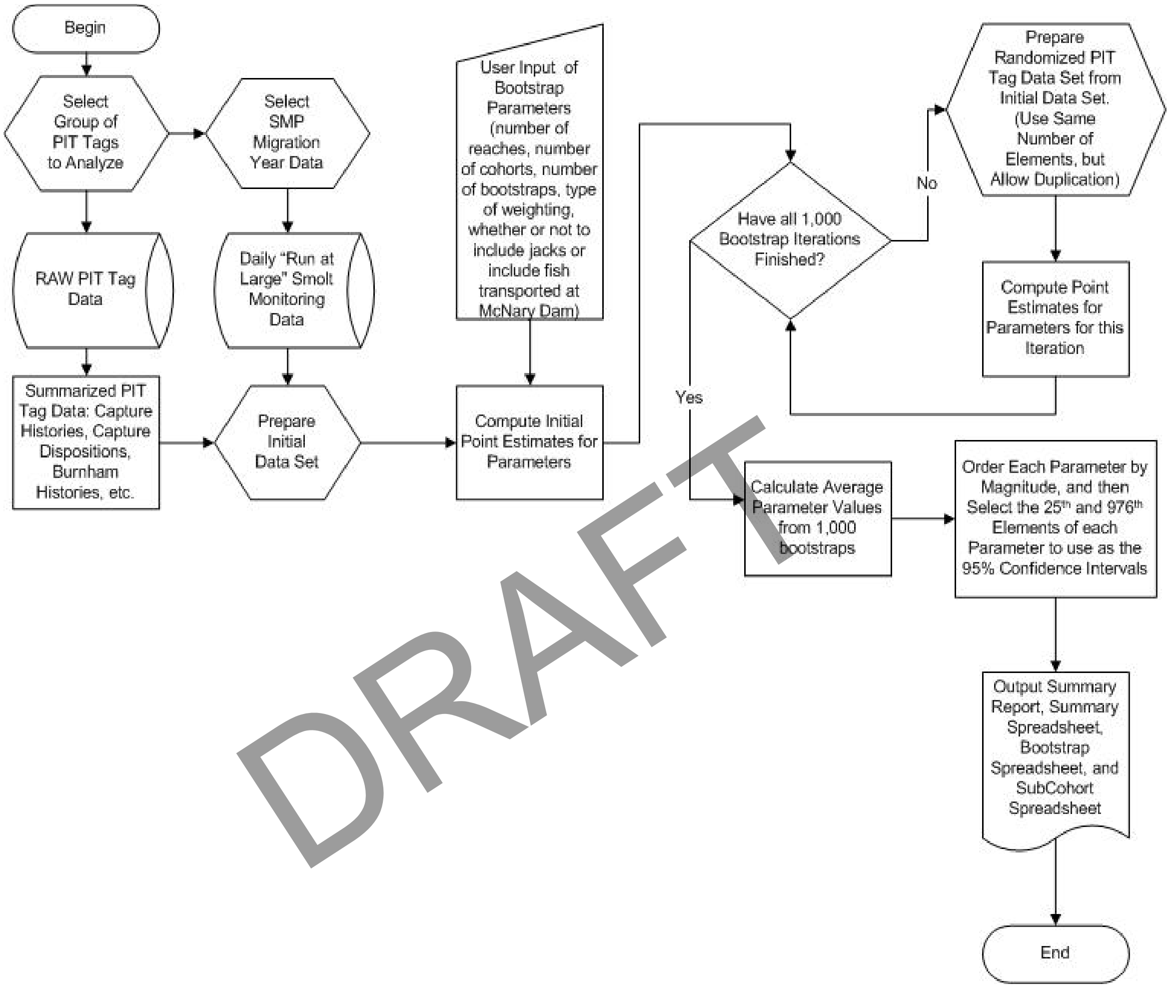
The symbols V_C and V_T, which were used in prior CSS reports, have been replaced with new symbols S_R and S_T, respectively, in the 10-yr report to more intuitively reflect the in-river survival rate parameters that are related to the experience of fish that migrate totally in-river versus those that migrate in-river only to a Snake River collector dam where they are transported.

In this equation, parameter S_R is the overall reach survival from LGR to BON of fish in Category C_0. Although the S_R in pre-1998 years is less reliable due to the expansion of a "per/mile" survival rate to over 50% of the full reach distance, the variation in the S_R estimates follows variation in hydroproject operations in that the S_R estimates were lowest in 1994 and 2001, the two years with limited or no spill provided at the Snake River collector dams.

Parameter S_T is the overall in-river survival from LGR to the transportation sites and on barges or trucks until released below BON for fish in Category T_0. Regardless of whether $\mathrm{SAR}_1(\mathrm{T}_0)$ or $\mathrm{SAR}_2(\mathrm{T}_0)$ is used in the computation of *D*, the estimate of S_T should be computed as $0.98 \bullet (\mathrm{t}_2 + \mathrm{t}_3 + \mathrm{t}_4)/(\mathrm{t}_2 + \mathrm{t}_3/\mathrm{S}_2 + \mathrm{t}_4/\mathrm{S}_2\mathrm{S}_3)$. This is because the same inriver survival exists from LGR to these two downstream collector dams regardless of which transport SAR estimator is utilized. When $\mathrm{SAR}_2(\mathrm{T}_0)$ was first introduced in the 2003/2004 Annual Report, the associated V_T (original symbol) was simply programmed as a constant 98%, which resulted in a slight under-estimate of parameter *D*. This was corrected in time for the 2005 CSS Annual Report. Estimated S_T have ranged between 88 and 98% (Berggren *et al*. 2006a) across the years, species, and rear types used in the CSS.

Program for Parameter Estimation and Confidence Intervals

A computer program was written to compute the in-river survivals, SARs, ratios of selected SARs, and D indices along with associated bootstrapped confidence intervals. The confidence intervals were produced using nonparametric bootstapping methods (Efron and Tibshirani 1993). During a bootstrapped iteration, the computer program obtained a random sample of PIT tags with replacement from the full set of PIT tags in the particular group of interest. During each iteration, all relevant study parameters were computed, while retaining the raw data used in the computations. From a set of iterations (typically 1,000 runs), non-parametric 80%, 90%, and 95% confidence intervals were computed for each parameter of interest. The 90% confidence intervals were chosen for reporting in the recent CSS annual reports in an attempt to better balance the making of Type I (failure to reject a false null hypothesis) and Type II (failure to accept a true alternative hypothesis) errors in comparisons of study groups of fish for the various parameters of interest. Appendix B Figure 2 is a flowchart overview of the bootstrapping methodology used by this computer program.



Appendix B Figure 2. Schematic of bootstrap program for estimating initial values, averages, and confidence intervals for study parameters.

Table B-1. Progression of methods of estimating study-specific SARs and *D* through the series of annual reports and design & analysis technical documents prepared by the CSS in 2000 to 2006 (see definitions of symbols in text).

CSS Document	Transport SARs	In-river SARs	Parameter *D*
Annual Report 2000 Published Oct. 2000 DOE/BP-00006203-1 Report covers 1996-1998 sp/su hatchery Chinook (HC) mark/recapture activities (adult returns to 2000)	HC smolt numbers: $T_0 = t_1 + t_2/s_2 + t_3/s_2s_3$ *where* $t_1 = X_{12}$; $t_2 = X_{102}$; and $t_3 = X_{1002}$ $SAR(T_0)=adult(T_0)/T_0$ Point estimates only; No confidence intervals Note: CSS PIT-tagged HC were not routed to transport in 1996, so only in-river SARs available for that migration year.	HC smolt numbers: $C_0 = m_{12}/p_2 – (m_{12}+ m_{13}/s_2 + m_{14}/s_2s_3)$ $C_1 = m_{12} + m_{13}/s_2 + m_{14}/s_2s_3 – (T+U+M)$ *where* $T = T_0$; U = separator only; most at LGR so no expansion made; M = study fish sacrificed at any dam (no split in morts between C_0 and C_1 groups) $SAR(C_0)=adult(C_0)/C_0$ $SAR(C_1)=adult(C_1)/C_1$ Point estimates only; No confidence intervals	Not computed.
Annual Report 2001 Published Feb. 2002 DOE/BP-00006203-2 Report covers 1997-2000 sp/su HC mark/recapture activities with SARs thru 1999 (adult returns to 2001) This report adds 1994 to 1999 wild Chinook (WC) with adult returns to 2001.	HC smolt numbers: $T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2s_3$ $SAR(T_0') =adult(T_0)/T_0$ A *Monte Carlo* 95% confidence interval is generated in same manner as described at right for in-river groups. WC smolt numbers: $T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2s_3 + X_{10002}/s_2s_3s_4$ (MCN included here) $SAR_T = (\sum W_J \bullet LGR_{A,J}) / (\sum W_J \bullet LGR_{S,J})$ *where* subscript J=dam, A=adults, S=smolts, LGR = # in LGR-equiv., and $W_J = PA_J/PO_J / \sum PA_J/PO_J$ *with* PA = actual # (includes untagged) and PO = tagged only. SAR_T has no computed confidence intervals.	HC & WC smolt numbers: $C_0 = R{\cdot}s_1 – (m_{12}+ m_{13}/s_2 + m_{14}/s_2s_3) – 2\Delta_0$ *since* $R{\cdot}s_1= m_{12}/p_2$ $C_1 = (m_{12} – \delta_2) + (m_{13} – \delta_3)/s_2 + (m_{14}– \delta_4)/s_2s_3 – 2\Delta_1$ *where* δ_J is total removals at J^{th} dam (include transport, morts, and separator only fish); and Δ is removals below LMN split between C_0 and C_1 groups (a factor of 2 used to offset an approx. survival rate of 50% from LGR since most of these removals are at JDA or BON) $SAR(C_0)=adult(C_0)/C_0$ $SAR(C_1)=adult(C_1)/C_1$ A *Monte Carlo* 95% confidence interval is generated for these SARs by applying a binomial draw of adults for the numerator and Gaussian draw of survival rates for computing the denominator within each of 1000 iterations of SAR formulas above. The rank order 25th and 976th positions values provided a 95% CI.	Parameter *D* is computed as: $[SAR(T_0)/V_T] / [SAR(C_0)/V_C]$ where $V_T = 0.98$ and V_C = survival rate from LGR to BON which is either obtained directly from the product of 5 reach survival rates or an expanded (per mile) estimate. **Note: Symbols V_T and V_C have been replaced by S_T and S_R, respectively, in the 10-yr report.**

CSS Document	**Transport SARs**	**In-river SARs**	**Parameter *D***
Design & Analysis Tech Report Apr. 2002 DOE/BP-00006203-3 Derivation of formulas to estimate smolt #'s, SARs, & *D*	Demonstrated that equation SAR_T used with wild Chinook in previous annual report is equivalent to formula $SAR(T_0) = [t_2 \cdot SAR(T_{LGR}) + t_3 \cdot SAR(T_{LGS})/s_2 + t_4 \cdot SAR(T_{LMN})/s_2s_3 + t_5 \cdot SAR(T_{MCN})/s_2s_3s_4] / [t_2 + t_3/s_2 + t_4/s_2s_3 + t_5/s_2s_3s_4]$ *where* t_J is estimated # of PIT-tagged smolts transported if done at rate of untagged fish. Note: this t_J is not the same used in AR 2000.	No changes from description of smolt numbers and SARs for groups C_0 and C_1 described in previous annual report.	Demonstrated that V_T in computing *D* needs to account for inriver mortality of fish transported at dams below LGR as: $V_T = 0.98 \cdot \{(t_2 + t_3 + t_4 + t_5) / (t_2 + t_3/s_2 + t_4/s_2s_3 + t_5/s_2s_3s_4)\}$ *where* t_J is estimated # of PIT-tagged smolts transported if done at rate of untagged fish.
Annual Report 2002 Published Nov. 2003[A] DOE/BP-00006203-4 Report covers 1997-2000 sp/su HC & 1994-2000 sp/su WC (adult returns to 2002)	With 1994 the last year of springtime transport from MCN and only 42 first-time detected PIT-tagged wild Chinook transported, it was not possible to obtain a site-specific SAR for MCN. Therefore, $SAR(T_0) = [t_2 \cdot SAR(T_{LGR}) + t_3 \cdot SAR(T_{LGS})/s_2 + t_4 \cdot SAR(T_{LMN})/s_2s_3] / [t_2 + t_3/s_2 + t_4/s_2s_3]$ (additional info at right)	Following applies to all parameters and groups (*i.e.*, T_0, C_0, and C_1): Two methods of estimating reach survival rates -- (1) "full sample CJS" & (2) "subcohort CJS." The latter approach gave weighted mean survival rates of stratified re-releases of detected PIT-tagged fish from LGR. Bootstrap 95% confidence intervals were computed for each SAR parameter starting in this annual report.	V_C computed with "subcohort CJS" method required more reaches to be estimated on "per mile" basis than "full sample CJS" method to fewer fish in stratified re-release blocks. First year of bootstrap 95% confidence intervals for *D*
Annual Report 2003/04 Published Apr. 2005[B] DOE/BP-00006203-5 Report covers 1997-2002 sp/su HC & 1994-2002 sp/su WC (adult returns to 2004)	Reinstated the transport SAR from AR2000 and renamed it $SAR_2(T_0)$ as alternative when a site-specific SAR was missing (*i.e.*, "0"). Renamed $SAR(T_0)$ from AR 2002 to $SAR_1(T_0)$. Overall weighted annual SAR is computed with CSS transport and in-river SARs weighted by estimated proportion of "untagged" population transported or migrating inriver each year. (see more info at right)	Following applies to all parameters and groups (*i.e.*, T_0, C_0, and C_1): estimating reach survival rates with the "subcohort CJS method was dropped; only "full sample CJS" survival rates were used in computing study parameters including transport and in-river SARs, TIRs, and *D*.	V_C computed with "full sample CJS." In *D* computation, V_T is correct with $SAR_1(T_0)$, but not with $SAR_2(T_0)$, where only 0.98 is erroneously used.

CSS Document	**Transport SARs**	**In-river SARs**	**Parameter *D***
Annual Report 2005 Published Dec. 2005 DOE/BP-00025634-1 Report covers sp/su HC and WC thru 2003 (adult returns to 2005) Report adds 1997-2002 wild steelhead (WS) & hatchery steelhead (HS) (adult returns to 2004)	$SAR_2(T_0)$ is primary transport SAR used in computing other study parameters. With equal proportions of PIT-tagged smolts routed to transport at the collector dam in recent years, $SAR_2(T_0)$ equals $SAR_1(T_0)$ in expected value. (see more info at right)	The method of Akçakaya (2002) was used to estimate the variance in PIT-tag SAR estimates from sampling error, and remove it from the total variance in the time series. This produced estimates of process error (inter-annual variation in survival rates), which were used in computing probability density functions of transport and in-river SARs for wild Chinook (as well as TIRs).	The correct V_T as shown above (see D&A 2002 Tech Report) is used with $SAR_2(T_0)$ in the *D* computation.
Annual Report 2006[C] Published Nov. 2006 DOE/BP-00025634-2 Report covers sp/su HC and WC thru 2004 (adult returns to 2006) Report covers HS and WS thru 2003 (adult returns to 2005)	No changes. Simulator program was completed during this reporting period; and simulation runs using default input values are conducted to illustrate comparisons between estimates of s_2, s_3, V_C, and smolt numbers in T_0, C_0, and C_1.	No changes from description of smolt numbers and SARs for groups C_0 and C_1 used in annual reports 2001 to present. The method of Akçakaya (2002) was not used in this annual report.	No changes.
Design & Analysis Tech Report Dec. 2006 DOE/BP-none[D]	Using formulas for expectation of smolt #s in groups T_0 and C_0 and returning adults under two scenarios, report demonstrated why expanding estimated smolt numbers to LGR-equivalents is necessary to obtain unbiased TIRs.	(see description at left)	Not addressed.

[A] BPA cover page to CSS Report erroneously shows April 2005 as publish date instead of November 2003.
[B] BPA cover page to CSS Report erroneously shows November 2003 as publish date instead of April 2005.
[C] BPA cover page to CSS Report erroneously shows 2005-2006 for Annual Report # instead of just 2006.
[D] BPA does not have this report on BPA publication website; however, it has two identical copies of the CSS Annual Report 2006 with different numbers -- DOE/BP-00025634-2 and DOE/BP-00025634-4.

Appendix C

Comparative Survival Study (CSS)

2006 Design and Analysis Report:

Methodology for Obtaining Unbiased T/C Ratio Estimates

BPA Contract #19960200

Prepared by

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Comparative Survival Study Oversight Committee Member

Project Leader:

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Final

December 31, 2006

Preface

A primary goal of the Comparative Survival Study (CSS) is to provide reliable (*i.e.*, unbiased, reasonably precise, and transparent) estimates of parameters describing the relative survival benefits due to various management strategies. In particular, the CSS estimates smolt-to-adult survival rates (SARs) for groups of fish (hatchery and wild spring/summer Chinook salmon, *Oncorhynchus tshawytscha*, and summer steelhead, *O. mykiss*) that out-migrate as juveniles via in-river and transportation passage routes, as well as the ratio of these SAR estimates (*i.e.*, transport:inriver ratio or *T*/*C*). Reviewers of the 2005 CSS Annual Report (see Appendix D in Berggren *et al.* 2005) suggested that the CSS estimators are inherently biased in their formulation and poorly documented. To address these concerns, the following document was prepared by Washington Department of Fish and Wildlife's Comparative Survival Oversight Committee member Kristen Ryding. While a description of the quantitative methods used to estimate CSS study parameters appears elsewhere (see Appendix A in Berggren *et al.* 2006), the purpose of this document is two fold: i) to provide a derivation of the main study parameters used by the CSS and ii) to describe their behavior, relative to a 'true' value, under various circumstances (*e.g.*, with and without actual transportation benefits).

The document is structured to build from a description of basic elements (*i.e.*, parameter definition and notation) to the theoretical expectation of key study parameters (*i.e.*, SARs and *T*/*C*) and their analogous estimators. Additionally, the main assumptions underlying the described estimators will be identified and discussed in brief. Finally, using a set of simple examples based on the derived estimators and a set of assumed inputs, this document illustrates that both SARs and *T*/*C*, as used in the CSS, are both accurate (*i.e.*, unbiased) and robust.

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Introduction

This section focuses on the derivation of the estimator used to assess the efficacy of transporting fish around dams on the Lower Snake and Columbia rivers versus migration using in-river routes. Fish are collected and put into the transport barges at one of three dams on the Lower Snake River. In order of occurrence, the three transport sites are Lower Granite Dam (LGR), Little Goose Dam (LGS), and Lower Monumental Dam (LMN). The transport system is considered to start at the first site, Lower Granite Dam and end at the barge release site below Bonneville Dam. Performance of the transportation system is assessed by comparing relative rate of adult returns back to Lower Granite Dam between juveniles that were transported and those that migrated in-river (control) through the hydro-system. Transport and control returns are compared by use of the transport-control or T/C ratio, the focus of this study.

The CSS study does not divide a cohort into transport and in-river groups before release, but rather at the first transport site, LGR. Fish pass a dam through either detected through bypass system and then possibly transported, or through other routes undetected. Essential to understanding the derivation of the T/C ratio are three elements of the study. First only fish not previously detected at a dam are barged. Second, probabilities of adult return back to LGR are based on the numbers of juveniles at LGR in each group. Third, fish passing undetected at LGR are considered to be in a transport or in-river migration route upon egress from the dam. This last condition owes to the fact that even in a river system where fish are subject to only transportation should they be detected, some mortality will occur in-river on the way to the barge site. Any loss associated with getting to the barge is part of the total mortality of transportation. Subsequently, fish are considered routed for either transportation at LGS or LMN prior to the onset of survival processes associated with downstream travel to these sites. All of these elements will be discussed further.

We outline the derivation of the T/C ratio from first principles. We begin by defining the notation and basic metrics used in the analysis. Derivation of the equations for calculating the numbers of juveniles and returning adults in each category follows. Next, we present the T/C ratio as a function of survival, detection, and transport probabilities and discuss its properties under the null condition analytically and through numerical examples. We conclude with a discussion of parameter estimation and associated assumptions of analytical methods.

Notation and Definitions

Unless otherwise indicated, the following subscripts are used to identify site-specific probabilities and observations following the convention of previous CSS reports;

1 = release site;

2 = Lower Granite Dam (LGR);

3 = Little Goose Dam (LGS);

4 = Lower Monumental Dam (LMN).

The following notation will be used in this section to show the derivation of the T/C estimator. Define the number of tagged fish released, survival, detection, and transport probabilities, and observations as follows,

N_0 = the number of tagged fish released;

S_1 = survival from release to Lower Granite Dam tailrace;

S_i^R = survival probability from the tailrace of site i to $i+1$ for fish passing in-river e.g.,

S_2^R = in-river survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam;

S_i^T = survival probability from the i to $i+1$ transport site for fish transported in the barge e.g., S_2^T = in-barge survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam;

S_L^x = the probability of surviving from the tailrace of LMN, the last transport site, through the Lower Snake and Columbia Rivers to the transport release site for group x, e.g., $S_L^{C_0}$ is the lower river survival probability for the in-river migration group;

S_O^x = the probability of surviving from the transport release site as juveniles back to Bonneville dam as adults for group x (includes estuary and marine survival);

S_A^x = the probability of surviving adult migration from Bonneville dam back to LGR;

p_i = detection probability (collection efficiency) at the *i*th site;

τ_i = the probability that a tagged, detected fish is transported at the *i*th site;

T_i = the number of juveniles in the transportation route (pathway) of the *i*th site;

T_0 = the total number of juveniles that entered the transport system, i.e., $\sum_i T_i$;

C_0 = the number of juveniles that migrated undetected at the transportation sites through the Lower Snake River hydro system, i.e., the in-river migration route;

$A_j^{T_i}$ = the number of age *j* adults returning to LGR out of T_i juveniles;

$A_j^{C_0}$ = the number of age j adults returning to LGR out of C_0 juveniles;

$SAR(T_0)$ = the proportion of fish that return as adults out of T_0 juveniles;

$SAR(T_i)$ = the proportion of fish that return as adults out of T_i juveniles, i.e., a site specific SAR;

$SAR(C_0)$ = the proportion of fish that return as adults out of C_0 juveniles.

Basic Metrics

Transportation effectiveness is measured against in-river migration by comparing smolt-to-adult return (SAR) proportion for the two groups as follows,

$$T/C = \frac{SAR(T_0)}{SAR(C_0)} \qquad (1)$$

where $SAR(T_0)$ and $SAR(C_0)$ are defined as above. Because the transportation system is regarded as starting at Lower Granite Dam (LGR), SARs are the proportion of fish in a cohort that survive from LGR as a juvenile back to LGR as an adult. The T/C ratio [Eq. (1)] is a measure of the relative rate of adult returns between the transportation group, (T_0), and in-river migrants, (C_0). Equation 1 will be greater than one when the number of adult returns relative to the number of juveniles in the transport group is greater than that of the in-river fish.

For the purposes of this study, *SAR*s are defined as the proportion of fish passing LGR as juveniles that return to LGR as adults and for control and transported fish are expressed in terms of adult returns and juveniles, as follows,

$$SAR\left(C_0\right) = \frac{A^{C_0}}{C_0} \tag{2}$$

and

$$SAR\left(T_0\right) = \frac{A^{T_0}}{T_0} \tag{3}$$

respectively. Numerators in Eq. (2) and (3) are the sums of adult returns from all age classes, e.g., $A^{T_0} = \sum_j A_j^{T_0}$. The *SAR* is a joint probability of surviving through several life stages that include migration from LGR through the Snake and Columbia Rivers (S_2, S_3, S_L), estuary migration and ocean residence (S_O), and adult return upstream back to LGR (S_A). Subsequently, an SAR can be expressed entirely as a function of independent survival probabilities.

Derivation of the smolt-to-adult return estimators: $SAR(C_0)$ ***and*** $SAR(T_0)$

Estimating the *SAR*s for in-river (control) and transported fish requires first calculating the numbers of juveniles (C_0 and T_0) and adults (A^{C_0} and A^{T_0}) comprising each group. Calculating the numbers of juveniles in each study group, C_0 and T_0, is the more complex part of the study and thus requires the most explanation. Central to understanding the methods used to arrive at $C_0, T_0, A^{C_0},$ and A^{T_0} are three elements of the study mentioned in the introduction,

1. Smolt-to-adult return ratios are measured as the proportion of juveniles in each group at LGR that return as adults to LGR.
2. Only fish not previously detected at a dam are transported.
3. Fish are considered routed to transport at a particular dam or in-river passage before mortality occurs.

Juveniles migrating downstream encounter the start of the hydro system at Lower Granite Dam, the first transport site. Comparing *SARs* between the two groups starting at LGR fully incorporates the experience of both groups. That only previously undetected fish are transported is meant to mimic the experience of the run-at-large, i.e., tagged and untagged fish. The last element of the study, that fish are considered as entering either one of four possible migration pathways at LGR, three transport and one control, is because we are interested in the survival of fish before and after the treatment is applied. Assigning routes before the survival process occurs gives an estimate of survival from beginning of the study at LGR to the end, also at LGR. Further, losses en route to a transport site are part of total transport mortality.

Conceptually, the “destined to be transported” part or third element of the CSS study can be difficult to convey. Consider a hypothetical river with two groups of fish, a treatment and control, and a dam, weir, or other obstacle in the middle (Figure 1). We are interested in studying the effect of the “treatment” (going through an obstacle), on survival from release to a point somewhere downstream of the treatment. In this study, logistics prevent assigning groups to the treatment ahead of time. A group of size N fish is released upstream at location A (Figure 1) and at location B, some fish go through the obstacle or treatment, at random, with probability p. Other fish do not encounter the obstacle, again at random, and pass freely down the river with probability $1-p$. The effect of the treatment on survival is measured by comparing total survival from release at location A to C, $S_A S_B$, for treatment fish and against that of the control group (**T** and **F** respectively).

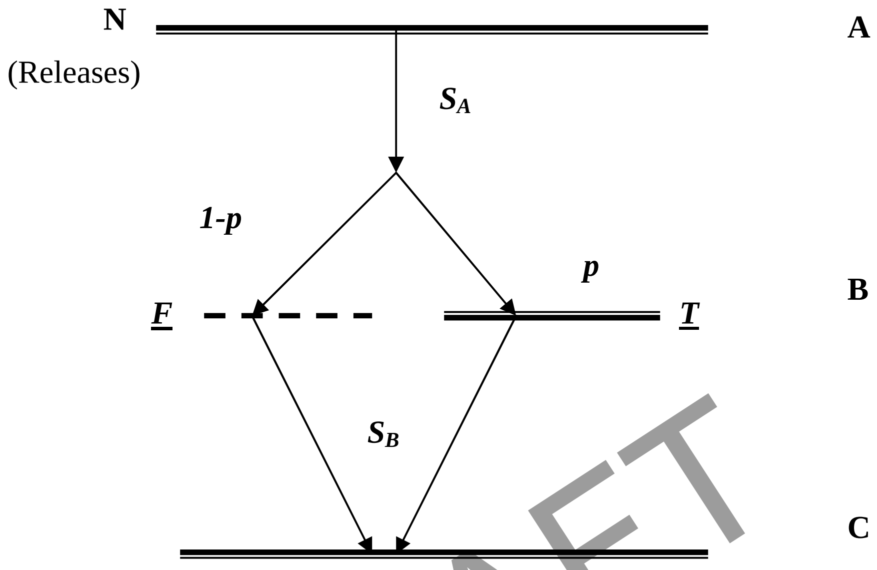

Figure 1. Diagram of a hypothetical river to illustrate the concept of “destined to be in a route of passage” in the CSS study.

Based on the branch diagram in Figure 1, one can estimate of the number of group **T** fish by considering survival *then* passage route. The number in group **T** is comprised of those that first survived with probability S_A *then* passed through the treatment with probability p and is expressed mathematically as follows,

$$T = NS_A p \, .$$

The number of treatment fish surviving from treatment application (passing the obstacle) to the end of the study at point **C** is as follows,

$$T_C = NS_ApS_B .$$

By use of the expression for the number of treatment fish above, the estimate of the proportion of fish surviving to the last point, is as follows,

$$\frac{T_C}{T} = \frac{NS_ApS_B}{NS_Ap} = S_B ,$$

This is not the original metric of interest, S_AS_B .

Now consider assigning a route of passage prior to the onset of survival processes between **A** and **B**. Any released fish can pass through the treatment with probability p (because they have not died yet). The expected number of released fish passing through the treatment is Np . Some of these fish will die along the way with probability $\left(1 - S_A\right)$, and the remainders survive with probability S_A. After the survivors pass through the treatment at **B**, some mortality will occur on the way to point **C** with probability $1 - S_B$, and the rest of the fish will survive to **C** with probability S_B. The total number in the treatment group is then comprised of those that died between **A** and **B**, and between **B** and **C**, plus the survivors from **A** to **C**, expressed mathematically as follows,

$$\begin{aligned} T &= \underbrace{Np\left(1 - S_A\right)}_{\text{Died between } \textbf{A} \text{ and } \textbf{B}} + \underbrace{NpS_A\left(1 - S_B\right)}_{\text{Died between } \textbf{B} \text{ and } \textbf{C}} + \underbrace{NpS_AS_B}_{\text{Survived to } \textbf{C}} \\ T &= Np. \end{aligned}$$

The proportion of fish surviving to site **C** out of T fish is now estimated as follows,

$$\frac{T_C}{T} = \frac{NS_ApS_B}{Np} = S_AS_B .$$

This is the original metric of interest. Hence, the idea of a destined route of passage is perhaps more accurately considered as the expected number of fish taking a particular route prior to mortality, where expectation is defined statistically as the number of trials (fish released) times the probability of being in a particular passage category.

Alternatively, one could partition site-to-site mortality between the two groups. The number of fish dying between points **A** and **B** is $N\left(1-S_B\right)$ (Figure 1). The expected number of treatment (**T**) and control (**F**) mortalities is $N\left(1-S_A\right)p$ and $N\left(1-S_A\right)\left(1-p\right)$, respectively. The expected number of fish surviving to site **B** but not to site **C** is $NS_A\left(1-S_B\right)$. The expected number of mortalities between sites **B** and **C** in the treatment and control groups is $NS_A\left(1-S_B\right)p$ and $NS_A\left(1-S_B\right)\left(1-p\right)$, respectively. The total number of fish in each group is the sum of the mortalities in each river section, plus the number surviving to site **C**. The total number of fish in control group **F** is calculated as follows,

$$\begin{aligned} F &= N\left(1-S_A\right)\left(1-p\right)+NS_A\left(1-S_B\right)\left(1-p\right)+NS_AS_B\left(1-p\right) \\ F &= N\left(1-p\right), \end{aligned}$$

and the total number of fish in the treatment group (**T**) calculated as above.

This simple example is analogous to the process encountered in the CSS study where the treatment for some groups is applied after the start of the experiment. Whether we pre-assign a route of passage, divide mortalities proportionally among the different groups, or divide by survival, e.g., $T = {}^{NS_Ap}\!\big/_{S_A}$, the results are the same. In all cases, we would arrive at an estimate of the number in each group that will allow us to estimate survival from the beginning to the end of the experiment. We will continue with the idea of taking into account particular “fates” and apportioning mortality among groups to further motivate the derivation of the T/C ratio as the system becomes more complex.

The fish release site, the three transportation sites in the Lower Snake River, and possible passage routes under consideration in this study are as in Figure 2. We present passage routes for the three transport dams, LGR, LGS, and LMN in detail because this is where juvenile fish are routed to transport or in-river passage. The river system can be considered as two separate sections. Below LNM, fish are in transport around the remaining dams or migrate in-river through the hydro system. Above Lower Monumental Dam fish are classified between the two main study groups, transport and control. It is here that mortality associated with potential passage routes is taken into account as described above.

At the start of a migration season a cohort of tagged fish is released into the Snake River above LGR (Figure 2). The expected number of tagged fish arriving at LGR regardless of eventual passage route is the number of tagged releases, N_0, multiplied by the probability of surviving to LGR, expressed as follows,

$$N_0 S_1^R .$$

At LGR, fish pass through the juvenile bypass system with probability p_2 (also called “collected”) or through other routes with probability $1 - p_2$. Fish entering the bypass system can be transported with probability τ_2 (Figure 2). Fish exiting LGR via non-detect routes can be transported at LGS or LMN, or migrate in-river undetected. Post LGR passage and the associated fates within the routes under consideration in the CSS are shown using a branch diagram (Figure 2).

The derivation of each of the metrics used to compare in-river migration to transportation performance will refer back to Figure 2. We derive mathematical expressions for the basic metrics T/C, $SAR(T_0)$, and $SAR(C_0)$, and present numerical examples from a deterministic perspective, i.e., no variance. Estimation of survival, detection, and transport parameters is discussed briefly. Estimators for $SARs$ and the T/C ratio are then expressed as functions of estimable parameters. We conclude by listing the assumptions of the methods and their importance in making inferences to the population.

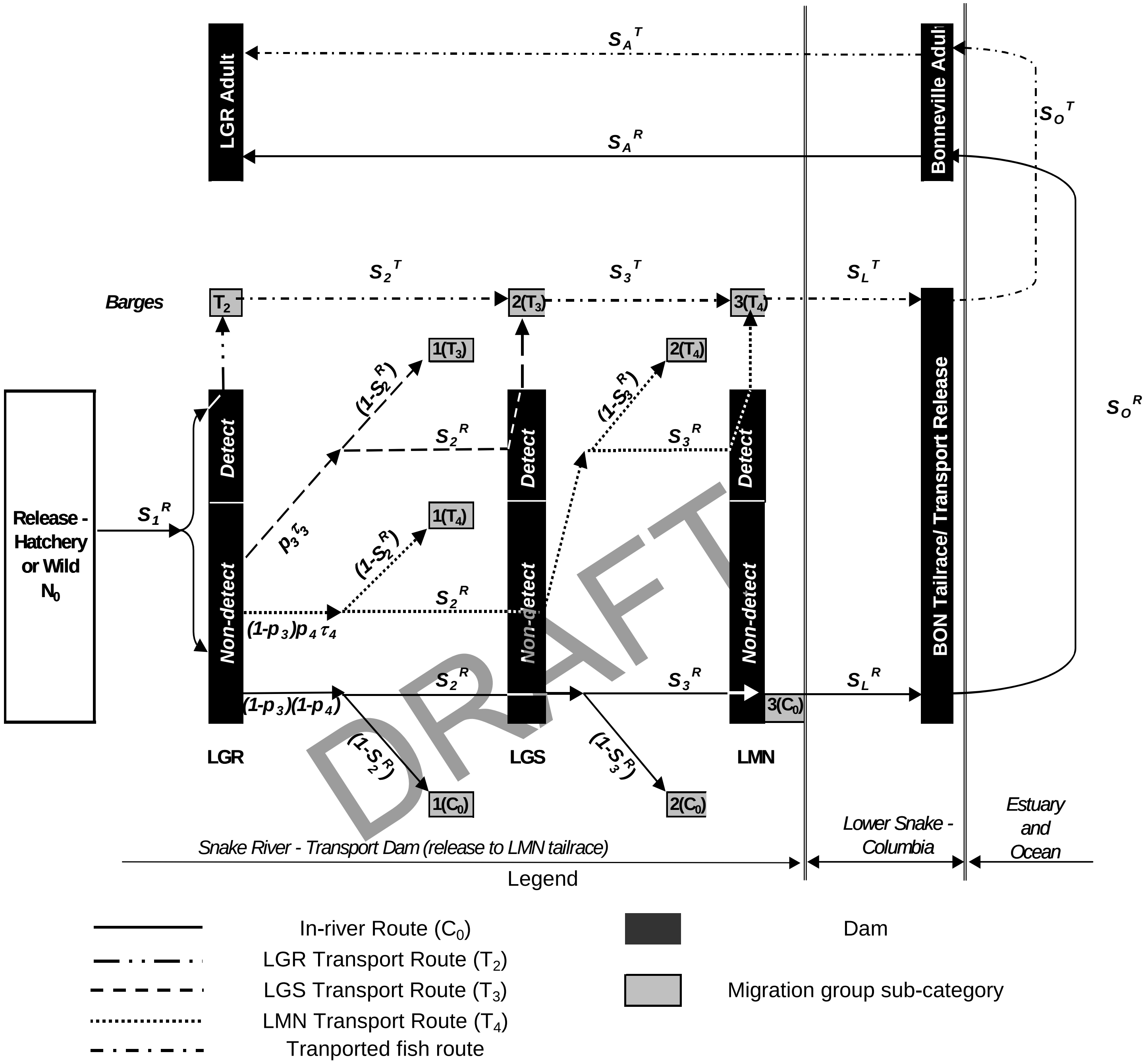

Figure 2. Schematic of the Lower Snake and Columbia River system with focus on the three transport sites, the migration routes, and the sub-categories or possible fates within each group.

Calculation of in-river (Control) SAR

Calculation of the number of juveniles for the undetected in-river passage group is the simplest among the three possible post LGR routes to describe (solid line, Figure 2). A fish passing undetected through the three transport sites is first undetected through LGR with probability $1-p_2$. Of the number of fish in the tailrace in LGR, an expected proportion of $\left(1-p_3\right)\left(1-p_4\right)$ will be in the in-river migration route or C_0 group.

Fish in this undetected pathway are comprised of three groups each representing a possible fate. First, a fish could die in-river between LGR and LGS with probability $\left(1-S_2^R\right)$ (C_0^1, Figure 2). Expressed as a function of cohort release size N_0, detection, and survival probabilities the number of C_0^1 juveniles is written as follows,

$$C_0^1 = N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right)\left(1-S_2^R\right).$$

The two other possible fates are represented by juveniles that survive to LGS but die between LGS and LMN with probability $S_2^R\left(1-S_3^R\right)$ (C_0^2, Figure 2) and fish that survive to the tailrace of LMN with probability $S_2^R S_3^R$ (C_0^3, Figure 2). The total number of fish in the undetected category, C_0, is the sum of the three groups and is expressed mathematically as follows,

$$C_0 = \left[\underbrace{N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right)\left(1 - S_2^R\right)}_{C_0^1} \right] + \left[\underbrace{N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right) S_2^R \left(1 - S_3^R\right)}_{C_0^2} \right]$$
$$+ \left[\underbrace{N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right) S_2^R S_3^R}_{C_0^3} \right],$$

or more simply,

$$C_0 = N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right). \tag{4}$$

A returning adult that migrated undetected through the Lower Snake River as a juvenile would have had to survive undetected from the LGR tailrace to the LMN tailrace with probability $\left(1 - p_3\right)\left(1 - p_4\right) S_2^R S_3^R$ and survive in-river to the Bonneville tailrace with probability S_L^R. Subsequent to in-river migration as a juvenile, a fish would then need to survive migration through estuary, then ocean residence back to Bonneville with probability S_O^R, and finally survive adult migration back to LGR with probability S_A^R (solid line, Figure 2). Under the assumption of independent probabilities, the number of fish in the C_0 group that return as adults, A^{C_0}, is expressed as a function of release numbers, detection, and survival as follows,

$$A_{C_0} = N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right)\left(1 - p_4\right) S_2^R S_3^R S_L^R S_O^R S_A^R. \tag{5}$$

By the definition of Eq. (2) and use of the juvenile and adult numbers (Eq. (4) and (5), respectively), the SAR for fish migrating in-river is as follows,

$$SAR\left(C_0\right)=\frac{A_{C_0}}{C_0},$$

or,

$$SAR\left(C_0\right)=\frac{N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right)S_2^R S_3^R S_L^R S_O^R S_A^R}{N_1 S_1^R\left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right)}.$$

Simplifying the above equation leads to an expression for $SAR\left(C_0\right)$ that is a function exclusively of survival probabilities through each life stage from LGR as a juvenile to LGR as an adult

$$SAR\left(C_0\right)=S_2^R S_3^R S_L^R S_O^R S_A^R. \tag{6}$$

Calculation of the transport *SAR*

Although conceptually similar, determining the number of fish in the transport system is more complex than calculating juvenile numbers passing in-river. The total number of T_0 juveniles is the sum of the number transported from each of the three barge sites, LGR, LGS, and LNM or T_2, T_3, and T_4, respectively. The derivation for the numbers of juveniles in each transport group is similar to that of the C_0 group where the possible fates of fish en route to the barge site are considered. Expressions for adult returns are more easily calculated than juvenile numbers. We derive the smolt-to-adult return rate for transported fish by considering site-specific transport route and adult return numbers.

Calculation of transported juveniles, returning adults, and SAR: Lower Granite Dam

The number of fish transported from LGR is the most easily calculated of all the transport groups (Figure 2). Fish survive from release to LGR with probability, S_1^R, are detected with probability p_2, and are transported with probability τ_2. The total number of fish transported from LGR, T_2, is expressed mathematically as follows,

$$T_2 = N_0 S_1^R p_2 \tau_2 . \qquad (7)$$

A fish transported as a juvenile at LGR returning as an adult to LGR has to first survive past LGS and LMN in the barge with joint probability $S_2^T S_3^T$, then survive transport through the lower Snake and Columbia rivers to the transport release site with probability S_L^T (Figure 2). Upon release, the same fish would have to survive estuary migration and ocean residence back to Bonneville with probability S_O^T and finally survive upstream migration to LGR with probability S_A^T (Figure 2). The total number of adults returning to LGR that were transported as juveniles, A_{T_2}, is expressed in terms of release numbers, detection, transport, and survival probabilities as follows,

$$A_{T_2} = N_0 S_1^R p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T . \qquad (8)$$

By the definition of Eq. (3), the site-specific return probability for fish transported from LGR, $SAR\left(T_2\right)$, is written as,

$$SAR\left(T_2\right) = \frac{A_{T_2}}{T_2} = \frac{N_0 S_1^R p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T}{N_0 S_1^R p_2 \tau_2}$$

or, more simply,

$$SAR\left(T_2\right) = S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2} \,. \tag{9}$$

Hence, the SAR for fish transported from LGR can be expressed solely as a joint survival probability through several life stages.

Calculation of transported juveniles, returning adults, and SAR: Little Goose Dam

The expected number of fish not detected at LGR is expressed as follows, $N_0 S_1^R \left(1 - p_2\right)$. Juveniles in this group are routed to one of three pathways, transport at LGS, transport at LMN, or in-river passage (Figure 2). The probability of being in the LGS transport group is $p_3 \tau_3$. Of these fish, some will die in-river on the way to LGS with probability $\left(1 - S_3^R\right)$ (T_3^1), and the rest survive with probability S_2^R (T_3^2). The expected number of fish in this route, T_3, can therefore be expressed as

$$T_3 = \underbrace{N_0 S_1^R \left(1 - p_1\right) p_3 \tau_3 \left(1 - S_2^R\right)}_{T_3^1} + \underbrace{N_0 S_1^R \left(1 - p_1\right) p_3 \tau_3 S_2^R}_{T_3^2} \,,$$

or

$$T_3 = N_0 S_1^R \left(1 - p_1\right) p_3 \tau_3 \,. \tag{10}$$

Fish returning to LGR as adults that were in the LGS transport pathway as juveniles in the tailrace of LGR (dotted line, Figure 2) would have had to survive in-river to the transport site with probability S_2^R. Subsequent to entering the barge at LGS, a fish would have had to survive in the barge past LMN to the transport release site with joint probability, $S_3^T S_L^T$, survive in the estuary migration, ocean residence and back to BON with probability S_O^T, and finally survive in-river migration as an adult back to LGR with probability S_A^T (dotted-dashed line, Figure 2). Hence, the number of fish in the LGS pathway surviving from LGR as a juvenile back to LGR as an adult can be written as,

$$A_{T_3} = N_0 S_1^R \left(1 - p_2\right) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T, \tag{11}$$

Following the definition of Eq. (3), the site specific smolt-to-adult return proportion for fish in the LGS transport route, $SAR\left(T_3\right)$, is as follows,

$$SAR\left(T_3\right) = \frac{N_0 S_1^R \left(1 - p_2\right) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T}{N_0 S_1^R \left(1 - p_2\right) p_3 \tau_3}$$

or more simply,

$$SAR\left(T_3\right) = S_2^R S_3^T S_L^T S_O^T S_A^T. \tag{12}$$

Again, the *SAR* for fish transported at LGS is a function of the probability of surviving from LGR as a juvenile back to LGR as an adult through all associated life stages. The $SAR\left(T_3\right)$ also includes S_2^R, the survival through that portion of the river traveled by juveniles to the transport site.

Calculation of transported juveniles, returning adults, and SAR: Lower Monumental Dam

The number of juveniles on the transport route to LMN, T_4, can meet three possible fates; not survive between LGR and LGS with probability $\left(1-S_2^R\right)$ (T_4^1), survive to LGS tailrace and die on the way to LMN with probability $S_2^R\left(1-S_3^R\right)$ (T_4^2), or survive to the transport site with probability $S_2^R S_3^R$ (T_4^3). The total number of fish in the LMN transport route is the sum of the number of fish in these groups and is expressed mathematically as,

$$T_4 = \left[\underbrace{N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4\left(1-S_2^R\right)}_{T_4^1}\right] + \left[\underbrace{N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4 S_2^R\left(1-S_3^R\right)}_{T_4^2}\right]$$
$$+\left[\underbrace{N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4 S_2^R S_3^R}_{T_4^3}\right].$$

Simplifying the above equation gives the number of fish in the LMN transport route as a function of tag release numbers, survival, detection, and transport probabilities as follows,

$$T_4 = N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4 . \qquad (13)$$

The number of fish surviving the LMN transport route and returning to LGR as adults is expressed mathematically as

$$A_{T_4} = N_0 S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T . \qquad (14)$$

By use of the definition in Eq. 3, the site-specific SAR for fish in the LMN transport route, $SAR\left(T_4\right)$, is expressed as,

$$SAR\left(T_4\right)=\frac{N_0S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4S_2^RS_3^RS_L^TS_O^TS_A^T}{N_0S_1^R\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4},$$

or more simply,

$$SAR\left(T_4\right)=S_2^RS_3^RS_L^TS_O^TS_A^T \tag{15}$$

Again, the SAR for fish in this passage route is a function of survival probabilities only, including some in-river survival associated with traveling to the transport site, i.e., $S_2^RS_3^R$.

Transport smolt-to-adult return rate, $SAR\left(T_0\right)$

The SAR for transported fish is, by definition [Eq. (3)], the number of returning adults divided by the number of juveniles in the transport system. Total juveniles in the transport system, T_0, are calculated from the numbers each transport sub-group [Eqs. (7), (10), and (13)] as follows,

$$T_0=N_0S_1^R\left(p_2\tau_2+\left(1-p_2\right)p_3\tau_3+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4\right). \tag{16}$$

The expected number of returning adults, A_{T_0}, out of T_0 transported juveniles is calculated by the sum of Eqs. (8), (11), and (14) as follows,

$$A_{T_0}=$$
$$N_0S_1^R\left(p_2\tau_2S_2^TS_3^TS_L^TS_O^TS_A^T+\left(1-p_2\right)p_3\tau_3S_2^RS_3^TS_L^TS_O^TS_A^T+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4S_2^RS_3^RS_L^TS_O^TS_A^T\right).$$

The smolt-to-adult return proportion for fish in the transport system [Eq. 3] is expressed as follows,

$$SAR\left(T_0\right)=\frac{A_{T_0}}{T_0},$$

or

$$SAR\left(T_0\right)=\frac{p_2\tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T+\left(1-p_2\right) p_3\tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T+\left(1-p_2\right)\left(1-p_3\right) p_4\tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T}{p_2\tau_2+\left(1-p_2\right) p_3\tau_3+\left(1-p_2\right)\left(1-p_3\right) p_4\tau_4} \qquad (17)$$

Alternatively, the transport *SAR* can be expressed as a weighted average across all transport groups, with weights equal to the proportion of fish transported from each site. The transport SAR as a weighted average is written as follows,

$$SAR\left(T_0\right)=\sum_{i=2}^{4} w_i SAR\left(T_i\right), \qquad (18)$$

where $w_i=\frac{T_i}{T_0}$, the proportion of fish in each of the *i* transport routes [Eqs. (7), (10), and (13) for $T_2, T_3,$ and T_4, respectively] and $SAR\left(T_i\right)$, the site specific *SARs* defined in Eqs. (9), (12), and (15).

T/C Ratio, behavior under the null hypothesis [$H_O:\left(T/C\right)=1$] and numerical examples

The transport to in-river survival ratio can be written in terms of site-specific adult return probabilities [Eq. (1)] as follows,

$$T/C=\frac{\dfrac{p_2\tau_2S_2^{T_2}S_3^{T_2}S_L^{T_2}S_O^{T_2}S_A^{T_2}+\left(1-p_2\right)p_3\tau_3S_2^{R}S_3^{T_3}S_L^{T_3}S_O^{T_3}S_A^{T_3}+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4S_2^{R}S_3^{R}S_L^{T_4}S_O^{T_4}S_A^{T_4}}{p_2\tau_2+\left(1-p_2\right)p_3\tau_3+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4}}{S_2^RS_3^RS_L^RS_O^RS_A^R}$$

or,

$$T\!\!\diagup\!\! C=\frac{p_2\tau_2S_2^{T_2}S_3^{T_2}S_L^{T_2}S_O^{T_2}S_A^{T_2}+\left(1-p_2\right)p_3\tau_3S_2^{R}S_3^{T_3}S_L^{T_3}S_O^{T_3}S_A^{T_3}+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4S_2^{R}S_3^{R}S_L^{T_4}S_O^{T_4}S_A^{T_4}}{S_2^RS_3^RS_L^RS_O^RS_A^R\left[p_2\tau_2+\left(1-p_2\right)p_3\tau_3+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4\right]}\qquad(19)$$

Using the convention of Sanford and Smith (1991) and Buchanan (2005), the site-specific $T\!\!\diagup\!\! C$ ratios can be expressed as $R_i=\dfrac{SAR\left(T_i\right)}{SAR\left(C_0\right)}$ and Eq. (19) re-expressed as,

$$T\!\!\diagup\!\! C=\frac{R_2\cdot p_2\tau_2+R_3\cdot\left(1-p_2\right)p_3\tau_3+R_4\cdot\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4}{\left[p_2\tau_2+\left(1-p_2\right)p_3\tau_3+\left(1-p_2\right)\left(1-p_3\right)p_4\tau_4\right]},$$

or

$$T\!\!\diagup\!\! C=\sum_{i=2}^{4}w_iR_i\qquad(20)$$

where w_i is defined as in Eq. (18). The overall $^{T}\!/_{C}$ ratio can be written as an average of site specific ratios, R_i weighted by the probability of being transported from each site. However, Eqs. (19) and (20) are specific to the design elements of the CSS study and not a general $^{T}\!/_{C}$ ratio for all possible situations.

Behavior of $^{T}\!/_{C}$ *under the null*

One of the ways to check the properties of an equation is to observe the behavior under the null hypothesis, the only condition under which the outcome is known. For the $^{T}\!/_{C}$ ratio, the null hypothesis means that there is no difference in the rate of relative adult returns between transported and in-river migrating juveniles. No difference in relative survival between transported and control fish could be satisfied under the following set conditions,

$$S_2^{T_i} = S_2^{R};\ S_3^{T_i} = S_3^{R};\ S_4^{T_i} = S_4^{R};\ S_L^{T_i} = S_L^{R};\ S_O^{T_i} = S_O^{R};\ \text{and } S_A^{T_i} = S_A^{R}, \forall i\,.$$

If true, then $R_i = 1$ for all *i* and Eq. (20), the $^{T}\!/_{C}$ ratio is equal to one. Note that the result does not depend on detection and transport probabilities but only on survival.

Numerical example 1a: Equal return rates between transport and control groups (Null model), 100% transport

To further illustrate the calculations to arrive the T/C ratio for a cohort of fish, we consider a year in which the rates of return are the same for both groups, i.e., the null condition of no difference between the transport and control group with regard to smolt-to-adult return ratios. Illustrating the properties of the T/C ratio is easiest under this scenario. Moreover, examining conditions under the null hypothesis is one way to verify that a particular estimator behaves as expected. In this example, probabilities of survival are the same for fish in the transport group and control groups (Table 1). For simplicity, detection probabilities are equal among the three sites and all detected fish are transported, i.e., $\tau_2 = \tau_3 = \tau_4 = 1$. We relax these last conditions in the next example. Numbers of fish comprising transport and control groups are presented in Table 2, given a fixed cohort release size and the stated probabilities. Starting from the release site to eventual return as an adult, we follow a cohort of fish through a simplified life history to illustrate the calculation of the T/C ratio (Eq. (19)).

Table 1. Hypotheical survival, detection, and transport probabilities for a cohort of 50,000 tagged fish.

Segment	Segment designation (*i*)	In River Survival S_i^R	Transport Route Survival S_i^T	Location (*i*)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.3	1.00
LGR to LGS	2	0.8	0.8	LGS (3)	0.3	1.00
LGS to LMN	3	0.8	0.8	LMN (4)	0.3	1.00
LMN-BON (L)	L	0.5	0.5			
BON-BON (Ocean)	O	0.05	0.05			
BON-LGR	A	0.8	0.8			

Table 2. Numbers of fish comprising each migration category sub-categories, e.g., C_0^1, for a hypothetical release of 50,000 fish and the probabilities given in Table 1. Shaded boxes correspond to the shaded sub-categories in Figure 2.

Segment	Fish Surviving to Site, In-river **(Bold)** (Undetected in Snake R.)			Total Mortalities Between Sites	In River Mortalities to C_0 category	In River Mortalities to T_0 category	Fish Added to Barge At Site **(Bold)**	Fish in Barge At Site (**Bold**)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to **LGR**	28000						12000 (T_2)	12000	
LGR to **LGS**	15680	10976 $(C_0^2+C_0^3)$	4704 $(T_4^2+T_4^3)$	5600	2744 (C_0^1)	1680 (T_3^1) 1176 (T_4^1)	6720 (T_3^2)	16320	2400
LGS to **LMN**	8781	8781 (C_0^3)		3136	2195 (C_0^2)	941 (T_4^2)	3763 (T_4^3)	16819	3264
LMN-**BON**	4390							8410	
BON-**BON** (Ocean residence)	220							420	
BON-**LGR**	176							336	

We begin by calculating the numbers of juveniles in each passage group, i.e., C_0 and T_0. At a hatchery above Lower Granite Dam, 50,000-tagged fish are released ($N_1 = 50,000$). Of this tag release group, 12,000 juveniles are put to the barge at LGR T_2, (Figure 2) calculated by Eq. (7) as follows,

$$\begin{aligned} T_2 &= N_0 S_1^R p_2 \tau_2 \\ &= 50000(0.8)(0.3)(1) \\ T_2 &= 12,000 \end{aligned}$$

Fish surviving to LGR pass undetected are comprised of the C_0, T_3, and T_4 groups, calculated as,

$$\begin{aligned} C_0 + T_3 + T_4 &= N_0 S_1^R (1 - p_2) \\ C_0 + T_3 + T_4 &= 50000(0.8)(1 - 0.3). \\ C_0 + T_3 + T_4 &= 28,000 \end{aligned}$$

Of the number of fish in the tailrace of LGR, $\left(1 - S_2^R\right)$% of each group will not make it to the next site (Figure 2). Because getting to an eventual passage route will have associated mortality, we apportion number of mortalities within the reach (segment of the river) according to the probability a fish will be in a particular route of passage among three groups. The total number of mortalities, $28000 \cdot \left(1 - S_2^R\right)$, between LGR and LGS are comprised of the $C_0^1, T_3^1,$ and T_4^1 groups (Figure 2), each calculated as follows,

$$\begin{aligned} C_0^1 &= N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4)\left(1 - S_2^R\right) \\ &= 50000(0.8)(0.7)(0.7)(0.7)(0.2) \\ C_0^1 &= 2744, \end{aligned}$$

$$\begin{aligned} T_3^1 &= N_0 S_1^R \left(1-p_2\right) p_3 \tau_3 \left(1-S_2^R\right) \\ &= 50000(0.8)(0.7)(0.3)(1)(0.2) \\ T_3^1 &= 1680, \end{aligned}$$

and

$$\begin{aligned} T_4^1 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right) p_4 \tau_4 \left(1-S_2^R\right) \\ &= 50000(0.8)(0.7)(0.7)(0.3)(1)(0.2) \\ T_4^1 &= 1176. \end{aligned}$$

The second fate for fish in the LGS transport path is survival to the barge. The number of fish in the T_3^2 group that is eventually added to the T_2 surviving fish already in the barge is calculated by,

$$\begin{aligned} T_3^2 &= N_0 S_1^R \left(1-p_2\right) p_3 \tau_3 S_2^R \\ &= 50,000(0.8)(0.7)(0.3)(1)(0.8) \\ T_3^2 &= 6720. \end{aligned}$$

All of the T_3 transport group, those on the LGS transport pathway (route) are accounted for at this site. The total number of T_3 fish is $T_3^1 + T_3^2 = 1,680 + 6,720 = 8,400$.

Arriving at the tailrace of LGS are the remainder of the fish in the C_0 and T_4 groups. Juveniles that will eventually migrate in-river (C_0 group) and have survived the second river segment (LGR to LGS) plus those that will be transported at LMN (T_4) and survived through this reach comprise the 15,680-tagged fish in the tailrace of LGS. Of these fish, $\left(1-S_3^R\right)$ percent, or 3,136 juveniles, will meet the second fate of not surviving to LMN, groups C_0^2 and T_4^2 (Figure 2). The numbers in each group are calculated as follows, respectively,

$$\begin{aligned} C_0^2 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right) S_2^R \left(1-S_3^R\right) \\ &= 50000(0.8)(0.7)(0.7)(0.7)(0.8)(0.2) \\ &= 2195 \end{aligned}$$

and

$$\begin{aligned} T_4^2 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right) p_4 \tau_4 S_2^R \left(1-S_3^R\right) \\ &= 50,000(0.8)(0.7)(0.7)(0.3)(1)(0.8)(0.2) \\ T_4^2 &= 941. \end{aligned}$$

The third fate for the C_0 fish is survival to the tailrace of LMN and eventual passage through the hydro system. The number in the group is calculated as

$$\begin{aligned} C_0^3 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right) S_2^R S_3^R \\ &= 50,000(0.8)(0.7)(0.7)(0.7)(0.8)(0.8) \\ C_0^3 &= 8781 \end{aligned}$$

The third fate for the fish in the LGS transport group, T_4^3, is eventual survival to the barge for downstream passage. The number of fish in this group is calculated as follows,

$$\begin{aligned} T_4^3 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right) p_4 \tau_4 S_2^R S_3^R \\ &= 50,000(0.8)(0.7)(0.7)(0.3)(1)(0.8)(0.8) \\ T_4^3 &= 3763 \end{aligned}$$

The total number of fish in the control group is the sum of the C_0 mortalities between LGR and LMN plus the number of fish surviving to LNM tailrace is computed as,

$$\begin{aligned} C_0 &= C_0^1 + C_0^2 + C_0^3 \\ C_0 &= 2744 + 2195 + 8781 \\ C_0 &= 13720 \end{aligned}$$

This is equivalent to calculating the expected number of C_0 fish by Eq. (4) as follows,

$$\begin{aligned} C_0 &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) \\ &= 50,000(0.8)(0.7)(0.7)(0.7) \\ C_0 &= 13720. \end{aligned}$$

The total number of fish in the T_0 group is the sum of all possible fates between LGR and LMN for fish in the transport routes, calculated as follows,

$$\begin{aligned} T_0 &= T_2 + \left(T_3^1 + T_4^1\right) + T_3^2 + T_4^2 + T_4^3 \\ &= 12000 + (2856) + 6720 + 941 + 3763 \\ T_0 &= 26280 \end{aligned}$$

Of the 8781 fish in the C_0 group that survived to LMN, 4,390 juveniles survived migration through the rest of the system to the tailrace of Bonneville with $8781 \cdot S_L^R$, and 220 eventually returned as adults to Bonneville Dam (BON). Of these adult returns, 176 fish were eventually observed at LGR. The expected number of adults in the control group returning to LGR is calculated by Eq. (5) as follows,

$$\begin{aligned} A_{C_0} &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R S_3^R S_L^R S_O^R S_A^R \\ &= 50,000(0.8)(0.7)(0.7)(0.7)(0.8)(0.8)(0.5)(0.05)(0.8) \\ A_{C_0} &= 176 \end{aligned}$$

The smolt-to-adult return proportion for control fish in calculated by the definition in Eq. (2) as follows,

$$\begin{aligned} SAR\left(C_0\right) &= \frac{A_{C_0}}{C_0} \\ &= \frac{176}{13720} \\ SAR\left(C_0\right) &= 0.0128 \end{aligned}$$

Alternatively, the SAR can be calculated as the product of survival probabilities [Eq. (6)] as follows,

$$\begin{aligned} SAR\left(C_0\right) &= S_2^R S_3^R S_L^R S_O^R S_A^R \\ &= \left(0.8\right)\left(0.8\right)\left(0.5\right)\left(0.05\right)\left(0.8\right) \\ SAR\left(C_0\right) &= 0.0128. \end{aligned}$$

The number of adults returning to LGR of the transported fish is again slightly more complex. Of the 12,000 T_2 juveniles put in the barge, 9600 survived to LGS and 2400 died on the way, i.e., $S_2^T = 0.8$. At the second transport site, LGS, 6,720 of the T_3 fish were added. A total of 16,320 juveniles were alive in the barge upon leaving LGS. Between LGS and LMN, 3,264 juveniles died, i.e., $S_3^T = 0.8$ and 3,763 T_4 surviving juveniles were added at LMN. Subsequently, there were 16,819 live fish in the barge upon entering the lower hydro system. Survival in the barge through the lower river, S_L^T was 50% , hence only 8,410 were released alive below BON. Of these, 420 survived to adult return (sum of all age classes; $S_O^T = 0.05$) at BON, and 336 were observed at LGR. From these data, the smolt-to-adult return proportion for fish in the T_0 group is calculated according to the definition of an SAR [Eq. (3)] as follows,

$$\begin{aligned} SAR\left(T_0\right) &= \frac{A_{T_0}}{T_0} \\ &= \frac{336}{26208} \\ SAR\left(T_0\right) &= 0.0128. \end{aligned}$$

The $SAR\left(T_0\right)$ can also be computed using site specific $SARs$ Eq (18) as follows,

$$\begin{aligned} SAR\left(T_2\right) &= S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2} \\ &= \left(0.8\right)\left(0.8\right)\left(0.5\right)\left(0.05\right)\left(0.8\right) \\ SAR\left(T_2\right) &= 0.0128 \end{aligned}$$

and for T_3 and T_4, $SAR\left(T_3\right) = 0.0128$ and $SAR\left(T_4\right) = 0.0128$, respectively. The proportions of T_0 fish transported from each site, $w_2, w_3,$ and w_4, are calculated as follows,

$$w_2 = \frac{12000}{26280} = 0.456, w_3 = \frac{8400}{26280} = 0.320, \text{ and } w_4 = \frac{5880}{26280} = 0.224,$$

respectively. Then, using Eq. (18) $SAR\left(T_0\right)$ is,

$$SAR\left(T_0\right) = w_2 SAR\left(T_2\right) + w_3 SAR\left(T_3\right) + w_4 SAR\left(T_4\right)$$

$$\begin{aligned} SAR\left(T_0\right) &= 0.456\left(0.0128\right) + 0.320\left(0.0128\right) + 0.224\left(0.0128\right) \\ SAR\left(T_0\right) &= 0.0128. \end{aligned}$$

By use of the definition in Eq. 1, the ${}^{T}\!/_{C}$ ratio is calculated as follows,

$$\begin{aligned} T/C &= \frac{SAR(T_0)}{SAR(C_0)} \\ &= \frac{0.0128}{0.0128} \quad , \\ T/C &= 1 \end{aligned}$$

or by Eq. (20) where $R_i = \frac{SAR(T_i)}{SAR(C_0)}$, as

$$\begin{aligned} T/C &= w_2R_2 + w_3R_3 + w_3R_4 \\ &= 0.456(1) + 0.320(1) + 0.224(1) \\ T/C &= 1. \end{aligned}$$

In the next example, not all collected (detected) fish are transported.

Numerical example 1b: Equal return rates between transport and control groups (Null model), differential detection and survival probabilities among transport sites.

In this example, all survival probabilities are as in example 1a, however, each transport site has a different detection (collection) probability (Table 3). Furthermore, transport probabilities are less than one and differ among the three sites (Table 3). Again, we follow a cohort of 50,000 tagged fish from release to eventual return as an adult to LGR and compute the number of fish in each category and at each stage of migration through the three transport dams (Table 4), the SAR s for each group and T/C ratio.

As in Example 1a, 40,000 fish survive to LGR, 24,000 of which are undetected (Table 4). However, this time only 10,560 of 16,000 collected (detected) juveniles are transported, i.e., $T_2 = 10{,}560$, Eq. (7). The remaining 5,440 juveniles that were detected (collected) are returned to the river for the purposes of estimating survival and detection probabilities. Because these fish have a prior detection history, they are not subject to transport, nor can they be included in the C_0 category. Thus, they are no longer part of the study except for purposes of parameter estimation.

Table 3. Hypothetical reach survival and site-specific detection and transport probabilities for Example 1b.

Segment	Segment designation (i)	In-river Survival S_i^R	Transport Route Survival S_i^T	Location (i)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.4	0.66
LGR to LGS	2	0.8	0.8	LGS (3)	0.35	0.5
LGS to LMN	3	0.8	0.8	LMN (4)	0.5	0.6
LMN-BON (L)	L	0.5	0.5			
BON-BON (Ocean)	O	0.05	0.05			
BON-LGR	A	0.8	0.8			

Table 4. Hypothetical numbers of fish in each category and sub-category (intermediate calculations) for Example 1b. Shaded cells correspond to sub-categories in Figure 2. Release size is 50,000 tagged fish.

Segment	Fish Surviving to Site **(Bold)**, In-river (Undetected in Snake R.)			Total Mortalities In-river Between Sites	In-river Mortalities to C_0 category	In-river Mortalities to T_0 category	Fish Added to Barge At Site **(Bold)**	Fish in Barge At Site (**Bold**)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to **LGR**	24000						10560 (T_2)	10560	
LGR to **LGS**	12480	6240 $(C_0^2 + C_0^3)$	3744 $(T_4^2 + T_4^3)$	4800	1560 (C_0^1)	840 (T_3^1) 936 (T_4^1)	3360 (T_3^2)	11808	2112
LGS to **LMN**	4992	4992 (C_0^3)		2496	1248 (C_0^2)	749 (T_4^2)	2995 (T_4^3)	12442	2362
LMN-**BON**		2496						6221	
BON-**BON**		125						311	
BON-**LGR**		100						249	

Of the 24,000 undetected fish in the tailrace of LGR, 4,800 die within the next river reach and include 1,560 C_0 fish (C_0^1, Figure 2; Table 1), 840 T_3 fish (T_3^1, Figure 2 and Table 4), and 936 T_4 fish (T_4^1, Figure 2; Table 4). The numbers in each of these sub-categories are calculated as follows, respectively,

$$\begin{aligned} C_0^1 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right)\left(1-S_2^R\right) \\ &= 50000\left(0.8\right)\left(0.6\right)\left(0.65\right)\left(0.5\right)\left(0.2\right) \\ C_0^1 &= 1,560, \end{aligned}$$

$$\begin{aligned} T_3^1 &= N_0 S_1^R \left(1-p_2\right) p_3 \tau_3 \left(1-S_2^R\right) \\ &= 50000\left(0.8\right)\left(0.6\right)\left(0.35\right)\left(0.5\right)\left(0.2\right) \\ T_3^1 &= 840, \end{aligned}$$

and

$$\begin{aligned} T_4^1 &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right) p_4 \tau_4 \left(1-S_2^R\right) \\ &= 50,000\left(0.8\right)\left(0.6\right)\left(0.65\right)\left(0.5\right)\left(0.6\right)\left(0.2\right) \\ T_4^1 &= 936. \end{aligned}$$

The 1,464 unaccounted for mortalities in the LGR-LGS reach ($4,800 - C_0^1 - T_3^1 - T_4^1 = 1,464$) are part of the group of juveniles that are detected in the Snake River at least once but are not transported and thus are no longer part of the study.

Surviving to transport at LGS are 3,360 juveniles ($T_3^2 = 3,360$). The number of juveniles placed in transport at LGS is calculated as follows,

$$\begin{aligned}T_3^1 &= N_0 S_1^R \left(1-p_2\right) p_3 \tau_3 S_2^R \\ &= 50000\left(0.8\right)\left(0.6\right)\left(0.35\right)\left(0.5\right)\left(0.8\right) \\ T_3^1 &= 3,360.\end{aligned}$$

The total number of fish in the LGS transport group is the sum of the two T_3 sub-groups, those dying in the second river reach (LGR to LGS) and those that survive to actual transport, or $T_3 = T_3^1 + T_3^2 = 4,200$. This is equivalent to the result obtained by computing the expected number fish in the LGS transport group by use of Eq. (10).

Entering the river reach below LGS are 6,240 and 3,744 fish remaining in the C_0, and T_4 migration routes, respectively. Of the control fish, 1,248 do not survive to the next dam (C_0^2), and 4,992 arrive at the tailrace of LMN (C_0^3). The numbers in each sub-category are calculated as,

$$\begin{aligned}C_0^2 &= N_1 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right) S_2^R \left(1-S_3^R\right) \\ &= 50,000\left(0.8\right)\left(0.6\right)\left(0.65\right)\left(0.5\right)\left(0.8\right)\left(0.2\right) \\ C_0^2 &= 1,248\end{aligned}$$

and

$$\begin{aligned}C_0^3 &= N_1 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right) S_2^R S_3^R \\ &= 50,000\left(0.8\right)\left(0.6\right)\left(0.65\right)\left(0.5\right)\left(0.8\right)\left(0.8\right) \\ C_0^3 &= 4,992.\end{aligned}$$

Of the 3,744 remaining fish in the LMN transport pathway, 749 die in the reach below LGS ($T_4^2 = 749$; Figure 2; Table 4), and 2,995 survive to actual transport ($T_4^3 = 2,995$). The numbers of fish in each of the T_4 sub-categories, T_4^2 and T_4^3, are estimated as follows,

$$\begin{aligned}T_4^2 &= N_1 S_1^R \left(1 - p_2\right)\left(1 - p_3\right) p_4 \tau_4 S_2^R \left(1 - S_3^R\right)\\ &= 50,000(0.8)(0.6)(0.65)(0.5)(0.6)(0.8)(0.2)\\ T_4^2 &= 749\end{aligned}$$

and

$$\begin{aligned}T_4^3 &= N_1 S_1^R \left(1 - p_2\right)\left(1 - p_3\right) p_4 \tau_4 S_2^R S_3^R\\ &= 50,000(0.8)(0.6)(0.65)(0.5)(0.6)(0.8)(0.8)\\ T_4^3 &= 2,995.\end{aligned}$$

The total number of fish in the LNM transport group (pathway) is the sum of fish experiencing one of three possible fates on the way to the barge: dying in the 2nd river reach (the T_4^1 group); surviving to the tailrace of LGS but not to LMN (the T_4^2 group); and arriving to actual transport at LMN (the T_4^3 fish). The total number of T_4 fish is,

$$\begin{aligned}T_4 &= T_4^1 + T_4^2 + T_4^3\\ &= 936 + 749 + 2995\\ T_4 &= 4,680.\end{aligned}$$

The total number of fish in the transport group, T_0, can be calculated by either summing the totals of the individual pathways as follows,

$$
\begin{aligned}
T_0 &= T_2 + T_3 + T_4 \\
&= 10,590 + 4200 + 4680 \\
T_0 &= 19,440,
\end{aligned}
$$

or by use of Eq.(16),

$$
\begin{aligned}
T_0 &= N_1 S_1^R \left[p_2 \tau_2 + (1 - p_2) p_3 \tau_3 + (1 - p_2)(1 - p_3) p_4 \tau_4 \right] \\
&= 50,000(0.8)\left[(0.4)(0.66) + (0.6)(0.35)(0.5) + (0.6)(0.65)(0.5)(0.6)\right] \\
T_0 &= 19,440
\end{aligned}
$$

The total number of juveniles in the control groups is calculated by use of subgroups as follows,

$$
\begin{aligned}
C_0 &= C_0^1 + C_0^2 + C_0^3 \\
&= 1560 + 1248 + 4992 \\
C_0 &= 7800
\end{aligned}
$$

or by use of Eq. (4)

$$
\begin{aligned}
C_0 &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) \\
&= 50,000(0.8)(0.6)(0.65)(0.5) \\
C_0 &= 7,800.
\end{aligned}
$$

The adults that return out of the T_0 juveniles in the transport routes are calculated by considering the 10,560 fish that were transported at LGR (Table 4). Of these fish, 80% survive to LGS where 3,360 fish are added (Table 3 and Table 4). Upon leaving LGS, 11,808 juveniles are in transport, i.e., $10,560(0.8) + 3,360 = 11,808$, with 80% surviving to LMN ($S_3^T = 0.8$; Table 3). At the final transport site, 2995 T_4^3 fish are added. Twelve-thousand four hundred forty-two (12,442) juveniles are then barged downstream past the dams on the Columbia River. Survival in the barge through the lower river reaches to the release site below Bonneville Dam is 50%. Hence, only 6,221 live fish are released from the barge. Survival from transport release back to Bonneville as an adult for the T_0 fish is 5%, and 311 adults are observed at BON. Adult in-river survival is 80% and 249 adult fish return out of the 19,440 in the T_0 group leaving LGR as juveniles. The SAR for the transport category is calculated by Eq. (3) as follows,

$$\begin{aligned} SAR(T_0) &= \frac{A_{T_0}}{T_0} \\ &= \frac{249}{19440} \\ SAR(T_0) &= 0.0128. \end{aligned}$$

Alternatively, $SAR(T_0)$ can be calculated use of Eq. (18). The SARs for each transport group are the same as in Example 1a , $SAR(T_2) = 0.0128$, $SAR(T_3) = 0.0128$ and $SAR(T_4) = 0.0128$. The proportion of T_0 fish in each of the three transport groups, $w_2, w_3,$ and w_4, are calculated as,

$$w_2 = \frac{10590}{19440} = 0.5448, w_3 = \frac{4200}{19440} = 0.2160, \text{ and } w_4 = \frac{4680}{19440} = 0.2407,$$

respectively, and $SAR(T_0)$ estimated as,

$$SAR(T_0) = \sum_{i=2}^{4} w_i SAR(T_i)$$

$$SAR(T_0) = 0.5448(0.0128) + 0.2160(0.0128) + 0.2407(0.0128)$$
$$SAR(T_0) = 0.0128.$$

Although not all detected fish were transported and detection probabilities differed among sites, $SAR(T_0)$ is the same as in Example 1a, indicating that the calculation for the smolt-to-adult return proportion depends only on survival probabilities.

The number of adults returning to LGR out of the 7,800 juveniles in the C_0 first must survive to the LMN tailrace. Out of the 4992 C_0 juveniles in the tailrace of LMN (Table 4), only half survive through the hydro system from below LNM to the tailrace of BON, or 2,496 fish. Survival back to BON as an adult is 5%. Hence, 125 C_0 fish are observed at BON as a returning adult, and 100 survive upstream migration to LGR. The $SAR(C_0)$ is calculated by Eq. (2) as follows,

$$\begin{aligned} SAR(C_0) &= \frac{A_{C_0}}{C_0} \\ &= \frac{100}{7800} \\ SAR(C_0) &= 0.0128, \end{aligned}$$

or by Eq. (6) as in Example 1a. The $SARs$ for both groups are the same as in the previous example and the T/C ratio is also the same, i.e., $T/C = 1$. The only change between the two examples is the detection and transport probabilities. Because the transport SAR does not depend on detection and transport probabilities when site-specific $SARs$ are the same, the

$^{T}/_{C}$ ratio as calculated by Eq. (19) (or Eq. (20)) is independent of these parameters under the null hypothesis, as expected.

Numerical example 2: Estimating the $^{T}/_{C}$ ratio using survival, detection and transport probabilities under Eq. (19)

The last two examples focused on the behavior of the $^{T}/_{C}$ ratio under the null hypothesis. In addition, the examples demonstrated how mortality between the groups can be partitioned by apportioning survival among possible routes of passage. The numerical examples further motivate the derivation of the $^{T}/_{C}$ ratio from first principles. In this next example, we examine a cohort release for which there was a clear benefit of transportation. However, we calculate the $^{T}/_{C}$ ratio entirely from survival, detection, and transport probabilities by use of Eq. (19).

Consider a cohort with survival, detection, and transport probabilities listed in Table 5. From these data $SAR(T_0)$ is estimated by use of Eq. (17) written as follows,

$$SAR(T_0) = \frac{p_2\tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T + (1-p_2)\,p_3\tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T + (1-p_2)(1-p_3)\,p_4\tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T}{p_2\tau_2 + (1-p_2)\,p_3\tau_3 + (1-p_2)(1-p_3)\,p_4\tau_4}.$$

The numerator is calculated by the probabilities in Table 5 as,

$$\begin{aligned}
Num. = {} & p_2\tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T \\
& +\left(1-p_2\right) p_3\tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T \\
& +\left(1-p_2\right)\left(1-p_3\right) p_4\tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T
\end{aligned}$$

$$\begin{aligned}
Num. = {} & \left(0.4\right)\left(0.5\right)\left(0.9\right)\left(0.8\right)\left(0.6\right)\left(0.075\right)\left(0.8\right) \\
& +\left(0.6\right)\left(0.6\right)\left(0.66\right)\left(0.8\right)\left(0.8\right)\left(0.6\right)\left(0.075\right)\left(0.8\right) \\
& +\left(0.6\right)\left(0.4\right)\left(0.5\right)\left(0.6\right)\left(0.8\right)\left(0.9\right)\left(0.6\right)\left(0.075\right)\left(0.8\right) \\
Num. = {} & 0.0125,
\end{aligned}$$

the denominator calculated as,

$$\begin{aligned}
Denom. = {} & p_2\tau_2 + \left(1-p_2\right) p_3\tau_3 + \left(1-p_2\right)\left(1-p_3\right) p_4\tau_4 \\
= {} & \left(0.4\right)\left(0.5\right) + \left(0.6\right)\left(0.6\right)\left(0.66\right) + \left(0.6\right)\left(0.4\right)\left(0.5\right)\left(0.6\right) \\
Denom. = {} & 0.5096,
\end{aligned}$$

and the $SAR\left(T_0\right)$ calculated as,

$$\begin{aligned}
SAR\left(T_0\right) &= \frac{Num.}{Denom.} \\
&= \frac{0.0125}{0.5096} = 0.0246
\end{aligned}.$$

The SAR for the control group is calculated by Eq. (6) as follows,

$$\begin{aligned}
SAR\left(C_0\right) &= S_2^R S_3^R S_L^R S_O^R S_A^R \\
&= \left(0.8\right)\left(0.9\right)\left(0.3\right)\left(0.075\right)\left(0.9\right)
\end{aligned}$$

$$SAR\left(C_0\right) = 0.0146$$

By the definition of Eq. (1), the ${}^{T}\!/_{C}$ ratio is,

$$T/C = \frac{SAR\left(T_0\right)}{SAR\left(C_0\right)}$$

$$= \frac{0.0246}{0.0146}$$

$$T/C = 1.69$$

Calculating the T/C ratio from the numbers of fish in each of the C_0 and T_0 sub-categories (Table 6) is presented as a check of the above equation as follows,

$$T/C = \frac{\left(\frac{A_{T_0}}{T_0}\right)}{\left(\frac{A_{C_0}}{C_0}\right)} = \left(\frac{\frac{501}{\left(8000+1901+7603+576+230+2074\right)}}{\frac{70}{\left(960+384+3456\right)}}\right)$$

$$T/C = 1.69\,.$$

Table 5. Hypothetical reach survival and site-specific detection and transport probabilities:used in Example 2.

Segment	Subscript (i)	In River Survival S_i^R	Transport Route Survival S_i^T	Location (*i*)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.4	0.5
LGR to LGS	2	0.8	0.9	LGS (3)	0.6	0.66
LGS to LMN	3	0.9	0.8	LMN (4)	0.5	0.6
LMN-BON (L)	L	0.3	0.6			
BON-BON	O	0.08	0.07			
BON-LGR	A	0.9	0.8			

Table 6. Number of fish in each category and sub-group calculated from the probabilities in Table 5 and a release size of 50,000 tagged fish. Shaded cells correspond to sub-categories in Figure 2.

Segment	Fish Surviving to Site, In-river **(Bold)** (Undetected in Snake R.)			Total Mortalities Between Sites	In River Mortalities to C_0 category	In River Mortalities to T_0 category	Fish Added to Barge At Site **(Bold)**	Fish in Barge At Site (**Bold**)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to **LGR**	28000						8000 (T_2)	8000	
LGR to **LGS**	7680	3840 $(C_0^2+C_0^3)$	2304 $(T_4^2+T_4^3)$	4800	960 (C_0^1)	1901 (T_3^1) 576 (T_4^1)	7603 (T_3^2)	14803	800
LGS to **LMN**	3456	3456 (C_0^3)		768	384 (C_0^2)	230 (T_4^2)	2074 (T_4^3)	13916	2961
LMN-**BON**	1037							8350	
BON-**BON**	78							626	
BON-**LGR**	70							501	

Estimation

We derived expressions for calculating $SAR\left(T_0\right)$, $SAR\left(C_0\right)$ and ${}^{T}\!\big/_{C}$ from first principles. We started by defining each metric then applied the definitions to arrive at a mathematical expression for them. An unbiased estimator of any of the above metrics should result in an appropriate expressions presented earlier, i.e., Eq 1, 2 or 3 for ${}^{T}\!\big/_{C}$, $SAR\left(C_0\right)$, and $SAR\left(T_0\right)$, respectively. An unbiased estimator of ${}^{T}\!\big/_{C}$ should reduce Eqs. (1), (19), or (20) given that only fish with no previous detection are transported, that survival is measured from LGR as juveniles to LGR as adults, that comparisons are made to a control group as defined earlier, and that no T_0 returning adults were un-transported (migrated in-river). To explain the derivation and concepts of the CSS study we used sub-categories that are not directly observable. In this section, we re-write the equations as functions of parameters that are estimable from detections of tagged fish.

Estimates of reach survival, and site-specific detection and transport probabilities are obtained by use of maximum likelihood methods described earlier. The numbers of juveniles in the transport and control groups are estimated by use of the maximum likelihood estimators (MLEs) of the survival parameters. The estimators for T_0 and C_0 are written as follows, respectively,

$$\hat{T}_0 = N_1\hat{S}_1^R\left(\hat{p}_2\hat{\tau}_2 + \left(1-\hat{p}_2\right)\hat{p}_3\hat{\tau}_3 + \left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right)\hat{p}_4\hat{\tau}_4\right)$$

and

$$\hat{C}_0 = N\hat{S}_1^R\left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right)\left(1-\hat{p}_4\right),$$

where the symbol ^ denotes an MLE of a parameter. The estimators for T_0 and C_0 will be unbiased if the MLEs are unbiased.

Once juveniles enter a transport barge they are not observed again until they return to Bonneville as adults. Hence, the survival probabilities S_2^T, S_3^T, S_L^T and S_O^T are not separately estimable for any of the T_i transport groups. Rather, we use the joint probability of surviving in the transport barge (from detection to release in the estuary) and subsequent marine residence to return at BON. By use of the joint probability, the expected number of adults observed at BON that were transported from LGR as juveniles is expressed as follows,

$$A_{T_2} = N_0 S_1^R p_2 \tau_2 \left(S_2^T S_3^T S_L^T S_O^T \right) S_A^T$$
$$A_{T_2} = N_0 S_1^R p_2 \tau_2 S_{BON}^{T_2} S_A^T$$

The SAR for fish in the LGR transport route is expressed as a function of estimable parameters as follows,

$$SAR\left(T_2\right) = S_{BON}^{T_2} S_A^T$$

and estimated by,

$$\widehat{SAR}\left(\hat{T}_2\right) = \hat{S}_{BON}^{T_2} \hat{S}_A^T \qquad (21)$$

where $\hat{S}_{BON}^{T_2}$ is the estimator for the joint probability $\left(S_2^T S_3^T S_L^T S_O^T\right)$.

The expected number of adult returns for juveniles that were in the LGS transport pathway is expressed as,

$$A_{T_3} = N_0 S_1^R \left(1 - p_3\right) p_3 \tau_3 S_2^R \left(S_3^T S_L^T S_O^T\right) S_A^T$$
$$A_{T_3} = N_0 S_1^R \left(1 - p_3\right) p_3 \tau_3 S_2^R S_{BON}^{T_3} S_A^T,$$

and the SAR for T_3 written as,

$$SAR\left(T_3\right) = S_2^R S_{BON}^{T_3} S_A^T,$$

and estimated by

$$\widehat{SAR}\left(\hat{T}_3\right) = \hat{S}_2^R \hat{S}_{BON}^{T_3} \hat{S}_A^T \tag{22}$$

where $\hat{S}_{BON}^{T_3}$ is the estimator for the joint the probability that a T_3 fish returns to BON as an adult. The number of adults and the SAR for T_4 fish, the LMN transport route are expressed as follows, respectively

$$A_{T_4} = N_0 S_1^R \left(1 - p_2\right)\left(1 - p_3\right) p_4 \tau_4 S_2^R S_3^R S_{BON}^{T_4} S_A^T$$

and

$$SAR\left(T_4\right) = S_2^R S_3^R S_{BON}^{T_4} S_A^T$$

with an associated estimator for the SAR,

$$\widehat{SAR}\left(\hat{T}_4\right) = \hat{S}_2^R \hat{S}_3^R \hat{S}_{BON}^{T_4} \hat{S}_A^T \tag{23}$$

where $\hat{S}_{BON}^{T_4}$ is the estimator for the joint probability $S_L^T S_O^T$. Hence, all of the site-specific transport $SARs$ are probabilities of making a round trip from LGR as a juvenile back to LGR as an adult.

The fish in the control group are never observed at any of the Snake River transport dams. Unlike the T_0 group, there are no direct observations of fish in the C_0 group and the number must be calculated from the estimated survival and detection probabilities. These fish may be detected in the Columbia River and will be observed upon adult return. Reach specific survival probabilities between transport sites, S_2^R and S_3^R, are estimable from detections of transported fish and non-transported fish passing through detection routes. However, for simplicity we will express the number of adult returns as follows,

$$\begin{aligned} A_{C_0} &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right)\left(S_2^R S_3^R S_L^R S_O^R\right) S_A^R \\ A_{C_0} &= N_0 S_1^R \left(1-p_2\right)\left(1-p_3\right)\left(1-p_4\right) S_{BON}^{C_0} S_A^R \end{aligned}$$

where $S_{BON}^{C_0}$ is the joint probability $\left(S_2^R S_3^R S_L^R S_O^R\right)$. The $SAR\left(C_0\right)$ is then written as,

$$SAR\left(C_0\right) = S_{BON}^{C_0} S_A^R$$

and estimated by,

$$\widehat{SAR}\left(\hat{C}_0\right) = \hat{S}_{BON}^{C_0} \hat{S}_A^R, \qquad (24)$$

where $\hat{S}_{BON}^{C_0}$ could be calculated from the number of control group observations at Bonneville Dam and $\hat{C}_0$.

Using the above joint probabilities, the T/C ratio is expressed as follows,

$$T/C = \frac{p_2\tau_2 S_{BON}^{T_2} S_A^{T_2} + \left(1-p_2\right) p_3\tau_3 S_2^R S_{BON}^{T_3} S_A^{T_3} + \left(1-p_2\right)\left(1-p_3\right) p_4\tau_4 S_2^R S_3^R S_{BON}^{T_3} S_A^{T_4}}{S_{BON}^R S_A^R \left[p_2\tau_2 + \left(1-p_2\right) p_3\tau_3 + \left(1-p_2\right)\left(1-p_3\right) p_4\tau_4 \right]}$$

and estimated by,

$$\widehat{T/C} = \frac{\hat{p}_2\hat{\tau}_2 \hat{S}_{BON}^{T_2} \hat{S}_A^{T_2} + \left(1-\hat{p}_2\right) \hat{p}_3\hat{\tau}_3 S_2^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_3} + \left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right) \hat{p}_4\hat{\tau}_4 \hat{S}_2^R \hat{S}_3^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_4}}{\hat{S}_{BON}^R \hat{S}_A^R \left[\hat{p}_2\hat{\tau}_2 + \left(1-\hat{p}_2\right) \hat{p}_3\hat{\tau}_3 + \left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right) \hat{p}_4\hat{\tau}_4 \right]}. \qquad (25)$$

Example 3: Estimation of T/C ratio using estimable survival, detection, and transport probabilities.

Consider a cohort release with estimated survival, detection, and transport probabilities listed in Table 7. The $SARs$ and ${}^{T}\!/_{C}$ ratio can be calculated from probabilities only using Eq. (25) . The numerator of Eq. (25) is calculated as follows,

$$\begin{aligned}\widehat{Eq(25)}_{NUM} &= \hat{p}_2\hat{\tau}_2\hat{S}_{BON}^{T_2}\hat{S}_A^{T_2} + \left(1-\hat{p}_2\right)\hat{p}_3\hat{\tau}_3\hat{S}_2^R\hat{S}_{BON}^{T_3}\hat{S}_A^{T_3} + \left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right)\hat{p}_4\hat{\tau}_4\hat{S}_2^R\hat{S}_3^R\hat{S}_{BON}^{T_3}\hat{S}_A^{T_4} \\ &= \left(0.3\right)\left(0.5\right)\left(0.0292\right)\left(0.75\right) \\ &\quad + \left(0.7\right)\left(0.4\right)\left(0.66\right)\left(0.9\right)\left(0.0324\right)\left(0.75\right) \\ &\quad + \left(0.7\right)\left(0.6\right)\left(0.3\right)\left(0.6\right)\left(0.9\right)\left(0.8\right)\left(0.0405\right)\left(0.75\right)\end{aligned}$$

$$\widehat{Eq(25)}_{NUM} = 0.0033 + 0.004 + 0.0017 = 0.0090$$

the denominator calculated as,

$$\begin{aligned}\widehat{Eq.\left(25\right)}_{DENOM} &= \hat{S}_{BON}^R\hat{S}_A^R\left[\hat{p}_2\hat{\tau}_2 + \left(1-\hat{p}_2\right)\hat{p}_3\hat{\tau}_3 + \left(1-\hat{p}_2\right)\left(1-\hat{p}_3\right)\hat{p}_4\hat{\tau}_4\right] \\ &= \left(0.8\right)\left(0.8\right)\left(0.0638\right)\left(0.85\right)\left[\left(0.3\right)\left(0.5\right) + \left(0.7\right)\left(0.4\right)\left(0.66\right) + \left(0.7\right)\left(0.6\right)\left(0.3\right)\left(0.6\right)\right] \\ &= 0.03468\left[0.15 + 0.1848 + 0.0756\right] \\ \widehat{Eq.\left(25\right)}_{DENOM} &= 0.0143\end{aligned}$$

and the ${}^{T}\!/_{C}$ ratio estimated by use of Eq. (25) as,

$$\widehat{{}^{T}\!/_{C}} = \frac{0.0090}{0.0143} = 0.631\,.$$

Table 7: Hypothetical survival, detection, and transport probabilities for Example 3.

Segment	Subscript (i)	In River Survival S_i^R	C_0 In-river route Survival	Transport Route Survival S_i^T	LGR (T_2) Transport Route Survival	LGS (T_3) Transport Route Survival	LMN (T_4) Transport Route Survival	Location (i)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8						LGR (2)	0.3	0.5
LGR to LGS	2	0.8		0.9		0.9	0.9	LGS (3)	0.4	0.66
LGS to LMN	3	0.8		0.8			0.8	LMN (4)	0.3	0.6
LMN-BON (L)	L	0.85	0.0408	0.9	0.0292	0.0324	0.0405			
BON-BON (Ocean)	O	0.075		0.045						
BON-LGR	A	0.85	0.85	0.75	0.75	0.75	0.75			

Assumptions

Empirical results can only be inferred to a population in the context of the assumptions under which a study was conducted. Estimation of survival, detection and transport probabilities, *SARs* and *T/C* ratios require the following set of assumptions.

1. Tagged fish in the study are representative of the population.
2. All fish in a release group have equal detection and survival probabilities.
3. All fish in a release group have equal probabilities of a particular capture history.
4. Fates of individual fish are independent.
5. Previous detections have no influence on subsequent survival or detection probabilities.
6. Release numbers, capture histories, and PIT tag codes are accurately recorded and known.
7. Only detected fish are subject to transport.
8. Tagged fish removed for use in other studies are known and accurately recorded.
9. All tagged fish in a cohort release migrate through the Snake and Columbia Rivers within the same season and while the bypass facility and transport systems are operational, i.e., there is no delayed migration of tagged fish.
10. Harvest survival is the same for transported and in-river categories.

11. River conditions for same-age returns of a cohort are the same for the T_0 and C categories.

The first five assumptions are regarded as statistical in that they dictate the choice of statistical model used in parameter estimation. Assumption 1 is required when making inferences to untagged fish. If tagged fish are not representative of the run-at-large, then inferences are limited to the segment of the population most represented by tagged fish or restricted only to tagged fish. Assumptions 2 through 5 are necessary to obtain unbiased estimates of detection, survival, and transport probabilities and associated variance estimates.

Assumptions 7 through 12 are associated with elements of the CSS study and the life history characteristics fish in the study. Assumption 7 is an element of the study and was discussed earlier. Unobserved tagged fish are regarded as either mortalities or non-detects. Hence, if fish are removed for use in other studies or for monitoring, tag codes should be accurately recorded and noted so that survival and or detection probabilities are not biased. Assumption 9 is required to meet the assumption that all fish have equal detection and transport probabilities. Equations for the metrics of the CSS study were derived under this assumption and severe departures from assumption 9 will require a different set of equations. The last two assumptions are meant to assure that transport and control fish differ only with regard to the treatment, i.e., juvenile migration through transport or in-river passage. Part of the treatment includes timing of estuary and ocean entrance. However, if fish in either group are subject to different harvest probabilities or river conditions as an adult, then differences in *SARs* will not be wholly attributable to the treatment.

Appendix D

Supporting Tables

Tables D-1 to D-4 present PIT-tag release numbers of wild and hatchery Chinook and steelhead in locations above LGR.

Table D-1. Number of PIT-tagged wild Chinook parr/smolts from the four tributaries above Lower Granite Dam and Snake River trap used in the CSS analyses for migration years 1994 to 2004.

Migr. Year	Number of PIT-tagged wild Chinook utilized in CSS by location of origin					
	Total PIT Tags	Clearwater River (Rkm 224)	Snake River trap[1] (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1994	49,657	8,292	1,423	8,828	27,725	3,391
1995	74,639	17,605	1,948	12,330	40,609	2,148
1996	21,523	2,246	913	7,079	7,016	4,269
1997	9,781	671	None	3,870	3,543	1,697
1998	33,836	4,681	921	8,644	11,179	8,411
1999	81,493	13,695	3,051	11,240	43,323	10,184
2000	67,841	9,921	1,526	7,706	39,609	9,079
2001	47,775	3,745	29	6,354	23,107	14,540
2002	67,286	14,060	1,077	9,715	36,051	6,428
2003	103,012	15,106	381	14,057	60,261	13,165
2004	99,743	17,214	541	12,104	56,153	13,731
Average % of total		16.3%	1.8%	15.5%	53.1%	13.3%

[1] Snake River trap collects fish originating in Salmon, Imnaha, and Grande Ronde rivers.

Table D-2. Number of PIT-tagged hatchery Chinook parr/smolts from key hatcheries located above Lower Granite Dam used in the CSS analyses for migration years 1997 to 2004.

Migr. Year	Rapid River H	Dworshak NFH	Catherine Creek AP	McCall H	Imnaha AP
1997	40,451	14,080	-----	52,652	13,378
1998	48,336	47,703	-----	47,340	19,825
1999	47,812	47,845	-----	47,985	19,939
2000	47,747	47,743	-----	47,705	20,819
2001	55,085	55,139	20,915	55,124	20,922
2002	54,908	54,725	20,796	54,734	20,920
2003	54,763	54,708	20,628	74,317	20,904
2004	51,969	51,616	20,994	71,363	20,910

Table D-3. Number of PIT-tagged wild steelhead smolts from the four tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS for migration years 1997 to 2003.

Migr. Year	Number of PIT-tagged wild steelhead (>130 mm) utilized in CSS by location of origin					
	Total PIT Tags	Clearwater River (Rkm 224)	Snake River trap[1] (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1997	7,703	5,518	68	248	1,158	711
1998	10,512	4,131	1,032	887	1,683	2,779
1999	15,763	5,095	886	1,628	5,569	2,585
2000	24,254	8,688	1,211	3,618	6,245	4,492
2001	24,487	8,845	867	3,370	7,844	3,561
2002	25,183	10,206	2,368	3,353	6,136	3,120
2003	24,284	5,885	1,197	4,261	6,969	5,972
Average % of total		36.6%	5.8%	13.1%	26.9%	17.6%

[1] Snake River trap located at Lewiston, ID, collects wild steelhead originating in Grande Ronde, Salmon, and Imnaha rivers.

Table D-4. Number of PIT-tagged hatchery steelhead smolts from the four tributaries above Lower Granite Dam (plus mainstem Snake River) used in the CSS for migration years 1997 to 2003.

Migr. Year	Number of PIT-tagged hatchery steelhead utilized in CSS by location of origin						
	Total PIT Tags	Clearwater River (Rkm 224)	Snake River trap[1] (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)	Snake River at Hells Canyon Dam (Rkm 397)[1]
1997	35,705	12,872	725	6,039	9,394	6,379	296
1998	30,913	8,451	4,209	4,904	8,457	4,604	288
1999	36,968	11,486	3,925	5,316	9,132	6,808	301
2000	32,000	8,488	3,290	5,348	8,173	6,436	265
2001	29,099	9,155	3,126	4,677	7,859	3,995	287
2002	26,573	7,819	4,722	3,888	7,011	2,839	294
2003	26,379	4,912	4,171	3,113	7,764	6,123	296
Average % of total		29.0%	11.1%	15.3%	26.6%	17.1%	0.9%

[1] Snake River trap located at Lewiston, ID, collects hatchery steelhead released in Grande Ronde, Salmon, and Imnaha rivers, and below Hells Canyon Dam.

<u>Tables D-5 to D-12 present estimated number of smolts per study category with associated 90% confidence interval and number of returning adults per study category for PIT-tagged wild and hatchery Chinook and steelhead.</u>

Table D-5. Estimated number of PIT-tagged wild Chinook (aggregate of fish tagged in 10-month period between July 25 and May 20) arriving Lower Granite Dam in each of the three study categories from 1994 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1994	15,260	T_0	2,004	(1,922 – 2,084)	9	
	(15,008 – 15,520)	C_0	1,801	(1,693 – 1,911)	5	
		C_1	4,431	(4,275 – 4,618)	3	
1995	20,206	T_0	2,283	(2,202 – 2,367)	8	
	(19,950 – 20,457)	C_0	2,709	(2,602 – 2,812)	10	
		C_1	14,206	(13,997 – 14,413)	36	
1996	7,868	T_0	400	(365 – 434)	2	
	(7,682 – 8,070)	C_0	1,917	(1,805 – 2,034)	5	
		C_1	5,209	(5,057 – 5,366)	7	
1997	2,898	T_0	230	(207 – 255)	4	
	(2,784 – 3,024)	C_0	680	(614 – 757)	16	
		C_1	1,936	(1,843 – 2,028)	18	
1998	17,363	T_0	1,271	(1,214 – 1,330)	15	
	(17,172 – 17,562)	C_0	3,081	(2,976 – 3,187)	42	
		C_1	12,276	(12,111 – 12,444)	131	
1999	33,662	T_0	1,768	(1,697 – 1,841)	43	
	(33,343 – 33,988)	C_0	4,469	(4,339 – 4,595)	95	
		C_1	26,140	(25,855 – 26,424)	495	
2000	25,053	T_0	839	(790 – 890)	12	21
	(24,721– 25,397)	C_0	6,494	(6,321 – 6,686)	155	184
		C_1	16,833	(16,574 – 17,087)	392	456
2001	22,415	T_0	547	(512 – 587)	7	10
	(22,234 – 22,595)	C_0	231	(208 – 253)	1[A]	1[A]
		C_1	20,307	(20,124 – 20,491)	29	32
2002	23,356	T_0	3,886	(3,775 – 3,995)	31	41
	(22,995 – 23,697)	C_0	6,218	(6,042 – 6,395)	76	86
		C_1	12,687	(12,455 – 12,922)	125	137
2003	31,093	T_0	8,713	(8,560 – 8,873)	30	29
	(30,744 – 31,490)	C_0	8,879	(8,660 – 9,094)	29	33
		C_1	12,694	(12,499 – 12,910)	22	22
2004[B]	32,546	T_0	12,887	(12,722 – 13,058)	39	49
	(32,296 – 32,828)	C_0	2,252	(2,168 – 2,354)	7	8
		C_1	16,504	(16,313 – 16,725)	30	35

[A] One returning adult with no detections may have inadvertently been transported so inriver SARs based solely on Category C_1 fish in 2001.

[B] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-6. Estimated number of PIT-tagged spring Chinook from Rapid River Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	15,765	T_0	4,324	(4,224 – 4,424)	34	
	(15,246 – 16,439)	C_0	4,176	(3,904 – 4,448)	19	
		C_1	6,843	(6,515 – 7,187)	36	
1998	32,148	T_0	12,876	(12,711 – 13,032)	257	
	(31,801 – 32,473)	C_0	4,402	(4,260 – 4,537)	53	
		C_1	13,597	(13,389 – 13,820)	91	
1999	35,895	T_0	12,857	(12,666 – 13,050)	391	
	(35,272 – 36,542)	C_0	7,040	(6,842 – 7,238)	167	
		C_1	14,456	(14,157 – 14,773)	235	
2000	35,194	T_0	16,587	(16,302 – 16,883)	349	492
	(34,652 – 35,769)	C_0	11,046	(10,676 – 11,427)	176	201
		C_1	5,248	(5,110 – 5,375)	70	90
2001	38,026	T_0	19,090	(18,904 – 19,273)	207	265
	(37,822 – 38,211)	C_0	966	(919 – 1,016)	2[A]	2[A]
		C_1	15,989	(15,802 – 16,177)	8	12
2002	41,471	T_0	11,589	(11,378 – 11,817)	117	132
	(40,785 – 42,099)	C_0	13,625	(13,303 – 13,950)	91	106
		C_1	14,854	(14,551 – 15,161)	94	104
2003	37,911	T_0	13,353	(13,138 – 13,586)	33	52
	(37,317 – 38,562)	C_0	16,858	(16,398 – 17,331)	39	41
		C_1	7,055	(6,897 – 7,212)	11	11
2004[B]	36,178	T_0	19,519	(19,332 – 19,719)	50	66
	(35,955 – 36,406)	C_0	3,484	(3,350 – 3,616)	5	5
		C_1	12,776	(12,615 – 12,946)	11	11

[A] Two returning adults with no detections may have inadvertently been transported so inriver SARs based solely on Category C_1 fish in 2001.

[B] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-7. Estimated number of PIT-tagged spring Chinook from Dworshak Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	8,175	T_0	1,931	(1,866 – 2,000)	16	
	(7,735 – 8,683)	C_0	2,529	(2,310 – 2,755)	13	
		C_1	3,613	(3,370 – 3,884)	12	
1998	40,218	T_0	14,728	(14,563 – 14,915)	132	
	(39,660 – 40,742)	C_0	11,151	(10,882 – 11,447)	139	
		C_1	13,128	(12,875 – 13,387)	118	
1999	40,804	T_0	9,787	(9,608 – 9,985)	115	
	(39,771 – 41,948)	C_0	10,484	(10,181 – 10,820)	125	
		C_1	19,083	(18,596 – 19,612)	181	
2000	39,412	T_0	18,317	(17,987 – 18,660)	183	296
	(38,782 – 40,101)	C_0	13,075	(12,612 – 13,529)	132	172
		C_1	5,416	(5,280 – 5,568)	44	56
2001	41,251	T_0	21,740	(21,555 – 21,934)	79	96
	(41,068 – 41,446)	C_0	886	(839 – 938)	0	0
		C_1	16,872	(16,672 – 17,062)	7	8
2002	45,233	T_0	9,665	(9,431 – 9,902)	60	80
	(44,268 – 46,304)	C_0	19,008	(18,512 – 19,582)	95	113
		C_1	14,914	(14,538 – 15,354)	74	80
2003	38,612	T_0	13,205	(12,984 – 13,447)	34	44
	(37,984 – 39,274)	C_0	17,697	(17,237 – 18,153)	38	45
		C_1	6,715	(6,573 – 6,881)	12	12
2004[A]	45,505	T_0	21,657	(21,443 – 21,897)	46	88
	(42,223 – 42,788)	C_0	6,280	(6,100 – 6,468)	14	18
		C_1	14,009	(13,822 – 14,189)	22	36

[A] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-8. Estimated number of PIT-tagged spring Chinook from Catherine Creek Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 2001 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
2001	10,885	T_0	4,790	(4,683 – 4,899)	11	18
	(10,747 – 11,021)	C_0	379	(345 – 414)	0	0
		C_1	4,642	(4,540 – 4,738)	2	3
2002	8,435	T_0	2,697	(2,600 – 2,797)	24	33
	(8,181 – 8,709)	C_0	2,445	(2,312 – 2,590)	12	11
		C_1	3,120	(2,992 – 3,258)	10	10
2003	7,202	T_0	2,494	(2,397 – 2,592)	9	10
	(6,932 – 7,487)	C_0	3,201	(3,010 – 3,421)	8	8
		C_1	1,403	(1,333 – 1,478)	5	6
2004[A]	5,348	T_0	2,877	(2,790 – 2,970)	10	13
	(5,225 – 5,465)	C_0	503	(455 – 551)	1	0
		C_1	1,869	(1,797 – 1,938)	6	7

[A] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-9. Estimated number of PIT-tagged summer Chinook from McCall Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	22,381	T_0	6,013	(5,888 – 6,136)	91	
	(21,588 – 23,224)	C_0	6,761	(6,398 – 7,132)	74	
		C_1	9,272	(8,854 – 9,738)	102	
1998	27,812	T_0	10,142	(9,988 – 10,286)	273	
	(27,474 – 28,141)	C_0	3,849	(3,721 – 3,983)	53	
		C_1	12,816	(12,578 – 13,060)	94	
1999	31,571	T_0	10,515	(10,281 – 10,742)	377	
	(30,816 – 32,358)	C_0	8,407	(8,122 – 8,675)	202	
		C_1	11,391	(11,062 – 11,684)	231	
2000	31,825	T_0	12,806	(12,552 – 13,083)	497	584
	(31,170 – 32,466)	C_0	13,064	(12,558 – 13,601)	269	299
		C_1	4,485	(4,349 – 4,624)	91	101
2001	36,784	T_0	16,704	(16,511 – 16,882)	206	246
	(36,578 – 36,994)	C_0	1,000	(946 – 1,052)	3[A]	3[A]
		C_1	15,536	(15,351 – 15,728)	6	7
2002	32,599	T_0	8,842	(8,666 – 9,027)	131	164
	(32,042 – 33,229)	C_0	10,280	(9,987 – 10,578)	106	127
		C_1	12,315	(12,029 – 12,631)	126	154
2003	43,144	T_0	14,006	(13,782 – 14,233)	111	124
	(42,527 – 43,752)	C_0	19,696	(19,221 – 20,166)	107	122
		C_1	8,669	(8,503 – 8,845)	30	32
2004[B]	40,150	T_0	20,858	(20,667 – 21,062)	65	92
	(39,912 – 40,408)	C_0	2,359	(2,262 – 2,453)	6	7
		C_1	16,297	(16,094 – 16,500)	19	31

[A] Three returning adults with no detections may have inadvertently been transported so inriver SARs based solely on Category C_1 fish in 2001.

[B] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-10. Estimated number of PIT-tagged summer Chinook from Imnaha River Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals).

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	8,254	T_0	2,147	(2.079 – 2,212)	25	
	(7,814 – 8,740)	C_0	2,219	(2,032 – 2,433)	19	
		C_1	3,785	(3,535 – 4,040)	26	
1998	13,577	T_0	4,809	(4,709 – 4,910)	41	
	(13,327 – 13,833)	C_0	1,995	(1,900 – 2,085)	11	
		C_1	6,335	(6,194 – 6,483)	19	
1999	13,244	T_0	4,827	(4,688 – 4,963)	130	
	(12,829 – 13,687)	C_0	2,869	(2,733 – 3,008)	41	
		C_1	5,084	(4,884 – 5,268)	62	
2000	14,267	T_0	6,789	(6,597 – 6,991)	211	262
	(13,926 – 14,650)	C_0	4,396	(4,159 – 4,672)	106	114
		C_1	2,254	(2,166 – 2,353)	37	41
2001	15,650	T_0	7,730	(7,609 – 7,855)	48	61
	(15,531 – 15,763)	C_0	336	(336 – 396)	1[A]	4[A]
		C_1	6,939	(6,819 – 7,055)	4	4
2002	13,962	T_0	3,912	(3,777 – 4,041)	31	41
	(13,560 – 14,380)	C_0	4,637	(4,429 – 4,853)	21	27
		C_1	5,135	(4,952 – 5,333)	28	33
2003	14,948	T_0	5,189	(5,044 – 5,345)	30	39
	(14,532 – 15,377)	C_0	6,683	(6,358 – 6,999)	32	38
		C_1	2,908	(2,801 – 3,015)	11	13
2004[B]	12,867	T_0	6,927	(6,801 – 7,049)	24	35
	(12,709 – 13,013)	C_0	1,302	(1,221 – 1,381)	3	5
		C_1	4,456	(4,349 – 4,554)	5	6

[A] One returning adult with no detections may have inadvertently been transported so inriver SARs based solely on Category C_1 fish in 2001.

[B] Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-11. Estimated number of PIT-tagged wild steelhead (aggregate of tagged fish >130 mm released in 12-month period between July 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals).

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)	LGR detected returning adults
1997	3,830	T_0	275 (248 – 301)	4
	(3,744 – 3,920)	C_0	454 (415 – 492)	3
		C_1	2,984 (2,905 – 3,066)	7
1998	7,109	T_0	480 (443 – 518)	1
	(7,010 – 7,208)	C_0	750 (700 – 800)	8
		C_1	5,150 (5,053 – 5,242)	11
1999	8,820	T_0	391 (358 – 424)	12
	(8,695 – 8,960)	C_0	1,113 (1,052 – 1,178)	15
		C_1	6,992 (6,878 – 7,114)	53
2000	13,609	T_0	466 (426 – 505)	13
	(13,418 – 13,818)	C_0	1,871 (1,780 – 1,961)	36
		C_1	10,616 (10,461 – 10,773)	192
2001[A]	12,929	T_0	201 (179 – 226)	5
	(12,810 – 13,066)	C_0	103 (87 – 120)	3[B]
		C_1	11,892 (11,748– 12,014)	8
2002[C]	13,378	T_0	317 (289 – 346)	9
	(13,148 – 13,598)	C_0	4,045 (3,908 – 4,197)	27
		C_1	8,726 (8,552 – 8,891)	82
2003[C]	12,926	T_0	2,210 (2,140 – 2,293)	44
	(12,696 – 13,153)	C_0	3,320 (3,185 – 3,459)	16
		C_1	7,132 (6,979 – 7,292)	37

[A] Estimates of number of smolts in study categories in 2001 are approximate due to potentially high holdover rate in lower Snake River affecting reach survival estimates and ultimately the smolt estimates in LGR-equivalents for each study category.

[B] Three returning adults with no detections may have inadvertently been transported or held-over to the following year so inriver SARs based solely on Category C_1 fish in 2001

[C] Migration year 2003 is incomplete until 3-salt returns occur at GRA.

Table D-12. Estimated number of PIT-tagged hatchery steelhead (aggregate of tagged fish released in 3-month period between April 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals).

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		LGR detected returning adults
1997	24,710 (24,477 – 24,933)	T_0	1,729	(1,665 – 1,798)	9
		C_0	3,390	(3,266 – 3,526)	8
		C_1	19,095	(18,895 – 19,307)	32
1998	23,507 (23,325 – 23,685)	T_0	1,365	(1,304 – 1,425)	7
		C_0	2,926	(2,826 – 3,023)	26
		C_1	17,958	(17,778 – 18,129)	40
1999	27,193 (26,959 – 27,426)	T_0	1,336	(1,274 – 1,395)	12
		C_0	3,952	(3,839 – 4,055)	41
		C_1	20,975	(20,767 – 21,192)	124
2000	24,565 (24,280 – 24,847)	T_0	668	(621 – 717)	14
		C_0	4,408	(4,237 – 4,589)	42
		C_1	18,804	(18,598 – 19,013)	197
2001[A]	20,877 (20,739 – 21,031)	T_0	427	(389 – 464)	4
		C_0	372	(334 – 414)	2[B]
		C_1	19,132	(18,985 – 19,294)	3
2002	20,681 (20,328 – 21,037)	T_0	284	(256 – 313)	3
		C_0	6,129	(5,917 – 6,338)	43
		C_1	14,038	(13,764 – 14,322)	102
2003[C]	21,400 (21,067 – 21,732)	T_0	4,595	(4,475 – 4,719)	83
		C_0	6,459	(6,248 – 6,671)	44
		C_1	10,118	(9,918 – 10,320)	37

[A] Estimates of number of smolts in study categories in 2001 are approximate due to potentially high holdover rate in lower Snake River affecting reach survival estimates and ultimately the smolt estimates in LGR-equivalents for each study category.

[B] Two returning adults with no detections may have inadvertently been transported or held-over to the following year so inriver SARs based solely on Category C_1 fish in 2001

[C] Migration year 2003 is incomplete until 3-salt returns occur at GRA

Tables D-13 to D-20 present estimated SARs per study category with associated 90% confidence interval for wild and hatchery Chinook and steelhead.

Table D-13. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2004 (with 90% confidence intervals).

Mig. Year	**$\text{SAR}_1(T_0)$**	**$\text{SAR}_2(T_0)$**	**$\text{SAR}(C_0)$**	**$\text{SAR}(C_1)$**
1994	NA[1]	0.45 (0.20 – 0.72)	0.28 (0.11 – 0.51)	0.07 (0.02 – 0.14)
1995	NA	0.35 (0.17 – 0.57)	0.37 (0.18 – 0.57)	0.25 (0.18 – 0.32)
1996	NA	0.50 (0.00 – 107)	0.26 (0.10 – 0.48)	0.13 (0.06 – 0.23)
1997	NA	1.74 (0.44 – 3.27)	2.35 (1.45 – 3.36)	0.93 (0.60 – 1.32)
1998	1.16 (0.66 – 1.68)	1.18 (0.71 – 1.70)	1.36 (1.05 – 1.70)	1.07 (0.91 – 1.22)
1999	2.50 (1.76 – 3.41)	2.43 (1.85 – 3.07)	2.13 (1.78 – 2.50)	1.89 (1.76 – 2.04)
2000	1.58 (0.83 – 2.44)	1.43 (0.74 – 2.14)	2.39 (2.08 – 2.72)	2.33 (2.12 – 2.52)
2001	NA	1.28 (0.54 – 2.14)	Assume = $\text{SAR}(C_1)$	0.14 (0.10 – 0.18)
2002	0.75 (0.49 – 1.07)	0.80 (0.57 – 1.04)	1.22 (0.99 – 1.45)	0.99 (0.84 – 1.14)
2003	0.35 (0.24 – 0.46)	0.34 (0.24 – 0.45)	0.33 (0.23 – 0.43)	0.17 (0.12 – 0.24)
2004 [2]	0.30 (0.22 – 0.39)	0.30 (0.22 – 0.39)	0.31 (0.13 – 0.52)	0.18 (0.13 – 0.24)
11-yr Avg.	**NA**	**0.98**	**1.10**	**0.74**
Std Error		**0.21**	**0.28**	**0.24**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR

[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-14. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	**$\text{SAR}_1(T_0)$**	**$\text{SAR}_2(T_0)$**	**$\text{SAR}(C_0)$**	**$\text{SAR}(C_1)$**
1997	NA[1]	0.79 (0.57 – 1.01)	0.45 (0.31 – 0.63)	0.53 (0.39 – 0.68)
1998	1.68 (1.47 – 1.93)	2.00 (1.80 – 2.21)	1.20 (0.95 – 1.48)	0.67 (0.56 – 0.79)
1999	2.72 (2.47 – 3.00)	3.04 (2.78 – 3.31)	2.37 (2.07 – 2.68)	1.63 (1.46 – 1.79)
2000	2.10 (1.90 – 2.26)	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)	1.08 (0.96 – 1.21)	{Assume =$\text{SAR}(C_1)$}	0.05 (0.02 – 0.08)
2002	1.00 (0.78 – 1.25)	1.01 (0.86 – 1.16)	0.67 (0.55 – 0.79)	0.63 (0.53 – 0.74)
2003	0.25 (0.17 – 0.32)	0.25 (0.17 – 0.32)	0.23 (0.17 – 0.29)	0.16 (0.08 – 0.24)
2004 [2]	0.26 (0.20 – 0.31)	0.26 (0.20 – 0.31)	0.14 (0.05 – 0.26)	0.09 (0.05 – 0.13)
8-yr Avg.		**1.32**	**0.84**	**0.64**
Std_error		**0.375**	**0.289**	**0.205**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.

[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-15. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	**$\text{SAR}_1(\text{T}_0)$**	**$\text{SAR}_2(\text{T}_0)$**	**$\text{SAR}(\text{C}_0)$**	**$\text{SAR}(\text{C}_1)$**
1997	NA[1]	0.83 (0.52 – 1.19)	0.47 (0.26 – 0.72)	0.36 (0.21 – 0.54)
1998	NA	0.90 (0.77 – 1.02)	1.25 (1.08 – 1.42)	0.90 (0.77 – 1.04)
1999	1.07 (0.86 – 1.28)	1.18 (1.01 – 1.35)	1.19 (1.01 – 1.37)	0.95 (0.82 – 1.07)
2000	1.00 (0.88 – 1.13)	1.00 (0.88 – 1.12)	1.01 (0.87 – 1.16)	0.81 (0.62 – 1.02)
2001	0.37 (0.30 – 0.44)	0.36 (0.29 – 0.43)	{Assume =$\text{SAR}(\text{C}_1)$}	0.04 (0.02 – 0.07)
2002	0.48 (0.35 – 0.63)	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)	0.26 (0.19 – 0.33)	0.21 (0.16 – 0.27)	0.18 (0.10 – 0.27)
2004[2]	0.21 (0.16 – 0.27)	0.21 (0.16 – 0.27)	0.22 (0.13 – 0.32)	0.16 (0.11 – 0.21)
8-yr Avg. **Std_error**	**---**	**0.67** **0.129**	**0.61** **0.168**	**0.49** **0.127**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.
[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-16. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 2001 to 2004 (with 90% confidence intervals).

Mig. Year	**$\text{SAR}_1(\text{T}_0)$**	**$\text{SAR}_2(\text{T}_0)$**	**$\text{SAR}(\text{C}_0)$**	**$\text{SAR}(\text{C}_1)$**
2001	NA[1]	0.23 (0.12 – 0.35)	{Assume =$\text{SAR}(\text{C}_1)$}	0.04 (0.00 – 0.09)
2002	NA	0.89 (0.59 – 1.20)	0.49 (0.28 – 0.74)	0.32 (0.18 – 0.50)
2003	NA	0.36 (0.17 – 0.59)	0.25 (0.12 – 0.41)	0.36 (0.14 – 0.64)
2004[2]	0.37 (0.17 – 0.57)	0.35 (0.17 – 0.55)	0.20 (0.00 – 0.61)	0.32 (0.11 – 0.56)
4-yr Avg. **Std_error**		**0.46** **0.147**	**0.25** **0.093**	**0.26** **0.074**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.
[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-17. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged summer Chinook from McCall Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	**$\text{SAR}_1(\text{T}_0)$**	**$\text{SAR}_2(\text{T}_0)$**	**$\text{SAR}(\text{C}_0)$**	**$\text{SAR}(\text{C}_1)$**
1997	1.89 (1.20 – 2.75)	1.51 (1.26 – 1.77)	1.09 (0.88 – 1.34)	1.10 (0.92 – 1.29)
1998	1.95 (1.70 – 2.22)	2.69 (2.44 – 2.96)	1.38 (1.05 – 1.69)	0.73 (0.62 – 0.87)
1999	3.58 (3.10 – 4.07)	3.59 (3.29 – 3.87)	2.40 (2.12 – 2.69)	2.03 (1.82 – 2.26)
2000	3.86 (3.60 – 4.15)	3.88 (3.60 – 4.18)	2.06 (1.84 – 2.29)	2.03 (1.68 – 2.38)
2001	1.25 (1.11 – 1.41)	1.24 (1.10 – 1.38)	{Assume =$\text{SAR}(\text{C}_1)$}	0.04 (0.01 – 0.07)
2002	1.31 (0.92 – 1.74)	1.48 (1.27 – 1.70)	1.03 (0.87 – 1.20)	1.02 (0.89 – 1.18)
2003	0.79 (0.68 – 0.91)	0.79 (0.68 – 0.91)	0.54 (0.46 – 0.63)	0.35 (0.25 – 0.45)
2004[2]	NA[1]	0.31 (0.24 – 0.38)	0.25 (0.09 – 0.43)	0.12 (0.07 – 0.16)
8-yr Avg. **Std_error**		**1.94** **0.461**	**1.10** **0.294**	**0.93** **0.277**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.
[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-18. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged summer Chinook from Imnaha River AP for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	$SAR_1(T_0)$	$SAR_2(T_0)$	$SAR(C_0)$	$SAR(C_1)$
1997	NA[1]	1.16 (0.77 – 1.60)	0.86 (0.53 – 1.22)	0.69 (0.48 – 0.93)
1998	NA	0.85 (0.65 – 1.09)	0.55 (0.28 – 0.83)	0.30 (0.20 – 0.42)
1999	2.52 (2.07 – 3.04)	2.69 (2.28 – 3.08)	1.43 (1.08 – 1.82)	1.22 (0.98 – 1.49)
2000	3.13 (2.79 – 3.47)	3.11 (2.77 – 3.44)	2.41 (2.01 – 2.83)	1.64 (1.22 – 2.08)
2001	NA	0.62 (0.49 – 0.78)	{Assume =$SAR(C_1)$}	0.06 (0.01 – 0.11)
2002	0.98 (0.53 – 1.45)	0.79 (0.56 – 1.04)	0.45 (0.29 – 0.63)	0.55 (0.38 – 0.72)
2003	0.58 (0.41 – 0.74)	0.58 (0.41 – 0.74)	0.48 (0.34 – 0.62)	0.38 (0.20 – 0.55)
2004[2]	0.35 (0.23 – 0.47)	0.35 (0.23 – 0.47)	0.23 (0.07 – 0.46)	0.11 (0.04 – 0.20)
8-yr Avg. **Std_ error**		**1.27** **0.368**	**0.81** **0.272**	**0.62** **0.196**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.

[2] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-19. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	$SAR_1(T_0)$	$SAR_2(T_0)$	$SAR(C_0)$	$SAR(C_1)$
1997	NA[1]	1.45 (0.36 – 2.80)	0.66 (0.0 – 1.34)	0.23 (0.10 – 0.39)
1998	NA	0.21 (0.0 – 0.63)	1.07 (0.51 – 1.73)	0.21 (0.12 – 0.33)
1999	3.39 (1.75 – 5.31)	3.07 (1.74 – 4.66)	1.35 (0.80 – 1.96)	0.76 (0.60 – 0.94)
2000	3.05 (1.65 – 4.58)	2.79 (1.55 – 4.11)	1.92 (1.40 – 2.49)	1.81 (1.59 – 2.03)
2001	NA	2.49 (0.93 – 4.37)	{Assume =$SAR(C_1)$}	0.07 (0.03 – 0.10)
2002	2.75 (1.37 – 4.44)	2.84 (1.52 – 4.43)	0.67 (0.46 – 0.90)	0.94 (0.77 – 1.11)
2003[2]	2.01 (1.50 – 2.54)	1.99 (1.49 – 2.49)	0.48 (0.30 – 0.68)	0.52 (0.38 – 0.66)
7-yr Avg. **Std_error**		**2.12** **0.382**	**0.89** **0.231**	**0.65** **0.227**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.

[2] Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

Table D-20. Estimated $\text{SAR}_{\text{LGR-to-LGR}}$ (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	$SAR_1(T_0)$	$SAR_2(T_0)$	$SAR(C_0)$	$SAR(C_1)$
1997	NA[1]	0.52 (0.24 – 0.81)	0.24 (0.09 – 0.39)	0.17 (0.12 – 0.22)
1998	0.53 (0.23 – 0.90)	0.51 (0.22 – 0.84)	0.89 (0.61 – 1.19)	0.22 (0.17 – 0.28)
1999	NA	0.90 (0.51 – 1.33)	1.04 (0.79 – 1.31)	0.59 (0.51 – 0.69)
2000	2.37 (1.41 – 3.53)	2.10 (1.22 – 3.07)	0.95 (0.71 – 1.19)	1.05 (0.92 – 1.18)
2001	NA	0.94 (0.24 – 1.78)	{Assume =$SAR(C_1)$}	0.016 (0.005 – 0.03)
2002	NA	1.06 (0.32 – 2.11)	0.70 (0.54 – 0.88)	0.73 (0.61 – 0.85)
2003[2]	1.80 (1.48 – 2.13)	1.81 (1.50 – 2.14)	0.68 (0.52 – 0.85)	0.37 (0.26 – 0.47)
7-yr Avg. **Std_error**		**1.12** **0.232**	**0.65** **0.144**	**0.45** **0.137**

[1] Not applicable since some sites have no adult returns for estimating a site-specific SAR.

[2] Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

Tables D-21 to D-28 present estimated S_R (in-river survival LGR to BON denoted as V_C in prior CSS reports), TIR (ratio of $SAR_2(T_0)/SAR(C_0)$, and *D* parameters with associated 90% confidence interval for wild and hatchery Chinook and steelhead.

Table D-21. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged wild Chinook for migration years 1994 to 2004 (with 90% confidence intervals).

Mig. Year	S_R		TIR		*D*	
1994	0.20	(77% expansion)[A]	1.62	(0.62 – 5.05)	0.36	(0.13 – 1.09)
1995	0.41	(51% expansion)	0.95	(0.39 – 2.14)	0.42	(0.17 – 1.09)
1996	0.44	(77% expansion)	1.92	(0.00 – 6.80)	0.92	(0.00 – 3.24)
1997	0.51	(77% expansion)	0.74	(0.17 – 1.58)	0.40	(0.08 – 0.95)
1998	0.61	(25% expansion)	0.87	(0.50 – 1.35)	0.55	(0.31 – 0.87)
1999	0.59	(0.53 – 0.68)	1.14	(0.82 – 1.51)	0.72	(0.52 – 0.98)
2000	0.48	(0.41 – 0.58)	0.60	(0.32 – 0.92)	0.32	(0.17 – 0.51)
2002	0.61	(0.52 – 0.76)	0.65	(0.45 – 0.94)	0.44	(0.29 – 0.68)
2003	0.60	(0.52 – 0.69)	1.05	(0.69 – 1.67)	0.68	(0.43 – 1.09)
2004 [B]	0.40	(0.33 – 0.51)	0.97	(0.53 – 2.37)	0.40	(0.21 – 1.03)
Geomean	**0.46**		**0.99**		**0.49**	
2001[C]	0.23	(0.20 – 0.27)	8.96	(3.61 – 16.8)	2.16	(0.87 – 4.16)

[A] Expansion shows percent of reach with a constant "per/mile" survival rate applied.

[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

[C] For migration year 2001, the $SAR(C_1)$ value is used in the denominator of the TIR ratio.

Table D-22. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged Rapid River Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R		TIR		*D*	
1997	0.33	(77% expansion)[A]	1.73	(1.08 – 2.85)	0.61	(0.37 – 1.09)
1998	0.59	(25% expansion)	1.66	(1.32 – 2.16)	1.01	(0.80 – 1.36)
1999	0.57	(0.49 – 0.67)	1.28	(1.11 – 1.51)	0.79	(0.65 – 0.99)
2000	0.58	(0.48 – 0.83)	1.32	(1.13 – 1.55)	0.82	(0.66 – 1.25)
2002	0.71	(0.60 – 0.84)	1.5	(1.20 – 1.91)	1.14	(0.87 – 1.52)
2003	0.66	(0.57 – 0.79)	1.07	(0.70 – 1.60)	0.75	(0.48 – 1.18)
2004 [B]	0.35	(0.27 – 0.52)	1.79	(0.94 – 5.25)	0.65	(0.32 – 2.09)
Geometric mean	**0.52**		**1.46**		**0.81**	
2001[C]	0.33	(0.28 – 0.40)	21.7	(13.3 – 54.1)	7.33	(4.40 – 16.9)

[A] Expansion shows percent of reach with a constant "per/mile" survival rate applied.

[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

[C] For migration year 2001, the $SAR(C_1)$ value is used in the denominator of the TIR ratio.

Table D-23. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged Dworshak Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
1997	0.49 (77% expansion)^A	1.75 (0.92 – 3.46)	0.88 (0.40 – 2.01)
1998	0.51 (25% expansion)	0.72 (0.59 – 0.88)	0.37 (0.30 – 0.47)
1999	0.54 (0.47 – 0.65)	0.99 (0.81 – 1.24)	0.60 (0.47 – 0.81)
2000	0.48 (0.40 – 0.65)	0.99 (0.82 – 1.19)	0.53 (0.42 – 0.75)
2002	0.62 (0.54 – 0.72)	1.24 (0.93 – 1.61)	0.84 (0.61 – 1.12)
2003	0.68 (0.59 – 0.80)	1.20 (0.82 – 1.80)	0.87 (0.58 – 1.36)
2004^B	0.50 (0.40 – 0.69)	0.95 (0.60 – 1.72)	0.49 (0.29 – 0.96)
Geometric mean	**0.54**	**1.08**	**0.62**
2001^C	0.24 (0.20 – 0.30)	8.76 (5.04 – 20.4)	2.21 (1.23 – 5.30)

[A] Expansion shows percent of reach with a constant “per/mile” survival rate applied.
[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the T/C ratio.

Table D-24. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged Catherine Creek AP spring Chinook for 2001 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
2002	0.65 (0.44 – 1.06)	1.81 (1.02 – 3.43)	1.23 (0.59 – 2.79)
2003	0.62 (25% expansion)^A	1.44 (0.60 – 3.56)	0.93 (0.38 – 2.29)
2004^B	0.33 (0.20 – 0.89)	1.75 (0.0 – 2.31)	0.59 (0.0 – 1.34)
Geometric mean	**0.51**	**1.66**	**0.88**
2001^C	0.25 (0.18 – 0.37)	5.33 (0.0 – 13.6)	1.38 (0.03 – 3.79)

[A] Expansion shows percent of reach with a constant “per/mile” survival rate applied.
[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-25. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged McCall Hatchery summer Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
1997	0.43 (77% expansion)^A	1.38 (1.06 – 1.80)	0.64 (0.43 – 0.93)
1998	0.56 (25% expansion)	1.96 (1.54 – 2.56)	1.16 (0.89 – 1.54)
1999	0.52 (0.46 – 0.61)	1.49 (1.29 – 1.73)	0.87 (0.72 – 1.07)
2000	0.61 (0.51 – 0.83)	1.89 (1.67 – 2.15)	1.24 (0.98 – 1.81)
2002	0.58 (0.51 – 0.68)	1.44 (1.18 – 1.79)	0.87 (0.68 – 1.14)
2003	0.70 (0.63 – 0.79)	1.46 (1.17 – 1.81)	1.08 (0.85 – 1.39)
2004^B	0.44 (0.35 – 0.58)	1.23 (0.66 – 2.98)	0.55 (0.30 – 1.31)
Geometric mean	**0.54**	**1.53**	**0.88**
2001^C	0.27 (0.22 – 0.34)	31.9 (17.9 – 88.4)	8.95 (4.87 – 24.1)

[A] Expansion shows percent of reach with a constant “per/mile” survival rate applied.
[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-26. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of of PIT-tagged Imnaha AP summer Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
1997	0.31 (77% expansion)[A]	1.36 (0.83 – 2.37)	0.45 (0.24 – 0.92)
1998	0.53 (25% expansion)	1.55 (0.93 – 3.15)	0.87 (0.51 – 1.72)
1999	0.54 (0.42 – 0.75)	1.89 (1.40 – 2.51)	1.11 (0.75 – 1.72)
2000	0.57 (0.43 – 0.83)	1.29 (1.06 – 1.58)	0.82 (0.56 – 1.25)
2002	0.50 (0.41 – 0.66)	1.75 (1.07 – 3.03)	0.95 (0.54 – 1.78)
2003	0.70 (25% expansion)	1.21 (0.79 – 1.89)	0.91 (0.58 – 1.42)
2004 [B]	0.37 (0.24 – 0.71)	1.50 (0.48 – 4.80)	0.58 (0.15 – 2.19)
Geometric mean	**0.49**	**1.49**	**0.78**
2001[C]	0.37 (0.27 – 0.61)	10.8 (4.94 – 39.8)	4.15 (1.83 – 15.3)

[A] Expansion shows percent of reach with a constant "per/mile" survival rate applied.
[B] Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-27. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged wild steelhead for migration years 1997 to 2003 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
1997	0.52 (25% expansion)[A]	2.20 (0.0 – 8.16)	1.18 (0.0 – 5.74)
1998	0.54 (25% expansion)	0.20 (0.0 – 0.70)	0.11 (0.0 – 0.41)
1999	0.45 (0.38 – 0.54)	2.28 (1.15 – 4.38)	1.07 (0.53 – 2.09)
2000	0.30 (25% expansion)	1.45 (0.77 – 2.40)	0.50 (0.27 – 0.82)
2002	0.52 (0.41 – 0.69)	4.25 (2.12 – 7.67)	2.24 (1.09 – 4.25)
2003[B]	0.37 (0.31 – 0.44)	4.13 (2.62 – 6.80)	1.64 (1.01 – 2.72)
Geometric Mean	**0.44**	**1.72**	**0.80**
2001[C]	0.038 (0.027 – 0.059)	37.0 (10.6 – 94.6)	1.46 (0.40 – 4.40)

[A] Expansion shows percent of reach with a constant "per/mile" survival rate applied.
[B] Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-28. Estimated inriver survival LGR to BON (S_R), TIR, and *D* of PIT-tagged hatchery steelhead for migration years 1997 to 2003 (with 90% confidence intervals).

Mig. Year	S_R	TIR	*D*
1997	0.40 (25% expansion)[A]	2.21 (0.99 – 5.66)	0.92 (0.36 – 2.67)
1998	0.64 (0.47 – 1.02)	0.58 (0.23 – 1.05)	0.39 (0.16 – 0.85)
1999	0.45 (0.39 – 0.53)	0.87 (0.48 – 1.41)	0.41 (0.22 – 0.70)
2000	0.22 (25% expansion)	2.20 (1.22 – 3.58)	0.55 (0.30 – 0.93)
2002	0.37 (0.29 – 0.49)	1.51 (0.38 – 3.33)	0.60 (0.14 – 1.38)
2003 [C]	0.51 (0.43 – 0.62)	2.65 (1.99 – 3.74)	1.43 (1.02 – 2.10)
Geometric Mean	**0.41**	**1.46**	**0.64**
2001	0.038 (0.023 – 0.082)	59.7 (0.0 – 215.6)	2.40 (0.0 – 10.05)

[A] Expansion shows percent of reach with a constant "per/mile" survival rate applied.
[B] Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.
[C] For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Tables D-29 to D-30 present annual pathway survival estimates (S) and contributions to overall SAR for wild Chinook and wild steelhead

Table D-29. Annual wild Chinook pathway survival estimates (*S*) and contributions to overall SAR (Path $S_i * \pi_i$), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate in-river. The resulting covariances used to estimate parameters for Figure 3.3 are Cov(1,2) = 2.59E-06; Cov(1+2,3) = 2.75E-06; and Cov(1+2+3,4) = 7.07E-06.

Year	Path1 *S* (%)	Path2 *S* (%)	Path3 *S* (%)	Path4 *S* (%)	Path1 contr	Path2 contr	Path3 contr	Path4 contr	1+2 contr	1+2+3 contr	Total *S* (%)
1994	0.67	0.42	0.00	0.28	0.30	0.07	0.00	0.06	0.37	0.37	0.43
1995	0.41	0.25	0.00	0.37	0.21	0.06	0.00	0.05	0.27	0.27	0.32
1996	0.37	1.07	0.00	0.26	0.13	0.26	0.00	0.06	0.39	0.39	0.45
1997	1.08	6.15	0.00	2.35	0.41	1.39	0.00	0.56	1.80	1.80	2.36
1998	1.34	0.84	1.08	1.36	0.64	0.20	0.12	0.23	0.84	0.97	1.19
1999	2.53	2.70	1.85	2.13	0.66	1.21	0.30	0.27	1.87	2.17	2.44
2000	1.22	2.21	0.83	2.39	0.41	0.64	0.10	0.62	1.05	1.15	1.77
2001	1.33	1.29	0.00	0.43	1.10	0.18	0.00	0.00	1.28	1.28	1.29
2002	0.61	0.97	0.54	1.22	0.15	0.30	0.10	0.32	0.44	0.54	0.87
2003	0.31	0.46	0.13	0.33	0.13	0.11	0.01	0.09	0.24	0.25	0.34

Table D-30. Annual wild steelhead pathway survival estimates (*S*) and contributions to overall SAR (Path $S_i * \pi_i$), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate in-river. The resulting covariances used to estimate parameters for Figure 3.4 are Cov(1,2) = -5.86E-06; Cov(1+2,3) = 6.72E-06; and Cov(1+2+3,4) = 1.86E-06.

Year	Path1 *S* (%)	Path2 *S* (%)	Path3 *S* (%)	Path4 *S* (%)	Path1 contr	Path2 contr	Path3 contr	Path4 contr	1+2 contr	1+2+3 contr	Total *S* (%)
1997	1.87	0.00	0.00	0.66	1.05	0.00	0.00	0.08	1.05	1.05	1.13
1998	0.34	0.00	0.00	1.07	0.21	0.00	0.00	0.11	0.21	0.21	0.32
1999	2.69	4.33	2.65	1.35	0.96	1.64	0.40	0.16	2.59	2.99	3.15
2000	3.50	2.66	1.96	1.92	1.81	0.65	0.20	0.26	2.46	2.66	2.92
2001	3.09	0.00	0.00	2.91	2.76	0.00	0.00	0.02	2.76	2.76	2.78
2002	3.91	1.52	2.44	0.67	1.24	0.36	0.33	0.21	1.60	1.93	2.14

Tables D-31 to D-38 present annual reach survival rates estimated with CJS method for PIT-tagged wild and hatchery Chinook and steelhead

Table D-31. In-river smolt survival rate estimates through hydrosystem for the PIT-tag aggregate of wild spring/summer Chinook in migration years 1994 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1994	S2 (lgr-lgs)	0.822	0.796	0.846
	S3 (lgs-lmn)	0.836	0.807	0.866
1995	S2 (lgr-lgs)	0.895	0.880	0.911
	S3 (lgs-lmn)	0.951	0.924	0.978
	S4 (lmn-mcn)	0.764	0.659	0.923
1996	S2 (lgr-lgs)	0.908	0.869	0.946
	S3 (lgs-lmn)	0.911	0.850	0.977
1997	S2 (lgr-lgs)	0.922	0.859	0.990
	S3 (lgs-lmn)	0.931	0.822	1.057
1998	S2 (lgr-lgs)	1.003	0.986	1.021
	S3 (lgs-lmn)	0.850	0.824	0.874
	S4 (lmn-mcn)	0.940	0.889	0.993
	S5 (mcn-jda)	0.854	0.763	0.965
1999	S2 (lgr-lgs)	0.958	0.948	0.967
	S3 (lgs-lmn)	0.924	0.914	0.934
	S4 (lmn-mcn)	0.889	0.869	0.908
	S5 (mcn-jda)	0.889	0.854	0.927
	S6 (jda-bon)	0.845	0.734	1.000
2000	S2 (lgr-lgs)	0.897	0.880	0.915
	S3 (lgs-lmn)	0.868	0.842	0.893
	S4 (lmn-mcn)	0.977	0.934	1.022
	S5 (mcn-jda)	0.734	0.674	0.804
	S6 (jda-bon)	0.866	0.708	1.097
2001	S2 (lgr-lgs)	0.930	0.925	0.936
	S3 (lgs-lmn)	0.772	0.762	0.782
	S4 (lmn-mcn)	0.684	0.670	0.698
	S5 (mcn-jda)	0.714	0.669	0.763
	S6 (jda-bon)	0.663	0.553	0.827
2002	S2 (lgr-lgs)	0.901	0.883	0.920
	S3 (lgs-lmn)	0.996	0.975	1.016
	S4 (lmn-mcn)	0.810	0.785	0.837
	S5 (mcn-jda)	0.873	0.826	0.927
	S6 (jda-bon)	0.967	0.780	1.268
2003	S2 (lgr-lgs)	0.893	0.877	0.910
	S3 (lgs-lmn)	0.878	0.852	0.905
	S4 (lmn-mcn)	0.990	0.955	1.023
	S5 (mcn-jda)	0.798	0.759	0.841
	S6 (jda-bon)	0.962	0.803	1.146
2004	S2 (lgr-lgs)	0.970	0.960	0.979
	S3 (lgs-lmn)	0.830	0.810	0.849
	S4 (lmn-mcn)	0.878	0.841	0.917
	S5 (mcn-jda)	0.744	0.667	0.843
	S6 (jda-bon)	0.756	0.581	1.021

Table D-32. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Rapid River Hatchery spring Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.390	0.376	0.406
	S2 (lgr-lgs)	0.964	0.903	1.027
	S3 (lgs-lmn)	0.803	0.746	0.867
1998	S1 (rel-lgr)	0.665	0.658	0.672
	S2 (lgr-lgs)	1.005	0.986	1.024
	S3 (lgs-lmn)	0.847	0.826	0.869
	S4 (lmn-mcn)	0.982	0.924	1.045
	S5 (mcn-jda)	0.798	0.713	0.897
1999	S1 (rel-lgr)	0.751	0.738	0.765
	S2 (lgr-lgs)	0.923	0.901	0.943
	S3 (lgs-lmn)	0.957	0.937	0.977
	S4 (lmn-mcn)	0.906	0.875	0.939
	S5 (mcn-jda)	0.945	0.882	1.022
	S6 (jda-bon)	0.750	0.622	0.923
2000	S1 (rel-lgr)	0.737	0.724	0.752
	S2 (lgr-lgs)	0.846	0.813	0.882
	S3 (lgs-lmn)	1.127	1.016	1.255
	S4 (lmn-mcn)	0.823	0.721	0.937
	S5 (mcn-jda)	0.945	0.760	1.250
	S6 (jda-bon)	0.782	0.546	1.171
2001	S1 (rel-lgr)	0.690	0.686	0.694
	S2 (lgr-lgs)	0.958	0.951	0.965
	S3 (lgs-lmn)	0.856	0.843	0.867
	S4 (lmn-mcn)	0.698	0.683	0.715
	S5 (mcn-jda)	0.924	0.854	1.013
	S6 (jda-bon)	0.618	0.497	0.802
2002	S1 (rel-lgr)	0.755	0.741	0.769
	S2 (lgr-lgs)	0.947	0.923	0.972
	S3 (lgs-lmn)	0.981	0.959	1.004
	S4 (lmn-mcn)	0.841	0.819	0.863
	S5 (mcn-jda)	0.953	0.895	1.018
	S6 (jda-bon)	0.951	0.770	1.191
2003	S1 (rel-lgr)	0.692	0.680	0.706
	S2 (lgr-lgs)	0.916	0.881	0.950
	S3 (lgs-lmn)	0.875	0.809	0.949
	S4 (lmn-mcn)	0.964	0.885	1.050
	S5 (mcn-jda)	0.902	0.834	0.976
	S6 (jda-bon)	0.947	0.788	1.195
2004	S1 (rel-lgr)	0.696	0.691	0.702
	S2 (lgr-lgs)	0.999	0.985	1.013
	S3 (lgs-lmn)	0.754	0.709	0.807
	S4 (lmn-mcn)	0.880	0.812	0.950
	S5 (mcn-jda)	0.766	0.667	0.897
	S6 (jda-bon)	0.696	0.478	1.120

Table D-33. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Dworshak Hatchery spring Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.581	0.547	0.613
	S2 (lgr-lgs)	1.047	0.959	1.148
	S3 (lgs-lmn)	0.810	0.725	0.908
1998	S1 (rel-lgr)	0.843	0.832	0.855
	S2 (lgr-lgs)	1.071	1.043	1.098
	S3 (lgs-lmn)	0.765	0.740	0.790
	S4 (lmn-mcn)	0.931	0.891	0.976
	S5 (mcn-jda)	0.782	0.696	0.891
1999	S1 (rel-lgr)	0.853	0.832	0.873
	S2 (lgr-lgs)	0.887	0.862	0.914
	S3 (lgs-lmn)	0.952	0.935	0.968
	S4 (lmn-mcn)	0.875	0.848	0.901
	S5 (mcn-jda)	0.899	0.849	0.959
	S6 (jda-bon)	0.816	0.684	1.010
2000	S1 (rel-lgr)	0.825	0.809	0.843
	S2 (lgr-lgs)	0.807	0.777	0.839
	S3 (lgs-lmn)	1.036	0.955	1.124
	S4 (lmn-mcn)	0.834	0.754	0.920
	S5 (mcn-jda)	0.944	0.804	1.145
	S6 (jda-bon)	0.730	0.543	1.007
2001	S1 (rel-lgr)	0.748	0.744	0.752
	S2 (lgr-lgs)	0.941	0.934	0.947
	S3 (lgs-lmn)	0.839	0.828	0.849
	S4 (lmn-mcn)	0.694	0.681	0.707
	S5 (mcn-jda)	0.693	0.654	0.739
	S6 (jda-bon)	0.636	0.510	0.839
2002	S1 (rel-lgr)	0.827	0.803	0.849
	S2 (lgr-lgs)	0.917	0.884	0.953
	S3 (lgs-lmn)	0.978	0.950	1.007
	S4 (lmn-mcn)	0.810	0.787	0.834
	S5 (mcn-jda)	0.931	0.877	0.995
	S6 (jda-bon)	0.910	0.758	1.086
2003	S1 (rel-lgr)	0.706	0.692	0.722
	S2 (lgr-lgs)	0.905	0.874	0.933
	S3 (lgs-lmn)	0.897	0.854	0.947
	S4 (lmn-mcn)	0.983	0.934	1.038
	S5 (mcn-jda)	0.856	0.804	0.908
	S6 (jda-bon)	0.990	0.833	1.217
2004	S1 (rel-lgr)	0.823	0.817	0.830
	S2 (lgr-lgs)	0.977	0.964	0.990
	S3 (lgs-lmn)	0.969	0.912	1.031
	S4 (lmn-mcn)	0.779	0.723	0.839
	S5 (mcn-jda)	0.790	0.701	0.910
	S6 (jda-bon)	0.858	0.640	1.270

Table D-34. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Catherine Creek Acclimation Pond spring Chinook in migration years 2001 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
2001	S1 (rel-lgr)	0.520	0.513	0.528
	S2 (lgr-lgs)	0.945	0.931	0.961
	S3 (lgs-lmn)	0.814	0.787	0.840
	S4 (lmn-mcn)	0.659	0.624	0.699
	S5 (mcn-jda)	0.768	0.654	0.901
	S6 (jda-bon)	0.639	0.419	1.101
2002	S1 (rel-lgr)	0.406	0.391	0.421
	S2 (lgr-lgs)	0.949	0.899	0.998
	S3 (lgs-lmn)	1.013	0.954	1.073
	S4 (lmn-mcn)	0.808	0.743	0.887
	S5 (mcn-jda)	0.928	0.779	1.125
	S6 (jda-bon)	0.896	0.562	1.726
2003	S1 (rel-lgr)	0.349	0.334	0.366
	S2 (lgr-lgs)	0.972	0.894	1.056
	S3 (lgs-lmn)	0.855	0.743	1.004
	S4 (lmn-mcn)	1.093	0.937	1.282
	S5 (mcn-jda)	0.764	0.641	0.918
2004	S1 (rel-lgr)	0.255	0.248	0.262
	S2 (lgr-lgs)	0.976	0.942	1.010
	S3 (lgs-lmn)	0.921	0.827	1.047
	S4 (lmn-mcn)	0.900	0.743	1.072
	S5 (mcn-jda)	0.704	0.513	1.040
	S6 (jda-bon)	0.579	0.271	2.149

Table D-35. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged McCall Hatchery summer Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.425	0.411	0.441
	S2 (lgr-lgs)	0.935	0.889	0.987
	S3 (lgs-lmn)	0.882	0.820	0.954
1998	S1 (rel-lgr)	0.588	0.580	0.595
	S2 (lgr-lgs)	0.991	0.971	1.012
	S3 (lgs-lmn)	0.843	0.820	0.867
	S4 (lmn-mcn)	0.942	0.884	1.007
	S5 (mcn-jda)	0.824	0.738	0.930
1999	S1 (rel-lgr)	0.658	0.642	0.675
	S2 (lgr-lgs)	0.908	0.880	0.939
	S3 (lgs-lmn)	0.936	0.908	0.961
	S4 (lmn-mcn)	0.913	0.872	0.957
	S5 (mcn-jda)	1.086	0.989	1.206
	S6 (jda-bon)	0.622	0.514	0.766
2000	S1 (rel-lgr)	0.667	0.650	0.685
	S2 (lgr-lgs)	0.867	0.813	0.932
	S3 (lgs-lmn)	0.917	0.807	1.036
	S4 (lmn-mcn)	1.034	0.911	1.181
	S5 (mcn-jda)	1.307	0.904	2.258
	S6 (jda-bon)	0.570	0.323	0.887
2001	S1 (rel-lgr)	0.667	0.663	0.672
	S2 (lgr-lgs)	0.928	0.920	0.937
	S3 (lgs-lmn)	0.771	0.756	0.786
	S4 (lmn-mcn)	0.647	0.628	0.666
	S5 (mcn-jda)	0.862	0.784	0.954
	S6 (jda-bon)	0.674	0.531	0.924
2002	S1 (rel-lgr)	0.596	0.583	0.609
	S2 (lgr-lgs)	0.964	0.936	0.992
	S3 (lgs-lmn)	0.990	0.964	1.016
	S4 (lmn-mcn)	0.837	0.809	0.869
	S5 (mcn-jda)	1.051	0.969	1.144
	S6 (jda-bon)	0.688	0.583	0.840
2003	S1 (rel-lgr)	0.581	0.570	0.590
	S2 (lgr-lgs)	0.921	0.892	0.949
	S3 (lgs-lmn)	0.884	0.838	0.933
	S4 (lmn-mcn)	1.014	0.964	1.070
	S5 (mcn-jda)	0.907	0.858	0.960
	S6 (jda-bon)	0.929	0.804	1.082
2004	S1 (rel-lgr)	0.563	0.559	0.567
	S2 (lgr-lgs)	0.938	0.927	0.949
	S3 (lgs-lmn)	0.993	0.942	1.052
	S4 (lmn-mcn)	0.754	0.695	0.812
	S5 (mcn-jda)	0.893	0.780	1.039
	S6 (jda-bon)	0.696	0.515	0.993

Table D-36. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Imnaha Acclimation Pond summer Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.617	0.586	0.654
	S2 (lgr-lgs)	0.994	0.909	1.082
	S3 (lgs-lmn)	0.768	0.693	0.856
1998	S1 (rel-lgr)	0.685	0.673	0.697
	S2 (lgr-lgs)	0.978	0.951	1.006
	S3 (lgs-lmn)	0.843	0.812	0.872
	S4 (lmn-mcn)	0.956	0.894	1.035
	S5 (mcn-jda)	0.784	0.685	0.907
1999	S1 (rel-lgr)	0.664	0.645	0.686
	S2 (lgr-lgs)	0.921	0.885	0.957
	S3 (lgs-lmn)	0.954	0.920	0.989
	S4 (lmn-mcn)	0.876	0.825	0.931
	S5 (mcn-jda)	0.944	0.840	1.075
	S6 (jda-bon)	0.740	0.548	1.103
2000	S1 (rel-lgr)	0.685	0.665	0.707
	S2 (lgr-lgs)	0.822	0.774	0.877
	S3 (lgs-lmn)	1.008	0.869	1.201
	S4 (lmn-mcn)	0.885	0.717	1.081
	S5 (mcn-jda)	0.893	0.677	1.293
	S6 (jda-bon)	1.013	0.570	2.469
2001	S1 (rel-lgr)	0.748	0.742	0.755
	S2 (lgr-lgs)	0.958	0.950	0.968
	S3 (lgs-lmn)	0.892	0.877	0.908
	S4 (lmn-mcn)	0.751	0.729	0.776
	S5 (mcn-jda)	0.853	0.763	0.958
	S6 (jda-bon)	0.678	0.462	1.226
2002	S1 (rel-lgr)	0.667	0.645	0.691
	S2 (lgr-lgs)	0.951	0.910	0.994
	S3 (lgs-lmn)	0.947	0.911	0.984
	S4 (lmn-mcn)	0.858	0.817	0.904
	S5 (mcn-jda)	0.828	0.753	0.914
	S6 (jda-bon)	0.788	0.603	1.120
2003	S1 (rel-lgr)	0.715	0.691	0.739
	S2 (lgr-lgs)	0.901	0.845	0.952
	S3 (lgs-lmn)	0.905	0.815	1.020
	S4 (lmn-mcn)	0.914	0.809	1.021
	S5 (mcn-jda)	1.027	0.913	1.163
2004	S1 (rel-lgr)	0.615	0.607	0.624
	S2 (lgr-lgs)	0.964	0.943	0.986
	S3 (lgs-lmn)	0.910	0.831	1.001
	S4 (lmn-mcn)	0.834	0.731	0.966
	S5 (mcn-jda)	0.878	0.701	1.126
	S6 (jda-bon)	0.576	0.333	1.274

Table D-37. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of wild summer steelhead in migration years 1997 to 2003.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S2 (lgr-lgs)	0.984	0.948	1.017
	S3 (lgs-lmn)	0.975	0.902	1.060
	S4 (lmn-mcn)	0.886	0.685	1.233
	S5 (mcn-jda)	0.721	0.368	2.096
1998	S2 (lgr-lgs)	0.969	0.945	0.995
	S3 (lgs-lmn)	0.843	0.807	0.879
	S4 (lmn-mcn)	0.889	0.805	1.000
	S5 (mcn-jda)	0.868	0.746	1.009
1999	S2 (lgr-lgs)	0.974	0.956	0.991
	S3 (lgs-lmn)	0.910	0.888	0.934
	S4 (lmn-mcn)	0.835	0.785	0.890
	S5 (mcn-jda)	1.040	0.937	1.148
	S6 (jda-bon)	0.580	0.473	0.761
2000	S2 (lgr-lgs)	0.790	0.771	0.807
	S3 (lgs-lmn)	0.910	0.878	0.943
	S4 (lmn-mcn)	0.860	0.800	0.931
	S5 (mcn-jda)	0.659	0.594	0.729
2001	S2 (lgr-lgs)	0.834	0.823	0.845
	S3 (lgs-lmn)	0.716	0.694	0.741
	S4 (lmn-mcn)	0.288	0.267	0.312
	S5 (mcn-jda)	0.230	0.191	0.281
	S6 (jda-bon)	0.958	0.618	1.714
2002	S2 (lgr-lgs)	0.943	0.921	0.965
	S3 (lgs-lmn)	1.164	1.122	1.215
	S4 (lmn-mcn)	0.522	0.493	0.553
	S5 (mcn-jda)	0.960	0.886	1.083
	S6 (jda-bon)	0.939	0.720	1.269
2003	S2 (lgr-lgs)	0.908	0.884	0.934
	S3 (lgs-lmn)	0.914	0.875	0.958
	S4 (lmn-mcn)	0.729	0.679	0.784
	S5 (mcn-jda)	0.913	0.826	1.21
	S6 (jda-bon)	0.664	0.552	0.818

Table D-38. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of hatchery summer steelhead in migration years 1997 to 2003.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S2 (lgr-lgs)	0.954	0.937	0.972
	S3 (lgs-lmn)	0.853	0.823	0.888
	S4 (lmn-mcn)	0.938	0.814	1.104
	S5 (mcn-jda)	0.656	0.440	1.187
1998	S2 (lgr-lgs)	0.950	0.936	0.963
	S3 (lgs-lmn)	0.854	0.834	0.875
	S4 (lmn-mcn)	0.820	0.775	0.868
	S5 (mcn-jda)	1.058	0.970	1.148
	S6 (jda-bon)	0.915	0.642	1.543
1999	S2 (lgr-lgs)	0.966	0.955	0.978
	S3 (lgs-lmn)	0.895	0.880	0.909
	S4 (lmn-mcn)	0.801	0.769	0.837
	S5 (mcn-jda)	1.044	0.985	1.111
	S6 (jda-bon)	0.622	0.519	0.772
2000	S2 (lgr-lgs)	0.693	0.673	0.717
	S3 (lgs-lmn)	0.812	0.778	0.854
	S4 (lmn-mcn)	0.803	0.735	0.877
	S5 (mcn-jda)	0.705	0.614	0.820
2001	S2 (lgr-lgs)	0.693	0.682	0.705
	S3 (lgs-lmn)	0.678	0.650	0.707
	S4 (lmn-mcn)	0.284	0.262	0.311
	S5 (mcn-jda)	0.353	0.286	0.463
	S6 (jda-bon)	0.805	0.418	2.455
2002	S2 (lgr-lgs)	0.908	0.887	0.930
	S3 (lgs-lmn)	0.970	0.943	1.001
	S4 (lmn-mcn)	0.570	0.536	0.610
	S5 (mcn-jda)	0.937	0.830	1.051
	S6 (jda-bon)	0.777	0.604	1.067
2003	S2 (lgr-lgs)	0.949	0.927	0.972
	S3 (lgs-lmn)	0.935	0.900	0.971
	S4 (lmn-mcn)	0.710	0.664	0.761
	S5 (mcn-jda)	0.954	0.856	1.056
	S6 (jda-bon)	0.842	0.695	1.049

Tables D-39 to D-44 present age distribution of returning adult Chinook and steelhead detected at LGR for unpriver populations and BON for downriver populations

Table D-39. Age composition of returning PIT-tagged wild Chinook jacks and adults detected at Lower Granite Dam that were PIT-tagged during the 10-month period from July 25 to May 20 for each migration year between 1994 and 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1994	1	11	11	4.3	47.8	47.8
1995	1	38	20	1.7	64.4	33.9
1996	0	11	5	0.0	68.8	31.3
1997	2	33	5	5.0	82.5	12.5
1998	17	148	47	8.0	69.8	22.2
1999	25	517	144	3.6	75.4	21.0
2000	9	259	312 (1[B])	1.5	44.6	53.7 (0.2 [B])
2001	2	30	15	4.3	63.8	31.9
2002	26	197	38	10.0	75.5	14.6
2003[A]	3	61	24	3.4	69.3	27.3
2004[A]	3	86	NA	--	--	--
Average				**4.2**	**66.2**	**29.6**

[A] Migration year 2004 is incomplete until 3-salt returns occur at GRA; not included in average.

[B] One 4-salt adult shown in parenthesis in 3-salt column.

Table D-40. Age composition of returning PIT-tagged John Day River wild Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	3	112	31	2.1	76.7	21.2
2001	7	90	15	6.3	80.4	13.4
2002	5	86	9	5.0	86.0	9.0
2003	5	110	13	3.9	85.9	10.2
2004[A]	5	68	NA	--	--	--
Average				**4.3**	**82.3**	**13.4**

[A] Migration year 2004 is incomplete until 3-salt returns occur at BOA; not included in average.

Table D-41. Number of returning PIT-tagged hatchery Chinook adults and jacks detected at Lower Granite Dam that migrated as smolts in 1997 to 2004 and percent of total return.

Hatchery (run)	Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
RAPH	1997	2	86	7	2.1	90.5	7.4
(spring)	1998	32	390	23	7.2	87.6	5.2
	1999	43	787	31	5.0	91.4	3.6
	2000	8	371	256	1.3	58.4	40.3
	2001	21	206	13	8.8	85.8	5.4
	2002	60	298	5	16.5	82.1	1.4
	2003	20	75	8	19.4	72.8	7.8
	2004 [A]	4	67	NA	--	--	--
Average					**8.6**	**81.2**	**10.2**
MCCA	1997	21	263	11	7.1	89.2	3.7
(summer)	1998	108	394	37	20.0	73.1	6.9
	1999	119	722	113	12.5	75.7	11.8
	2000	144	635	239 (1[B])	14.1	62.3	(0.1[B])
	2001	62	200	23	21.8	70.2	8.1
	2002	116	347	18	24.1	72.1	3.7
	2003	129	222	27	34.1	58.7	7.1
	2004 [A]	25	91	NA	--	--	--
Average					**19.1**	**71.6**	**9.3**
DWOR	1997	1	36	6	2.3	83.7	14.0
(spring)	1998	51	372	23	11.4	83.4	5.2
	1999	14	393	44	3.1	87.1	9.8
	2000	3	180	197	0.8	47.4	51.8
	2001	14	79	10	13.6	76.7	9.7
	2002	52	222	8	18.4	78.7	2.8
	2003	5	73	12	5.6	81.1	13.3
	2004 [A]	1	85	NA	--	--	--
Average					**7.9**	**76.9**	**15.2**
IMNA	1997	24	63	7	25.5	67.0	7.4
(summer)	1998	54	69	2	43.2	55.2	1.6
	1999	81	226	12	25.4	70.8	3.8
	2000	149	289	79	28.8	55.9	15.3
	2001	30	49	4	36.1	59.0	4.8
	2002	46	81	2	35.7	63.8	1.6
	2003	93	71	2	56.0	42.8	1.2
	2004 [A]	9	33	NA	--	--	--
Average					**35.8**	**59.2**	**5.1**
CATH	2001	2	13	0	13.3	86.7	0.0
(spring)	2002	11	45	1	19.3	79.0	1.8
	2003	5	22	0	18.5	81.5	
	2004 [A]	2	17	NA	--	--	--
Average					**17.0**	**82.4**	**0.6**

[A] Migration year 2004 is incomplete until 3-salt returns occur at GRA; not included in average.

[B] One 4-salt adult shown in parenthesis in 3-salt column.

Table D-42. Age composition of returning PIT-tagged Carson NFH Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	5	302	124 (1[A])	1.2	69.9	28.7 (0.2[A])
2001	3	205	18	1.3	90.7	8.0
2002	5	148	3	3.2	94.9	1.9
2003	0	32	2	0	94.1	5.9
2004[B]	4	79	NA	--	--	--
Average				**1.4**	**87.4**	**11.2**

[A] One 4-salt adult Chinook shown in parenthesis in 3-salt column.

[B] Migration year 2004 is incomplete until 3-salt returns occur at BOA; not included in average.

Table D-43. Age composition of returning PIT-tagged wild steelhead adults detected at Lower Granite Dam that were PIT-tagged during the 12-month period from July 1 to June 30 for each migration year between 1997 and 2003.

Migration Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	4	10	0	28.6	71.4	0
1998	16	8	0	66.7	33.3	0
1999	33	51	2	38.4	59.3	2.3
2000	132	131	3	49.6	49.3	1.1
2001	5	14	2	23.8	66.7	9.5
2002	59	60	1	49.2	50.0	0.8
2003[A]	38	63	NA	(37.6)	(62.4)	--
Average				**42.7**	**55.0**	**2.3**

[A] Migration year 2003 is incomplete until 3-salt returns occur at GRA; not included in average.

Table D-44. Age composition of returning PIT-tagged hatchery steelhead adults detected at Lower Granite Dam that migrated as smolts in 1997 to 2003.

Migration Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	34	15		69.4	30.6	0
1998	45	32		58.4	41.6	0
1999	85	96	1	46.7	52.7	0.5
2000	178	89	1	66.4	33.2	0.4
2001	3	8		27.3	72.7	0
2002	99	49	1	66.4	32.9	0.7
2003[A]	90	77	NA	(53.9)	(46.1)	--
Average				**55.8**	**43.9**	**0.3**

[A] Migration year 2003 is incomplete until 3-salt returns occur at GRA; not included in average.

Appendix E (to be included with second draft)

Tables of initial values, bootstrap averages, standard deviations, coefficient of variation, and 90% parametric and non-parametric confidence intervals of key CSS parameters for PIT-tagged wild Chinook 1994-2004, hatchery Chinook (individually for each facility) 1997-2004, wild steelhead 1997-2003, and hatchery steelhead 1997-2003 originating above Lower Granite Dam

Appendix F (to be included with second draft)

Plots of timing of PIT-tagged wild and hatchery Chinook and steelhead at Lower Granite Dam for upriver stocks and at Bonneville Dam for upriver and downriver stocks

Appendix G

Comments and response from ISRP/ISAB

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August 23, 2002

Northwest Power Planning Council
Attention Judi Hertz
Response to ISRP
851 SW 6th Avenue, Suite 1100
Portland, Oregon 97204

RE: Project ID: 199602000 – Comparative Survival Study (CSS) of Hatchery PIT tagged chinook and the Comparative Survival Study Oversight Committee.

Dear Ms. Hertz:

Attached, please find the response to ISRP comments on the subject proposal.

Sincerely,

Michele DeHart

Michele DeHart

Response to ISRP comments

Project ID 199602000

Comparative Survival Rate Study (CSS) of PIT tagged Chinook
&
Comparative survival Study Oversight Committee

1. ISRP Comment: "The response must include an outside peer review of the estimation process by a qualified statistician(s) or there must be a programmatic review by the ISRP allowing adequate time for careful evaluation of the estimation process before a positive recommendation for funding can be given. Previous reviews by the ISAB and the ISRP resulted in the conclusion that the overall design of the data collection was adequate to meet the primary objectives of the project, but that the statistical properties of the proposed analysis procedures (mathematical formulas) should be further investigated before conclusions are based on data from this study. The previous ISRP and ISAB reviews did not approve the specific mathematical formulas in the reports issued by this project. Adequate review of the proposed analysis procedures is not feasible in the time allocated for the review for all proposals in the Mainstem and System wide Province."

Response: The study has been reviewed in detail by the ISAB on January 14, 1997, and January 8, 1998, and most recently in December 2001. John Skalski, University of Washington, provided the most recent review comments on the present study design, on December 3, 2001. A copy of those comments and the response to comments are attached. In addition, those comments and the response to those comments were appended to the annual report for 2001, which is available at http://www.fpc.org/fpc_docs/css/CSS_Report_FINAL.pdf in Appendix F.

The CSS Oversight Committee is amenable to outside independent reviews and to the ISRP detailed review discussed in their comments. The CSS Oversight Committee is scheduled to discuss the statistical and study design details with the ISRP on September 24, 2002 to facilitate the ISRP detailed review. Additionally, in response to Question # 4 posed by the ISRP, the Oversight Committee plans to begin work to publish results this winter. A broad range of peer review of statistical analysis and methodology will occur through that process.

2. ISRP Comment: "When will the project end? The reason for the project stated on page 2 is to answer, *can transportation of fish to below Bonneville compensate for the effect of the hydro system on juvenile survival rates of Snake River spring and summer chinook salmon during their downstream migration?* It appears that the direction of the project is changing to the point that the proposal should be considered a new proposal. The project began in 1996 yet the proposal notes a rather tentative goal on page 2, and repeated on page 3, *This study is intended to begin to provide the basis for the Mainstem Monitoring and Evaluation (M&E) Program's analysis of long term alternatives for recovery of depressed listed and unlisted stocks of chinook and steelhead."*

Response: This is an ongoing, long-term project, which monitors and evaluates salmon survival (smolt to adult) related to existing hydrosystem management actions (in-river migration and transportation) across a broad range of environmental conditions (e.g., runoff volumes, estuary/ocean). The project has maintained a consistent scope, which has since its inception included the identified transportation question but also several questions which are outlined in tasks and objectives of the proposal (see proposal Section 9 f). These include upstream-downstream comparisons, the development of long-term, consistent, time series of SARs, and the hydro system passage history of smolts. The CSS Oversight Committee previously responded to this question of project duration by the Northwest Power Planning Council (September 8, 1997 memo, DeHart to Casavant) as follows: "*The Salmon Managers initially proposed the PIT tagging at hatcheries as a means of evaluating mitigation measures aimed at recovery of listed wild chinook. Since recovery will take many years, there will be the need for the release of marked fish for the evaluation of recovery measures. Therefore, we will consider this study a long-term effort. Although hatchery stocks are predominately used now, as wild stock population sizes increase, they would be considered for tagging. The key element of this PIT tagging effort is to provide a level of consistent marking over time to address the effects of the primary mitigation measures. This long-term study is designed to conform with and compliment the NPPC adaptive management approach as outlined in the draft framework paper*." The ISAB review (January 8, 1998) also recommended a long-term, expanded CSS project (recommendation 2): "*So long as the present configuration and operation of the hydroelectric system exists, extend (or continue) PIT tagging to include naturally reproducing populations of spring chinook whenever population sizes may permit. Continue PIT tagging other life history types, and extend PIT tagging to other life history types of other species of salmon, including steelhead, whenever possible*."

The direction of the project is essentially the same as proposed in 1996 and 1997; however, the project has proposed additions of specific study populations to better meet the project goals, respond to project reviews by the ISAB and other reviewers, and adapt to changes in the Fish and Wildlife Program, additional ESA listings and regional programs. The key response variables have continued to be empirical smolt-to-adult return rates (SARs) compared to those needed for survival and recovery, and SAR comparisons between transport and inriver migration routes and upstream and downstream populations. The project has contained since its inception the task of exploring feasibility of developing lower river wild spring chinook index stocks to estimate smolt-to-adult return rates to compare with those of Snake River wild stocks. The current proposal, which adds steelhead groups, is consistent with the original project vision and the specific recommendation of the ISAB cited above.

The initial and present intent of this study is "*to begin to provide the basis for the Mainstem Monitoring and Evaluation (M&E) Program's analysis of long term alternatives for recovery of depressed listed and unlisted stocks of chinook and steelhead*." The basic challenge identified by the ISRP is that some components of a mainstem / systemwide M&E program are in place (including the CSS study), but the overall M&E program is not. Clearly, these component programs (including CSS) will need to mesh functionally in the future for a successful systemwide M&E program. As discussed below, formally combining projects does not seem to be necessary or beneficial at this stage so long as data collection and analytical activities are closely coordinated through the proposed umbrella project.

3. ISRP Comment: **"The response should contain a careful self-review evaluating the advantages and disadvantages of combining this project with the CBFWA proposal #35033 to form a system wide monitoring and evaluation project."**

Response: The CBFWA proposal #35033 for collaborative, systemwide monitoring and evaluation (if funded) would provide a framework within which the CSS (and other projects of similar scale) could operate to monitor and evaluate life cycle survival of listed and unlisted Columbia Basin salmon, steelhead (as well as resident species). Note that the CBFWA proposal did not propose to incorporate administration and implementation of projects like CSS, but rather to integrate Tier 1, 2 and 3 data from these component projects into a systemwide M&E program, and make recommendations for filling critical information gaps related to key management questions facing the region.

Until a systemwide M&E program is actually established, there does not seem to be any advantage to combining the ongoing CSS project with an un-funded proposal such as #35033. In the future, an advantage of combining this project with the CBFWA proposal #35033 might be to ensure project coordination and to prioritize CSS M&E activities. The alternative model is to keep projects separate but have close coordination between the CBFWA M&E project and the various components (including CSS) to ensure efficiency of data collection and analyses. The disadvantage to combining CSS with CBFWA proposal #35033 is primarily one of logistics of project administration and implementation. The scale of CSS is currently workable, with implementation carried out by the Smolt Monitoring Program, and project design, data analyses and oversight carried out by an interagency oversight committee. We foresee no advantages to CSS project administration or implementation from a formal incorporation of CSS into the CBFWA project, because the existing logistical burden would simply fall to the CBFWA project (and subsequently back to the Smolt Monitoring Project). Potential benefits to the CSS study design or data analyses tasks from combining projects could be achieved alternatively through coordination between the CSS project and the CBFWA proposed M&E project, especially considering the overlap of sponsoring agencies and biologists/biometricians on the two projects.

4. ISRP Comment: "The proponents should summarize progress toward publication of the results and methods in the peer reviewed literature, if any attempt has been made."

Response: A part of the CSS results concerning survival rates by route of passage has been published in the North American Journal of Fisheries Management (Budy et al. 2002). However, the majority of the methods and results are contained in the report "Comparative Survival Study of PIT tagged spring/summer Chinook Status Report for Migration Years 1997-2000 Mark/Recapture Activities" in great detail (Bouwes et al. 2002). The CSS oversight committee has been planning to submit a couple of publications, one on the methodologies and another on the results of basinwide comparisons for spring/summer chinook survival rate patterns. The publications rely on finishing the analysis of the non-parametric bootstrap technique for confidence limits for smolt-to adult return rates. In addition, we could not publish results in previous years because the adult returns were not complete until 3 years after marking. Therefore, in order to have three years of data the returns were not complete until 2002. We anticipate submitting these manuscripts for publication this winter.

5. ISRP Comment: "It was mentioned that bootstrapping would be used to obtain confidence intervals on the point estimates and we agree that this may be an appropriate procedure. However, the problem is deeper than estimation of variances. The formulas proposed are ratios of ratios and the magnitude of mathematical bias in the point estimates should also be evaluated. In addition, maximum likelihood estimators and perhaps others

should be developed and contrasted to the proposed ad hoc estimators to determine the most accurate and precise estimates possible with the available data."

Response: The ISRP agrees that the bootstrap may be an appropriate procedure for estimation of variance, but they would like to see an evaluation of potential bias in SARs, ratios of SARs, and the delayed mortality index D. The CSS researchers realize that there is a potential for biases in the estimation process that should be evaluated. For example, estimating the number of smolts in the T_0 (total transported in LGR equivalents) and C_1 (in-river migrating smolts detected at a transportation site in LGR equivalents) categories requires unbiased estimates of survival from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (this expands to McNary Dam tailrace in years that springtime transportation at McNary occurs). As part of the estimation process, we look for patterns in the survival estimates between these dams that may be reflective of potential biases. An unbiased estimate of the number of smolts in the C_0 (in-river migrating smolts not detected at a transportation site in LGR equivalents) category requires unbiased survival estimates to produce results in LGR equivalents and an unbiased estimate of the population of PIT tagged fish at Lower Granite Dam (undetected and detected fish). Most of the variance and potential bias of the estimated number of smolts in Category C_0 will arise from the estimation of population at Lower Granite Dam.

We ran simulations of the process of estimating the number of undetected wild fish at Lower Granite Dam, which included seasonally and randomly varying detection probabilities, smolt travel times, and survival rates. The results suggest that our proposed method results in very small (< 1%) bias in estimates of undetected smolts at Lower Granite, with 95% confidence intervals well within ± 10% of the true value. This method must be used for wild fish, and can also be used with hatchery fish.

The ISRP recommends that we should develop maximum likelihood estimators and contrast them to our "ad hoc" estimators to determine which provides more accurate and precise parameter estimates. However, some of the quantities we already estimate, such as reach survival rates, in fact use maximum likelihood estimation, and the Lower Granite Dam population estimates are generated using components that are maximum likelihood estimators (*e.g.,* estimated collection efficiency). It is these estimates that determine the accuracy and precision of the estimated smolt numbers. These estimates in combination with the actual count data create the estimated number of smolts in each category. This is not an "ad hoc" approach as implied by the ISRP, but rather a set of computational formula based on the underlying probabilities of survival between dams, probability of collection at a dam, and probability of being transported once collected at a dam.

Where practicable, theoretical formulas for variance and/or profile confidence intervals from maximum likelihood estimation (MLE) will be employed with the original data to compare with estimates of variance and confidence intervals generated from the bootstrap program. Likelihood profiles for SARs (where the denominator is known with little error) can be generated using the binomial probability distribution and observed releases and recaptures. Variance for log-transformed ratios of SARs with denominators that are presumed to be known with little error [*e.g.,* SAR(T_{LGR}) and SAR(C_1)] can be estimated with the formula derived from the ratio of two binomial random variables [see Equation (1) of Townsend and Skalski (1997)]. Additionally, MLE for ratios of these SARs will be performed using a likelihood formula similar to Equation (14) of Townsend and Skalski (1997), generating likelihood curves and support functions, which will give means and confidence intervals which can be compared to those generated from the bootstrap. If the bootstrap estimates of these relatively simple SAR and T/C estimates exhibit low bias and robust confidence intervals, it will provide assurance that more involved estimation procedures (*e.g.*, for D) are reasonable.

Because estimates of in-river survival from Lower Granite Dam tailrace to Bonneville Dam tailrace (LGRBON reach) have generally required some extrapolation of survival across sections of river for which no direct estimate is possible, there is the potential for biases to enter into the estimation of D. In years prior to 1998, there were greater chances of biases in these expansions because of the limited PIT tag detection capabilities at John Day and Bonneville dams, compared to 1998 and subsequent years. In 1998 and subsequent years the distance of river over which in-river survival has had to be extrapolated has been reduced, thus reducing the potential for biases in the LGRBON reach survival estimate. In the bootstrapping program, we have added a feature that allows the researcher to pre-select the number of reaches over which to use existing estimates of in-river survival and to choose among alternative methods of extrapolation. This will allow us to compare the sensitivity of the resulting LGRBON reach survival estimate to the amount of reach (distance) being extrapolated, and the method used.

6. ISRP Comment: "Why is NMFS not on the interagency Comparative Survival (CSS) Oversight Committee? It seems that they are one of the primary users of the results and should be directly involved in oversight of the project."

Response: NMFS was invited to join the Oversight Committee at the inception of the Committee and the CSS study. NMFS declined to participate in day-to-day Oversight Committee discussions. However, NMFS Science Center staff participated in the early stages of study statistical design development. NMFS has not been excluded from the Oversight Committee and has a standing invitation to join if they so desire. NMFS as well as any other agency or individual is provided the opportunity to review and comment on the CSS, annual report, annual proposal study designs and any other aspect of the CSS. NMFS has taken the opportunity to provide comments on this study through the NMFS ESA Section 10 permit process for the CSS.

7. Action Agencies/ NMFS RME Group Comments: "The RME Hydro subgroup recognizes that the proposed research has the potential to provide data and estimates useful in satisfying elements in those RPAs, Hydro-related RME RPAs 185, 187, 188, and 189. The smolt survival estimates have further application in the context of testing compliance with the Hydro performance standards as noted for other proposals in this review. The proposal was thorough in specifying sample sizes comprising key index treatment groups. However it would be beneficial if that information was translated into precision estimates. Alternatively power analyses for key hypothesis tests could be presented to demonstrate the estimates will be satisfactory for evaluating key hypothesis remaining in the region. This would also aid in assessing the utility of the information in performance tests that would be performed at the check-ins."

Response: The CSS provides data useful to addressing hydro-related RPA 185 (SARs of in-river and transported smolts and associated estimation of delayed mortality of transported fish), RPA 187 (relation between ocean entry timing and SARs of in-river and transported smolts), RPA 188 (SARs of lower Columbia River basin wild stocks for use in evaluating effects of hydro system on upriver stocks), and RPA 189 (SARs of smolts with different passage histories through the hydro system, including effects such as number of bypasses detected and which particular bypasses detected). Through the large scale PIT tagging of hatchery yearling chinook and steelhead, the CSS will provide a database containing smolt passage histories and adult return histories. For Snake River basin smolts, this database will provide direct comparisons of SARs of in-river and transported smolts with a 90% power of detecting differences of at least 50% between the two outmigration routes as long as the smaller SAR does not drop below 1%. For Mid-Columbia River basin smolts, this database will provided direct comparisons of SARs of in-river smolts against the COE's McNary Dam transported smolts with a 90% power of detecting differences of at least 30% between the two outmigration routes as long as the smaller SAR does not drop below 1%. Once any other specific hypothesis of interest to the region is formulated, it would be feasible to evaluate the power of testing that hypothesis using the CSS database. However, we cannot guarantee that the power will be as high for those specific tests if the numbers of smolts available for these new hypothesis tests are much lower than the number of smolts required for the original hypotheses. The PIT tagging of wild smolts at tributary traps will provide marked fish in addition to those NMFS is PIT tagging at the dams for use in estimating SARs from and back to Lower Granite Dam. From the composite of wild stocks, estimates of SARs and ratios of SARs will be possible, but given the uncertainty of collecting large enough numbers of fish of wild origin, the power of the tests will typically be lower than what is possible with the fish of hatchery origin.

The precision of the estimated SARs for in-river and transported smolts will be obtained through bootstrapping techniques. The bootstrap will also provide precision of the ratios of SARs and the associated delayed mortality "D" index. The bootstrap can be an effective tool to obtain a valid measure of variability in a parameter, even when that parameter is a computation based on a set of values, each of which must be estimated. For example, when the ratio of returning adults to a known (fixed) number of smolts is used to generate an estimated SAR, the underlying binomial distribution may be used to obtain the associated measure of precision of the SAR estimate. However, when the number of smolts must also be estimated, the underlying distribution of the ratio of two estimated parameters becomes more complex. For these situations, the non-parametric bootstrap technique is useful (Dixon 1993). Likewise, the ratio of pairs of these SARs (*e.g.*, ratio of transported LGR-LGR SAR to in-river LGR-LGR SAR) would form a complex underlying distribution for which the use of the bootstrap is a preferred approach. This is also true of the estimation of delayed transportation mortality, the D parameter or the ratio of BON-LGR SARs . Programmers at the Fish Passage Center are currently writing a computer program to perform bootstrapped estimates of variance and confidence intervals for individual SARs, ratios of SARs, and D. The next CSS annual status report will contain bootstrapped estimates of precision for all parameters presented. This will allow NMFS to assess the utility of using the CSS's estimated parameters at their periodic check-ins.

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ISAB Review of the 2005 Comparative Survival Studies' Annual Report and Applicability of Comparative Survival Studies' Analysis Results

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ISAB Review: The 2005 CSS Annual Report and Applicability of CSS Analysis Results

ISAB Review: The 2005 CSS Annual Report and Applicability of CSS Analysis Results

Executive Summary

On December 20, 2005, the Council requested that the Independent Scientific Advisory Board (ISAB) review the 2005 Annual Report for the Comparative Survival Study (CSS) prepared by the Fish Passage Center (FPC) and the Comparative Survival Study Oversight Committee, as well as critical comments on the draft of that report by the Bonneville Power Administration (BPA) and NOAA Fisheries. The CSS is a field study, begun in 1996, that addresses important and technically complex issues regarding the survival of PIT-tagged Spring/Summer Chinook and PIT-tagged Summer Steelhead through the Columbia River hydrosystem from juveniles through returning adults. The study focuses on relative survival of fish that traveled downstream as juveniles by alternative routes (e.g., in river, transported, different routes of dam passage, and different numbers of dams passed). The results can have important implications for operation of the hydrosystem to ensure protection and propagation of anadromous salmonids. The Council expressed a desire to aid resolution of disputes over the study by obtaining the ISAB review.

The Council asked that the ISAB assess the overall integrity and scientific soundness of the CSS report and address the following specific questions:

> *1. Are the design, implementation, and interpretation of the statistical analyses underpinning the report based on the best available methods? Does the ISAB have suggestions for improving the analyses?*
>
> *2. What is the applicability of the CSS results, taking into account whatever scientific criticisms of the analyses that the ISAB decides are valid, if any? In other words, what weight should the analyses be given and what qualifiers should be considered when using the analyses for decision-making?*

The ISAB accepted the assignment on January 12, 2006 and received a briefing on the CSS Annual Report from the study's Principal Investigators on January 27th. The ISAB considers that there are two parts to this review: (1) review of the 2005 CSS Annual Report and (2) a determination of the utility of the CSS comparative survival estimates for various management and hydrosystem operational decisions.

The ISAB finds that the CSS is an ambitious, long-term study that is being criticized because its objectives are not yet fully met, despite prodigious efforts in both the field and in complex data analyses. The CSS has used the PIT-tag technology to mark and track individual salmon and steelhead through their smolt-to-adult life stages. Expectations of this mark-recapture technology exceed the results that are practically attainable, and its use is still evolving. The CSS study participants have been major players in this evolution. We find the present annual report to be a further incremental step in the direction of documenting different survival rates of different stocks under different migration conditions. That the present report is not a perfect reconstruction of differential survival histories is largely a result of the current analytical capabilities and available sample sizes. The deficiencies seem to be highlighted in some aspects because of experimental design and analytical approaches taken by the authors. The ISRP comment from their 2002 review still applies that "the formulas [used to compute relative survival rates] are complicated, convoluted, and in general, very unsatisfactory from a statistical point of view."

Specific Responses to the Council's Questions

1. Are the design, implementation, and interpretation of the statistical analyses underpinning the report based on the best available methods? Does the ISAB have suggestions for improving the analyses?

All in all, the design, implementation, and interpretation of the *statistical analyses* underpinning the report are very good. Nonetheless, there are broader concerns over the design of the study such as sample size, sampling sites, time periods for analyses, and other features. Improvements can be made, and our recommendations follow.

Since the region is unwilling to conduct the manipulative experiments in the hydrosystem that the ISAB and ISRP have recommended for many years, the CSS is doing the next best thing. That is, the study is following as many fish through their life cycle as possible, calculating the survival, and comparing outcomes.

2. What is the applicability of the CSS results, taking into account whatever scientific criticisms of the analyses that the ISAB decides are valid, if any? In other words, what weight should the analyses be given and what qualifiers should be considered when using the analyses for decision-making?

The ISAB believes the Council should view the CSS as a good, long-term monitoring program, the results of which should be viewed with increasing confidence as years pass. Under scrutiny from periodic peer reviews and agency comments, the methods should improve and the results become ever more valuable. The project is definitely worthy of Council support.

The Council's question is difficult to answer with the present annual progress report. The project needs a synthesis report that clearly describes the analytical methods and summarizes the project results in a holistic way for its decade of effort.

The ISAB recognizes a disconnect between the present status of results and much of the decision-making that takes place regarding hydrosystem operations and fish protection. Although the project is making good progress at addressing such issues as the value of transportation and the relative survival from different passage routes, many relationships between survival and specific operational alternatives or environmental features during migration cannot be resolved when data are aggregated simply by year of migration. For this information to be most useful for making management decisions, aggregations of data within years and across years for different operational options and environmental constraints should be pursued. We encourage the project to move in that direction.

The results of the CSS appear to indicate that PIT-tagged fish do not have the same survival rate as untagged fish. This conclusion is not emphasized by the current progress report, but it has major implications for many uses of the PIT-tag technology. Comparisons among PIT-tagged groups of fish are probably appropriate, but extrapolations of the results from PIT-tagged fish to untagged populations should be made with caution.

Recommendations

- It has been ten years since the CSS was initiated. The report the ISAB reviewed was the latest in a series of annual progress reports, and thus lacking a holistic perspective. The ISAB recommends that the CSS produce a ten-year summary report providing an in-depth description of methods and detailed analyses and interpretation of the data in a retrospective style.

- The CSS needs to more effectively present the methodologies used in their analyses so the criticism of complicated and convoluted formulas can be avoided. The scattered explanations in several annual progress reports could be consolidated in the ten-year summary recommended above.

- The ISAB agrees with critics who express concern that two downriver sites (Carson Hatchery and John Day River) are probably insufficient to give accurate upriver-downriver comparisons of SARs. This concern is bolstered by the variability among upriver hatcheries shown by the CSS data. For this upriver-downriver comparison to be generally accepted, it seems prudent to add more downriver sites in the future.

- Data on size of all PIT-tagged fish from hatcheries and other release sites should be included in the report in much greater detail. Size at release may be a significant factor in differential SARs. The ISAB recommends including a specific section in the report focusing on the potential effects of size at release on survival of all PIT-tagged fish.

- Aggregation of data solely by juvenile migration year should be supplemented with analyses that group data on environmental and operational factors that may be amenable to control.

- Assumptions inherent in the analyses should be specifically tested, with continued vigilance toward avoiding bias.

- Pre-assigning the intended routes of passage at the time of release into inriver and transport groups would greatly simplify calculation of SARs and eliminate much criticism of current methods that are unnecessarily complex. This modification to the study design is scheduled for implementation in 2007, but should begin in 2006, if feasible.

- Analyses could emphasize more diverse metrics of differential survival, thus avoiding the criticism that the project staff focuses mainly on contentious issues such as the relative survival of transported and in-river migrants (T/C ratios) and differential delayed mortality between transported and in-river migrants (*D*). Passage routes, numbers of dams bypassed, distance from ocean, different hatchery practices, and other features have been explored beyond the issue of transportation.

- The CSS should be supplemented by funded research into analytical methods that can improve, and hopefully simplify, the mathematical and statistical approaches currently in use. It is not clear from available information whether the problem is that the formulas are unnecessarily complicated, inappropriately specified, or just not well explained (see bullet #2 above).

- More attention should be given by the CSS and the region as a whole to the apparent documentation that PIT-tagged fish do not survive as well as untagged fish. This point has major implications for all uses of PIT-tagged fish as surrogates for untagged fish.

I. Introduction and Background

Review Assignment

On December 20, 2005, the Council requested that the Independent Scientific Advisory Board (ISAB) review the 2005 Annual Report for the Comparative Survival Study (CSS) prepared by the Fish Passage Center (FPC) and the Comparative Survival Study Oversight Committee. The CSS is a field study of the survival of PIT-tagged Spring/Summer Chinook and PIT-tagged Summer Steelhead through the hydrosystem from juveniles through returning adults, with a focus on relative survival of fish that traveled as juveniles by alternative routes (e.g., in river, transported, different routes of dam passage, and different numbers of dams passed). The annual report reviews recent mark/recapture activities and bootstrap analysis for generating confidence intervals.

The CSS is important, as it is one of the few organized attempts to systematically release PIT-tagged, hatchery-reared fish, and wild smolts into the Columbia River for the purpose of monitoring and evaluation. Most aspects of the study, from its design and methods to the analytical results, have been strongly debated in the Region because the relative survival rates of salmonids under different hydrosystem operations and environmental constraints is at the heart of water and fish management policies.

In response to the release of the draft version of this annual progress report, both the Bonneville Power Administration and NOAA Fisheries provided the FPC with letters setting forth both broad concerns and detailed criticisms of the findings and results reported in the draft report. Before finalizing the report, the FPC provided detailed responses to both Bonneville and NOAA Fisheries addressing their concerns. The Council expressed its wish to contribute to the resolution of these important and technically complex issues by having the ISAB conduct its own review of the final progress report and the attendant letters. In conducting the review, the Council asked that the ISAB assess the overall integrity and scientific soundness of the CSS report and address the following specific questions.

1. Are the design, implementation, and interpretation of the statistical analyses underpinning the report based on the best available methods? Does the ISAB have suggestions for improving the analyses?

2. What is the applicability of the CSS results, taking into account whatever scientific criticisms of the analyses that the ISAB decides are valid, if any? In other words, what weight should the analyses be given and what qualifiers should be considered when using the analyses for decision-making?

The ISAB accepted this important assignment on January 12, 2006 and received a briefing on the CSS Annual Report from the study's Principal Investigators on January 27th. The ISAB considers that there are two parts to this review: (1) review of the 2005 CSS Annual Report and (2) a determination of the utility of the CSS comparative survival estimates for various management and hydrosystem operational decisions.

The CSS was initiated in 1996 by the Northwest fishery agencies and tribes as a long-term study to estimate survival rates over different life stages of spring and summer Chinook salmon produced in hatcheries in the Snake River basin and selected lower hatcheries in the lower Columbia River. The study has expanded somewhat to encompass wild Chinook salmon and steelhead, and the mix of hatcheries has changed with experience. The premise of the research was that, through use of PIT tags implanted in juveniles at the point of release from hatcheries or rearing facilities, the survival of unique groups of fish could be determined as they passed through PIT-tag detectors in juvenile bypasses at dams or in adult fish ladders on their return. From these survival rates it was hypothesized that one could quantify differential survival according to passage route. Of particular interest were differences in survival related to distance from the ocean, between transported and in-river fish and the delayed effects of hydrosystem passage (by juveniles) on adult returns.

Previous Reviews

Both the ISAB and the ISRP previously reviewed the CSS study proposals in 1998 (ISAB 1998) and 2002 (ISRP 2002) and the recommendations from those reviews were generally as follows (recommendations are provided in full in Appendix A):

In 1998, the ISAB supported funding of the study. They recommended including naturally reproducing populations as well as hatchery fish and suggested that other life-history types of Chinook salmon and steelhead be included. They recommended quantifying survival from tributary hatcheries to Lower Granite Dam and McNary Dam, and through the entire hydrosystem when sufficient detectors were functional. They encouraged attempts to compare survival of PIT-tagged fish to untagged fish or fish tagged by other methods. The ISAB also saw this as a way to coordinate the PIT-tagging efforts of many agencies and to provide an opportunity for periodic workshops to review results.

The ISRP reviewed the continuation proposal in 2002 and also recommended funding. The “best” formulas for calculating smolt-to-adult survival rates from then-available data were judged “complicated, convoluted, and in general, very unsatisfactory from a statistical point of view.” It was noted that arguments over these methods would likely continue and spawn even more detailed arguments and counter-arguments. Much of the difficulty lies in small sample sizes due to both numbers of fish tagged and the number of detections. Improved detection at Bonneville Dam was recommended. The ISRP recommended more research on mathematical and statistical methods both within this project and outside it for estimating life-cycle survival.

II. Review of 2005 CSS Annual Report

Methods (Chapter 2)

There are three principal issues over the study's methods. One concerns the selection of hatcheries (or other release sites), especially for comparisons between smolts with long passage routes through the hydrosystem and those migrating from lower in the basin with few dams to pass. Another relates to the mathematical and statistical methods employed in the analyses, including potential biases and the types of aggregation of data for summaries. A major point raised by NOAA Fisheries is the unreliability of the PIT-tag method to represent the survival of untagged fish (the CSS data indicate that PIT-tagged fish do not survive as well as untagged fish, and therefore are not adequate surrogates for untagged fish in the population).

Some study methods are not fully described in this annual progress report. We did not seek out previous annual progress reports to fill in the information gaps. This difficulty begs for a summary report that can provide a more complete description of methods.

It would be useful to have the SARs analyzed as a function of size at release. This could be tested for rather than just presenting size data. Also, data on size of all PIT-tagged fish from hatcheries and other release sites should be included in much greater detail than median lengths at tagging reported in Table 2 (e.g., include mean lengths, weights, and ranges). Sizes at release may be a significant factor in differential SARs from various sources. Fish size is generally not accorded much significance in the CSS studies despite a well-known survival advantage for larger fish. As raised in comments by NMFS, these size effects need to be given more consideration in further analyses. The ISAB recommends including a specific analyses focusing on the effects of size at release on SAR values of all PIT-tagged fish.

The numbers of fish available for tagging is a major constraint. As tables 2-5 demonstrate, the number of tagged fish vary considerably by location and year. The study participants have had to be opportunistic despite an intended experimental design. To their credit, they appear to have been quite successful in obtaining numerous stocks and years to compare.

Holdovers (fish not migrating fully through the hydrosystem in the year of initial outmigration; Connor et al. 2002) cause methodological problems. The authors have tried to account for these fish in different ways in this and the previous annual report. They believe the present method has less bias for estimating survival. This needs to be evaluated in later years.

We admire the study participants for attempting to segregate fish among their several migration-route histories. Although the term "destined" seems too strongly pre-ordained for the current methods of release and tracking, fish do have the three options listed: in-river by non-bypass routes, in-river through dam bypasses, or routed to transportation at the collector dams. They have these options at most dams (not all dams have facilities to collect fish for transportation), thus expanding the number of possible migration histories. Equipment failures, changes in protocols at a particular dam from year to year, and other irregularities complicate matters even more. This is a real "haystack" of PIT-tag data from which to extract the key "needles" in the form of meaningful comparisons of survival among both source groups and passage histories.

As in the comments by BPA and NMFS, we are critical of the authors' choice to summarize SAR results only on an annual basis. The determinants of SAR likely vary as much with the environment within a migration year as between years, and these could be tested. The environmental status and hydrosystem-operating mode at the specific time a fish migrates through the system represents the features that are most relevant to survival and are specific targets for modification, rather than average conditions over a migration year. It has been an ongoing criticism of the FPC that they do not further refine their data analyses to within-year conditions (e.g., the ISAB's comments on the FPC flow augmentation analyses reported in ISAB flow augmentation reviews (ISAB 2004-2)).

We recognize the problems presented by segregating migration histories within years. For example, fish from a release batch disperse in the river and do not all pass a dam at the same time, and therefore individuals experience different environmental and operational histories. However, further breakdown by operational modes or environmental features (such as temperature ranges) could greatly enhance the value of further analyses of the CSS data. The annual summaries can be considered as broad "first cuts" that may be modified by these additional analyses.

The evolving nature of these analyses is reflected in Table 8, which shows older and more recent estimates of the comparison of the differential delayed mortality between transported and in-river fish (*D*). Despite the number of significant figures reported, the overall number can change, as the influences on it are better understood and included in calculations. Although labeled as a "correction" based on comments on the draft report we see the change as progressive improvement (they may change again).

The study has necessarily aggregated batches of tagged fish, as described at the bottom of page 12. The authors seem to have accounted for this in a reasonable way.

As an overall perspective, there is no way of avoiding the realization that there are a lot of assumptions inherent in the study, from tagging through analyses and presentation of data. Further research should test these assumptions, or tag a sufficient number of appropriate fish so that empirical data can replace assumptions.

Much of the continuing controversy is related to the mathematical and statistical methods employed. We agree with the earlier ISAB comment that the "formulas are complicated, convoluted, and in general, very unsatisfactory from a statistical point of view." That said, we think the FPC response to the issues raised by NMFS and BPA is quite good. Where questions of bias in estimators are raised, the primary issue appears to be estimating SAR starting from the population at Lower Granite Dam rather than from other projects. However, the ISAB found the explanation by the CSS scientists as to why the estimate was made in this manner to be reasonable.

There are assumptions made no matter which method is proposed for estimation. For example, the CSS makes the assumption that the transportation proportion for the unmarked population of each hatchery group and the aggregate wild group is approximately the same. Also, it is assumed that the PIT tagged and untagged smolts have the same probability of surviving to and being collected at the dams in the hydro system. These assumptions should be tested.

With respect to the assertion that the PIT tagging reduces survival (see NOAA Fisheries' comments below), we are concerned about the basic premise of the CSS, namely that PIT-tagged fish can serve as surrogates for the unmarked population. If this assertion stands up to further scrutiny, then use of PIT tags should be restricted to comparisons among PIT-tagged groups, and not with unmarked fish.

The use of the bootstrap method to estimate confidence intervals is appropriate. The methodology is now widely used in many statistical applications.

The ISAB hopes the sponsors will more effectively present the methodologies used in the next (2006) Annual Report or in the 10-year summary report we recommend so the criticism of complicated and convoluted formulas can be avoided.

Results (Chapter 3)

The level of scientific satisfaction with the results varies among the species and stocks analyzed. In some cases the results as presented are fairly robust; in other cases where data are scant, trends may be visible but lack statistical significance. The authors present what they have.

Wild Chinook

The problem of small sample sizes for wild Chinook is clearly illustrated by Table 9, which presents the age composition of their PIT-tagged returns. Although a few years had three-digit numbers per age category (1999, 2000, 2002), other years had single- or double-digit numbers. Expansions, while logical, still do not avoid the problem of having few adult returns. Regrettably, it is the wild Chinook that suffer most severely from this concern.

The low return rates of tagged wild Chinook cause the SAR estimates to be very uncertain. The 90% confidence limits of the transport SAR calculations (Table 11) show very wide ranges. What reasonable conclusions can one make when the 90% confidence ranges from zero to over 3? The results do more to demonstrate the *lack* of ability to determine the true SAR than anything. The authors recognize this difficulty in the text on page 15, and we can take their analyses as a straightforward presentation of the SAR values they calculated using limited data.

The authors were criticized for comparing their calculated SAR values (inexact as they probably are) to the 2% for stable stocks and 4% for recovery recommended by Marmorek et al. (1998). We find no fault with their flagging their calculated values near 1% as a likely problem. We agree with critics of the study that there are better estimates now of stock-specific returns needed for stable populations and recovery, and better calculations of SAR values would be an improvement. But the general trend is unsettling and the CSS results should be taken in their intended context.

The consistent trend in the comparison of SAR values for smolts collected at a collector dam (C_1) and those not detected (C_0) (page 16) also is troubling, despite understood problems with the data. A difference of 25% might just be real. (The table referred to should be Table 12, not Table 10).

In our view, the scant data provide essentially no meaningful information on the relative survival of transported smolts and in-river migrants (T/C ratio) for wild Chinook salmon in all years except 2001 (Figure 4). That year most smolts were transported because of extremely low river flows and high temperatures for in-river migrants, and the transport SAR was high. The values of the differential delayed mortality between transported and in-river migrants (*D*) have a similar limitation, as the authors note.

We are inclined to view the further analysis of wild Chinook data on pages 19-24 as not warranted based on the scant amount of data available. Perhaps we do not follow the intent of the authors in this section. Further combining of SARs, T/Cs, and *D*s to come up with sample sizes suitable for statistical analysis seems to us to be inappropriate. The more fruitful direction for the longer term would seem to be to tag more fish in order to match these values with specific operational and environmental regimes that could (at least for operations) be modified to obtain better survival.

Hatchery Chinook

The foundation of data for hatchery Chinook salmon is much better than for wild Chinook (Table 17). However, when taken to the level of specific source hatchery (Table 19), in many cases the data look nearly as sparse as for wild Chinook.

We did not specifically critique the authors' results or discussion of each specific hatchery. The variation among hatcheries is rather expected, based on different rearing conditions, fish size at release, distance from the ocean, etc. The authors seem to have made logical attempts to explain differences in SAR performances. It is interesting that the Rapid River Hatchery seems to be the closest surrogate for wild Chinook. Size effects noted earlier probably deserve more attention.

The T/C ratios among hatcheries are nearly all above 1, indicating superior survival of the transported fish. The ratios are not far above 1, however, and only the estimated error bounds get above 2 (the expected T/C in the absence of *D*).

Wild Steelhead

The numbers of returning adult steelhead are even fewer than for wild Chinook, and thus the results are even less reliable. We view these results as merely presentation of what is available, rather than providing a strong case for any conclusion. Within the limitations of the data, some of the same trends appear as for Chinook, such as higher SAR values for fish not detected as smolts, somewhat higher SARs for transported fish (for steelhead this was above 2 three of 5 years, excluding 2001), and widely varying D values. The issue of residualism is important for steelhead, as the authors point out.

Hatchery Steelhead

Low numbers of fish make this analysis problematic. Small sample sizes yield no statistically significant results. However, the authors carry through with the same analyses as for the other groups. The most interesting suggestion is that a possible relationship between fish detected at collector dams and those undetected through the hydrosystem appears to have disappeared in 2000 and 2002.

Adult Drop-out Rates (Chapter 4)

The potential for loss of adults migrating upstream being influenced by the outmigration experiences of the fish as smolts has been raised in the region. We were pleased to see the adult PIT-tag detection data used to track adult upstream movements and losses. The data seem to support conclusions that dropout is higher where there is a fishery (not unexpected), hatchery fish dropped out somewhat more than wild (not stressed by the authors), and that transported fish had a somewhat higher dropout rate than in-river fish. The comparisons in this report just scratch the surface of what can be learned from these data. More important than the Transport/In-river comparisons are potential insights into migration rates at different flows and other environmental differences. Perhaps the emphasis on “survival” in the CSS led to the more narrow focus.

Hatchery-to-Hatchery SARs for Various Hatcheries (Chapter 5)

A basic premise of the CSS was that different survival rates could be calculated for each hatchery from which smolts were released. After many adjustments for terminal fisheries and other factors, this chapter seems to be a straightforward presentation of the SAR values from hatchery back to hatchery for five hatcheries. The problem of small sample sizes is evident. In order to have enough fish for hatchery comparisons, the authors did not do a transported vs. in-river comparison.

Upriver-Downriver Comparisons (Chapter 6)

A prime motivation for the CSS was the hypothesis that the SARs for salmonids that must pass downstream through the hydropower system as juveniles would be lower than those for fish passing no or few dams. To test this hypothesis, there must be adequate representation from both upriver and downriver fish sources.

We concur with critics who express concern that the two downriver sites (Carson Hatchery and John Day River) are probably too few to give accurate upriver-downriver comparisons. This concern is bolstered by the variability among upriver hatcheries shown by the CSS data. For this upriver-downriver comparison to be reliable, it seems prudent to add more downriver sites in the future.

Partition of results into common-year effects and differential mortality as carried out by Deriso et al. (2001) and this study appears reasonable and justified, despite criticisms from Williams et al. (2005). As an editorial note, “fig.y” and later “fig yy” need their numbers.

Estimates of differential upriver-downriver mortality based on spawner-recruit and PIT-tag SAR values provide useful confirmation during the one year of overlap (2000). It would be useful to continue these parallel analyses. We do not understand, however, how averaging 1.48, 0.78, and 1.18 supports the conclusion that upriver stocks survive “about 1/3 as well as John Day populations for these years.”

We were puzzled that the conclusions listed for this chapter did not mention the upriver-downriver comparison for which the chapter was titled. Instead, the conclusions relate to common survival patterns estimated by the two techniques, comparison of wild and hatchery fish, and high correlations among populations. It would have been informative and appropriate to include the comparative survival information (upriver populations survived about 1/3 as well) in the conclusions.

Simulated PIT-tag data to test CJS survival estimates (Chapter 7)

In principle, one can test the reliability of analytical methods by developing simulated data sets and conducting analyses on them. We generally concur that testing the analytical approach with simulated data should provide a useful evaluation of the approach. The present section provides insufficient information, however, to understand what is being done. The abbreviation CJS needs to be defined.

ISAB Evaluation of Comments by BPA and NOAA Fisheries

BPA Comments

BPA was critical of the observational nature of the CSS, the use of a “heuristic analytical approach” devoid of a statistical model, bias in the estimates that lead to incorrect conclusions, misguided emphasis on *D*, a misguided upriver-downriver comparison, and generally flawed and skewed interpretations that minimize the benefits of transportation and the return rates of salmonids. It provided its own mathematical derivation of transported SAR as an appendix.

BPA’s initial criticism that the CSS cannot make direct causal inferences about any particular natural or anthropogenic factor is technically correct, as is the need for manipulative and replicated experiments in order to do so. However, the ISAB and its precursor advisory bodies have requested such manipulative and replicated experiments in the FCRPS for more than a decade, and the requests have been refused by BPA and other action agencies as impractical. BPA is criticizing the CSS for deficiencies in their study when these deficiencies have been caused largely by BPA policy decisions. What the CSS is doing is consistent with its initial study proposal, continuing objectives, and periodic technical reviews.

We do not fault the CSS for its empirical approach. First, the CSS authors do not merely compare hatchery-to-hatchery SAR values, but try several measures of survival along the migration corridor. Survival to Lower Granite Dam is used as a more reliable measure than returns to the hatchery of origin, for example. The CSS has standardized much of its data to the LGR site. We do not see that the approaches used in the CSS analysis are appropriately characterized as biased. As the BPA commenter notes, the issue is somewhat moot because the CSS results do show advantages for transportation in some years, especially in the drought year of 2001.

We do not see that the CSS has focused on *D* as a primary gauge of the effectiveness of transportation. It seems to be presented as one measure along with others. We believe that use of multiple metrics benefits the comparisons. In addition, delayed mortality is real. Therefore, why shouldn’t one calculate the difference in this delayed mortality between transported and in-river fish? We note that the CSS has updated its estimates of *D* based on comments, which we take as a sign of continual improvement.

Some inconsistency between earlier progress reports and this one are to be expected. That’s why they are “progress reports.” This criticism is one reason why the ISAB sees the need for a ten-year summary report as well as the incremental annual reports.

We concur that the upriver-downriver comparison has problems. The BPA commenter correctly criticizes the CSS for relying on just one downstream hatchery when the upstream hatcheries showed such wide variation in results. But the BPA comment does not acknowledge that the CSS also used the John Day River stock for the downriver set. The Hilborn et al. (1993) paper cited by BPA (without reference) does not eliminate the possibility that information other than that used by Hilborn et al. could show differences between upriver and downriver performance. We would encourage the CSS participants to build on this critique and bolster the downriver samples.

NOAA Fisheries Comments

The NOAA Fisheries comments reflected their belief that the analyses in the progress report are incomplete, do not fully support the findings in the executive summary and chapters, and lack a holistic approach to analyzing all available data. They argue for more in-depth analyses and broader discussion of all relevant data on the effects of the hydropower system on salmonid stocks. They opine that PIT-tagged fish do not represent the untagged populations, that the CSS made selective use of data, that statistical significance is used inconsistently, and that there are biases in the comparisons between treatments and controls. A major point is that the PIT-tagged fish really do not provide a true representation of the untagged population, based on the CSS data. In addition to these general topics, they provided detailed comments by section.

The ISAB suggests that the NOAA Fisheries' expectation that the present annual progress report be a holistic evaluation of all data is unrealistic. That criticism would be more appropriate for a final or periodic summary report. An annual progress report is, by design, of more limited scope. We do agree, however, that a holistic summary is sorely needed after 10 years of work and incremental progress reports.

The NOAA commenter states that the PIT-tagged fish do not represent the survival of the untagged population, while the CSS premise is that they would and the report implies that they do. This is an important difference. In the NOAA Fisheries' comments (and in the technical memo they cite), they note that the PIT-tagged fish returned at about ½ the rate of untagged fish. The data to make these comparisons is in the CSS report, but the CSS authors do not make the comparisons. We agree with NOAA Fisheries that this difference is not trivial and that the CSS must discuss it as well as simply present results. In our view, however, the CSS quite fairly presents the PIT-tag data as its best estimate, although admittedly imperfect. The difficulty comes from comparing the results to the published 2% value for sustainability of a population (tagged and untagged).

We concur that there is some vagueness in statements about statistical significance. On some points, the CSS report simply relies on overlap of the 90% confidence limits. In other places it is not so clear. The CSS could improve this aspect of its reporting. Statistical significance should be tested for and the nature and level of significance of the tests reported.

We concur that size of fish matters and that more attention should be placed on fish sizes in subsequent CSS analyses.

We agree that the Executive Summary could better reflect the results of Chapter 3 in regard to the degree to which hatchery fish can be used as surrogates for wild fish. Nonetheless, the statement that the CSS continues to evaluate this seems appropriate.

As NOAA Fisheries comments, the bullets for Chapter 3 could better represent the text. But these bullets need to be understood as brief summaries of what the text reports.

As we noted before, we concur that use of only one hatchery for the downriver comparison is not good practice, considering the variation seen in results for upstream hatcheries.

The detailed comments are valuable for the CSS to consider as it moves along with the work.

III. ISAB Answers to Council's Questions

1. Are the design, implementation, and interpretation of the statistical analyses underpinning the report based on the best available methods? Does the ISAB have suggestions for improving the analyses?

All in all, the design, implementation, and interpretation of the *statistical analyses* underpinning the report are very good. Nonetheless, there are broader concerns over the design of the study such as sample size, sampling sites, time periods for analyses, and other features. Improvements can be made, and our recommendations follow.

Since the region is unwilling to conduct the manipulative experiments in the hydrosystem that the ISAB and ISRP have recommended for many years, the CSS is doing the next best thing. That is, the study is following as many fish through their life cycle as possible, calculating the survival, and comparing outcomes.

The study design could be improved in several ways. Adding more downriver hatcheries to make more valid upstream/downstream survival comparisons. Much more attention should be given to the size of tagged fish at various release locations, because survival is known to be affected strongly by fish size. The data could be aggregated to more closely meet the needs of hydrosystem managers. Whether by design or implementation, the aggregation of data simply by year of outmigration is insufficient to resolve many of the important issues related to environmental influences and hydrosystem operations. The numbers of fish tagged may never be sufficient for resolving in-season patterns of survival. However, as data are accumulated over more years, it may be feasible to partition analyses into environmental or operational categories across years to obtain more functional correlations. Having a controlled and manipulated experimental design would be preferable (as BPA asserts), but the chance of this happening is slim. Repeated entreaties by the ISAB, its predecessor advisory bodies and the ISRP have all been met with objections to the effect that such a system wide experiment is not possible to manage (although we note that the region managed to implement high spill in 2005 on court order, although no planned experiments were conducted). The opportunistic approach of documenting survival under whatever conditions are dealt seems to be the only alternative.

Implementation would be improved by tagging more fish (particularly wild), but there is likely a limit to the amount that can be accomplished due to manpower limitations. The study managers have been quite opportunistic in arranging tagging and in coordinating tagging efforts among many different entities. Pre-assignment of fish to either inriver or transport passage routes at the time of release would greatly improve study design and make the analyses and results more transparent. Assignment of passage route at release is planned for implementation in 2007 (i.e., a given tag number would really be “destined” to be shunted to a particular route, if possible). This modification should be implemented in 2006, if possible.

The data analyses require extensive statistical manipulations to extract useful information from the mass of PIT-tag detections. We can only agree with the earlier ISRP comment that the "formulas are complicated, convoluted, and in general, very unsatisfactory from a statistical point of view." Pre-assignment of fish to inriver and transport groups at time of release should help. The study participants have gone to great lengths to seek ways to analyze the data appropriately. Bootstrapping confidence limits is a major improvement. We do not find any particular bias in the analyses or interpretations. Likewise, we see no inherent problem with the assumptions, and some assumptions will always have to be made. These assumptions should be tested as the project progresses.

Taken alone, the current progress report does not adequately present the analytical methods and some data presentations are difficult to follow (e.g., labeling axes as log survival instead of actual survival). The ISAB encourages the sponsors to more effectively present the methodologies in a summary report (perhaps as part of the 2006 Annual Report) so the methods of analysis can be better understood.

2. What is the applicability of the CSS results, taking into account whatever scientific criticisms of the analyses that the ISAB decides are valid, if any? In other words, what weight should the analyses be given and what qualifiers should be considered when using the analyses for decision-making?

The Council’s question is difficult to answer with just the present annual progress report. The value of this project for informing management decisions on the hydropower system would be greatly enhanced if a synthesis report were produced that clearly describes the analytical methods and summarizes the project results in a holistic way for its decade of effort. We recognize that this is what NOAA Fisheries hoped to see.

The CSS is providing long-term monitoring of lifetime survival of salmon and steelhead stocks using a technology that the region has spent a great deal of money developing and implementing. As an ongoing effort, subject to periodic review and comment, it is providing an evolving picture. It would be wrong to believe that the results as of today are the end-all for making decisions about the operation of the hydrosystem. The CSS is learning as it goes, which is to be expected. More years and more analyses of specific questions are needed.

Because the CSS is focusing on annual data, the relationships to specific operational and environmental factors within years are not addressed. As commenters have pointed out, these more specific correlations would be more useful for guiding operational decisions. The ISAB recognizes a disconnect between the present status of results and much of the decision-making that takes place regarding hydrosystem operations and fish protection. Although the project is making good progress at addressing such issues as the value of transportation and the relative survival from different passage routes, many relationships between survival and operational or environmental features during migration cannot be resolved when data are aggregated simply by year of migration. For this information to be most useful for making decisions, aggregations of data within years or across years for different operational options and environmental conditions need to be pursued. Even after aggregating the available, relevant data across several years, there may not be a sufficient number of tag detections to make such correlations for all important combinations of operational status and environmental conditions. Either more fish need to be tagged or correlations made after more years of data for which operational and environmental modes can be grouped. The former would be the more expeditious approach.

IV. ISAB Conclusions and Recommendations

The CSS is an ambitious, long-term study that is being criticized because its objectives are not yet fully met, despite prodigious efforts in both the field and in complex data analyses. It has used the PIT-tag technology to mark and track individual salmon and steelhead through their smolt-to-adult life stages. Expectations of this mark-recapture technology exceed the results that are practically attainable, and its use is still evolving. The CSS study participants have been major players in this evolution. We find the present annual report to be a further incremental step in the direction of documenting different survival rates of different stocks under different migration conditions. That the present report is not a perfect reconstruction of differential survival histories is largely a result of the current analytical capabilities and available sample sizes. The deficiencies seem to be highlighted in some aspects because of experimental design and analytical approaches taken by the authors. The ISRP comment from their 2002 review still applies that “the formulas are complicated, convoluted, and in general, very unsatisfactory from a statistical point of view.”

The Council should view the CSS as a good, long-term monitoring program the results of which will become increasingly valuable to managers as years pass. Scrutiny from periodic peer reviews and agency comments will help ensure that the methods and analytical approaches improve. The project is definitely worthy of Council support.

Recommendations

- It has been ten years since the CSS was initiated. The report the ISAB reviewed was the latest in a series of annual progress reports, and thus lacking a holistic perspective. The ISAB recommends that the CSS produce a ten-year summary report providing an in-depth description of methods and detailed analyses and interpretation of the data in a retrospective style.

- The CSS needs to more effectively present the methodologies used in their analyses so the criticism of complicated and convoluted formulas can be avoided. The scattered explanations in several annual progress reports could be consolidated in the ten-year summary recommended above.

- The ISAB agrees with critics who express concern that two downriver sites (Carson Hatchery and John Day River) are probably insufficient to give accurate upriver-downriver comparisons of SARs. This concern is bolstered by the variability among upriver hatcheries shown by the CSS data. For this upriver-downriver comparison to be generally accepted, it seems prudent to add more downriver sites in the future.

- Data on size of all PIT-tagged fish from hatcheries and other release sites should be included in the report in much greater detail. Size at release may be a significant factor in differential SARs. The ISAB recommends including a specific section in the report focusing on the potential effects of size at release on survival of all PIT-tagged fish.

- Aggregation of data solely by juvenile migration year should be supplemented with analyses that group data on environmental and operational factors that may be amenable to control.

- Assumptions inherent in the analyses should be specifically tested, with continued vigilance toward avoiding bias.

- Pre-assigning the intended routes of passage at the time of release into in-river and transport groups would greatly simplify calculation of SARs and eliminate much criticism of current methods that are unnecessarily complex. This modification to the study design is scheduled for implementation in 2007, but should begin in 2006, if feasible.

- Analyses could emphasize more diverse metrics of differential survival, thus avoiding the criticism that the project staff focuses mainly on contentious issues such as the relative survival of transported and in-river migrants (T/C ratios) and differential delayed mortality between transported and in-river migrants (*D*). Passage routes, numbers of dams bypassed, distance from ocean, different hatchery practices, and other features have been explored beyond the issue of transportation.

- The CSS should be supplemented by funded research into analytical methods that can improve, and hopefully simplify, the mathematical and statistical approaches currently in use. It is not clear from available information whether the problem is that the formulas are unnecessarily complicated, inappropriately specified, or just not well explained (see bullet #2 above).

- More attention should be given by the CSS and the Region as a whole to the apparent documentation that PIT-tagged fish do not survive as well as untagged fish. This point has major implications for all uses of PIT-tagged fish as surrogates for untagged fish.

References

ISAB 1998. Review of Comparative Survival Rate Study of Hatchery PIT Tagged Chinook. Report ISAB 98-1, Northwest Power Planning Council and National Marine Fisheries Service, Portland, Oregon.

ISRP 2002. Final Review of Fiscal Year 2003 Mainstem and Systemwide Proposals. Report ISRP 2002-14. Northwest Power and Conservation Council, Portland, Oregon.

Appendix A: Previous Review Comments by ISAB and ISRP

ISAB Comments (ISAB 1998)

- Fund the proposed study.

- So long as the present configuration and operation of the federal hydroelectric system exists, extend (or continue) PIT tagging to include naturally reproducing populations of spring chinook whenever population sizes may permit. Continue PIT tagging other chinook life history types, and extend PIT tagging to other life history types of other species of salmon, including steelhead, whenever possible.

- Apply enough PIT tags to spring chinook production from Kooskia, Pahsimeroi, McCall, Sawtooth, and Clearwater (Powell, Crooked River and Red River Ponds) hatcheries to estimate survival to Lower Granite Dam. Whenever possible apply enough PIT tags to spring chinook at these hatcheries to estimate survivals to McNary Dam.

- Compare rates of return to each hatchery of PIT tagged and untagged adults to establish degree of comparability of survivals of PIT tagged juvenile salmon to survivals of juveniles not PIT tagged. To investigate rate of shedding of PIT tags through the adult stage, and where straying of adults from another hatchery is possible, investigate thermal mass marking of all hatchery production. Where smolt to adult survival of PIT tagged fish is compared to that of coded wire tagged (CWT) fish, develop a procedure to study tag loss and to compare rate of return of PIT to CWT within the hatchery release.

- Make estimates of survival applicable to the entire Snake-Columbia River federal hydroelectric system as soon as possible.

- Promote coordination and cooperation among agencies applying PIT tags and other marks by including a list of other agencies marking salmon and steelhead of the same origin in the proposal, along with comments from those other agencies. Sponsor an interagency workshop on the use of tagging data at five-year intervals. The workshop would produce consensus recommendations and procedures for coordinating tagging activities.

ISRP Comments (ISRP 2002)

Various scientists in the region, in particular scientists from the Comparative Survival Study project and NMFS, have considered the problems in estimating the LGD to LGD smolt-to-adult survival rates (SARs) from currently available data and have apparently arrived at what they consider to be the “best” formulas. Unfortunately, the formulas are complicated, convoluted, and in general, very unsatisfactory from a statistical point of view. Accordingly, there is high probability that these methods will continue to spawn arguments and counter-arguments over trivial issues that will occupy the resources of the region, because the stakes are high (e.g., high costs of spill, high costs of transportation, unknown long term effects of the non-normative transportation, high costs of flow augmentation, etc).

The long-term solutions to the mathematical and statistical problems in estimation of smolt-to-adult return rates (Bonneville to Bonneville and Bonneville to Low Granite SARs) appear to be: 1) detection of sufficient numbers of PIT tagged juveniles passing Bonneville Dam Powerhouse II at the planned corner collector; 2) estimates of mortality of fish passing via that route; 3) and/or sufficiently large sample sizes of PIT tagged fish downstream of Bonneville. The ISRP recommends that these sampling efforts for PIT tagged juveniles be given high priority by the Council and the Corps of Engineers. In particular, Task 2 of NMFS proposal #198331900 for development of PIT tag detection in the corner collector at Bonneville Dam Powerhouse II should be given high priority.

We do not provide unqualified endorsement of the particular estimation formulas that are proposed, and we recommend that continuing statistical methods research be directed at investigating the performance of various proposed estimators and possible alternatives, including but not limited to the proposed methods and planned bootstrapping. Such research on mathematical and statistical methods could be pursued by the sponsors of this project, and by others. As an aid to clarity in comparison among possible alternative analyses, we recommend that the FPC make available a single reference data set which includes all the necessary interpretation of route of passage of PIT tagged fish and culls any suspect or ambiguous data that might be subject to further interpretation. The budget for the recommended mathematical and statistical analyses is relatively minor compared to the total cost of the project so investigation of our unresolved questions about statistical methods should not require substantial reallocation of the budget in this project to ensure compatibility of objectives, common methods and protocols. This coordination could be accomplished under the favorably reviewed CBFWA proposal #35033.

United States Department of the Interior

FISH AND WILDLIFE SERVICE

Columbia River Fisheries Program Office
1211 SE Cardinal Court, Suite 100
Vancouver, Washington 98683

May 31, 2007

Patty O'Toole
Program Implementation Manager
Northwest Power and Conservation Council
851 SW 6th Avenue, Suite 1100
Portland, OR 97204-1348

Dear Patty,

Below is our response to the Independent Scientific Review Panel's (ISRP) review of the Comparative Survival Study (Project 19960200 – PIT tagging spring/summer Chinook). This project was recommended for funding by the Mainstem/Systemwide Review Team (MSRT) as a Core Project. It has been recommended by the MSRT to fund project 199602000 at FY 2007 level of $1,365,000.

Please let me know if you need any additional information.

Sincerely,

Howard Schaller, Ph.D.
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cc: Eric Merrill, NPCC
Tom Iverson, CBFWA

RESPONSE TO QUESTIONS FROM ISRP REVIEW OF PROJECT 199602000 (PIT TAGGING SPRING/SUMMER CHINOOK- Comparative Survival Study) PROPOSAL FOR 2007 TO 2009

Proposal sponsored by USFWS - Columbia River Fisheries Program Office.

In the ISRP review of the Comparative Survival Study (Project 19960200 – PIT tagging spring/summer Chinook), they stated "*this is a supportable proposal but a response is needed to address issues raised in the ISAB's recent report: Review of the 2005 Comparative Survival Studies' (CSS) Annual Report and Applicability of Comparative Survival Studies' Analysis Results* (www.nwcouncil.org/library/isab/isab2006-3.htm)."

The ISRP lists recommendations from the ISAB report to which the USFWS proposal sponsors need to make a written response before final decision is made on the funding status for this proposed study. Each of the recommendations (shown in italics) is followed by our response (normal type).

Recommendation 1:

It has been ten years since the CSS was initiated. The report that the ISAB reviewed was the latest in a series of annual progress reports, and thus lacking a holistic perspective. The ISAB recommends that the CSS produce a ten-year summary report providing an in-depth description of methods and detailed analyses and interpretation of the data in a retrospective style.

Response 1:

The CSS will produce a ten-year summary report in FY 2007, which will look in depth at issues such as fish size effects on inriver collection efficiency and subsequent SARs, seasonal trends in SARs of transported and bypassed fish, and environment's (flow, spill, and temperature) effects on in-river survival and SARs of in-river migrating smolts including both bypassed and non-bypassed fish. In addition, the computer program developed over the past two years to create simulated datasets will be used to evaluate assumptions of the Cormack-Jolly-Seber release/recapture model, and robustness of inriver survival estimates to violations of key assumptions.

Recommendation 2:

The CSS needs to more effectively present the methodologies used in their analyses (in this proposal as well as their annual report), so the criticism of complicated and convoluted formulas can be avoided. The scattered explanations in several annual progress reports could be consolidated in the ten-year summary recommended above.

Response 2:

One of the deliverables to BPA in 2006 will be a new design and analysis report that will present the methodologies in a more succinct mathematical framework. The WDFW member of the CSS Oversight Committee is working on the preparation of this document showing the likelihood function derivations of the SARs for each study category in the CSS including $SAR_1(T_0)$, $SAR_2(T_0)$, $SAR(C_0)$, and $SAR(C_1)$, plus the mathematical derivation of the formulas that estimate number of smolts in each study category, T/C ratios and D.

Recommendation 3:
The ISAB agrees with critics who express concern that two downriver sites (Carson Hatchery and John Day River) are probably insufficient to give accurate upriver-downriver comparisons of SARs. This concern is bolstered by the variability among upriver hatcheries shown by the CSS data. For this upriver-downriver comparison to be generally accepted, it seems prudent to add more downriver sites in the future.

Response 3:
Another downriver site in the Warms Springs River is planned for wild Chinook tagging for 2007 to complement the ongoing tagging in the John Day River. If additional downstream site are to be added to the CSS, then more funding must be made available. To date the CSS has not been able to fund any more tagging than has occurred since 2001.

Recommendation 4:
Data on size of all PIT-tagged fish from hatcheries and other release sites should be included in the report in much greater detail. Size at release may be a significant factor in differential SARs. The ISAB recommends including a specific section in the report focusing on the potential effects of size at release on survival of all PIT-tagged fish.

Response 4:
Based on findings published by NOAA Fisheries researchers on potential size effects on collection efficiency and subsequent survival, the CSS plans to include a chapter in the 2007 CSS Summary Report to look at the effects of size at tagging. Lengths were taken on 10% of hatchery Chinook being PIT-tagged at Dworshak, Rapid River, and McCall hatcheries during the spring tagging season. Wild Chinook that were PIT-tagged in the spring primarily at the lower tributary traps on the Salmon, Imnaha, Grande Ronde, and Clearwater rivers may be good candidates for investigation of potential effects due to size at tagging for wild Chinook stocks. Lengths of wild fish tagged during late summer to fall of the year prior to springtime migration would not reflect lengths at migration and these fish may be less useful for examining effects of length on collection efficiency and subsequent survival.

Recommendation 5:
Assumptions inherent in the analyses should be specifically tested, with continued vigilance toward avoiding bias.

Response 5:
We plan to create sets of simulated data to evaluate how sensitive CJS survival estimates are to violations of assumptions used in the estimation process. . These evaluations will be reported in the ten year CSS summary Report.

Recommendation 6:

Pre-assigning the intended routes of passage at the time of release into in-river and transport groups would greatly simplify calculation of SARs and eliminate much criticism of current methods that are unnecessarily complex. This modification to the study design is scheduled for implementation in 2007 (according to the 2005 Annual Report but this change in protocol should be indicated in the proposal).

Response 6:

Beginning with the 2006 migration year, the CSS already adopted the approach of pre-assigning a group of PIT-tagged fish to represent the untagged populations' experience through the hydrosystem and a second group of PIT-tagged fish to provide the required in-river survival estimates with the CJS release/recapture methods. Pre-assigned groups were used in the CSS for 2006 including each individual Chinook hatchery, the aggregate wild Chinook, aggregate wild steelhead, and aggregate hatchery steelhead. Two-thirds of the PIT-tags were pre-assigned to groups reflecting the untagged populations and the remaining one-third were pre-assigned to the group used to obtain inriver survival estimates. This approach will continue to be implemented in future years as well.

Recommendation 7:

Analyses could emphasize more diverse metrics of differential survival, thus avoiding the criticism that the project staff focuses mainly on contentious issues such as the relative survival of transported and in-river migrants (T/C ratios) and differential delayed mortality between transported and in-river migrants (D). Passage routes, numbers of dams bypassed, distance from ocean, different hatchery practices, and other features have been explored beyond the issue of transportation.

Response 7:

In preparing the 2007 CSS Summary Report, a 10-year synthesis of what has been learned to date from this study, we plan to explore additional metrics of differential survival, as recommended by the ISAB. In 2006, transportation began later at the Snake River collector dams, and we plan to evaluate the earlier years data with regard to whether higher overall SARs would have occurred on collected fish if all fish were bypassed until later in April before beginning transportation. These evaluations will address the question raised by the COE regarding "what to do with the collected fish – transport or bypass them?" PIT-tagged fish have been monitored at the Rapid River Hatchery outfall since 1999 and since fish volitionally exit that facilitie's pond, we plan to evaluate temporal differences in survival rates to Lower Granite and subsequent SARs for earlier, middle, and later outmigrating smolts. Smolts in study category C_0 pass the three collector dams on the Snake River inriver through non-bypass routes, either through spill or the turbines.

We plan to look at relations between estimated SAR for C_0 fish and levels of spill (volume or proportion of discharge) occurring at these dams. The question raised by NOAA Fisheries researchers that smaller fish may be prone to higher collection in the bypass, but lower overall survival will also be investigated. For wild Chinook, we will use PIT-tagged fish released from Smolt Monitoring Program traps on the lower Salmon, Imnaha, Grande Ronde, and Clearwater rivers. These fish are PIT-tagged in the spring with lengths taken on each tagged fish, and migrate to Lower Granite Dam relatively quickly so any further growth would be negligible. For hatchery Chinook, we will use PIT-tagged fish released from Dworshak, Rapid River, and McCall hatcheries. These fish are PIT tagged one to two months before release with lengths taken on 10% of the tagged fish. Some additional growth may occur between tagging and when these fish arrive at Lower Granite Dam, but it is unlikely the size differences would diminish by the time they enter hydrosystem, thus allowing a greater opportunity to see differences in collection efficiency and subsequent SARs, if they do indeed occur.

We also plan to investigate SARs (BON-BON) based on arrival timing to Bonneville Dam between C0, C1 and T0 groups of Snake River and downriver wild and hatchery Chinook.

Recommendation 8: *In addition to the ISRP recommendations, the ISAB noted that more attention should be given by the CSS and the Region as a whole to the apparent documentation that PIT-tagged fish do not survive as well as untagged fish. This point has major implications for all uses of PIT-tagged fish as surrogates for untagged fish.*

Response 8: We plan to compare SARs estimated from PIT tagged spring/summer Chinook groups with SARs estimated from untagged fish that rely upon methods outlined in Petrosky et al. (2001) and Williams et al. (2005).

Other comments -- A:

A timeline with years (1996 - current) should be included within the background section to improve the proposal. Details in this section are sparse and references are lacking. The proponents either assume that the reviewers know all the background and justification for this project or decided not to go through the work needed to provide the details.

Response A:

The project began in 1996 and has had extensive regional review. The ISAB reviewed the CSS on January 14, 1997, and followed that review with a face-to-face meeting in Spokane WA on March 10, 1997. As a result of the 1997 reviews, the ISAB was better informed on purposes of upstream/downstream portion of study. They recommended an oversight committee for the study and recommended that NMFS be represented, but attempts by CSS to include NMFS failed due to disagreements in validity of upstream/downstream comparisons. Based on the ISAB 1997 review, the CSS was consolidated from two separate BPA project numbers (#198712700 and #199602000) into one project number #199602000.

Another review by the ISAB occurred on January 6, 1998. In that review the ISAB recommended adding other species of salmon including steelhead, but to date CSS has not been able to get BPA funding for steelhead. We are attempting to add steelhead to the CSS again in the 2007 – 2009 proposal. In the 1998 review, the ISAB also concurred with shift from proportional tagging to PIT tagging a minimum of 45,000 hatchery Chinook at key study hatcheries for assessing hatchery-specific SARs. In addition, the ISAB recommended resampling or other methods for variances of SAR; thereafter CSS began work on a non-parametric bootstrap approach, which is now incorporated in CSS annual reports.

On July 16, 2002, CSS Oversight Committee members made a presentation on the estimation formulas used in the CSS plus the bootstrap used for estimating confidence interval during an ISRP review meeting. The ISRP was also briefed on the importance of T/C ratios and D in assessing management actions. The presentation was followed up with written responses by CSS to ISRP comments on August 23, 2002. Based on ISRP recommendations, the CSS Oversight Committee added a chapter to the 2002 Annual Report comparing the bootstrap with likelihood-based confidence intervals. In addition, we began programming to implement the ISRP recommendation for *Monte Carlo* simulations to assess validity of bootstrap confidence interval coverage. On September 18, 2002, the ISRP provided additional questions to CSS, which were addressed in face-to-face meeting in Seattle on September 24, 2002.

On January 27, 2006, Oversight Committee members, Tom Berggren, FPC, Howard Schaller, USFWS, Charlie Petrosky, IDFG and Paul Wilson, USFWS had a face-to-face meeting with the ISAB in Seattle, Washington. At the meeting, the Oversight Committee members delivered a presentation covering the 2005 CSS Annual Report and goals of the CSS. The Oversight Committee members answered questions about possible bias identified in the BPA/NOAA comments and asked again at the meeting by Steve Waste of the NPCC. The primary criticism from BPA/NOAA was that the estimates produced by the CSS were biased due to the estimation of the transport and inriver SARs. The Oversight Committee explained that the CSS technique appropriately answers a specific set of questions. These questions are (1) what is the SAR of fish arriving Lower Granite Dam "destined" for transportation and (2) what is the SAR of fish arriving Lower Grantie Dam "destined" to remain inriver and undetected at Lower Granite, Little Goose, and Lower Monumental dams. By starting at Lower Granite Dam we are comparing the transported and inriver fish over the same reach (i.e., from Lower Granite Dam as smolts to Lower Granite Dam as adults). The BPA recommendation is to start the estimation only after the fish to be transported are in the barge or truck. We told the ISAB that both approaches are unbiased, and the only difference is in where you want to start indexing the SAR for transported fish. Dr. John Skaski, in 2000 recommended using Lower Monumental Dam tailrace as the starting location for the inriver migrants in order to obtain an "unbiased" SAR. As we explained to the ISAB, if we take the BPA recommended transport SAR and divide it by Dr. Skalski's recommended inriver SAR we would obtain lower T/C ratios than what we obtain when staring all fish at Lower Granite Dam. These differences still don't mean that one method is biased and the other is not biased; instead they only reflect the differences in SARs that will be obtained when the starting location for indexing SAR changes. The difference is that the CSS approach measures the SARs that the run at large experienced for transport and inriver fish. In other words, the CSS approach is measuring transport and inriver SARs, T/Cs and D values for a set of conditions the fish experienced. Using the BPA recommended approach would be for a set of conditions the fish do not experience presently. The differences in approach become more of a philosophical question (Should we measure a set of condition that does not exist precisely, or should we measure the actual set of conditions that fish experience with slightly less precision?) than a statistical question.

A large proportion of the presentation was geared at informing the ISAB on the purposes and modeling approach used in the upstream/downstream comparison. We presented the ISAB with the background, hypotheses, and rationale behind the design of the CSS. The CSS is a coordinated regional effort under the auspices of a regional oversight committee and is closely tied to the goals of the Mainstem Monitoring and Evaluation Program. The ISAB asked many questions and the session ended with them having a much better understanding of the background, history, motivation for the study and evaluation techniques used in the CSS project. Thus far, ten years of juvenile marking have been completed. Adult returns from migration years 1996 to 2003 have been analyzed in five Project Status Reports completed in 2001, 2002, 2003, April 2005, and December 2005. At the recommendation of the ISAB during the project review meeting of January 26, 2006, a more detailed retrospective compilation of what has been learned in the CSS from these ten years of study will be produced in FY 2007.

Other comments -- B:

The project history section consists of only a few sentences and is lacking sufficient detail to provide project accomplishments and give adequate justification for continued support. For such a long-running project there have been a number of important accomplishments and completed documents that need to be listed in this section.

Response B:

CSS was begun in 1996 with approximately 5% of hatchery spring/summer Chinook production above Lower Granite Dam PIT-tagged in numbers proportional to total hatchery release. All fish were returned-to-river at Snake River collector dams for inriver survival estimation. In 1997 the CSS was modified to fixed release numbers at four specific hatcheries – Dworshak, Rapid River, McCall, Imnaha, and Lookingglass (onsite release and Imnaha acclimation pond). Beginning in that year the study was expanded to include the routing of a proportion of PIT-tags to transportation at the collector dams. From 1997 to 1999, Lower Granite Dam was considered the primary transportation site with the overall transportation quota met either by that site alone (1997) or that site in combination with Little Goose Dam for part of the season (1998 and 1999). By migration year 2000, it was determined that potential differences in site-specific SARs may occur among the three collector dams on the Snake River and so for all years from 2000 to 2005, an equal proportion of first-time detected PIT-tagged at Lower Granite, Little Goose, and Lower Monumental dams has been routed to transportation (proportions ranging from 50% to 67% depending on year and species/rearing type). When ODFW ceased making the Lookingglass Hatchery onsite releases in 1999, the CSS switched to the Lookingglass Hatchery release at Catherine Creek Acclimation Pond in 2001. Beginning in 2002 the CSS began coordinating with other research programs to allow a portion of their PIT-tagged wild Chinook to be routed to transportation at the Snake River collector dams, as well as fund additional PIT tagging of wild Chinook at key Smolt Monitoring Program traps and provide 14,500 PIT tags at other IDFG tributary traps to supplement ongoing tagging activities there. The

CSS began a similar effort of coordinating with other research programs to allow a portion of their PIT-tagged wild steelhead to be transported in 2003.

PIT tagging of hatchery Chinook at downstream hatchery facilities began in 1996 at Round Butte Hatchery (Deschutes River) and Cowlitz Hatchery (Cowlitz River), with Carson Hatchery (Wind River) added in 1997. The Cowlitz Hatchery tagging occurred only in 1996 and 1997, and the Round Butte Hatchery tagging occurred only in 1996, 1997, and 1998. The difficult logistics in obtaining fish to tag coupled with BKD levels at the hatchery caused us to discontinue using Round Butte Hatchery, while at Cowlitz Hatchery, the primary concern was that the spring Chinook production was more ocean type than stream type in rearing and not as directly comparable to the upstream hatchery fish as Carson Hatchery fish. The Carson Hatchery stock has been PIT tagged for the CSS in each year of study since 1997. Wild Chinook PIT tagged in the John Day River under an ODFW contract with BPA have provided a source of fish for SAR computation since 2000 in the CSS. These downstream stocks have provided SAR information that has been used in spawner/recruit modeling efforts to investigate hydrosystem effects on Chinook stocks originating in tributaries above Lower Granite Dam.

In 2006 at the request of the ISAB and NOAA representative to the ISAB, the CSS began the approach of pre-assigning PIT tags at time of tagging to one of two groups – one group reflecting the untagged population in which case any fish entering the bypass/collection system at Lower Granite, Little Goose, or Lower Monumental Dam will be transported whenever the run-at-large is being transported, and the other group will be bypassed back-to-river if entering the bypass/collection system at any of these sites. In both groups, PIT-tagged fish passing through spill or turbines at a given dam will be undetected at that site. The bypass group consisting of undetected and detected fish remaining inriver will provide the CJS inriver survival estimates between release and Lower Granite Dam tailrace and between Lower Granite Dam and Bonneville Dam for use in indexing SARs to Lower Granite Dam and computations of the delayed mortality parameter (D).

The CSS has produced five project status reports (completed in October 2000, February 2002, November 2003, April 2005, and December 2005) and a report documenting the CSS design and analysis (completed in 2001). References for these documents are listed below. Bootstrap confidence intervals for study parameters have been computed and presented in the past three project status reports. A flowchart of the simulation program was presented in Chapter 6 of the 2003/04 CSS Annual Report. A series of simulation runs to evaluate validity of T_0, C_0 and C_1 SARs estimates and proper coverage of confidence intervals resulting from bootstrap program is planned for the 2006 CSS Annual Report, with further work on this topic continuing into the proposal years of 2007 to 2009. The 2007 CSS Summary Report will provide be a more detailed retrospective compilation of what has been learned in the CSS from these ten years of study as recommended by the ISAB following the January 26, 2006, review meeting on the CSS. In addition, an updated CSS design and analysis report is being produced for 2006 showing a detailed mathematical treatment of the estimators used in the CSS for SARs, T/C ratios, and D.

The CSS Oversight Committee also conducted a workshop in February 2004 on effects of hydrosystem configuration and operation on salmon and steelhead survival. Objectives were to: synthesize results of CSS and other research studies; document and assess evidence related to various factors that can affect survival rates over different life history stages, including hydrosystem passage, delayed mortality, time of ocean entry and travel time; produce a report synthesizing and assessing the evidence for and against hypothesized mechanisms for differential survival (hatchery-wild; upstream-downstream) and SARs; and provide a foundation for a series of publications in peer-reviewed journals. Workshop proceedings were published as Marmorek et al. (2004).

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Addendum

Reference list of CSS produced documents:

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Appendix H

Glossary

The following is a partial list of the acronyms and terms and their definitions used in this report. This list will be amended in future versions.

BON	Bonneville Dam
BPA	Bonneville Power Administration
CRITFC	Columbia River Inter-Tribal Fish Commission
CJS	Cormack-Jolly-Seber. The multiple mark-recapture survival estimation method that is employed using the PIT tag detections from the array of detection sites in the Snake and Columbia Rivers.
CSS	Comparative Survival Study
CWT	Coded-Wire Tag
D	The estuary and ocean survival rate of Snake River transported fish relative to fish that migrate inriver through the FCRPS. It is a ratio of SARs similar to the TIR, except the starting point for juvenile outmigrating fish is below Bonneville Dam.
FCRPS	Federal Columbia River Power System
FTT	Fish Travel Time. The number of days a fish spends migrating through the reservoirs or defined reaches.
FPC	Fish Passage Center
IDFG	Idaho Department of Fish and Game
IHR	Ice Harbor Dam
ISRP	Independent Scientific Review Panel
ISAB	Independent Scientific Advisory Board
JDA	John Day Dam
LGR	Lower Granite Dam
LGS	Little Goose Dam
LMN	Lower Monumental Dam
LSRCP	Lower Snake River Compensation Plan
MCN	McNary Dam
NMFS	National Marine Fisheries Service
NOAA-Fisheries	National Oceanic and Atmospheric Administration, Fisheries
NPPC	Northwest Power Planning Council
NPCC	Northwest Power and Conservation Council
ODFW	Oregon Department Fish and Wildlife
PIT tag	Passive Integrated Transponder tag. Glass-encapsulated transponders, 11-12 mm in length with a unique identification code, that can be implanted into a fish's abdomen using a hand-held syringe. These tags are generally retained and function throughout the life of the fish. The tag's code can be read and recorded with an electronic scanner.
PTAGIS	PIT tag Information System. Regional depository and clearing house for the Columbia Basin PIT tag release and detection information.
S	Reach- or life-stage specific survival.

SAR	Smolt to Adult Return ratio. The survival from a beginning point as a smolt to an ending point as an adult. SARs are calculated from LGR to LGR and can also be estimated at BON to BON or LGR, or below BON to BON.
TIR	Ratio of SARs that relates survival of transported fish to inriver migrants. The ratio is the SAR of fish transported from LGR to BON and returning as adults, divided by the SAR of fish outmigrating from LGR to BON and returning to LGR as adults.
TWX	Trawling operation by NMFS in the lower Columbia River in the vicinity of Jones Beach that detects PIT-tagged fish.
USACE	U.S. Army Corp of Engineers
USFWS	U.S. Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife