COMPARATIVE SURVIVAL STUDY (CSS) of PIT Tagged Spring/Summer Chinook

2002 Annual Report
Migration Years 1997 – 2000
Mark/Recapture Activities and Bootstrap Analysis

BPA Contract #8712702

Prepared by

Fish Passage Center and
Comparative Survival Study Oversight Committee:

Thomas Berggren, Henry Franzoni, and Larry Basham, Fish Passage Center
Paul Wilson and Howard Schaller, U.S. Fish and Wildlife Service
Charlie Petrosky, Idaho Department of Fish and Game
Earl Weber, Columbia River Inter-Tribal Fish Commission
Ron Boyce, Oregon Department of Fish and Wildlife
Nick Bouwes, EcoLogical Research

representing the

Columbia Basin Fish & Wildlife Agencies
and
Columbia Basin Tribes

Project Leader:
Michele DeHart, Fish Passage Center

Final
11/26/2003

TABLE OF CONTENTS

LIST OF TABLES

Page

Page

Page

LIST OF FIGURES

ACKNOWLEDGEMENTS

The Comparative Survival Rate Study (CSS) relies on the cooperation of multiple agencies and individuals to ensure that the major tasks of marking, handling, releasing and recovery of fish in three States and at hatcheries and dams are completed successfully.

The PIT tag systems that are maintained by PSMFC personnel enable PIT tag data to be collected on a real-time basis. We commend Carter Stein and his staff for their diligence in repair of PIT tag equipment, both in the juvenile and adult fish passage systems; providing the support, computers, software, and databases used for “by-code” diversion at Lower Granite, Little Goose, and Lower Monumental dams; and providing the smooth transfer of PIT tag data to the PIT Tag Operations Center in Portland, OR. In addition, we thank Dave Marvin of PSMFC, who provided the support in using the multimon program with CSS study fish to perform the routine “by-code” operations at the dams.

This report covers yearling hatchery chinook supplied for the CSS by Idaho Department of Fish and Game (IDFG), U.S. Fish and Wildlife Service (USFWS), and Oregon Department of Fish and Wildlife (ODFW) at the following hatcheries. IDFG hatcheries include McCall (1997-2000) and Rapid River (1997-2000). USFWS hatcheries include Dworshak (1997-2000) and Carson (1997-2000). ODFW hatcheries include Lookingglass (1997-1999) and Imnaha (1997-2000). We appreciate and extend thanks to the Fish and Wildlife agencies and all hatchery managers and staff personnel for their assistance in the planning, raising of, and recovery of study fish at the hatcheries.

From 1997 through 2000, approximately 800,000 hatchery spring/summer chinook were PIT tagged by State and Federal personnel for the CSS Program. This required a lot of time and effort from individual marking crews to complete tagging of these fish. The USFWS Dworshak Fisheries Resource Office (FRO) personnel PIT tagged fish at Dworshak Hatcheries while the Vancouver, Washington, FRO personnel marked fish at Carson Hatcheries. PIT tagging at IDFG hatcheries was completed with supervision provided by the IDFG office in Lewiston, Idaho. Chinook at the Lookingglass complex were PIT tagged by ODFW personnel from the Northeast District fisheries office in LaGrande, Oregon. We thank the field supervisors and crews for an excellent job in completing the PIT tagging operations at these hatcheries.

We appreciate the diligence and efforts of the Fish Passage Center in its role in the implementation of this program by coordinating PIT tagging and field logistics, performing database development, data compilation and preliminary analyses, and overseeing the budgetary aspects of this study. In addition to the coauthors, FPC staff members Michele DeHart, Jerry McCann, Sergie Rassk, and Dona Watson also provided a valuable contribution to the success of this program. A special thanks goes to coauther Henry Franzoni, who wrote the computer code for the bootstrap program highlighted in this report, and to coauthors Paul Wilson and Nick Bouwes, who were instrumental in the early development of the bootstrap program. Steve Haeseker of US Fish and Wildlife Service provided helpful review comments on report drafts.

Bonneville Power Administration (BPA Project Number 87127-02) funded this project through the Northwest Power Planning Council Fish and Wildlife Program.

EXECUTIVE SUMMARY

The Comparative Survival Study (CSS) was initiated in 1996 as a multi-year program of the fishery agencies and tribes to estimate survival rates over different life stages for spring and summer chinook (hereafter, chinook) produced in major hatcheries in the Snake River basin and from selected hatcheries in the lower Columbia River. Much of the information evaluated in the CSS is derived from fish tagged with Passive Integrated Transponder (PIT) tags. A comparison of survival rates of chinook marked in two different regions (which differ in the number of dams chinook have to migrate through) provides insight into the effects of the Snake/Columbia hydroelectric system (hydrosystem). The CSS also compares the smolt-to-adult survival rates (SARs) for Snake River chinook that were transported versus those that migrated in-river to below Bonneville Dam. Additional comparisons can be made within in-river experiences as well comparison between the different collector projects from which smolts are transported. CSS also compares these survival rates for wild Snake River spring and summer chinook. These comparisons generate information regarding the relative effects of the current management actions used to recover this listed species.

Scientists and managers have recently emphasized the importance of delayed hydrosystem mortality to long-term management decisions. Delayed hydrosystem mortality may be related to the smolts experience in the Federal Columbia River Power System, and could occur for both smolts that migrate in-river and smolts that are transported. The CSS PIT tag information on in-river survival rates and smolt-to-adult survival rates (SARs) of transported and in-river fish are relevant to estimation of ”D”, which partially describes delayed hydrosystem mortality. The parameter D is the differential survival rate of transported fish relative to fish that migrate in-river, as measured from below Bonneville Dam to adults returning to Lower Granite Dam. When D = 1, there is no difference in survival rate after hydrosystem passage. When D < 1, then transported smolts die at a greater rate after release below Bonneville Dam than smolts that have migrated in-river to below Bonneville Dam. While the relative survival rates of transported and in-river migrants are important, the SARs must be also be sufficient to allow the salmon to persist and recover (Mundy et al. 1994). Decreased SARs could result from delayed hydrosystem mortality for either transported or in-river migrants, or both.

Major objectives of the CSS include: (1) development of a long-term index of transport SAR to in-river SAR for Snake River hatchery and wild spring and summer chinook smolts measured at Lower Granite Dam; (2) develop a long-term index of survival rates from release of smolts at Snake River hatcheries to return of adults to the hatcheries; (3) compute and compare the overall SARs for selected upriver and downriver spring and summer chinook hatchery and wild stocks; and (4) begin a time series of SARs for use in hypothesis testing and in the regional long-term monitoring and evaluation program. Primary CSS focus in this report is for wild and hatchery spring/summer chinook that outmigrated in 1997 to 2000 and returned in 2003.

Another goal of CSS was to help resolve uncertainty concerning marking, handling and bypass effects associated with control fish used in National Marine Fisheries Service.s (NMFS) transportation research and evaluation. Significant concern had been raised that the designated control groups, which were collected, marked and released at dams, did not experience the same conditions as the in-river migrants which were not collected and bypassed under existing management, and that the estimated ratios of SARs of transported fish to SARs of control fish may be biased (Mundy et al. 1994). Instead of marking at the dams, as traditionally done for NMFS transportation evaluations, CSS began marking sufficient numbers of fish at the hatcheries and defining in-river groups from the detection histories at the dams (e.g., total arrivals, never detected, detected one or more times).

The CSS PIT tagged and released annually more than 200,000 smolts from Snake River hatcheries (primarily Dworshak, McCall, Rapid River, and Imnaha) and 5,000-13,000 smolts from a downriver hatchery (Carson) in 1997-2000 (ODFW ceased production of Lookingglass Hatchery stock in 2000). PIT-tagged smolts from the Snake River are detected in collection systems at Snake and Columbia River dams and diverted into transportation or bypassed to the river according to the annual study design. Detection histories are used to estimate numbers of smolts in in-river and transport categories, and to estimate survival between release and the first dam encountered (Lower Granite Dam), and from Lower Granite Dam to subsequent dams (Chapter 1).

In-river groups of Snake River hatchery chinook in 1997-2000 were those smolts that were never collected or bypassed at Snake River collector dams (C_0) and smolts that were collected and bypassed at one or more Snake River collector dams (C_1). Hatchery chinook smolts transported from all projects (T_0) were the primary transport group evaluated in 1997-2000, although we also evaluated transportation from Lower Granite Dam (T_{LGR}). Returning PIT tagged adults are detected at Lower Granite Dam and assigned to appropriate in-river and transport groups. SARs (measured from smolts at Lower Granite to adult returns to Lower Granite) were calculated for transport and in-river groups, and ratios of transport SAR to in-river SAR (T/I ratios) were analyzed for each hatchery and year. In addition, we estimated the ratio of SAR from below Bonneville Dam back to Lower Granite Dam for transported groups relative to in-river groups (parameter D) for information about the delayed impacts of the hydrosystem on survival rates that occur in the estuary and ocean.

The CSS focus to date has been on hatchery spring and summer chinook, in part, because of the extremely low abundance of wild Snake River stocks. However, evaluating smolt mitigation and recovery strategies by tracking the performance of wild spring and summer chinook has been a CSS study objective since the beginning, and recommended in project reviews by the Independent Scientific Review Panel. In addition, it is important to evaluate the extent to which response of hatchery chinook to management actions can be used as a surrogate for wild chinook. This report incorporates available wild chinook PIT tag data from smolt migration years 1994-2000 to estimate wild chinook SARs, to compare wild chinook SARs between transportation and in-river migration, and to compare wild and hatchery chinook responses (T/I ratios, "D" values) to management actions (Chapter 1). CSS increased PIT tag sample sizes of juvenile wild chinook for the 2002 and 2003 out-migrations (with plans to continue through 2004) to provide a comparison of SARs between transported and in-river wild Snake River migrants, as well as between Snake River and downriver wild stocks with similar life-history characteristics.

Another focus of this annual report (Chapter 2) is the partitioning of survival from hatchery smolt release to Lower Granite Dam (LGR), adult return to LGR and to the hatchery. A long-standing question has been whether straying is greater in returning adults that had been transported as smolts rather than allowed to migrate through the hydro system (Mundy et al. 1994). Accounting for adult survival between LGR and the natal hatchery requires accounting for any harvest in the terminal fisheries. Based on PIT detections at the hatchery racks, the conversion rate of adults from LGR to the rack is approximately 50% after adjusting for harvest. However, the SARs estimated from total production and PIT tag SARs differed and the reasons are unresolved.

Estimates of SARs of selected downriver wild and hatchery spring chinook will allow for comparisons to Snake River stocks (Chapter 3). The CSS has begun cooperative efforts with ODFW to increase PIT tag sample sizes of juvenile wild chinook from the John Day River (downriver stock above three dams) to aid in these regional SAR comparisons, and preliminary SAR data are becoming available from return year 2002. The CSS has PIT tagged hatchery spring chinook at the Carson Hatchery for migration years 1997-2000. Hatchery SARs were estimated from smolt release to smolts at Bonneville Dam (BON), adults returning to BON, and finally adults to the hatchery for smolts that outmigrated in 1998 to 2000.

Bootstrap confidence intervals on parameter estimates were investigated, and distributions of bootstrap and likelihood-based confidence intervals were compared (Chapter 4). A bootstrap method is needed where individual components of the point estimates need themselves to be estimated (such as in-river SARs, where number of smolts in category C_0 is an estimate).

The following bullets summarize the findings to date:

The extent to which hatchery chinook can be used for a surrogate for wild chinook for survival over the different life stages is inconclusive from the 4 years of information where this comparison was possible.

Point estimates of T/I and *D* values tend to be higher for Snake River hatchery chinook than for wild chinook, possibly due to how the different rearing types of fish respond to in-river and transport conditions. In 1997, wild chinook exhibited quite different in-river survivals, LGR-LGR SAR(T_0), BON-LGR SAR(T_0), LGR-LGR SAR(C_0), BON-LGR SAR(C_0), and T/I than hatchery chinook (*D* values were similar). However, this year had the lowest sample sizes and likely least precise estimates for wild fish of the 4 years evaluated. Differences between hatchery and wild chinook survival rates were not as pronounced in 1998 and 1999, but were still considerable.

SARs of transported and in-river migrants were much less than 2-6% SARs needed to recover Snake River spring/summer chinook (Marmorek and Peters 1996).

The LGR-LGR SAR of wild chinook from 1994 to 1996 were mostly less than 0.5%, while in 1997 to 2000, the LGR-LGR SARs were mostly in the 1-2.5% range. The LGR-LGR SARs for hatchery chinook that outmigrated in 1997 to 2000 were very hatchery specific being lowest for Dworshak and Lookingglass spring chinook hatcheries (mostly below 1.25%). SARs were similar between in-river and transported fish for Dworshak and Lookingglass hatcheries. Spring chinook from Rapid River Hatchery, and summer chinook from Imnaha and McCall hatcheries had SARs that increased yearly reaching levels over 2% in most study categories in 1999 and 2000. Transported smolts had higher SARs for these latter three hatcheries than their in-river counterparts in most cases. The highest SAR consistently occurred for McCall Hatchery summer chinook (the latest migrating stock). SARs of McCall Hatchery smolts transported from Lower Granite Dam exceeded 4% in two years (1999 and 2000).

Transportation benefits were more evident for summer chinook stocks than spring chinook stocks of Snake River hatchery chinook in 1997-2000.

The CSS study design focused on estimating transport SAR(T_{LGR}) from the upper Snake River dam in 1997-1999, however we also estimated transport SAR from all projects (T_0) to simulate actual management operations. Starting in smolt migration year 2000, the CSS began diverting hatchery chinook to transportation from all collector projects to provide transport SAR estimates that better match actual management operations. The 4-year geometric mean ratio of transport LGR-LGR SAR(T_0) to in-river LGR-LGR SAR(C_0), or the T/I ratio, estimated for spring chinook stocks (Dworshak and Rapid River) was approximately 1.2, while that for summer chinook stocks (Imnaha and McCall) was approximately 1.4. Approximately 40% of the T/I estimates for individual hatcheries and years were significantly greater than 1.0 although confidence intervals were large.

Little or no transport benefits were evident in most years for Snake River wild chinook based on available PIT tag data, 1994-2000.

The overall 7-yr geometric mean T/I ratio was approximately 1.1 for 1994-2000. In 4 of the 7 years analyzed, the T/I ratio for wild fish was less than one. Small sample size and past research operations that bypassed most PIT-tagged wild chinook (whereas untagged smolts were transported) somewhat limit inferences from the T/I estimates for 1994-2000. The CSS project has expanded sampling for wild chinook and implemented changes in research protocols to better represent actual transportation management for 2002-2004.

Delayed hydrosystem mortality was evident for transported Snake River hatchery chinook smolts, which died at a greater rate after release than hatchery smolts that migrated through the hydrosystem in 1997-2000.

The 4-yr geometric mean ratio of *D* for CSS hatchery chinook was 0.62 for spring chinook stocks and 0.84 for summer chinook stocks for 1997-2000. *D* values were highly variable between hatcheries and years.

Delayed hydrosystem mortality was evident for transported Snake River wild chinook smolts, which died at a greater rate after release than wild smolts that migrated through the hydrosystem in 1994-2000.

The 7-yr geometric mean *D* for wild chinook was 0.52 for 1994-2000. The geometric mean *D* for wild chinook was 0.50 for 1997-2000, years for which we have comparable estimates for hatchery stocks. This range of *D* values is considerably lower than the *D* of 0.7 used in NMFS’ 2000 Biological Opinion.

The CSS found evidence of delayed hydrosystem mortality of in-river migrants associated with collection and bypass at Snake River dams in 1997-2000 for hatchery chinook.

In-river migrant hatchery chinook that were collected and bypassed at one or more Snake River collector dams (C_1) had a SAR only 78% as high as the SAR of hatchery chinook that were not collected and bypassed at Snake River collector dams (C_0). The average of the geometric mean SARs across years for the four hatcheries present in each year was 1.09 for category C_0 fish and 0.85 for category C_1 fish. Category C_0 fish best represented in-river migrants under management operations for 1997-2000 because most of the untagged smolts (i.e., the run at large) that were collected at Snake River dams (Lower Granite, Little Goose, Lower Monumental) were transported from these projects, rather than bypassed (note 1997 exceptions to this rule, discussed in Chapter 1). Because the direct mortality of going through a dam undetected (through a combination of turbine and spillway routes) is generally higher than going through detected (through the bypass system), the decrease in SAR for the C_1 group can only be explained by the decrease in survival after smolts migrate through the hydrosystem.

INTRODUCTION

Fisheries agencies and tribes have developed a multi-year program, the Comparative Survival Study (CSS), for the purpose of monitoring and evaluating the impacts of the mitigation measures and actions (e.g., flow augmentation, spill, and transportation) under the National Marine Fisheries Service (NMFS) Biological Opinion to recover listed stocks. This annual status report presents adult return information collected from PIT tagged wild spring/summer chinook that outmigrated during 1994 to 2000 and PIT tagged hatchery spring/summer chinook that outmigrated during 1997 to 2000. All study fish used in this report were uniquely identifiable based on a passive integrated transponder (PIT) tag implanted in the body cavity during the smolts 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 age provide estimates of survival. This allows comparisons of survival over different life stages between fish with different experiences in the hydrosystem (e.g. different routes of dam passage, transportation vs. in-river migrants, and migration through various numbers of dams). The CSS has PIT tagged large numbers of hatchery chinook to obtain adequate sample sizes for these different comparisons. In addition, PIT tagged wild chinook from other regional studies have also been used for survival estimation. This includes the following: (i) survival of migrating smolts over different reaches of the hydro system; (ii) survival of smolts-to-adults (SARs) from either Lower Granite Dam (LGR) back to LGR or Bonneville Dam (BON) back to LGR; (iii) the ratio of the LGR-LGR SARs of fish transported around the dams to LGR-LGR SARs of fish that migrated in-river (T/Is); and, (iv) the ratio of the BON-LGR SARs of transported fish to BON-LGR SARs of in-river fish (Ds). By comparing the estimates of these parameters for hatchery and wild chinook, it possible to determine if hatchery fish are a reasonable surrogate for wild fish in aspects of hydro system passage survival. If so, hatchery fish could be used to track wild stocks in years where there are too few wild smolts to mark. The objectives of this study are as follows:

1. Develop a long-term index of transport to in-river survival rate (smolt-to-adult) for Snake River hatchery yearling chinook and wild yearling chinook smolts.

   Task 1(a): Compute an annual ratio of transport to in-river survival rate (measured at LGR-to-LGR) and an associated confidence interval.

   Task 1(b): Test if the annual ratio of transport to in-river survival rate (measured at LGR-to-LGR) is greater than 1.5 with sufficient power to provide a high probability that the ratio is greater than 1.0.

   Task 1(c): In years when the NMFS transport study is in place, evaluate whether in-river controls obtained from fish PIT tagged at the hatcheries have higher smolt-to adult survival rates from LGR-to-LGR than in-river controls obtained from migrating fish that were collected, handled, and PIT tagged at LGR.

2. For Snake River and Mid-Columbia River basin hatcheries, develop a long-term index of survival rates from release of yearling chinook smolts at hatcheries to return of adults to hatcheries. (Mid-Columbia River basin hatcheries are to be added in future years and therefore are not covered in the current annual report).

Task 2(a): For Snake River hatchery fish -- Partition survival rates (*i*) from hatchery (smolts) to LGR (smolts), (*ii*) from LGR (smolts) to back to LGR (adults), and (*iii*) from LGR (adults) to the hatchery (adults). Beginning in 2002, returning adults were detected at BON and MCN, so adult survival from BON to MCN and MCN to LGR will also be generated within partition (*ii*).

Task 2(b): For Snake River hatcheries, compute the annual survival rate of smolts transported at LGR and returning as adults to the hatcheries.

Task 2(c): For Snake River hatcheries, compute the annual survival rate of smolts migrating in-river and returning as adults to the hatcheries.

Task 2(d): Explore the feasibility of increasing PIT tag release numbers to improve precision in the annual ratio of transport survival rate to in-river survival rate [Task 1(a)] measured back to the hatchery.

3. Compute and compare overall smolt-to-adult survival rates for selected upriver and down-river yearling spring/summer chinook hatchery and wild stocks.

Task 3(a): Compute annual survival rates (adjusted for terminal harvest rates) using both CWT and PIT tags for yearling chinook from selected upriver hatcheries (Snake River and Mid-Columbia River basin) and the down-river Carson Hatchery stock. Compare survival rates of CWT and PIT tag estimates. Estimate survival rates (smolt-to-adult) for these hatchery stocks from previous production-type CWT releases.

Task 3(b): Compute an annual ratio of down-river hatchery survival rate to upriver hatchery survival rate (all measured at the hatcheries and adjusted for terminal harvest) with associated confidence interval.

Task 3(c): Test if the annual ratio of down-river hatchery survival rate to upriver hatchery survival rate (all measured at the hatcheries) is greater than 2.0 with sufficient power to provide a high probability that the ratio is greater than 1.0.

Task 3(d): Test, aggregately and individually, if the annual ratio of down-river hatchery survival rate to upriver hatchery's transported smolts survival rate (all measured at the hatcheries) is greater than 2.0 with sufficient power to provide a high probability that the ratio is greater than 1.0.

Task 3(e): Explore the feasibility of PIT tagging wild chinook in the lower Columbia River basin for comparing smolt-to-adult survival rates with the upstream wild chinook stocks. This task began with wild chinook PIT tagged in the John Day River by ODFW in migration years 2000 and 2001. This task required the ability to detect all adults passing Bonneville Dam, a capability that began in 2002.

4. Begin a time series of smolt-to-adult survival rates for use in the regional long-term monitoring and evaluation program, which is under development.

5. Evaluate growth patterns of transported and in-river migrating smolts, and of upriver and down-river stocks (discontinued after 2001).

Objective 5 was completed and reported in Appendix E of the CSS 2001 Annual Status Report. The analysis of the scale pattern data collected on returning adults that outmigrated as smolts in 1997 and 1998 showed no significant difference in growth patterns between smolts that outmigrated inriver and those that were transported to below Bonneville Dam. Because we are only evaluating the smolts that successfully survived to adults, size selective mortality may have masked the ability to determine if differential delayed growth effects truly exist between treatment groups. This objective was subsequently dropped from future CSS work.

The 2002 CSS Annual Report is organized into four chapters. The first chapter presents the methods and estimated in-river survivals, SARs, T/Is, and Ds for both hatchery and wild PIT-tagged Snake River spring/summer chinook. Estimating the associated variance of these parameters is important in evaluating the relevance of these parameters and the in evaluating whether the study needs to be modified to provide adequate precision. Because the estimation of these parameters is complex, theoretical estimates of variance are extremely difficult. An alternative approach is to bootstrap the estimation procedure to produce the appropriate variance estimates. A major accomplishment during this contract year was the development of the bootstrap computer program that provides non-parametric 95% confidence intervals for each parameter estimated in this study. Future year's hypothesis testing will stem from these analytical approaches; however, the main goal in 2002 was in the area of parameter estimation and assessing the representativeness of these estimates based on groups of PIT tagged smolts to the unmarked population. The CSS continues to make progress in building the long-term time series of smolt-to-adult survival rates. This time series of SAR estimates will be useful to fishery managers regardless of the type of regional long-term monitoring and evaluation program adopted. The estimates of smolt-to-adult survival rates may also be useful for investigating the relationship between survival rates and hydro system experiences for yearling chinook and steelhead.

The second chapter presents estimated adult survival rates from Lower Granite Dam fish ladder back to the hatcheries. These estimates require adjustments for the sport and tribal fisheries on these fish prior to arriving at the hatcheries. The estimated survival rate incorporates straying and unaccountable losses within the mortality factor.

The third chapter presents the hatchery-to-hatchery SARs for Carson Hatchery chinook, which is the key group in the planned upstream-downstream comparison objective of this study. The yearly trends in Carson Hatchery SARs compared to upstream hatcheries (Rapid River, McCall, Dworshak, and Imnaha) are presented. In additional, early information on the 2-ocean SARs of PIT tagged wild chinook from John Day River are noted.

The fourth chapter presents a comparison of confidence intervals of SARs and other selected quantities generated with the bootstrap program to confidence intervals of those same quantities derived from the profile likelihood method. This chapter provides a verification of the use of the bootstrap method in all but the extreme cases of low PIT tag sample sizes.

CHAPTER 1

Smolt-to-adult survival rate from Lower Granite Dam (smolts) to Lower Granite Dam (adults)

METHODS

PIT Tagging

Yearling chinook at key hatcheries were PIT tagged specifically for the CSS, whereas the PIT tagged wild chinook were obtained from all available marking efforts in the Snake River basin above Lower Granite Dam. Hatcheries were selected across 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. The wild stocks included chinook PIT tagged as parr (summer/fall tagging season) and smolts (spring tagging season) in each major tributary above Lower Granite Dam.

Each PIT tag has a unique code. The tags are glass encapsulated and 11-12 mm in length. Individual PIT tags were implanted into the fish's underbelly using a hand-held syringe. 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 hatcheries, fish were obtained across as wide a set of ponds and raceways as possible to allow effective representation of 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 PIT tags were read as the fish passed through the coils of a detector. For detection of smolts, there are detectors installed 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 from a special trawling operation (TWX) by NMFS in the lower Columbia River in the vicinity of Jones Beach (located about half-way between BON and the mouth of the Columbia River). These site abbreviations will be used throughout this document. PIT tagged fish out-migrating as smolts in a year later than the expected were excluded because these "hold-over" fish would experience a different set of riverine and dam operational conditions. PIT tagged returning adults were detected at LGR in each year. Beginning in return year 2002, detectors were installed at BON and MCN, allowing detection of returning PIT tagged adults at these additional locations.

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. 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 95% confidence intervals were computed for each parameter of interest. Figure 1 is a flowchart overview of the bootstrapping methodology used by this computer program.

FIGURE 1

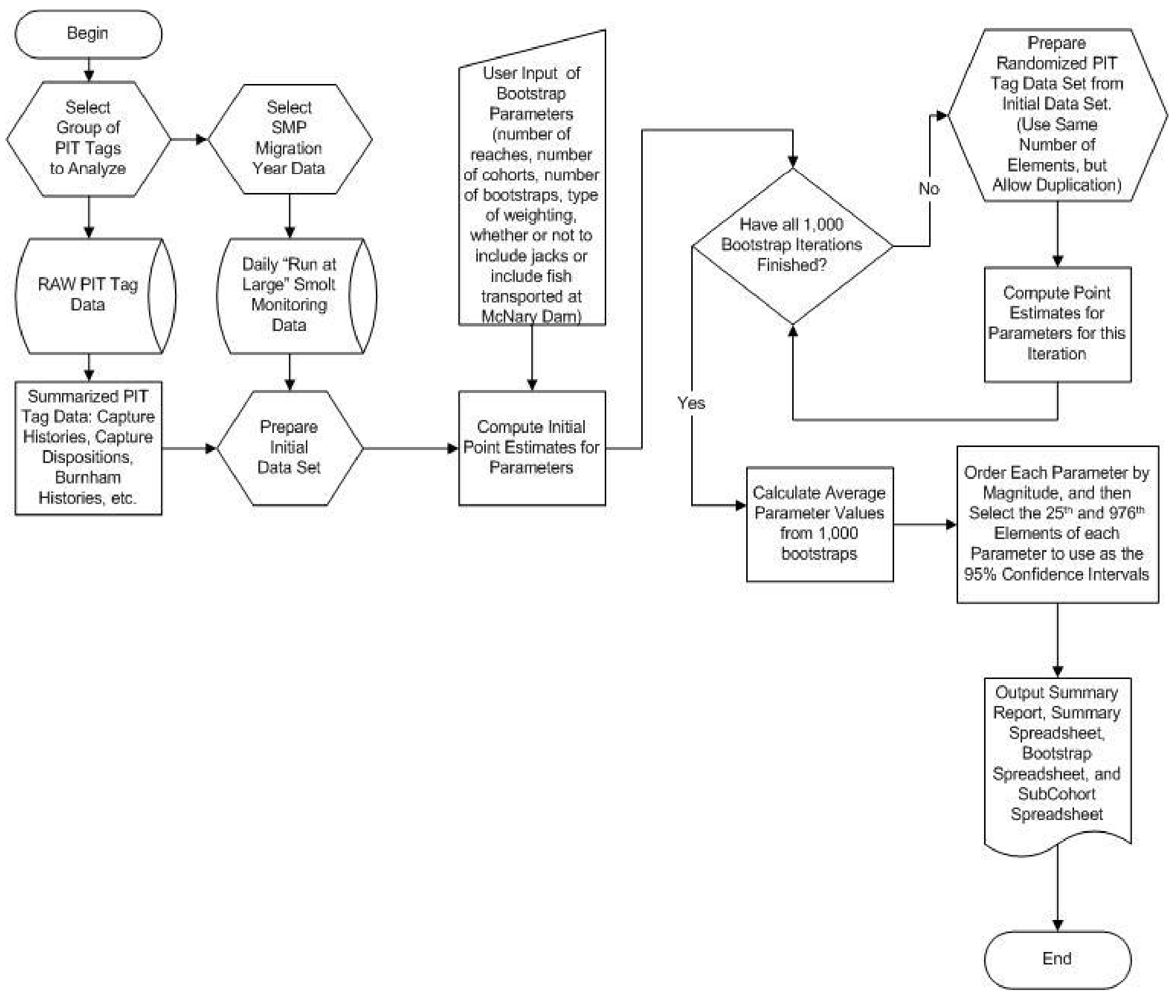

Figure 1. Schematic of bootstrap program for estimating study parameters and associated 95% confidence intervals.

In-river Survival Estimation

PIT-tagged smolts can be detected in the bypass/collection facilities at LGR, LGS, LMN, MCN, JDA and BON, 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 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 only possible 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. An estimate of survival was considered unreliable when its coefficient of variation exceeded 25%. 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, …, 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, termed V_C, 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 higher 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.

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 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 BON. These three ways of hydro system passage define the study categories C_0, C_1 and T_0, respectively, of the CSS.

One 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. In 1995 to 2000, there were only 11 late-migrating PIT tagged wild yearling chinook smolts first-detected at MCN and transported from there. 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. Therefore, this status report only addresses the effects of the transportation of yearling wild and hatchery spring/summer chinook from the Snake River dams.

The PIT tagged study groups should be representative of their non-tagged counterparts, hence PIT tagged fish passing through the hydro system must mimic the experience of non-tagged fish. For example, only first-time detected smolts at a dam may be considered for transportation since non-tagged smolts are nearly always transported when they enter a bypass/collector facility (where PIT tag detectors are in operation) at the Snake River dam. For convenience, we make comparisons between different groups of smolts with different hydrosystem experiences from a common starting and end points. Thus, LGR-LGR SARs must be estimated for all groups even if a smolt was not detected at LGR. Smolts destined for transport at the lower projects include a larger group than actually transported at the lower projects, due to mortality from migrating in-river from LGR to the lower projects. Therefore, an estimated survival rate is needed to convert actual transport numbers at LGS and LMN into their LGR starting number (in 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. 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

$$T_0 = X_{12} + X_{102}/S_2 + X_{1002}/S_2S_3.$$

Symbol Definitions:

X_{12} = number transported at LGR
X_{102} = number first-detected and transported at LGS
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 (Lower Granite Dam)
m_{13} = number of fish first detected at LGS (Little Goose Dam)
m_{14} = number of fish first detected at LMN (Lower Monumental Dam)
m_{15} = number of fish first detected at MCN (McNary Dam)
m_{16} = number of fish first detected at JDA (John Day Dam)
m_{17} = number of fish first detected at BON (Bonneville Dam)
m_{18} = number of fish first detected at TWX (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 MCN, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at JDA 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 MCN, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at JDA 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

The PIT tagged smolts that migrate past the Snake River dams undetected and remain in-river below LMN, the last transportation site in the spring season, defines the group most representative of the non-tagged smolts that migrate in-river. These PIT tagged fish form Category C_0. 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 "full sample" CJS estimate of LGR collection efficiency specific for the chinook group of interest. Based on simulations, this approach, which previously had only been applied to hatchery groups, was found to be less biased over the method of estimating daily LGR collection efficiencies described in Sandford and Smith (2002) for wild chinook groups. Smolts detected at MCN, JDA, and BON are included in this group as 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 number of fish in Category C_0 is

$$C_0 = m_{12}/p_2 - (m_{12} + m_{13}/S_2 + m_{14}/S_2S_3) - 2d_0$$

where:

$$p2 = m_{12} /(m_{12} + Z_2(R_2/r_2))$$
$$Z_2 = m_{13} + m_{14} + m_{15} + m_{16} + m_{17} + m_{18},$$
$$R_2 = (m_{12} - d_2), \text{ and}$$
$$r_2 = m_{23} + m_{24} + m_{25} + m_{26} + m_{27} + m_{28}$$

The last group of interest is 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. These fish are important because of the need to estimate reach survival components. 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. Using symbols defined in the text box, the formula for estimating the number of fish in Category C_1 is

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

Estimation of SARs and Ratios of SARs for Study Categories

To date, LGR has been the primary upriver evaluation site for many objectives of the CSS. 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. Therefore, returning adults reaching LGR will continue 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 (fish with no previous detections at any dam are automatically assigned to Category C_0).

As stated earlier, we only used first-time detections for transported smolts in order to represent the non-tagged smolts. Smolts have been transported at LGR, LGS, and LMN throughout the migration season and starting 1995 only during the summer season at McNary Dam. To accurately portray the overall springtime transportation operations, all Snake River collection projects where smolts were collected and transported must be included. However, because most PIT-tagged wild chinook were returned to river at the collector dams and the CSS hatchery chinook were mostly transported at LGR in the early years of this study, the number of PIT-tagged smolts transported at some projects did not adequately reflect the run-at-large. However, because a portion of the PIT tagged fish are returned to the river to allow for a mark-recapture estimate of in-river survival, the proportion of tagged smolts transported at a collection facility may not represent the proportion of non-tagged fish that were transported at these sites. Therefore, when site-specific SARs exist, estimates of the overall SARs of the aggregate dams must account for the proportion of the PIT-tagged smolts transported to the proportion of the run-at-large that actually was transported at each project to avoid bias. Using a stratified sampling approach, each dam was considered a stratum containing an estimated number of tagged and untagged smolts that are to be transported. Details of the theory are presented in Berggren *et al*. (2002). The resulting formula for estimating $SAR(T_0)$ uses the site-specific SAR (adults at LGR / smolts at specific dam) along with estimates of the total number of PIT tagged fish that would have been transported at each dam (estimates t_j for the j^{th} dam) if all PIT tagged fish had been routed to transport at the same rate as the untagged fish.

$$SAR(T_0) = [t_2 \bullet SAR(T_{LGR}) + t_3 \bullet SAR(T_{LGS}) + t_4 \bullet SAR(T_{LMN})] / [t_2+(t_3/S_2)+(t_4/S_2S_3)]$$

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 addition, the difference between $SAR(T_0)$ and $SAR(C_0)$ was characterized as the ratio of this pair of SARs. In this report, the adult count is the sum of all 2-ocean and 3-ocean returning chinook for the category of interest. All jacks (1-ocean) and mini-jacks (0-ocean) are excluded from the adult count.

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 smolts-to-adults includes survival rates through the hydropower system for transported (V_T) and for in-river (V_C) smolts as well as survival after smolts pass Bonneville Dam (BON) and return to LGR. Like parameter T/I, the parameter D is the ratio of survival of transported smolts relative to smolts migrating in-river; however, survival is measured from BON-

LGR SAR. If the *D* ratio is around 1, there is no differential mortality occurring between transported and in-river migrating smolts once they are both below BON. However, with *D* ratios averaging around 0.6 for hatchery and wild chinook in recent years (see Bouwes 2002), 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,

$$D = \text{BON-LGR } SAR_T / \text{BON-LGR } SAR_C$$

However, the 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 V_T and V_C are removed from their respective LGR-LGR SAR values. The resulting estimate of *D* is

$$D = [\text{SAR(T0)} / V_T] / [\text{SAR(C0)} / V_C]$$

where V_C is the estimated in-river survival from LGR tailrace to BON tailrace and V_T is the assumed direct transportation survival rate of 98% adjusted for survival to the respective transportation site.

In the denominator of *D* (in-river portion), the ratio is simply $\text{SAR}(C_0)/V_C$, where V_C is estimated through the CJS estimate expanded to the entire hydro system (LGR to BON). Errors in estimates of V_C influence the accuracy of *D* estimates. Recall that when it was not possible to estimate CJS in-river survival directly to BON tailrace, an expansion based on a "per mile" 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 ratio is $\text{SAR}(T_0)/V_T$, where V_T must be estimated following the same logic that was applied to $\text{SAR}(T_0)$. The parameter V_T takes into account an estimate of survival to each transportation site, effectively putting V_T into LGR equivalents as is $\text{SAR}(T_0)$, and a fixed 98% survival rate for the fish once they are placed into the transportation vehicle (truck or barge). The resulting formula for estimating V_T uses estimates of the total number of PIT tagged fish that would have been transported at each dam (estimates t_j for the j^{th} dam) if all PIT tagged fish had been routed to transport at the same rate as the untagged fish. The V_T estimate is

$$V_T = 0.98 * [t_2 + t_3 + t_4] / [t_2 + (t_3/S_2) + (t_4/S_2S_3)].$$

Dividing V_T into $\text{SAR}(T_0)$ and simplifying terms produces the numerator of *D* as

$$\text{SAR}(T_0)/V_T = [t_2 \bullet \text{SAR}(T_{LGR}) + t_3 \bullet \text{SAR}(T_{LGS}) + t_4 \bullet \text{SAR}(T_{LMN})] / [0.98(t_2 + t_3 + t_4)].$$

RESULTS

In the previous CSS Status Report, estimates of SAR's were made for wild yearling chinook released above Lower Granite Dam in migration years 1994 to 1999, and for hatchery yearling chinook released above LGR in migration years 1997 to 1999. The present CSS Status Report adds the 2000 migration year to the analysis and reanalyzes the 1994 to 1999 migration data with the purpose of providing confidence intervals on each of the parameters estimated. The bootstrap method (Efron and Tibshirani 1993) was used to provide 95% confidence intervals for all parameters estimated.

Wild Spring/Summer Yearling Chinook

The PIT tagged wild chinook used in the CSS were initially PIT tagged to satisfy the goals of several different research studies. Therefore, we had to ensure that smolts used in our annual aggregate groups were actually migrating out in the respective year of interest. Tagging activities at upper basin traps may have periods of time when more than one age class of smolts are being PIT tagged and recorded in the same tagging file. This occurs primarily in late spring and early summer during the transition from the tagging of the current year's outmigrants and to the tagging of the next year's outmigrants. Review of tagging files in PTAGIS and dates of detections at dams, we found a window after May 20 and before July 25 as having the greatest overlap in tagging of multiple age classes of wild chinook. Therefore, for a particular migration year designated by the researchers, the CSS also looks at the release date of the PIT tagged wild chinook and retains those fish released from July 25 of the preceding year through May 20 of the migration year of interest. In addition, wild chinook within the ten month period from July 25 to May 20 that were still detected at the dams or trawl in a year outside the migration year were also excluded (this was less than 0.1% in all years except 1994 when it was 0.25%) because estimates of collection efficiency and survival must reflect a single year. The resulting numbers of wild chinook per year used in the annual aggregates are presented in Table 1.

Table 1. Numbers of wild spring/summer chinook in the annual aggregate groups of PIT tagged smolts originating above Lower Granite Dam from 1994 to 2000 based on 10-month tagging period from July 25 to May 20.

Migration Year	Wild chinook PIT tagged between 7/25 and 5/20	Number migrating outside of expected migration year	Final number of wild chinook in each annual aggregate group
1994	49,783	126	49,657
1995	74,719	80	74,639
1996	21,536	13	21,523
1997	9,792	11	9,781
1998	33,852	16	33,836
1999	81,495	2	81,493
2000	67,882	42	67,840

The number of returning wild chinook adults and jacks from migration years 1994 to 2000 is shown in Table 2. Overall, approximately 3.4% of the total return for a migration year is jacks. All further analyses involving adult returns include only 2-ocean and 3-ocean fish, thereby excluding all jacks from the adult count.

Table 2. Number of returning PIT tagged wild chinook adults and jacks 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 2000.

Migration Year	Jacks 1-ocean	Adults 2-ocean	Adults 3-ocean	Percent of total return as jacks
1994	1	11	11	4.3
1995	1	38	20	1.7
1996	0	11	5	0.0
1997	2	33	5	5.0
1998	17	148	48	8.0
1999	25	517	144	3.6
2000	9	259	310	1.6
Total	55	1,017	543	3.4

The numbers of PIT tagged wild chinook actually transported in migration years 1994 to 2000 has been relatively small due to the fact that the standard protocol in those years was to return all PIT tagged smolts back to the river (Table 2). At each dam there exists a sampling program that obtains a daily timed collection (typically 2-6 subsamples per hour of varying duration for 24-hrs) of fish for hands-on counts by species and condition indexing. This process requires anesthetizing the fish collected. Both PIT tagged and untagged fish are collected for processing during the timed subsamples. Most of the PIT tagged wild chinook utilized in the CSS evaluation to date were transported following this collection process. Beginning in 2002 the CSS has coordinated the routing of a proportion of the PIT tagged wild chinook from participating studies directly to transportation at the Snake River dams, an action that will provide more PIT tagged wild chinook smolts in the transportation category.

Although dam-specific transportation SARs [*e.g.*, SAR(T_{LGR}), SAR(T_{LGS}), and SAR(T_{LMN})] were computed for the Snake River dams for migration years 1994 to 2000, most of these SAR estimates had wide confidence intervals (Table 4) due to extremely small numbers of PIT tagged wild chinook transported at each dam (Table 3). For example, the 95% CI lower limit for SAR(T_{LGS}) and SAR(T_{LMN}) was zero in 1994 to 1998, while the 95% CI lower limit for SAR(T_{LGR}) was zero in 1996 and 1997. The non-parametric 95% confidence intervals were right skewed, with widths over twice the magnitude of their respective point estimates (Table 4). The extremely small numbers of transported PIT tagged wild chinook from LMN resulted in no adult returns and SAR(T_{LMN}) of zero in 5 of 7 years at LMN. However, 14% of the total wild yearling chinook transported in the Snake River occurred at LMN on average (Table 3). The inclusion of LMN in the computations would negatively bias the estimate of SAR(T_0) because of the low probability that an adult would return from the small number of PIT tagged smolts released. On the other hand, one PIT tagged adult returning out of 30 PIT tagged smolts transported at LGS in 1997 produced an extremely high SAR of 6.67 which would contribute positive bias to the computed SAR(T_0) for that year. The small numbers of PIT tagged smolts routed to transportation in these early years made it difficult to obtain reliable total Snake River transportation SARs for wild chinook. For this reason, beginning in migration year 2002, the CSS program has coordinated with state and tribal research programs to purposely route 50% of the first-time detected PIT tagged wild chinook smolts at the Snake River transportation facilities.

Table 3. Number of PIT tagged wild chinook actually transported from each dam and estimate (t_i) of total PIT tagged wild chinook that would have been transported if all PIT tagged fish had been transported at same rate as the untagged run-at-large – the t_j for the Snake River dams are used in estimating SAR(T_0).

Migr. Year	Lower Granite Dam		Little Goose Dam		Lower Monumental Dam		McNary Dam	
	Actual	t_2	Actual	t_3	Actual	t_4	Actual	t_5
1994	1,051	6,849	387	2,094	330	1,308	42	1,206
1995	1,702	9,656	356	3,626	156	1,490	7	8
1996	268	2,269	85	1,749	32	927	1	8
1997	185	1,064	30	335	11	171	1	N/A
1998	820	7,669	359	4,002	79	1,632	0	N/A
1999	1,107	8,183	319	14,213	287	4,594	0	N/A
2000	327	7,159	244	6,603	185	2,146	2	20
7-yr mean percent[1]		49 %		37 %		14 %		N/A

[1] Estimated percentage of total transported population transported at each Snake River dam.

Table 4. Estimated dam-specific transportation SAR (dam-to-LGR in percentages) of PIT tagged wild spring/summer chinook in the annual aggregate groups for migration years 1994 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year	SAR(T_{LGR})	Adults #	SAR(T_{LGS})	Adults #	SAR(T_{LMN})	Adults #
1994	0.67 (0.19 – 1.15)	7	0.52 (0.0 – 1.34)	2	0	None
1995	0.41 (0.17 – 0.72)	7	0.28 (0.0 – 0.96)	1	0	None
1996	0.37 (0.0 – 1.19)	1	1.18 (0.0 – 3.95)	1	0	None
1997	1.08 (0.0 – 2.8)	2	6.67 (0.0 – 17.2)	2	0	None
1998	1.34 (0.61 – 2.18)	11	0.84 (0.0 – 1.96)	3	1.27 (0.0 – 4.40)	1
1999	2.52 (1.63 – 3.47)	28	2.82 (1.29 – 4.69)	9	2.09 (0.70 – 3.86)	6
2000	1.22 (0.28 – 2.52)	4	2.46 (0.83 – 4.70)	6	1.07 (0.0 – 2.84)	2

The estimated population numbers of PIT tagged wild spring/summer chinook smolts arriving at Lower Granite Dam in each CSS study category, T_0, C_0, and C_1, are presented in Table 5, along with the bootstrapped 95% confidence intervals. There are two estimates of the number of smolts in each study category based on which of the two methods of in-river survival estimation was used in reaches between Lower Granite Dam tailrace and Lower Monumental Dam tailrace. The estimated numbers of PIT tagged smolts in each study category do not differ greatly based on in-river survival methods used because the survival estimates between Lower Granite Dam tailrace and Lower Monumental Dam tailrace are similar. From 1995 to 2000, over two-thirds of the PIT tagged wild chinook population arriving Lower Granite Dam were destined for Category C_1, which reduces the numbers available in categories T_0 and C_0. These latter two categories mimic the untagged population in each year except 1997. During the springtime migration of 1997, all tagged and untagged smolts passing Little Goose and Lower Monumental dams were bypassed back to the river under the following schedule: all fish on B-raceway flume routed to the river from April 10 to June 25 at Little Goose and Lower Monumental dams; all fish on A-raceway flume routed to river from May 8 to May 17 at Little Goose Dam and from May 8 to May 16 at Lower Monumental Dam. During 1997, an unknown mixture of categories C_0 and C_1 tagged fish mimic the untagged smolt population.

Table 5. Estimated numbers of wild spring/summer chinook in the annual aggregate groups of PIT tagged smolts arriving at Lower Granite Dam from 1994 to 2000 based on the 10-month tagging period from July 25 to May 20. These numbers represent a partition of the population at Lower Granite Dam "destined" to become a member of each of the three study groups. Bootstrap 95% confidence intervals are shown in parenthesis.

Migr. Year	Estimate LGR population	Study category	Estimated number of smolts in study category using two estimates of in-river survival	
			CJS Survival	Wt Mean Survival
1994	15,250	T_0	2,001 (1,906 – 2,094)	1,906 (1,820 – 1,995)
	(14,949 – 15,543)	C_0	1,798 (1,668 – 1,936)	2,261 (2,073 – 2,417)
		C_1	4,388 (4,201 – 4,585)	4,133 (3,960 – 4,344)
1995	20,203	T_0	2,283 (2,184 – 2,379)	2,266 (2,169 – 2,364)
	(19,915 – 20,494)	C_0	2,709 (2,595 – 2,831)	2,914 (2,750 – 3,044)
		C_1	14,204 (13,981 – 14,449)	14,032 (13,811 – 14,288)
1996	7,868	T_0	400 (361 – 443)	394 (354 – 440)
	(7,643 – 8,112)	C_0	1,917 (1,791 – 2,051)	2,054 (1,492 – 2,339)
		C_1	5,209 (5,037 – 5,396)	5,096 (4,839 – 5,678)
1997	2,898	T_0	230 (201 – 260)	231 (201 – 262)
	(2,756 – 3,046)	C_0	680 (603 – 755)	663 (431 – 759)
		C_1	1,936 (1,826 – 2,054)	1,951 (1,831 – 2,184)
1998	17,362	T_0	1,271 (1,205 – 1,345)	1,281 (1,216 – 1,358)
	(17,123 – 17,613)	C_0	3,081 (2,954 – 3,206)	2,948 (2,796 – 3,066)
		C_1	12,279 (12,072 – 12,483)	12,390 (12,186 – 12,610)
1999	33,662	T_0	1,764 (1,677 – 1,850)	1,764 (1,677 – 1,847)
	(33,267 – 34,041)	C_0	4,469 (4,316 – 4,616)	4,546 (4,355 – 4,719)
		C_1	26,138 (25,787 – 26,478)	26,057 (25,700 – 26,402)
2000	25,047	T_0	839 (778 – 902)	805 (748 – 868)
	(24,670 – 25,453)	C_0	6,491 (6,279 – 6,687)	7,120 (6,782 – 7,372)
		C_1	16,832 (16,541 – 17,138)	16,274 (15,973 – 16,651)

Computed SARs for study categories T_0, C_0, and C_1 and associated bootstrapped 95% confidence intervals for wild chinook are presented in Table 6. Because of the potential biases in estimates of SAR(T_0) for Category T_0 fish, the SAR(T_{LGR}) for fish transported at LGR in each year is also presented for comparison with the in-river categories. Within each year, the 95% confidence intervals of each study category overlap except in 1994 for SAR(T_0) and SAR(C_1). No spill was provided in 1994 at LGR and LMN until May 11, well after the majority of PIT tagged wild chinook had passed

Table 6. Estimated SAR (LGR-to-LGR in percentages) of PIT tagged wild spring/summer chinook in the annual aggregate groups for each study category for migration years 1994 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year	Study category	Estimated SAR (LGR-to-LGR) percentages based on two approaches to estimating in-river survival	
		CJS Survival	Wt Mean Survival
1994	T_{LGR}	0.67 (0.19 – 1.15)	Same[1]
	T_0	0.50 (0.21 – 0.80)	0.52 (0.22 – 0.83)
	C_0	0.28 (0.06 – 0.56)	0.22 (0.05 – 0.46)
	C_1	0.09 (0.02 – 0.19)	0.10 (0.02 – 0.20)
1995	T_{LGR}	0.41 (0.17 – 0.72)	Same
	T_0	0.32 (0.11 – 0.56)	0.33 (0.11 – 0.57)
	C_0	0.37 (0.15 – 0.63)	0.34 (0.14 – 0.59)
	C_1	0.25 (0.17 – 0.33)	0.26 (0.17 – 0.34)
1996	T_{LGR}	0.37 (0.0 – 1.19)	Same
	T_0	0.55 (0.0 – 1.52)	0.56 (0.0 – 1.58)
	C_0	0.26 (0.05 – 0.50)	0.24 (0.05 – 0.53)
	C_1	0.17 (0.08 – 0.29)	0.18 (0.08 – 0.30)
1997	T_{LGR}	1.08 (0.0 – 2.78)	Same
	T_0	2.08 (0.34 – 4.40)	2.07 (0.33 – 4.43)
	C_0	2.35 (1.30 – 3.67)	2.41 (1.38 – 4.39)
	C_1	0.93 (0.53 – 1.43)	0.92 (0.51 – 1.39)
1998	T_{LGR}	1.34 (0.61 – 2.18)	Same
	T_0	1.16 (0.61 – 1.85)	1.15 (0.60 – 1.83)
	C_0	1.36 (0.96 – 1.80)	1.42 (1.01 – 1.90)
	C_1	1.08 (0.90 – 1.26)	1.07 (0.89 – 1.25)
1999	T_{LGR}	2.53 (1.63 – 3.47)	Same
	T_0	2.50 (1.56 – 3.53)	2.50 (1.56 – 3.54)
	C_0	2.13 (1.71 – 2.59)	2.09 (1.67 – 2.56)
	C_1	1.90 (1.73 – 2.08)	1.91 (1.74 – 2.08)
2000	T_{LGR}	1.22 (0.28 – 2.52)	Same
	T_0	1.58 (0.76 – 2.67)	1.64 (0.78 – 2.72)
	C_0	2.37 (2.00 – 2.75)	2.16 (1.84 – 2.53)
	C_1	2.33 (2.10 – 2.57)	2.41 (2.16 – 2.66)
1994 – 1996 Geometric Mean	T_{LGR}	0.47	Same
	T_0	0.44	0.46
	C_0	0.30	0.26
	C_1	0.16	0.17
1997 – 2000 Geometric Mean	T_{LGR}	1.45	Same
	T_0	1.76	1.77
	C_0	2.00	1.98
	C_1	1.45	1.46

[1] Same value as shown in CJS Survival column since no survival expansion is required at LGR itself.

those sites. During 1995 to 2000, both over-generation spill and BIOP spill were provided at each Snake River dam during the springtime migration.

Higher estimates of SAR(T_{LGR}), SAR(T_0), SAR(C_0), and SAR(C_1) for PIT tagged wild spring/summer chinook occurred in migration years 1997 to 2000 than occurred in migration years 1994 to 1996 (Table 6). The SARs computed using the direct CJS in-river seasonal survival estimates and the weighted mean of in-river subcohort survival estimates are very similar, because the estimates of survival from LGR tailrace to LMN tailrace computed with the two methods are similar. The overlap in confidence intervals between SAR's of fish in each study category made it difficult to determine whether there were significant differences between the SAR's of transported and in-river migrating wild chinook in individual years. Although SAR(C_1) was not significantly different from other study categories, it did follow a trend of lower point estimates than the other three categories in all years except migration year 2000. This may reflect a reduction in overall survival due to passage through bypass systems at Snake River dams, or to the fact that fish in Category C_1 have greater opportunity to pass through multiple bypasses (1 to 6 bypasses) than those fish in Category C_0 (0 to 3 bypasses) as they migrate in-river through the Snake and lower Columbia rivers.

Because the greatest differences in estimated reach survival from the two survival estimation approaches occurred in the reaches below LMN tailrace, there will be greater impact on the expanded LGR-to-BON in-river survival estimates (see V_c in Table 8) than on the LGR-to-LGS and LGR-to-LMN survival estimates of S_2 and S_2S_3, respectively. For PIT tagged wild chinook, the furthest downstream site possible for direct estimation of in-river survival using both methods together (*i.e.*, last site before the two methods began providing totally different and meaningless individual reach survival estimates) was the tailraces of LMN in 1994, 1996, and 1997, MCN in 1995, and JDA in 1998, 1999, and 2000. Individual reach survival estimates for these migration years are presented in Appendix Table A-1.

The number of PIT tagged fish detected at the lower dams limited the number of reaches for which we could directly estimate in-river survival components (S_j), and this number was related to how many fish were available at Lower Granite Dam for estimation purposes. With the weighted mean method (sub-cohorts approach), only PIT tagged fish detected at LGR are used. This is a subset of the full population of detected and undetected (but alive) PIT tagged fish at LGR used in the full sample CJS method (Table 7). Differences in the PIT tagged population available for estimating in-river survival components between the two approaches can be seen by comparing the combined number of smolts in categories C_0 and C_1 (available for full sample CJS survivals) with one-third of the total number of smolts returned-to-river at Lower Granite Dam (available for each sub-cohort in the weighted mean CJS survival method). As shown in Table 7, an individual sub-cohort will have 70 – 92% fewer PIT tagged fish available for survival estimation than would the full sample approach.

Table 7. Reduction in numbers of PIT tagged wild chinook smolts available for in-river reach survival estimation with the sub-cohort approach (use only fish detected and returned-to-river at LGR) compared to the full sample approach (uses all fish from the LGR estimated population).

Survival method	1994	1995	1996	1997	1998	1999	2000
Full sample CJS	6,186	14,204	7,126	2,616	15,360	30,607	23,325
Sub-cohorts CJS	1,915	2,843	800	305	2,438	2,514	2,651
Percent fewer fish used in survival estimation with subcohort method	69%	80%	89%	88%	84%	92%	89%

Beginning in migration year 2002, with the routing of 50% of the first-time detected PIT tagged wild chinook to transportation at the Snake River dams, there will be half the number of PIT tagged fish returned-to-river at LGR as would have occurred under the operations of the prior years. This will reduce the percent of PIT tagged smolts available for reach survival estimation based on the sub-cohort approach even greater than the percentages shown above. In turn, this may further reduce the usefulness of the sub-cohorts approach (weighted mean survival method) for estimating individual reach survival components. In future simulation studies, we plan to explore the trade off between this small sample size issue discussed above and the alternative issue of using the fixed seasonal individual reach survival estimate obtained from the full sample CJS approach when there may exist temporal heterogeneity in reach survival due to different fish passage experiences over the migration season.

This PIT tag sample size impact was also seen in the estimated LGR-BON survival rate V_C and associated estimated D value that were computed with the two methods (Table 8). Because of the importance of V_C in the computation of D, high variability in estimated V_C will influence the variability observed in estimated D. The point estimates of D ranged from 0.34 to 1.08 across the two methods and years, however none of the D estimates were significantly different regardless of method used. A 7-year geometric mean of D was 0.52 using the full CJS survival data in V_C and V_T and 0.62 using the weighted mean survival data in V_C and V_T. The 7-year geometric mean of the T/I ratio was 1.10 using the full CJS survival data and 1.18 using the weighted mean survival data. Obtaining T/I ratios well below 2 was further evidence of the presence of delayed mortality in transported PIT tagged wild chinook smolts after release below Bonneville Dam. Even though estimates of T/I and D, respectively, may not be significantly different over the available 7-years of PIT tagged wild spring/summer chinook data, this does not imply that low overall geometric mean T/I < 1.2 and D < 0.65, regardless of method used for in-river survival components, has no relevance. The pattern of the data suggests that transporting smolts as a mitigation tool is not working well enough to guarantee recovery of the listed wild spring/summer chinook originating in the Snake River basin above LGR.

Table 8. Estimated in-river survival LGR to BON (V_C), SAR(T_0)/SAR(C_0) ratio, and *D* value of PIT tagged wild spring/summer chinook in the annual aggregate groups for migration years 1994 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year	Estimated parameter	Estimated V_C, T/I ratio, and *D* using two estimates of in-river survival	
		CJS Survival	Wt Mean Survival
1994	V_C	0.20 (0.17 – 0.23)	0.35 (0.28 – 0.41)
	T/I	1.80 (0.57 – 6.41)	2.35 (0.74 – 8.52)
	D	0.40 (0.13 – 1.46)	0.89 (0.28 – 3.16)
1995	V_C	0.41 (0.30 – 0.62)	0.60 (0.28 – 1.02)
	T/I	0.87 (0.28 – 2.38)	0.95 (0.30 – 2.60)
	D	0.39 (0.12 – 1.14)	0.61 (0.14 – 1.71)
1996	V_C	0.44 (0.33 – 0.58)	0.44 (0.11 – 0.92)
	T/I	2.09 (0.0 – 10.6)	2.30 (0.0 – 11.6)
	D	1.01 (0.0 – 5.48)	1.08 (0.0 – 6.7)
1997	V_C	0.51 (0.32 – 0.89)	0.41 (0.08 – 0.97)
	T/I	0.88 (0.14 – 2.38)	0.86 (0.11 – 2.17)
	D	0.48 (0.07 – 1.57)	0.38 (0.02 – 1.42)
1998	V_C	0.61 (0.53 – 0.71)	0.48 (0.33 – 0.61)
	T/I	0.85 (0.43 – 1.54)	0.80 (0.39 – 1.45)
	D	0.54 (0.26 – 0.97)	0.41 (0.18 – 0.72)
1999	V_C	0.62 (0.59 – 0.66)	0.62 (0.54 – 0.68)
	T/I	1.17 (0.72 – 1.81)	1.20 (0.73 – 1.83)
	D	0.78 (0.48 – 1.20)	0.79 (0.48 – 1.20)
2000	V_C	0.46 (0.42 – 0.52)	0.59 (0.45 – 0.68)
	T/I	0.67 (0.31 – 1.14)	0.76 (0.35 – 1.30)
	D	0.34 (0.16 – 0.59)	0.48 (0.20 – 0.81)
1994 – 2000 Geometric Mean	T/I	1.10	1.18
	D	0.52	0.62

Hatchery Spring/Summer Yearling Chinook

The PIT tagged hatchery chinook used in the CSS were PIT tagged specifically to satisfy the goals of this study. Therefore, large enough releases of PIT tagged smolts were made at each hatchery participating in the CSS to provide estimation of parameters to the level of each individual hatchery for migration years 1997 to 2000. A check that all hatchery chinook released actually outmigrated in their expected migration year was made to guarantee that estimates of collection efficiency and survival would reflect a single year. The number of PIT tagged hatchery chinook released per year for the CSS is presented in Table 9.

Table 9. Numbers of PIT tagged hatchery spring/summer chinook released from hatcheries participating in the CSS from 1997 to 2000.

Hatchery	Migration Year			
	1997[A]	1998	1999	2000
Rapid River Hatchery RAPH	40,452	48,336	47,812	47,747
McCall Hatchery MCCA	52,652	47,340	47,985	47,705
Dworshak Hatchery DWOR	14,080	47,703	47,845	47,743
Imnaha R Acclimation Pond IMNA	13,378	19,825	19,939	20,819
Loohingglass Hatchery LOOH	40,027	44,232	44,551	Not tagged

[A] Pahsimeroi Hatchery chinook PIT tagged for CSS only in 1997, so not used in multi-year analysis.

The number of returning hatchery chinook adults and jacks from migration years 1994 to 2000 is shown in Table 10 for spring and summer races of chinook. Spring chinook are from Dworshak, Rapid River, and Lookingglass hatcheries, and summer chinook are from McCall Hatchery and Imnaha Acclimation Pond (AP). Overall, the average percentage of the total return that were jacks was less than 5% for spring stocks, whereas for summer chinook stocks the jack percentage was 12.8% for McCall Hatchery and 30.7% for Imnaha AP. The Imnaha stock is considered a spring race by ODFW, which operates the hatchery, but it is considered a summer race by the Nez Perce tribe, which operates a trap on the lower Imnaha River. We will consider the Imnaha chinook as a summer race for two reasons. First, the timing of the adult return is later for Imnaha AP chinook than that of the other spring chinook hatchery fish used in the CSS. Second, the return rate of spring chinook jacks tends to be lower than that of summer chinook. The Imnaha AP chinook had the highest jack return rate of any CSS hatchery. Because of the highly variable jack return rates among hatcheries and extremely low jack return rate observed with the wild chinook, all further analyses involving adult return counts include only 2-ocean and 3-ocean fish (no jacks).

Table 10. Number of returning PIT tagged hatchery chinook adults and jacks detected at Lower Granite Dam that migrated as smolts in 1997 to 2000 and percent of return as jacks.

Hatchery (run)	Migration Year	Jacks 1-ocean	Adults 2-ocean	Adults 3-ocean	Percent of total return as jacks
RAPH (spring)	1997	2	86	7	2.1
	1998	32	390	23	7.2
	1999	43	787	31	5.0
	2000	8	371	256	1.3
	MEAN				**3.9**
MCCA (summer)	1997	21	263	11	7.1
	1998	108	394	37	20.0
	1999	119	722	113	12.5
	2000	114	635	237	11.6
	MEAN				**12.8**
DWOR (spring)	1997	1	36	6	2.3
	1998	51	372	23	11.4
	1999	14	393	44	3.1
	2000	3	180	197	0.8
	MEAN				**4.4**
IMNA (summer)	1997	24	63	7	25.5
	1998	54	69	2	43.2
	1999	81	226	12	25.4
	2000	149	289	79	28.8
	MEAN				**30.7**
LOOH (spring)	1997	5	95	5	4.8
	1998	3	71	9	3.6
	1999	11	172	9	5.7
	MEAN				**4.7**

A portion of the CSS PIT tagged hatchery chinook was purposely diverted into transportation at Lower Granite Dam in each of the years 1997 to 2000, but this was not the case at the other two Snake River transportation facilities until 2000 (Table 11). At Little Goose Dam 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). The CSS PIT tagged hatchery chinook were not intentionally routed to transportation at Lower Monumental Dam until 2000. Therefore, the low PIT tag numbers of hatchery chinook first-time detected at Lower Monumental Dam and transported from that facility limit inferences that may be made from that particular dam. Springtime transportation did not occur at McNary Dam in migration years 1997 to 2000, and as a result only five PIT tagged hatchery chinook smolts were transported in those four years.

Although dam-specific transportation SARs [*e.g.*, SAR(T_{LGR}), SAR(T_{LGS}), and SAR(T_{LMN})] were computed for each Snake River facility for migration years 1997 to 2000, there was the problem of low precision in the estimates of SAR(T_{LGS}) and SAR(T_{LMN}) in several of these years (Table 12). There were extremely low numbers of first-time detected PIT tagged smolts routed to transportation from LGS in 1997 and from LMN in 1997 and 1998. As was the case with the wild chinook, there will be bias and imprecision in estimated SAR(T_0) for migration years 1997 and 1998 in particular due to very low numbers of first-time detected PIT tagged hatchery chinook being routed to transportation at LGS and LMN in those years. This problem was exacerbated for hatchery stocks that tended to have low adult return rates. For example, we detected three or fewer PIT tagged Lookingglass Hatchery chinook adults at LGS or LMN in any of the three years that stock was available. The small numbers of PIT tagged smolts routed to transportation in these early years has made it difficult to obtain reliable total Snake River transportation SAR for hatchery chinook prior to 2000 when we began to route similar proportions of first-time PIT tagged hatchery to transportation at each Snake River transportation dam.

Table 11. Number of PIT tagged hatchery chinook actually transported from each dam and estimate (t_i) of total PIT tagged hatchery chinook that would have been transported if all PIT tagged fish had been transported at same rate as the untagged run-at-large – the t_j for the Snake River dams are used in estimating SAR(T_0).

Migr. Year & Hatchery	Lower Granite Dam		Little Goose Dam		Lower Monumental Dam		McNary Dam	
	Actual	t_2	Actual	t_3	Actual	T_4	Actual	t_5
1997								
RAPH	4,135	5,365	132	1,618	38	949	0	20
MCCA	5,851	7,428	105	2,241	31	1,153	0	27
DWOR	1,864	2,351	52	970	15	517	1	12
IMNA	2,074	2,603	45	954	12	487	1	11
LOOH	6,026	7,597	116	2,546	45	1,545	0	42
1998								
RAPH	11,279	15,274	1,359	7,578	197	3,100	0	35
MCCA	8,988	12,178	896	6,970	157	3,073	1	23
DWOR	11,096	14,350	3,574	9,326	225	3,887	2	117
IMNA	4,036	5,621	606	3,749	97	1,354	0	16
LOOH	10,847	14,229	1,768	7,192	147	2,681	0	39
1999								
RAPH	7,385	9,488	4,724	12,750	290	3,818	0	3
MCCA	4,730	6,374	4,986	10,584	203	3,515	0	3
DWOR	4,930	6,346	3,798	14,602	484	5,304	0	5
IMNA	2,160	2,785	2,293	5,129	114	1,428	0	1
LOOH	5,166	6,593	456	11,918	271	3,742	0	3
2000								
RAPH	10,367	14,386	4,182	6,123	1,213	1,625	0	50
MCCA	8,496	11,734	2,821	4,086	776	1,279	0	51
DWOR	9,806	13,399	4,911	7,206	2,030	2,539	0	72
IMNA	3,862	5,447	1,812	2,705	530	713	0	17
4-yr avg percent[1]		50 %		37 %		13 %		N/A

Table 12. Estimated dam-specific transportation SAR (dam-to-LGR in percentages) of PIT tagged hatchery spring/summer chinook that migrated as smolts in 1997 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migr. Year & Hatchery	SAR(T_{LGR})	Adults #	SAR(T_{LGS})	Adults #	SAR(T_{LMN})	Adults #
1997 RAPH	0.80 (0.54 – 1.09)	33	0	None	2.63 (0.0 – 9.76)	1
1997 MCCA	1.49 (1.17 – 1.81)	87	2.86 (0.0 – 6.48)	3	3.23 (0.0 – 10.7)	1
1997 DWOR	0.86 (0.48 – 1.29)	16	0.0	None	0.0	None
1997 IMNA	1.21 (0.75 – 1.73)	25	0.0	None	0.0	None
1997 LOOH	0.37 (0.23 – 0.53)	22	0.86 (0.0 – 2.86)	1	0.0	None
1998 RAPH	2.12 (1.85 – 2.37)	239	1.18 (0.66 – 1.80)	16	1.02 (0.0 – 2.54)	2
1998 MCCA	2.93 (2.60 – 3.29)	263	1.00 (0.44 – 1.70)	9	0.64 (0.0 – 2.34)	1
1998 DWOR	0.99 (0.81 – 1.17)	110	0.62 (0.39 – 0.89)	22	0	None
1998 IMNA	0.92 (0.62 – 1.23)	37	0.66 (0.16 – 1.45)	4	0	None
1998 LOOH	0.45 (0.33 – 0.59)	49	0.17 (0.0 – 0.40)	3	2.04 (0.0 – 4.73)	3
1999 RAPH	3.20 (2.80 – 3.58)	236	3.22 (2.75 – 3.75)	152	1.03 (0.0 – 2.42)	3
1999 MCCA	4.36 (3.80 – 4.94)	206	3.23 (2.78 – 3.73)	161	4.93 (2.15 – 8.37)	10
1999 DWOR	1.26 (0.96 – 1.55)	62	1.29 (0.94 – 1.65)	49	0.83 (0.20 – 1.72)	4
1999 IMNA	3.43 (2.67 – 4.26)	74	2.31 (1.71 – 2.94)	53	2.63 (0.0 – 5.77)	3
1999 LOOH	0.81 (0.57 – 1.06)	42	0.66 (0.0 – 1.50)	3	0.74 (0.0 – 1.96)	2
2000 RAPH	2.34 (2.06 – 2.65)	243	1.89 (1.52 – 2.30)	79	2.23 (1.43 – 3.06)	27
2000 MCCA	4.54 (4.12 – 5.01)	386	3.26 (2.56 – 3.90)	92	2.45 (1.42 – 3.58)	19
2000 DWOR	1.18 (0.96 – 1.41)	116	1.08 (0.80 – 1.37)	53	0.69 (0.34 – 1.08)	14
2000 IMNA	3.99 (3.34 – 4.63)	154	2.48 (1.77 – 3.24)	45	2.26 (1.09 – 3.57)	12

The estimated population number of PIT tagged chinook from specific hatcheries arriving at LGR with bootstrapped 95% confidence intervals are presented in Table 13 for spring stocks and Table 14 for summer stocks. Additionally in each table, we present the estimated number of smolts (along with bootstrapped 95% confidence intervals) from the LGR population in each CSS study category, T_0, C_0, and C_1, utilizing two methods of computing the in-river survival components between LGR tailrace and LMN tailrace.

Table 13. Estimated numbers of PIT tagged hatchery spring chinook in the study categories arriving Lower Granite Dam from 1997 to 2000. These numbers represent a partition of the population at Lower Granite Dam "destined" to become a member of each of the three study groups. Bootstrap 95% confidence intervals are shown in parenthesis.

Migr. Year & Hat.	Estimate LGR population	Study category	Estimated number of smolts in study category using two estimates of in-river survival	
			CJS Survival	Wt Mean Survival
1997 RAPH	15,765 (15,246 – 16,439)	T_0	4,321 (4,204 – 4,451)	4,332 (4,214 – 4,476)
		C_0	4,176 (3,889 – 4,506)	3,714 (1,458 – 4,653)
		C_1	6,843 (6,477 – 7,254)	7,284 (6,415 – 9,497)
1997 DWOR	8,175 (7,735 – 8,683)	T_0	1,931 (1,856 – 2,015)	1,932 (1,859 – 2,033)
		C_0	2,529 (2,283 – 2,798)	2,379 (<0 – 3,088)
		C_1	3,613 (3,344 – 3,938)	3,760 (3,096 – 6,743)
1997 LOOH	23,989 (23,258 – 24,749)	T_0	6,207 (6,078 – 6,354)	6,220 (6,093 – 6,366)
		C_0	6,349 (5,990 – 6,762)	5,581 (4,051 – 6,257)
		C_1	11,124 (10,636 – 11,647)	11,870 (11,103 – 13,414)
1998 RAPH	32,148 (31,801 – 32,473)	T_0	12,862 (12,659 – 13,057)	12,857 (12,655 – 13,055)
		C_0	4,402 (4,232 – 4,563)	4,589 (4,322 – 4,796)
		C_1	13,597 (13,344 – 13,841)	13,438 (13,178 – 13,736)
1998 DWOR	40,218 (39,660 – 40,742)	T_0	14,708 (14,486 – 14,927)	14,890 (14,649 – 15,165)
		C_0	11,151 (10,770 – 11,483)	10,668 (9,930 – 11,108)
		C_1	13,128 (12,831 – 13,412)	13,398 (13,045 – 13,993)
1998 LOOH	31,232 (30,845 – 31,631)	T_0	12,829 (12,624 – 13,020)	12,782 (12,590 – 12,979)
		C_0	5,152 (4,942 – 5,346)	5,605 (5,209 – 5,888)
		C_1	12,231 (11,951 – 12,511)	11,858 (11,566 – 12,256)
1999 RAPH	35,895 (35,272 – 36,542)	T_0	12,833 (12,602 – 13,078)	12,612 (12,383 – 12,866)
		C_0	7,040 (6,799 – 7,323)	7,841 (7,317 – 8,331)
		C_1	14,456 (14,123 – 14,810)	13,924 (13,556 – 14,383)
1999 DWOR	40,804 (39,771 – 41,948)	T_0	9,783 (9,549 – 10,022)	9,517 (9,288 – 9,793)
		C_0	10,484 (10,109 – 10,930)	11,473 (10,216 – 12,367)
		C_1	19,081 (18,473 – 19,705)	18,372 (17,658 – 19,451)
1999 LOOH	29,306 (28,797 – 29,892)	T_0	5,959 (5,814 – 6,095)	5,941 (5,794 – 6,075)
		C_0	4,776 (4,595 – 4,962)	5,164 (4,855 – 5,796)
		C_1	17,696 (17,258 – 18,168)	17,342 (16,652 – 17,878)
2000 RAPH	35,192 (34,526 – 35,910)	T_0	16,584 (16,249 – 16,925)	16,171 (15,828 – 17,096)
		C_0	11,046 (10,582 – 11,568)	11,647 (10,362 – 12,223)
		C_1	5,244 (5,097 – 5,408)	5,168 (5,009 – 5,362)
2000 DWOR	39,410 (38,652 – 40,203)	T_0	18,314 (17,915 – 18,726)	17,604 (17,047 – 19,220)
		C_0	13,075 (12,516 – 13,644)	14,089 (11,897 – 14,900)
		C_1	5,416 (5,249 – 5,583)	5,263 (5,051 – 5,530)

Table 14. Estimated numbers of PIT tagged hatchery summer chinook in the study categories arriving Lower Granite Dam from 1997 to 2000. These numbers represent a partition of the population at Lower Granite Dam "destined" to become a member of each of the three study groups. Bootstrap 95% confidence intervals are shown in parenthesis.

Migr. Year & Hat.	Estimate LGR population	Study category	Estimated number of smolts in study category using two estimates of in-river survival	
			CJS Survival	Wt Mean Survival
1997 MCCA	22,381 (21,588 – 23,224)	T_0	6,001 (5,859 – 6,138)	5,998 (5,862 – 6,139)
		C_0	6,761 (6,339 – 7,214)	6,901 (5,271 – 7,453)
		C_1	9,272 (8,779 – 9,795)	9,135 (8,545 – 10,750)
1997 IMNA	8,254 (7,814 – 8,740)	T_0	2,135 (2.050 – 2,223)	2,137 (2,055 – 2,233)
		C_0	2,219 (1,993 – 2,478)	2,120 (698 – 2,482)
		C_1	3,785 (3,475 – 4,091)	3,882 (3,529 – 5,304)
1998 MCCA	27,812 (27,474 – 28,141)	T_0	10,080 (9,916 – 10,258)	10,058 (9,888 – 10,236)
		C_0	3,849 (3,685 – 4,006)	4,265 (3,976 – 4,643)
		C_1	12,816 (12,537 – 13,075)	12,454 (12,052 – 12,766)
1998 IMNA	13,577 (13,327 – 13,833)	T_0	4,773 (4,648 – 4,895)	4,755 (4,629 – 4,879)
		C_0	1,995 (4,884 – 2,104)	2,164 (1,981 – 2,359)
		C_1	6,335 (6,156 – 6,523)	6,197 (5,992 – 6,406)
1999 MCCA	31,571 (30,816 – 32,358)	T_0	10,457 (10,200 – 10,710)	10,262 (9,962 – 10,586)
		C_0	8,407 (8,081 – 8,734)	9,090 (8,028 – 9,880)
		C_1	11,391 (11,037 – 11,782)	10,939 (10,447 – 11,743)
1999 IMNA	13,244 (12,829 – 13,687)	T_0	4,779 (4,616 – 4,955)	4,745 (4,559 – 5,017)
		C_0	2,869 (2,690 – 3,050)	2,963 (2,262 – 3,245)
		C_1	5,084 (4,871 – 5,327)	5,030 (4,790 – 5,567)
2000 MCCA	31,825 (31,017 – 32,692)	T_0	12,725 (12,398 – 13,043)	13,225 (12,163 – 15,519)
		C_0	13,064 (12,440 – 13,748)	12,222 (8,615 – 13,956)
		C_1	4,481 (4,319 – 4,651)	4,655 (4,298 – 5,437)
2000 IMNA	14,267 (13,864 – 14,779)	T_0	6,706 (6,469 – 6,960)	6,425 (6,226 – 7,626)
		C_0	4,396 (4,113 – 4,746)	4,815 (3,131 – 5,200)
		C_1	2,254 (2,148 – 2,356)	2,175 (2,023 – 2,304)

The estimated numbers of PIT tagged smolts in each study category did not differ greatly based on in-river survival methods used because estimated survival components between Lower Granite Dam tailrace and Lower Monumental Dam tailrace were similar. Unlike their wild chinook counterparts, the PIT tagged hatchery chinook populations arriving at Lower Granite Dam were fairly well split across the three study three categories. This gave relatively large numbers in categories T_0 and C_0. These latter two categories are assumed to mimic the untagged population in each year except 1997. During the springtime migration of 1997, all tagged and untagged smolts passing Little Goose and Lower Monumental dams were bypassed back to the river under the following schedule: all fish on B-raceway flume routed to river from April 10 to June 25 at Little Goose and Lower Monumental dams; all fish on A-raceway flume routed to river from May 8 to May 17 at Little Goose Dam and from May 8 to May 16 at Lower Monumental Dam. During 1997, an unknown mixture of categories C_0 and C_1 tagged fish mimic the untagged smolt population

There was an increasing trend in the magnitude of the LGR-to-LGR SARs in recent years for hatchery chinook. For migration years 1997 to 2000, the highest estimates of LGR-to-LGR SARs for PIT tagged hatchery chinook occurred for the spring

Table 15. Estimated SAR (LGR-to-LGR in percentages) of PIT tagged hatchery spring chinook for each study category for migration years 1997 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year & Hatchery	Study category	Estimated SAR (LGR-to-LGR) percentages based on two approaches to estimating in-river survival	
		CJS Survival	Wt Mean Survival
1997 RAPH	T_{LGR}	0.80 (0.54 – 1.09)	Same[1]
	T_0	0.82 (0.39 – 1.66)	0.80 (0.36 – 1.55)
	C_0	0.46 (0.25 – 0.66)	0.51 (0.28 – 1.31)
	C_1	0.53 (0.36 – 0.71)	0.49 (0.31 – 0.67)
1997 DWOR	T_{LGR}	0.86 (0.48 – 1.29)	Same[1]
	T_0	0.52 (0.29 – 0.78)	0.51 (0.25 – 0.75)
	C_0	0.47 (0.24 – 0.78)	0.50 (0.00 – 2.91)
	C_1	0.36 (0.19 – 0.57)	0.35 (0.14 – 0.55)
1997 LOOH	T_{LGR}	0.37 (0.23 – 0.53)	Same[1]
	T_0	0.40 (0.15 – 0.82)	0.39 (0.15 – 0.78)
	C_0	0.58 (0.40 – 0.79)	0.66 (0.46 – 1.03)
	C_1	0.35 (0.25 – 0.47)	0.33 (0.23 – 0.44)
1998 RAPH	T_{LGR}	2.12 (1.85 – 2.37)	Same[1]
	T_0	1.68 (1.41 – 1.95)	1.69 (1.42 – 1.97)
	C_0	1.20 (0.88 – 1.54)	1.15 (0.84 – 1.49)
	C_1	0.67 (0.53 – 0.80)	0.68 (0.54 – 0.81)
1998 DWOR	T_{LGR}	0.99 (0.81 – 1.17)	Same[1]
	T_0	0.72 (0.59 – 0.84)	0.71 (0.58 – 0.82)
	C_0	1.25 (1.04 – 1.47)	1.30 (1.09 – 1.56)
	C_1	0.91 (0.75 – 1.08)	0.89 (0.72 – 1.06)
1998 LOOH	T_{LGR}	0.45 (0.33 – 0.59)	Same[1]
	T_0	0.53 (0.29 – 0.83)	0.54 (0.30 – 0.84)
	C_0	0.14 (0.04 – 0.24)	0.12 (0.04 – 0.22)
	C_1	0.15 (0.09 – 0.21)	0.15 (0.09 – 0.22)
1999 RAPH	T_{LGR}	3.20 (2.81 – 3.58)	Same[1]
	T_0	2.72 (2.43 – 3.06)	2.80 (2.49 – 3.14)
	C_0	2.37 (2.03 – 2.76)	2.13 (1.82 – 2.51)
	C_1	1.63 (1.43 – 1.84)	1.69 (1.47 – 1.90)
1999 DWOR	T_{LGR}	1.26 (0.96 – 1.55)	Same[1]
	T_0	1.07 (0.85 – 1.33)	1.11 (0.88 – 1.37)
	C_0	1.20 (0.98 – 1.41)	1.09 (0.89 – 1.31)
	C_1	0.95 (0.82 – 1.10)	0.99 (0.85 – 1.15)
1999 LOOH	T_{LGR}	0.81 (0.57 – 1.06)	Same[1]
	T_0	0.68 (0.34 – 1.14)	0.69 (0.35 – 1.17)
	C_0	0.61 (0.37 – 0.82)	0.56 (0.34 – 0.75)
	C_1	0.57 (0.47 – 0.69)	0.58 (0.48 – 0.71)
2000 RAPH	T_{LGR}	2.34 (2.06 – 2.65)	Same[1]
	T_0	2.10 (1.87 – 2.33)	2.15 (1.89 – 2.36)
	C_0	1.59 (1.34 – 1.83)	1.51 (1.30 – 1.83)
	C_1	1.35 (1.06 – 1.69)	1.37 (1.07 – 1.70)
2000 DWOR	T_{LGR}	1.18 (0.96 – 1.41)	Same[1]
	T_0	1.00 (0.86 – 1.16)	1.04 (0.87 – 1.19)
	C_0	1.01 (0.84 – 1.20)	0.94 (0.79 – 1.20)
	C_1	0.85 (0.60 – 1.11)	0.87 (0.62 – 1.14)

[1] Same value shown in CJS Survival column since no estimate of survival is required to expanded to LGR equivalents at LGR itself.

Table 16. Estimated SAR (LGR-to-LGR in percentages) of PIT tagged hatchery summer chinook for each study category for migration years 1997 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year & Hatchery	Study category	Estimated SAR (LGR-to-LGR) percentages based on two approaches to estimating in-river survival	
		CJS Survival	Wt Mean Survival
1997 MCCA	T_{LGR}	1.15 (1.12 – 1.81)	Same[1]
	T_0	1.86 (1.09 – 2.90)	1.90 (1.09 – 2.84)
	C_0	1.09 (0.86 – 1.37)	1.07 (0.85 – 1.51)
	C_1	1.10 (0.88 – 1.32)	1.11 (0.84 – 1.29)
1997 IMNA	T_{LGR}	1.21 (0.75 – 1.73)	Same[1]
	T_0	0.75 (0.46 – 1.06)	0.74 (0.44 – 1.02)
	C_0	0.86 (0.50 – 1.28)	0.90 (0.52 – 2.55)
	C_1	0.69 (0.44 – 0.98)	0.67 (0.38 – 0.93)
1998 MCCA	T_{LGR}	2.93 (2.60 – 3.29)	Same[1]
	T_0	1.95 (1.65 – 2.33)	1.98 (1.67 – 2.36)
	C_0	1.38 (1.03 – 1.75)	1.24 (0.92 – 1.58)
	C_1	0.73 (0.58 – 0.87)	0.75 (0.60 – 0.90)
1998 IMNA	T_{LGR}	0.92 (0.65 – 1.23)	Same[1]
	T_0	0.69 (0.43 – 0.97)	0.70 (0.44 – 0.99)
	C_0	0.55 (0.25 – 0.90)	0.51 (0.22 – 0.83)
	C_1	0.30 (0.17 – 0.45)	0.31 (0.18 – 0.46)
1999 MCCA	T_{LGR}	4.36 (3.80 – 4.94)	Same[1]
	T_0	3.58 (3.07 – 4.21)	3.69 (3.13 – 4.31)
	C_0	2.40 (2.09 – 2.73)	2.22 (1.91 – 2.63)
	C_1	2.05 (1.79 – 2.32)	2.13 (1.84 – 2.41)
1999 IMNA	T_{LGR}	3.43 (2.67 – 4.26)	Same[1]
	T_0	2.52 (2.01 – 3.13)	2.54 (2.01 – 3.14)
	C_0	1.43 (1.01 – 1.87)	1.38 (0.99 – 2.03)
	C_1	1.22 (0.92 – 1.51)	1.23 (0.91 – 1.52)
2000 MCCA	T_{LGR}	4.54 (4.12 – 5.01)	Same[1]
	T_0	3.86 (3.53 – 4.21)	3.70 (3.05 – 4.18)
	C_0	2.05 (1.80 – 2.30)	2.19 (1.83 – 3.15)
	C_1	2.05 (1.63 – 2.49)	1.98 (1.50 – 2.42)
2000 IMNA	T_{LGR}	3.99 (3.34 – 4.63)	Same[1]
	T_0	3.13 (2.70 – 3.61)	3.27 (2.59 – 3.67)
	C_0	2.41 (1.95 – 2.89)	2.20 (1.85 – 3.41)
	C_1	1.64 (1.13 – 2.20)	1.70 (1.17 – 2.28)

[1] Same value shown in CJS Survival column since no estimate of survival is required to expanded to LGR equivalents at LGR itself.

stocks that migrated in 1999 (Table 15) and for summer stocks that migrated in 1999 and 2000 (Table 16). The SARs computed using the direct CJS in-river seasonal survival estimates and the weighted mean of subcohort CJS in-river survival estimates are very similar for the hatchery chinook, just as they were for the wild chinook. This is because most deviations between the two methods of estimating survival occur in the reaches below LMN tailrace, a problem that has little impact on the LGR-to-LGR SARs.

From 1998 to 2000 the LGR-to-LGR SAR's for Rapid River Hatchery spring chinook generally were higher than the SAR's for spring chinook from Dworshak and Lookingglass hatcheries, and these differences were significant for Rapid River Hatchery spring chinook in the T_{LGR}, T_0, and C_0 categories in 1999 and 2000 (Table 15). In addition, Rapid River Hatchery spring chinook had significantly higher SARs for fish transported at LGR (SAR(T_{LGR}) > 3% in 1999) than the in-river Category C_0 fish that mimicked the untagged in-river migrants in 1998 to 2000. The transportation SAR dropped when LGS and LMN were added, partly due to bias from low sample sizes causing dam-specific SARs estimates of zero for some hatcheries in the early years and partly due to the trend across years of generally lower dam-specific SARs from Little Goose and Lower Monumental dams compared to Lower Granite Dam. In each year that Lookingglass Hatchery spring chinook were being released, the SARs from that facility were lowest (but not always significantly different) of the three spring chinook hatcheries. Of these three spring chinook hatcheries, the fish from Dworshak Hatchery had SARs that were most similar in magnitude (around 1%) between transported (T_{LGR} or T_0 groups) and the in-river category C_0 fish (Table 15). PIT tagged spring chinook from Dworshak and Lookingglass hatcheries migrated past Lower Granite Dam earlier than their Rapid River Hatchery counterparts in 1997 to 2000. The later migration period of Rapid River Hatchery spring chinook may contribute to their higher transportation SARs, as this same pattern was observed with the two summer chinook stocks.

Summer chinook from McCall Hatchery had significantly higher SARs for fish transported at LGR [SAR(T_{LGR}) > 4% in 1999 and 2000] than the in-river category C_0 fish that represented the untagged in-river migrants in 1998 to 2000 (Table 16). These differences for McCall Hatchery summer chinook were also significant between the total transport T_0 category fish in 1999 and 2000 when larger numbers of PIT tagged smolts were transported from LGS and LMN than in the previous two years. As smolts, the McCall Hatchery fish have the latest passage timing distribution of any of the hatcheries used in the CSS through 2000. Likewise, in 1999 and 2000 the summer chinook from Imnaha AP had significantly higher SARs for fish transported at LGR than for fish in the in-river category C_0, whereas in 1998 the difference was not significant. Imnaha AP summer chinook migrated past Lower Granite Dam as smolts at a time similar to that of the Rapid River Hatchery spring chinook smolts.

The number of smolts PIT tagged at each hatchery was set to fixed numbers regardless of size of the hatchery production starting in1998 to ensure similar numbers of PIT tagged smolts at each hatchery. The factor P_h is the proportion of PIT tags in population released from the h^{th} hatchery. Dividing the number of PIT tags detected at the various dams by P_h provides an estimate of the total population of that particular hatchery collected at the various dams. In a similar manner, dividing the number of PIT tagged smolts in categories T_{LGRh}, T_{0h}, C_{0h}, and C_{1h} by ?$_h$ for the h^{th} hatchery (found in Tables 11, 13, and 14) provides an estimate of the total number of tagged and untagged smolts from that hatchery in those categories. Considering each hatchery as a stratum, the seasonal average SAR across a set of hatcheries utilizes the populations (T_{0h}/P_h), (C_{0h}/P_h), and (C_{1h}/P_h) as the proper stratum weights for the h^{th} hatchery. The values of P_h for each hatchery across migration years 1997 to 2000 are presented in Table 17.

Table 17. Proportion of PIT tags in hatchery release number (P_h) for CSS hatchery groups migrating in 1997 to 2000.

Hatchery	Migration Year	Hatchery Release	Number of PIT Tags Released	Proportion of PIT tags in hatchery release (P_h)
Rapid River H (RAPH)	1997	85,838	40,452	0.4713
	1998	896,170	48,336	0.0539
	1999	2,847,283	47,812	0.0168
	2000	2,462,354	47,747	0.0194
Dworshak H (DWOR)	1997	53,078	14,080	0.2653
	1998	973,400	47,703	0.0490
	1999	1,044,511	47,845	0.0458
	2000	1,017,873	47,743	0.0469
Lookingglass H (LOOH)	1997	153,478	40,027	0.2608
	1998	295,559	44,232	0.1497
	1999	312,145	44,551	0.1427
McCall H (MCCA)	1997	239,647	52,652	0.2197
	1998	393,872	47,340	0.1202
	1999	1,143,083	47,985	0.0420
	2000	1,039,930	47,705	0.0459
Imnaha AP (IMNA)	1997	50,911	13,378	0.2628
	1998	93,108	19,825	0.2129
	1999	184,725	19,939	0.1079
	2000	179,797	20,819	0.1158

Migration years 1999 and 2000 stood out as having the highest seasonal SARs across the four key hatcheries in all four years (Table 18). Lookingglass Hatchery was not considered in any of the averages shown in Table 18 because the Rapid River stock of fish used at Lookingglass Hatchery always had very low SARs relative to the other stocks and production at Lookingglass Hatchery was dropped after 1999 by ODFW in favor of more endemic stocks to the Grande Ronde River basin. The summary data in Table 18 used the SARs computed with the CJS Survival Method with data from Tables 15 and 16. The strata weighted seasonal means were most influenced by the large production hatcheries such as Rapid River and least influenced by the relatively small hatchery production at Imnaha River AP. Therefore, an unweighted mean is also presented in Table 18. Although year-to-year differences between the weighted and unweighted mean SAR for each study category occurred, the overall 4-year geometric mean for each study category showed similar results for weighted and unweighted SAR data. The overall mean SAR across four years for the combined Rapid River, Dworshak, McCall, and Imnaha River hatcheries was about 60% for fish transported from LGR than the fish undetected at a transportation site and remaining in-river below LMN. The overall mean SAR across these same years and combined stocks was about 25% lower for those fish having one or more detections at a transportation site before remaining in-river below LMN than those in-river migrants not detected at a transportation site in the Snake River.

Table 18. Seasonal stratified (hatchery population) weighted mean SAR and seasonal arithmetic mean SAR of the four CSS hatcheries used in migration years 1997 to 2000.

Migration Year	Composite Rapid River, Dworshak, McCall, and Imnaha hatcheries[1]							
	Strata weighted mean SAR				Arithmetic mean SAR			
	T_{LGR}	T_0	C_0	C_1	T_{LGR}	T_0	C_0	C_1
1997	1.06	N/A[2]	0.86	0.81	0.94	N/A[2]	0.67	0.66
1998	1.71	N/A	1.23	0.76	1.74	N/A	1.10	0.65
1999	3.43	2.52	1.43	1.22	3.06	2.47	1.85	1.46
2000	2.57	2.22	1.59	1.38	3.01	2.57	1.77	1.47
geometric mean	2.00	N/A	1.24	1.01	1.97	N/A	1.25	0.98

[1] Lookingglass Hatchery is not included since its stock was discontinued by ODFW in 2000 as the hatchery program began shifting toward rearing endemic stocks only.
[2] Not applicable due to potential bias from few smolts transported from LGS and LMN in 1997 and 1998.

The four-year geometric mean SARs for the individual four key CSS hatchery stocks show that McCall Hatchery had the highest mean SARs and Dworshak Hatchery had the lowest mean SARs in each of the three study groups shown in Table 19. Although the 4-year geometric mean SARs differ greatly between the McCall and Dworshak hatcheries, there was a similar trend across study categories that emerged for all four hatcheries. For each of the four hatcheries in Table 18, the geometric mean SAR of fish transported from LGR was the highest, followed by the geometric mean SAR of fish in Category C_0, and lastly by the geometric mean SAR of fish in Category C_1. Because of the previously discussed biases that could occur in the 1997 and 1998 estimates of SAR(T_0), no four-year geometric mean was computed for Category T_0.

Table 19. Hatchery-specific geometric mean of SARs for migration years 1997 to 2000.

		4-yr geometric mean (1997 – 2000) SAR		
Hatchery	**Stock**	T_{LGR}	C_0	C_1
Rapid River H	Spring	1.67	1.02	0.82
Dworshak H	Spring	0.90	0.77	0.57
McCall H	Summer	2.66	1.51	1.23
Imnaha AP	Summer	1.86	1.07	0.77
Arithmetic mean		1.77	1.09	0.85

The trend in SARs across study groups for hatchery chinook was different from the trend in SARs observed for wild chinook (Table 20). Migration years 1998 to 2000 had high adult return numbers for both wild and hatchery chinook stocks, which allowed us to look for similarities and differences in the pattern of SARs across the study categories for these two rearing types. The pattern of SAR(T_{LGR}) > SAR(C0) > SAR(C1) observed for the hatchery chinook was not seen with the wild chinook. For wild chinook the pattern looked more like SAR(C_0) > SAR(C_1) = SAR(T_{LGR}). These 3-year average patterns do not necessarily represent statistical equivalence or differences, but simply trends in the SARs across study categories. If these patterns persist in future years, it may indicate that one should not use hatchery stocks to project how SARs for wild stocks may change through the various routes of hydro system passage.

Table 20. Seasonal SARs of wild chinook versus weighted seasonal SARs of hatchery chinook in migration years 1998 to 2000.

Migration Year	Seasonal SARs for wild chinook[1]			Weighted Seasonal SARs for hatchery chinook[2]		
	T_{LGR}	C_0	C_1	T_{LGR}	C_0	C_1
1998	1.34	1.36	1.08	1.71	1.23	0.76
1999	2.53	2.13	1.90	3.43	1.43	1.22
2000	1.22	2.37	2.33	2.57	1.59	1.38
geometric mean	1.61	1.90	1.68	2.47	1.41	1.09

[1] Data from Table 6 (CJS Survival column)
[2] Data from Table 18 (Strata mean SAR columns)

Like the wild chinook, there has been difficulty in directly estimating in-river survival for hatchery chinook below McNary Dam. Most deviations between the two methods of estimating survival occur in the reaches below LMN tailrace. This impacts the calculation of a reliable in-river survival component V_c, which is needed to obtain the BON-to-LGR SARs that are integral to the calculation of *D*. Direct estimates of in-river survival to John Day Dam tailrace were made for each hatchery except Imnaha AP in migration year 1999, while in migration years 1998 and 2000 the in-river estimates were made for all hatcheries to McNary Dam tailrace (individual reach survival estimates are presented in Appendix A-2 to A-6 for the five hatcheries). In 1997, the lack of trawl detections and limited detection capability at John Day Dam resulted few detections in the lower Columbia River and the direct estimation of in-river survival being made consistently across all hatcheries only to Lower Monumental Dam tailrace. All expansions to Bonneville Dam were based on a per-mile survival rate.

The number of PIT tagged fish detected at the lower dams limited the number of reaches for which we could directly estimate in-river survival components (S_j), and this number was related to how many fish were available at Lower Granite Dam for estimation purposes. With the weighted mean method (sub-cohorts approach), only PIT tagged fish detected at LGR are used. This is a subset of the full population of detected and undetected (but alive) PIT tagged fish at LGR used in the full sample CJS method (Table 21). Differences in the PIT tagged population available for estimating in-river survival components between the two approaches can be seen by comparing the combined number of smolts in categories C_0 and C_1 (available for full sample CJS survivals) with one-third of the total number of smolts returned-to-river at Lower Granite Dam (available for each sub-cohort in the weighted mean CJS survival method). As shown in Table 21, an individual sub-cohort will have 91 – 98% fewer PIT tagged fish available for survival estimation than would the full sample approach.

Because of the large differences in numbers of PIT tagged hatchery chinook available for estimation purposes between the two methodologies, there existed large differences in the computed estimates of *D* using the two methods for both spring stocks (Table 22) and summer stocks (Table 23). Confidence intervals of *D* from these two methods were very wide and showed considerable overlap across hatcheries and years in most cases. In spite of the low precision of estimated *D*, there was the pattern of a higher estimated *D* for summer chinook than occurs for spring chinook. For the spring chinook hatcheries used in all four migration years 1997 to 2000 (Rapid River and Dworshak hatcheries in Table 22), a 4-year geometric mean of *D* was 0.62 using the full CJS

Table 21. Reduction in numbers of PIT tagged smolts available for inriver reach survival estimation with the sub-cohort approach (utilizes only fish detected and returned-to-river at Lower Granite Dam) compared to the full sample approach (utilizes all fish from the Lower Granite Dam estimated population).

Hatchery	Survival method	1997	1998	1999	2000
RAPH	Full sample CJS	11,019	17,999	21,496	16,290
	Sub-cohorts CJS	324	1,613	794	1,396
	Percent fewer fish used in survival estimation with subcohort method	97%	91%	96%	91%
DWOR	Full sample CJS	6,142	24,279	29,565	18,491
	Sub-cohorts CJS	151	1,317	505	1,253
	Percent fewer fish used in survival estimation with subcohort method	98%	95%	98%	93%
LOOH	Full sample CJS	17,473	17,383	22,472	N/A
	Sub-cohorts CJS	493	1,388	538	
	Percent fewer fish used in survival estimation with subcohort method	97%	92%	98%	
MCCA	Full sample CJS	16,033	16,665	19,798	17,545
	Sub-cohorts CJS	466	1,245	587	1,099
	Percent fewer fish used in survival estimation with subcohort method	97%	93%	97%	94%
IMNA	Full sample CJS	6,004	8,330	7,953	6,650
	Sub-cohorts CJS	161	625	239	557
	Percent fewer fish used in survival estimation with subcohort method	97%	92%	97%	92%

survival data in V_C and V_T and 0.45 using the weighted mean survival data in V_C and V_T. For the summer chinook hatcheries used in migration years 1997 to 2000 (Table 23), a 4-year geometric mean of *D* was 0.84 using the full CJS survival data in V_C and V_T and 0.78 using the weighted mean survival data in V_C and V_T. Because of the low number of PIT tagged smolts available by the subcohort method, calculation of *D* using the full CJS survival data would be considered more reliable based on the narrower 95% confidence interval. Because importance of the V_C estimate in computations of *D*, we will be exploring the utility of using additional PIT tag detection data from Rice and East Sand island's bird colonies as another detection site below Bonneville Dam in addition to the trawl site. This approach appears promising based on results in estimating Carson Hatchery spring chinook survival to Bonneville Dam shown in Chapter 3 of this report. At this time, the relatively low hatchery chinook PIT tag detections in the lower Columbia River have made it difficult to reliably estimate V_C and therefore *D*.

Just as was noted for the wild chinook, obtaining T/I ratios below 2 was further evidence of the presence of delayed mortality in transported PIT tagged hatchery chinook smolts after release below Bonneville Dam. The 4-year geometric mean of the T/I ratio for spring chinook was 1.18 using the full CJS survival data and 1.21 using the weighted mean survival data (Table 22). The 4-year geometric mean of the T/I ratio for summer chinook was 1.42 using the full CJS survival data and 1.49 using the weighted mean survival data (Table 23). Regardless of which in-river survival data was used in the T/I estimation for the individual hatcheries that comprised the spring and summer stocks, Rapid River Hatchery spring chinook had higher T/I ratios than Dworshak Hatchery spring chinook in all four years, and McCall Hatchery summer chinook had higher T/I ratios than Imnaha AP summer chinook in 3 of the 4 migration years.

Table 22. Estimated in-river survival LGR to BON (V_C), SAR(T_0)/SAR(C_0) ratio, and *D* value of PIT tagged hatchery spring chinook from migration years 1997 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year & Hatchery	Estimated parameter	Estimated V_C, T/I ratio, and *D* using two estimates of in-river survival	
		CJS Survival	Wt Mean Survival
1997 RAPH	V_C	0.33 (0.23 – 0.46)	0.39 (0.10 – 0.85)
	T/I	1.80 (0.72 – 4.57)	1.56 (0.39 – 3.89)
	D	0.63 (0.23 – 1.72)	0.30 (0.01 – 1.88)
1997 DWOR	V_C	0.49 (0.28 – 0.84)	0.18 (0.0 – 2.10)
	T/I	1.09 (0.54 – 2.45)	1.01 (0.0 – 2.19)
	D	0.55 (0.22 – 1.48)	0.21 (0.0 – 3.42)
1997 LOOH	V_C	0.31 (0.24 – 0.40)	0.17 (0.06 – 0.31)
	T/I	0.69 (0.25 – 1.55)	0.59 (0.18 – 1.22)
	D	0.23 (0.08 – 0.52)	0.11 (0.02 – 0.28)
1998 RAPH	V_C	0.69 (0.62 – 0.78)	0.56 (0.39 – 0.73)
	T/I	1.40 (1.04 – 1.96)	1.46 (1.09 – 2.03)
	D	1.01 (0.74 – 1.43)	0.85 (0.53 – 1.29)
1998 DWOR	V_C	0.58 (0.52 – 0.63)	0.48 (0.27 – 0.63)
	T/I	0.58 (0.45 – 0.75)	0.54 (0.42 – 0.69)
	D	0.34 (0.27 – 0.45)	0.27 (0.15 – 0.38)
1998 LOOH	V_C	0.47 (0.41 – 0.53)	0.49 (0.30 – 0.64)
	T/I	3.88 (1.67 – 13.0)	4.30 (1.87 – 14.6)
	D	1.91 (0.82 – 6.43)	2.16 (0.76 – 7.30)
1999 RAPH	V_C	0.69 (0.63 – 0.77)	0.49 (0.22 – 0.87)
	T/I	1.15 (0.93 – 1.39)	1.32 (1.06 – 1.59)
	D	0.86 (0.69 – 1.06)	0.68 (0.29 – 1.22)
1999 DWOR	V_C	0.58 (0.54 – 0.64)	0.57 (0.28 – 0.77)
	T/I	0.90 (0.69 – 1.20)	1.02 (0.75 – 1.38)
	D	0.59 (0.44 – 0.80)	0.63 (0.30 – 0.97)
1999 LOOH	V_C	0.56 (0.52 – 0.61)	0.51 (0.30 – 0.70)
	T/I	1.12 (0.53 – 2.23)	1.23 (0.59 – 2.48)
	D	0.68 (0.32 – 1.35)	0.67 (0.27 – 1.46)
2000 RAPH	V_C	0.61 (0.53 – 0.70)	0.64 (0.04 – 0.84)
	T/I	1.32 (1.10 – 1.60)	1.42 (1.12 – 1.70)
	D	0.86 (0.69 – 1.06)	0.95 (0.07 – 1.24)
2000 DWOR	V_C	0.48 (0.42 – 0.55)	0.30 (0.02 – 0.53)
	T/I	0.99 (0.80 – 1.24)	1.11 (0.79 – 1.36)
	D	0.53 (0.42 – 0.67)	0.36 (0.02 – 0.65)
4-yr Geometric Mean (combined RAPH & DWOR)[1]	T/I	1.18	1.21
	D	0.62	0.45

[1] Lookingglass Hatchery chinook not included since only available for 3 years.

Table 23. Estimated in-river survival LGR to BON (V_C), SAR(T_0)/SAR(C_0) ratio, and *D* value of PIT tagged hatchery summer chinook from migration years 1997 to 2000. Bootstrap 95% confidence intervals are shown in parenthesis.

Migration Year & Hatchery	Estimated parameter	Estimated V_C, T/I ratio, and *D* using two estimates of in-river survival	
		CJS Survival	Wt Mean Survival
1997 MCCA	V_C	0.43 (0.30 – 0.63)	0.41 (0.08 – 0.92)
	T/I	1.72 (0.95 – 2.80)	1.77 (0.87 – 2.74)
	D	0.79 (0.38 – 1.44)	0.76 (0.10 – 1.98)
1997 IMNA	V_C	0.31 (0.19 – 0.51)	0.37 (0.02 – 1.54)
	T/I	0.87 (0.47 – 1.72)	0.83 (0.21 – 1.50)
	D	0.29 (0.13 – 0.68)	0.33 (0.01 – 1.39)
1998 MCCA	V_C	0.61 (0.54 – 0.70)	0.68 (0.49 – 0.88)
	T/I	1.41 (1.06 – 2.02)	1.60 (1.19 – 2.33)
	D	0.91 (0.67 – 1.32)	1.12 (0.69 – 1.77)
1998 IMNA	V_C	0.62 (0.53 – 0.72)	0.99 (0.55 – 1.35)
	T/I	1.25 (0.63 – 2.93)	1.37 (0.69 – 3.33)
	D	0.81 (0.40 – 1.95)	1.41 (0.59 – 3.26)
1999 MCCA	V_C	0.80 (0.71 – 0.92)	0.80 (0.26 – 1.08)
	T/I	1.49 (1.23 – 1.85)	1.66 (1.29 – 2.08)
	D	1.31 (1.03 – 1.68)	1.42 (0.43 – 2.05)
1999 IMNA	V_C	0.59 (0.52 – 0.67)	0.44 (0.20 – 0.64)
	T/I	1.76 (1.22 – 2.66)	1.84 (1.12 – 2.84)
	D	1.13 (0.77 – 1.74)	0.88 (0.33 – 1.47)
2000 MCCA	V_C	0.67 (0.57 – 0.79)	0.25 (0.03 – 0.50)
	T/I	1.88 (1.63 – 2.21)	1.69 (0.98 – 2.21)
	D	1.36 (1.11 – 1.70)	0.48 (0.04 – 1.00)
2000 IMNA	V_C	0.53 (0.42 – 0.70)	0.36 (0.02 – 0.59)
	T/I	1.30 (1.02 – 1.67)	1.49 (0.79 – 1.80)
	D	0.76 (0.57 – 1.06)	0.56 (0.02 – 0.93)
4-yr Geometric Mean (combined MCCA & IMNA)	T/I	1.42	1.49
	D	0.84	0.78

SUMMARY AND CONCLUSIONS

- Early indication from the CSS evaluations of SARs for wild chinook and hatchery chinook suggest that hatchery chinook may not be an adequate surrogate for wild chinook with regard to SARs based on route of passage through the hydro system. However, we are only comparing 4 years of complete returns with information that is, due to the low numbers of adult returns of wild chinook, is highly variable.

- With hatchery chinook, there appears to be hatchery-specific differences in LGR-LGR smolt-to-adult survival rates (SARs), with Dworshak and Lookingglass Hatchery spring chinook consistently had lower SARs and McCall Hatchery summer chinook consistently had the highest SARs among the CSS hatcheries.

- Yearling chinook from Rapid River, Imnaha, and McCall hatcheries had higher LGR-LGR SARs for fish transported from Lower Granite Dam than for those that migrated in-river through the hydro system, and most of these differences were statistically significant between 1998 and 2000. Estimated SARs of hatchery smolts transported from Little Goose and Lower Monumental dams may be similar or lower than smolts transported from Lower Granite Dam, but the data is inconclusive since total season transportation of CSS PIT tagged fish from the dams did not start until 2000.

- Yearling chinook from Dworshak Hatchery transported from Lower Granite Dam had relatively similar LGR-LGR SARs compared to those that migrated in-river through the hydro system. There were year-to-year variations, but no significant differences within years between migration routes for these fish.

- Evidence of delayed mortality of transported hatchery chinook smolts exists since T/I ratios seldom exceed 2.0 and averaged around 1.2 for spring stocks and 1.4 for summer stocks over the years 1997 to 2000. Precise estimation of *D*, a parameter that reflects the magnitude of delayed mortality due to transportation relative to in-river migration, has proven difficult due to imprecision in estimating in-river survival below McNary Dam to Bonneville Dam.

- Likewise, evidence of delayed mortality of transported wild chinook smolts exists since T/I ratios seldom exceed 2.0 and averaged around 1.1 over the years 1994 to 2000. Precise estimation of *D* has proven difficult due to imprecision in estimating in-river survival below McNary Dam to Bonneville Dam.

- There is an emerging pattern of lower SARs for wild and hatchery chinook that are detected in the bypass at Lower Granite, Little Goose, or Lower Monumental Dam and returned-to-river (Category C_1) compared to the chinook that pass those three dams undetected through the combined routes of spill and turbines (Category C_0). Although many of these differences were not statistically significant, an emerging pattern among the point estimates was evident.

- The precision of estimated SARs of transported and in-river migrating wild chinook was low due to low numbers of PIT tagged smolts in the two key study groups of interest, namely Category T_0 and Category C_0. Most PIT tagged wild chinook occurred in Category C_1 in 1994 to 2000 due to the standard protocol of routing all detected PIT tagged wild (and most hatchery) smolts back to the river in those years.

- We found that the use of hydro system reach survival estimates derived from the full population of interest arriving at Lower Granite Dam is superior to the method of using only those fish detected at Lower Granite Dam and then partitioned into a series of temporal sub-cohorts. In the reaches from Lower Granite Dam tailrace to Lower Monumental Dam tailrace both methods work well, however in the reaches below Lower Monumental Dam, the utility of the sub-cohorts method is diminished due to problems associated with small sample size.

- Because of PIT tag diversion operations at the dams in past years, there have been very few PIT tagged wild chinook released in locations above Lower Granite Dam that actually were transported. In 2002, several fishery agencies and tribes have allowed the CSS to purposely route a portion of their PIT tagged wild chinook to transportation at the dams. This will greatly improve our ability make statistical comparisons between the SARs of transported and in-river migrating wild chinook in the future.

REFERENCES

Berggren, Tom – Fish Passage Center, Nick Bouwes – Eco Logical Research, Howard Schaller, Paul Wilson – USFWS, Charlie Petrosky – IDFG, Earl Weber – CRITFC, Shane Scott – WDFW, Ron Boyce – ODFW. 2002. Comparative Survival Rate Study (CSS) 2002 Design and Analysis Report, Report to Bonneville Power Administration, Contract No. 00006203, Project No. 199602000, 34 electronic pages (BPA Report DOE/BP-00006203-3)

Nick Bouwes – Eco Logical Research, Charlie Petrosky – IDFG, Howard Schaller, Paul Wilson – USFWS, Earl Weber – CRITFC, Shane Scott – WDFW, Ron Boyce – ODFW. 2002. Comparative Survival Rate Study (CSS) of Hatchery PIT tagged Chinook, Status Report for Migration Years 1997–2002 Mark/Recapture Activities, 2001 Annual Report, Report to Bonneville Power Administration, Contract No. 00006203, Project No. 199602000, 100 electronic pages (BPA Report DOE/BP-00006203-2)

Cormack, R.M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429-438.

Efron, B. and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman & Hall, NY.

Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration – stochastic model. Biometrik 52: 225-247.

Sandford, B.P., and S.G. Smith. 2001. Estimation of Smolt-to-Adult Return Percentages for Snake River Basin Anadromous Salmonids, 1990-1997. Journal of Agricultural, Biological, and Environmental Statistics.

Seber, G.A.F. 1965. A note on the multiple-recapture census. Biometrika 52: 249-259.

Chapter 1

APPENDIX A

Reach Survival Estimates
Using the Full Sample and Sub-Cohorts Approaches

Appendix Table A-1. Estimates of in-river survival rates of PIT tagged wild chinook smolts for migration years 1994 to 2000 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1994	S2 (lgr-lgs)	0.822	0.799	0.847	0.890	0.858	0.918
	S3 (lgs-lmn)	0.837	0.810	0.869	0.881	0.834	0.926
1995	S2 (lgr-lgs)	0.895	0.880	0.910	0.934	0.913	0.954
	S3 (lgs-lmn)	0.951	0.926	0.978	0.916	0.872	0.949
	S4 (lmn-mcn)	0.764	0.658	0.930	0.914	0.627	1.185
1996	S2 (lgr-lgs)	0.908	0.869	0.948	0.976	0.906	1.049
	S3 (lgs-lmn)	0.911	0.852	0.976	0.848	0.618	0.992
1997	S2 (lgr-lgs)	0.922	0.863	0.990	0.931	0.824	1.030
	S3 (lgs-lmn)	0.931	0.826	1.060	0.876	0.626	1.092
1998	S2 (lgr-lgs)	1.003	0.984	1.020	0.979	0.957	0.999
	S3 (lgs-lmn)	0.850	0.823	0.876	0.854	0.818	0.887
	S4 (lmn-mcn)	0.940	0.890	0.994	0.934	0.847	1.014
	S5 (mcn-jda)	0.855	0.763	0.978	0.736	0.563	0.904
1999	S2 (lgr-lgs)	0.958	0.948	0.967	0.965	0.953	0.975
	S3 (lgs-lmn)	0.924	0.913	0.935	0.912	0.891	0.933
	S4 (lmn-mcn)	0.889	0.869	0.911	0.909	0.866	0.954
	S5 (mcn-jda)	0.889	0.850	0.925	0.872	0.780	0.947
2000	S2 (lgr-lgs)	0.898	0.880	0.915	0.951	0.921	0.977
	S3 (lgs-lmn)	0.867	0.845	0.892	0.886	0.835	0.928
	S4 (lmn-mcn)	0.977	0.933	1.024	0.977	0.893	1.048
	S5 (mcn-jda)	0.734	0.675	0.805	0.812	0.677	0.931

Appendix Table A-2. Estimates of in-river survival rates of PIT tagged Rapid River Hatchery chinook smolts for migration years 1997 to 2000 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1997	S2 (lgr-lgs)	0.964	0.907	1.022	0.939	0.817	1.043
	S3 (lgs-lmn)	0.803	0.750	0.859	0.715	0.413	0.999
1998	S2 (lgr-lgs)	1.005	0.988	1.024	0.998	0.873	1.027
	S3 (lgs-lmn)	0.847	0.823	0.871	0.913	0.858	0.961
	S4 (lmn-mcn)	0.982	0.929	1.042	0.825	0.692	0.951
1999	S2 (lgr-lgs)	0.923	0.902	0.946	0.961	0.930	0.993
	S3 (lgs-lmn)	0.957	0.935	0.976	0.968	0.896	1.029
	S4 (lmn-mcn)	0.906	0.875	0.940	0.855	0.748	0.960
	S5 (mcn-jda)	0.945	0.878	1.021	0.737	0.406	1.148
2000	S2 (lgr-lgs)	0.846	0.812	0.883	0.903	0.813	0.972
	S3 (lgs-lmn)	1.127	1.014	1.273	1.145	0.736	1.436
	S4 (lmn-mcn)	0.823	0.720	0.931	0.776	0.241	1.037

Appendix Table A-3. Estimates of in-river survival rates of PIT tagged Dworshak Hatchery chinook smolts for migration years 1997 to 2000 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1997	S2 (lgr-lgs)	1.047	0.967	1.135	1.114	0.869	1.299
	S3 (lgs-lmn)	0.810	0.725	0.910	0.618	0.231	1.164
1998	S2 (lgr-lgs)	1.071	1.044	1.100	1.016	0.969	1.056
	S3 (lgs-lmn)	0.765	0.740	0.790	0.806	0.724	0.875
	S4 (lmn-mcn)	0.931	0.887	0.975	0.852	0.672	0.996
1999	S2 (lgr-lgs)	0.887	0.857	0.914	0.947	0.902	0.986
	S3 (lgs-lmn)	0.952	0.935	0.968	0.883	0.779	0.984
	S4 (lmn-mcn)	0.875	0.849	0.902	0.852	0.643	0.970
	S5 (mcn-jda)	0.899	0.847	0.956	0.911	0.608	1.171
2000	S2 (lgr-lgs)	0.807	0.778	0.838	0.881	0.778	0.948
	S3 (lgs-lmn)	1.036	0.953	1.128	1.035	0.684	1.386
	S4 (lmn-mcn)	0.834	0.756	0.924	0.610	0.184	0.864

Appendix Table A-4. Estimates of in-river survival rates of PIT tagged Lookingglass Hatchery chinook smolts for migration years 1997 to 1999 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1997	S2 (lgr-lgs)	0.951	0.906	0.998	0.920	0.826	1.003
	S3 (lgs-lmn)	0.804	0.763	0.847	0.725	0.564	0.836
1998	S2 (lgr-lgs)	0.983	0.962	1.006	0.999	0.962	1.034
	S3 (lgs-lmn)	0.815	0.789	0.846	0.892	0.816	0.955
	S4 (lmn-mcn)	0.860	0.806	0.916	0.789	0.624	0.919
1999	S2 (lgr-lgs)	0.934	0.912	0.955	0.954	0.926	0.993
	S3 (lgs-lmn)	0.951	0.936	0.966	0.955	0.896	1.017
	S4 (lmn-mcn)	0.831	0.807	0.859	0.759	0.646	0.875
	S5 (mcn-jda)	0.877	0.821	0.929	0.873	0.612	1.088

Appendix Table A-5. Estimates of in-river survival rates of PIT tagged McCall Hatchery chinook smolts for migration years 1997 to 2000 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1997	S2 (lgr-lgs)	0.935	0.885	0.991	0.968	0.850	1.064
	S3 (lgs-lmn)	0.882	0.813	0.961	0.841	0.578	1.050
1998	S2 (lgr-lgs)	0.991	0.974	1.012	0.993	0.969	1.034
	S3 (lgs-lmn)	0.843	0.821	0.866	0.943	0.877	1.006
	S4 (lmn-mcn)	0.942	0.885	1.006	0.885	0.746	0.988
1999	S2 (lgr-lgs)	0.908	0.880	0.938	0.939	0.894	0.988
	S3 (lgs-lmn)	0.936	0.909	0.963	0.969	0.828	1.081
	S4 (lmn-mcn)	0.913	0.875	0.955	0.771	0.620	0.928
	S5 (mcn-jda)	1.086	0.990	1.203	1.206	0.553	1.521
2000	S2 (lgr-lgs)	0.867	0.817	0.926	0.845	0.605	1.096
	S3 (lgs-lmn)	0.917	0.823	1.030	0.661	0.398	0.980
	S4 (lmn-mcn)	1.034	0.911	1.168	0.913	0.366	1.195

Appendix Table A-6. Estimates of in-river survival rates of PIT tagged Imnaha Hatchery chinook smolts for migration years 1997 to 2000 in the hydro system between the tailrace of Lower Granite Dam and the tailrace of the furthest downstream dam utilizing the full sample and sub-cohort weighted mean CJS methodologies.

Migr Year	Parameter	Full Sample CJS Estimates			SubCohort Wt Mean Estimates		
		Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI	Point Estimate	Bootstrap Lower CI	Bootstrap Upper CI
1997	S2 (lgr-lgs)	0.994	0.914	1.083	0.929	0.761	1.049
	S3 (lgs-lmn)	0.768	0.691	0.852	0.858	0.425	1.241
1998	S2 (lgr-lgs)	0.978	0.951	1.005	0.997	0.961	1.043
	S3 (lgs-lmn)	0.843	0.814	0.876	0.878	0.799	0.958
	S4 (lmn-mcn)	0.956	0.890	1.030	1.134	0.869	1.309
1999	S2 (lgr-lgs)	0.921	0.885	0.957	0.933	0.852	0.987
	S3 (lgs-lmn)	0.954	0.919	0.990	0.952	0.777	1.079
	S4 (lmn-mcn)	0.876	0.829	0.928	0.757	0.555	0.930
2000	S2 (lgr-lgs)	0.822	0.769	0.878	0.934	0.793	1.053
	S3 (lgs-lmn)	1.008	0.870	1.197	0.910	0.345	1.231
	S4 (lmn-mcn)	0.885	0.721	1.076	0.713	0.269	1.076

CHAPTER 2

Hatchery-to-hatchery smolt-to-adult survival rates for key upstream chinook hatcheries adjusted for harvest

METHODS AND RESULTS

Recovery activities at McCall, Imnaha, Lookingglass, Dworshak, and Rapid River hatcheries

The following sections provide a brief description of the adult sampling facilities and methods of handling the PIT tagged fish that return to hatcheries used consistently in the CSS program during migration years 1997 to 2000. Adult fish sampled at LGR trap or missed at that trap are free to continue migrating upstream to their hatchery release sites. The normal operation of a hatchery is to either sample fish as they arrive at the hatchery site (on a daily basis) or when a given number of fish enter the holding pond. During these sampling periods, fish are interrogated for presence of PIT tags and pertinent data is collected on these marked fish. Finally, the PIT tagged adult fish are spawned at the hatchery for the next brood cycle.

McCall Hatchery: South Fork Salmon Weir

IDFG operates the trapping facility on the South Fork Salmon River for collection of adult summer chinook broodstock for McCall Hatchery. Returning adult salmon migrate 522 kilometers up the Columbia River, then 303 kilometers up the Snake River and 215 kilometers up the Salmon River before turning off into the South Fork Salmon River. The adults continue to migrate 111 kilometers upstream to a weir that diverts them to a holding area. Total distance traveled is 1,151 kilometers (about 715 miles) from the ocean. Adult salmon are held at the South Fork site in ponds until spawned. Eggs are then transferred to McCall Hatchery for incubation and rearing until release as yearling chinook at the Knox Bridge site, located about one mile above the weir.

Returning PIT tagged adult McCall Hatchery summer chinook were detected at the Lower Granite Dam adult trap prior to arriving at the South Fork Salmon River weir site. In years of high flows, early returning adults could pass upstream of the weir site before the weir was installed. Weir installation was limited to when flows have receded to the point where IDFG could place the weir leads and pickets without being washed out. The dates given by the hatchery when the weir was installed for return years 1998, 1999, 2000, 2001, and 2002 were July 6, July 8, June 19, May 31, and June 26, respectively. The weir was set up in the main South Fork Salmon River and diverted all fish into a small fish ladder that led to a holding area, where IDFG personnel would process the adult fish. The holding tank has a floor that rises on a slant to where the fish can be netted and the sampling process initiated. Individual fish were held in the net until exhausted and then processed without use of any anesthetic bath. Normally, each adult fish had length recorded along with other pertinent data. All fish were scanned with a hand-held PIT tag detector to check for tags. In addition, those fish selected for broodstock received a second check for PIT tags as they passed through a flume with PIT tag detection coils installed to the holding ponds located adjacent to the trapping site. All recorded PIT tag information at the trapping site was eventually downloaded to the PTAGIS database for storage.

Imnaha River Acclimation Pond: Imnaha River Weir

ODFW operates an adult trapping facility and juvenile acclimation facility on the Imnaha River. Returning adult salmon migrate 522 kilometers up the Columbia River, then 308 kilometers up the Snake River and 74 kilometers up the Imnaha River to a weir that diverts adults to a holding area. Total distance traveled is 904 kilometers (about 562 miles) from the ocean. Adult spring/summer chinook were trapped at this facility for collection of Imnaha River chinook broodstock for Lookingglass Hatchery. Adult salmon were transferred from holding ponds by truck to Lookingglass Hatchery where they were later spawned. The eggs were incubated and the fry reared until yearling age at Lookingglass hatchery. These chinook were then transported back to the Imnaha River site and released after an acclimation time of about one month.

Returning PIT tagged adult Imnaha summer chinook were detected at the Lower Granite Dam adult trap prior to arriving at the Imnaha weir site. Normally, most Imnaha stock chinook pass LGR in June. The dates that hatchery personnel installed the Imnaha River weir for return years 1998, 1999, 2000, 2001, and 2002 were July 6, July 21, July 12, June 5, and July 11, respectively. The weir was normally placed in the Imnaha River after flows receded to the point that the anchors and weir sections could be installed without washing out. However, ODFW estimated that up to 40% of the chinook could pass upstream of the weir prior to its installation in some years.[1]

Once the weir had been set in the river, all fish had to pass through a small fish ladder that led to a holding area. ODFW personnel would begin sampling the adult fish based on numbers of fish in the holding area. When sampling occurred, fish in the holding area were crowded to an enclosed area (elevator) where they are lifted and shunted into tank containing a mixture of water and the anesthetic MS-222. As a rule, only 3 or 4 fish were placed into the anesthetic tank at a time. When individual fish were lethargic, ODFW hatchery personnel collected pertinent data such as length, sex of the animal, and mark information. Fish were then placed headfirst into an adult PIT tag detector to check for presence of a PIT tag. The sampler held the adult fish by the caudal peduncle and withdrew the fish from the detector after it had passed over the detection coils. The PIT tag code was then recorded along with the other data gathered for that fish. This information was eventually reported to the PTAGIS database for storage.

A predetermined percentage of the sampled fish was placed in the hatchery truck and hauled to Lookingglass Hatchery. Another percentage of the chinook was trucked to a site in the Imnaha basin and outplanted. The remaining percentage was shunted directly back to the river above the weir to spawn naturally in the Imnaha River.

Lookingglass Hatchery

Adult spring chinook returning to Lookingglass Hatchery were intercepted at the LGR adult trap and trucked to their final destination. Returning adult salmon migrate 522 kilometers up the Columbia River, then 173 kilometers up the Snake River to this collection site. Total distance traveled is 695 kilometers (about 432 miles) from the

[1] Personal Communication – Pat Keniry, ODFW, LaGrande, OR; May 2003.

ocean. Once collected at the LGR adult trap, the adults and jacks were trucked to either Lookingglass or Walla Walla hatcheries. The stock of fish used at Lookingglass Hatchery was originally Rapid River stock, but use of this stock by ODFW has now been shifted from the Grande Ronde River drainage to Walla Walla River. The smolts that outmigrated in 1999 were the last group of PIT tagged Lookingglass Hatchery fish available to the CSS program. Starting in 2001, the CSS began using spring chinook from Catherine Creek acclimation pond, an endemic stock from the Grande Ronde River basin. All PIT tagged spring chinook that were captured at LGR were entered into the PTAGIS database as recaptures. Along with the individual PIT tag code, these recaptured fish had sex, length, and other pertinent information also stored.

Dworshak National Fish Hatchery

Dworshak NFH annually produces juvenile spring chinook salmon (and summer steelhead) for release into the Clearwater River basin. Returning adult salmon migrate 522 kilometers up the Columbia River, then 224 kilometers up the Snake River and 65 kilometers up the Clearwater River before turning off into the North Fork Clearwater River and entering the hatchery ladder. Total distance traveled is 841 kilometers (about 523 miles) from the ocean. Normally, adult spring chinook pass LGR from late April to early June and enter the hatchery in June and July.

Returning PIT tagged adult Dworshak Hatchery spring chinook were detected at the Lower Granite Dam adult trap prior to final collection in the fish ladder on the North Fork Clearwater River that leads into the hatchery. The fish ladder was opened for return years 1998, 1999, 2000, 2001, and 2002 on May 21, June 3, June 15, June 12, and June 3, respectively. During the return years of 2000 through 2002, the Dworshak fish ladder was opened and closed by IDFG personal several times over the spring chinook salmon adult collection period (Table 24) in an attempt to manage the large number of returning adult fish. Fish were unable to enter the hatchery during times of non-operation of the fish ladder. This allowed tribal and sport fishermen a better opportunity to reduce the number of fish that the hatchery would have to sort through in excess of spawning requirements. Adult spring chinook salmon were held in the hatchery holding ponds until spawning occurred.

To sample the adult chinook, hatchery personnel crowded the fish at one end of the holding pond where the fish could enter an elevator system that lifted them to the sampling platform. Prior to being lifted, all fish were anesthetized using MS-222. Approximately 10 fish at a time were lifted to the sampling table where the data collection and inoculation of the fish occurred. Prior to spawning, all fish were checked by USFWS hatchery personnel to identify sex and verify that inoculations had occurred, and that pertinent data on fish length and marks had been recorded. From the sampling table, individual fish were shunted through a tunnel-style adult PIT tag detector containing two PIT tag coils. If an individual chinook had a PIT tag, then that PIT tag information was reported to the PTAGIS database for storage. All sampled fish were then placed into a pipe with flowing water that directed the fish to a separate holding pond for recovery. All mortalities from the holding ponds are checked for presence of PIT tags.

Table 24. Ladder operation[1] for returning adult spring chinook salmon at Dworshak NFH, return years 2000 to 2002.

Return Year	Date Opened	Date Closed	Number Trapped	Season Total
2000	June 15	June 16	28	
	June 19	June 20	400	
	June 28	June 30	400	
	July 5	Sept 18	2,374	3,202
2001	June 12	June 12	175	
	July 2	July 5	450	
	July 9 only, July 12	July 17	539	
	July 20	Sept 14	2,854	4,018
2002	June 3	June 7	255	
	June 27	July 3	386	
	July 16	Sept 12	1,516	2,157

[1] Source: DNFH – Production Narrative June-Sept, 2000-2002; IFRO – SCSent00-02.wk4.

Rapid River Hatchery

Rapid River Hatchery annually produces spring chinook salmon that are released directly from the hatchery ponds into Rapid River. Returning adult salmon migrate 522 kilometers up the Columbia River, then 303 kilometers up the Snake River and 140 kilometers up the Salmon River before turning off into the Little Salmon River for a 7 kilometer journey to the confluence with Rapid River. The hatchery's adult trapping site is located an additional 5 km up Rapid River. Total distance traveled is 977 kilometers (about 607 miles) from the ocean. The adult chinook pass Lower Granite Dam in late April through early June with the salmon entering the hatchery in June and July.

Returning PIT tagged adult Rapid River Hatchery spring chinook were detected at the LGR adult trap prior to arriving at an impassable velocity barrier located one mile below the hatchery. At that point, the returning adult fish were diverted from Rapid River into a holding and resting area. IDFG hatchery personnel would assess number of fish in the lower section of the holding area and raise a hinged floor that forced these fish into an upper section. If number of fish was less than 50, the hatchery personnel could elect to net them and process them inside the building. An anesthetic bath of MS-222 was set up and all pertinent information was then taken on the fish.

The normal way of sampling the adult chinook was to operate the Alaskan Steeppass (Denil-type fishway) that has its entrance in the upper section of the holding pool where the chinook are located. Fish would voluntarily swim up the Steeppass and slide down a chute into a tank(s) that contained the anesthetic MS-222 mixed with water. Once an individual fish was anesthetized, the hatchery crew collected data on length, sex, presence of marks such as PIT tags and CWT, and whether the fish was "hatchery" or "natural." All fish to be used for broodstock were transported by truck to the hatchery holding pond and held there until they were spawned during August or September. The "natural origin" fish were taken to the river upstream from the velocity barrier after they have awakened from the effects of the anesthetic and were released to spawn naturally. Whenever the hatchery crews were not selecting chinook for broodstock, river water was used in the tank instead of the anesthetic mixture. These fish were held and hand scanned for the presence of PIT tags, and then placed in a tank for distribution to another location.

As an example, many of the fish returning in years 2001 and 2002 were outplanted to other streams or trucked to a location and "recycled" through the sport fishery in the Salmon/Little Salmon Rivers. All PIT tags were recorded as recaptures and the information was sent to the PTAGIS database for storage.

Juvenile Migration Timing at Lower Granite Dam

Figure 2 shows cumulative plots of PIT tagged smolt's passage timing at LGR in migration years 1997 to 2000 for hatcheries participating in the CSS. For the 1997 to 2000 migration years, there have been fairly specific timing trends among the five hatcheries used in the CSS. In each year of its presence, Lookingglass Hatchery chinook smolts were either the earliest or second earliest group passing LGR. In 1998, Dworshak Hatchery chinook smolts were passing LGR earlier than Lookingglass Hatchery smolts, but in the other years the passage timing of Dworshak Hatchery smolts was closer to that of the other CSS hatcheries. The McCall Hatchery summer chinook smolts generally had

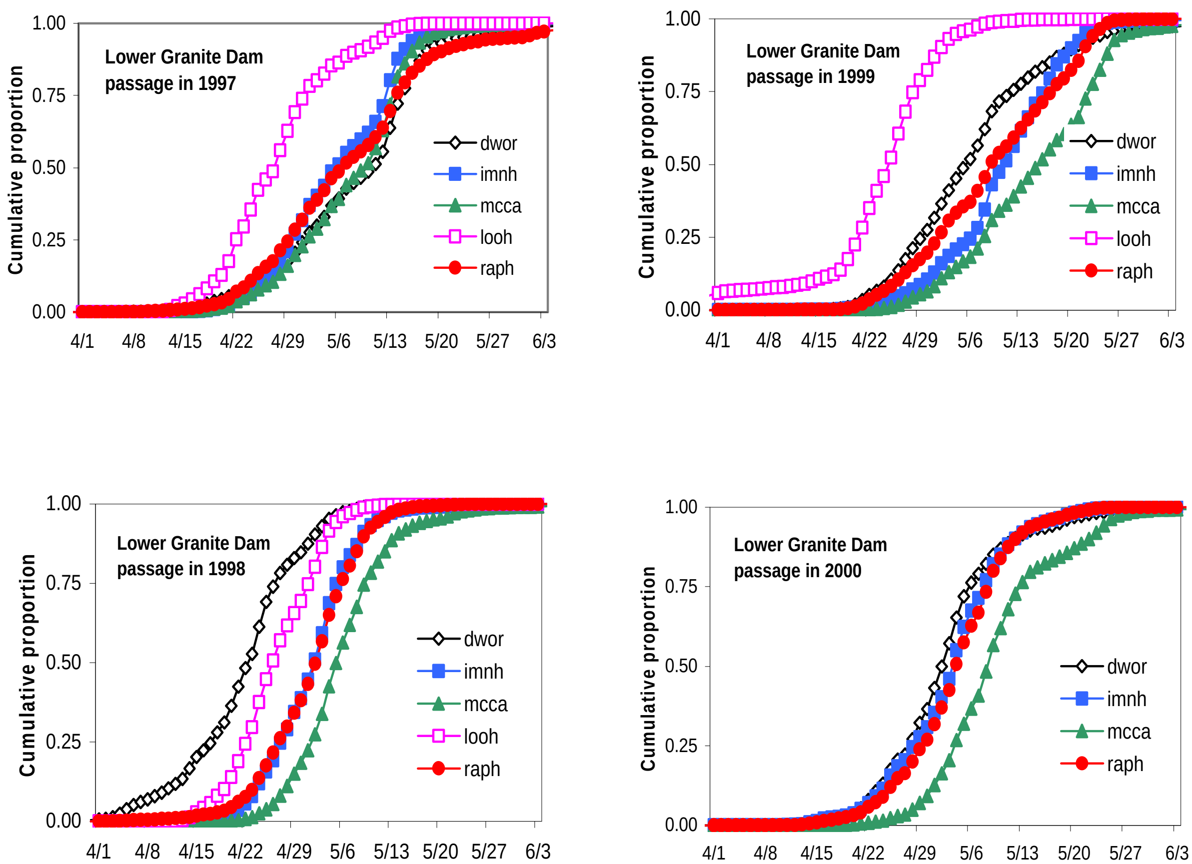

Figure 2. Cumulative passage timing of PIT tagged hatchery chinook smolts at Lower Granite Dam in migration years 1997 to 2000 for tagged hatchery fish released for the CSS (dwor= Dworshak H, imnh= Imnaha AP, mcca= McCall H, looh= Lookingglass H, and raph= Rapid River H).

the latest migration timing of all the CSS hatchery groups. Chinook smolts from Rapid River Hatchery and Imnaha Acclimation Pond (AP) had very similar passage timing at LGR, with timing between that of the other three hatcheries.

Juvenile Migration Survival Rates

For McCall, Imnaha, Lookingglass, Dworshak, and Rapid River Hatchery chinook smolts, LGR is the first dam encountered during their outmigration. LGR incorporates PIT tag detection systems in the fish bypass channels that transfers data to the PTAGIS computer system in Portland, OR. Survival estimates for the five CSS hatcheries from hatchery release site to LGR tailrace are presented in Table 25 for migration years 1997 to 2000.

Table 25. Estimated chinook survival from key upstream CSS hatcheries to Lower Granite Dam tailrace for migration years 1997 to 2000.

Hatchery	Parameter	Migration year			
		1997	1998	1999	2000
McCall H	PIT tag release number	52,652	47,340	47,985	47,705
	Survival S_1	0.425	0.588	0.658	0.667
	Standard Error	0.00768	0.00363	0.00817	0.00899
	Lower limit of 95% CI	0.410	0.580	0.642	0.651
	Upper limit of 95% CI	0.441	0.594	0.674	0.686
Imnaha AP	PIT tag release number	13,378	19,825	19,939	20,819
	Survival S_1	0.617	0.685	0.664	0.685
	Standard Error	0.01736	0.00621	0.01102	0.01077
	Lower limit of 95% CI	0.584	0.673	0.643	0.665
	Upper limit of 95% CI	0.653	0.697	0.686	0.709
Dworshak H	PIT tag release number	14,080	47,703	47,845	47,743
	Survival S_1	0.581	0.843	0.853	0.825
	Standard Error	0.01690	0.00586	0.01147	0.00869
	Lower limit of 95% CI	0.549	0.831	0.831	0.809
	Upper limit of 95% CI	0.617	0.854	0.877	0.843
Rapid River H	PIT tag release number	40,452	48,336	47,812	47,747
	Survival S_1	0.390	0.665	0.751	0.737
	Standard Error	0.00756	0.00341	0.00644	0.00677
	Lower limit of 95% CI	0.377	0.658	0.738	0.724
	Upper limit of 95% CI	0.406	0.672	0.764	0.750
Lookingglass H	PIT tag release number	40,027	44,232	44,551	Production release discontinued
	Survival S_1	0.599	0.706	0.658	
	Standard Error	0.00963	0.00430	0.00632	
	Lower limit of 95% CI	0.581	0.697	0.646	
	Upper limit of 95% CI	0.618	0.715	0.671	

Adult Chinook Migration Timing at Bonneville Dam in Return Year 2002

Because the adult PIT tag system was not fully installed at BON until the 2002 return season, we are limited in the amount of adult passage timing information available at BON for this status report. In Figure 3, the BON adult return timing of 2-ocean PIT tagged hatchery spring chinook from migration year 2000 was nearly identical for the upstream stocks of Dworshak and Rapid River hatcheries and the downstream stock of Carson Hatchery. The adult return timing of 2-ocean PIT tagged hatchery summer chinook from Imnaha AP and McCall Hatchery was about 1½ months later.

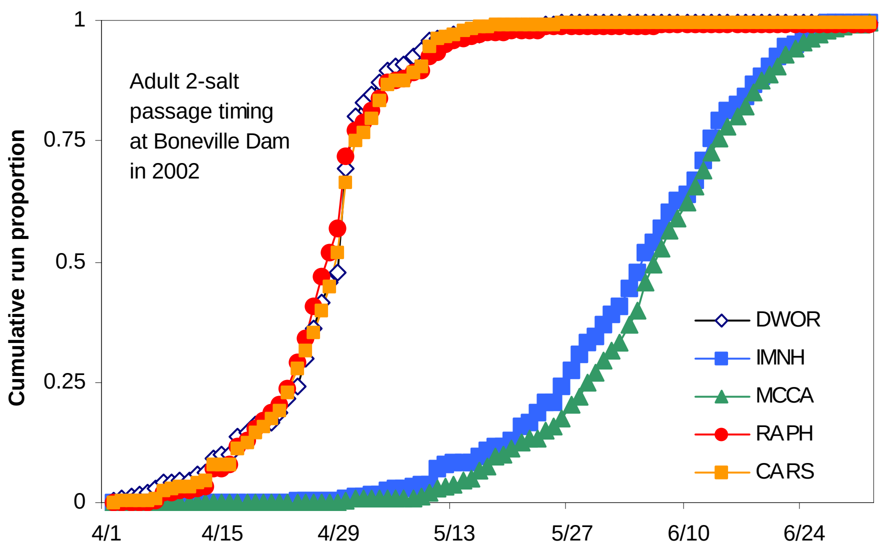

Figure 3. Passage timing at Bonneville Dam of the 2-ocean returning adults for PIT tagged hatchery fish released as smolts in 2000 for the CSS (dwor= Dworshak H, imnh= Imnaha AP, mcca= McCall H, raph= Rapid River H, and cars= Carson H).

Adult Chinook Migration Timing at Lower Granite Dam for returns from migration years 1997 to 2000

Returning adults from Dworshak, Lookingglass, and Rapid River hatcheries are typical spring chinook stocks that arrive at LGR primarily between mid-April and mid-May each year (Figure 4). Returning adults from Imnaha AP and McCall Hatchery are the next groups to pass LGR primarily between late May and the end of June (Figure 4). As stated in Chapter 1, the return timing of the Imnaha AP adults is a key reason for considering these fish a summer stock.

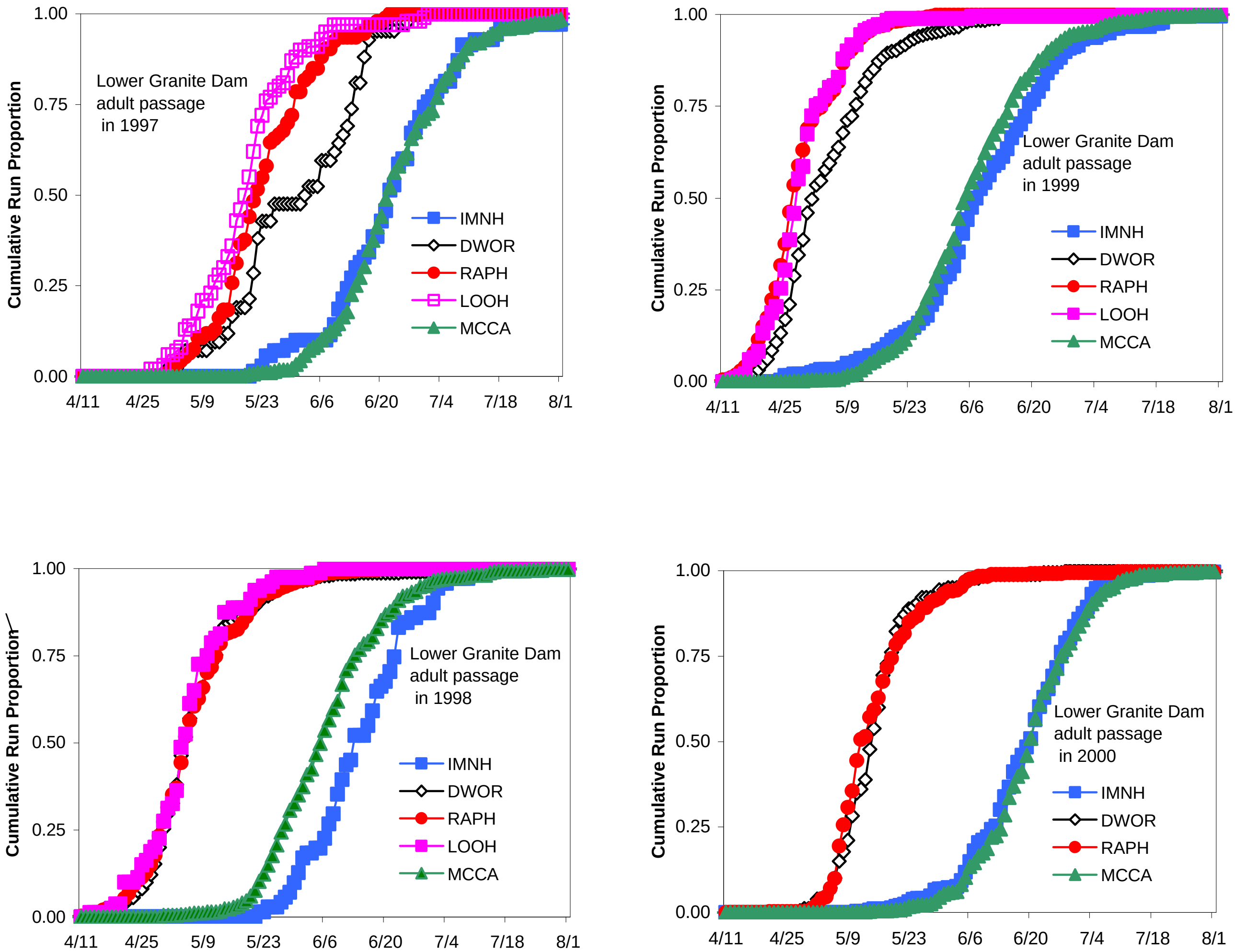

Figure 4. Passage timing at Lower Granite Dam of PIT tagged hatchery chinook adults (composite of the two return years for the 2- and 3-ocean fish from the same brood year) for PIT tagged hatchery fish released as smolts in 1997 to 2000 for the CSS (dwor= Dworshak H, imnh= Imnaha AP, mcca= McCall H, looh= Lookingglass H, and raph= Rapid River H).

PIT tag detection information at Lower Granite Dam adult trap and the hatcheries

The total numbers of PIT tagged adult chinook detected at LGR and also at the hatcheries are presented in Table 26 for each CSS hatchery. This table includes all returning CSS fish including the primary study categories C_0, C_1, and T_0, and the extra categories containing fish that had an unknown passage route at a transportation dam (designate as Category U) and fish that were transported after having had prior detections at upstream dams (designated as Category T_1). PIT tagged fish in study categories C_0, C_1, and T_0 were analyzed in Chapter 1 relative to survival rates from LGR as smolts to LGR as adults. These three categories plus the PIT tagged fish in categories U and T_1

were utilized in this chapter to determine adult survival rates from LGR back to the hatchery of origin.

Table 26. Number of returning PIT tagged hatchery chinook adults and jacks detected at Lower Granite Dam (LGR) and the hatchery racks (HAT) from smolts migrating in 1997 to 2000. Includes all returning jacks and adults from chinook PIT tagged for the CSS regardless of final category assignment.

Hat. (run)	Return status	Migration Year							
		1997		1998		1999		2000	
		HAT	LGR	HAT	LGR	HAT	LGR	HAT	LGR
RAPH	Jacks	0	2	12	32	7	43	1	8
(sp)	2-ocean	40	86	44	390	85	787	60	371
	3-ocean	1	7	0	23	2	31	n/a[1]	256
MCCA	Jacks	7	21	63	108	84	119	46	144
(su)	2-ocean	139	263	269	394	211	722	179	635
	3-ocean	6	11	5	37	20	113	n/a[1]	237
DWOR	Jacks	0	1	40	51	4	14	0	3
(sp)	2-ocean	15	36	81	372	80	393	29	180
	3-ocean	1	6	9	23	4	44	n/a[1]	197
IMNA	Jacks	15	24	25	54	4	81	36	149
(su)	2-ocean	30	63	33	69	102	226	27	289
	3-ocean	1	7	0	2	1	12	n/a[1]	79
LOOH	Jacks	Same	5	Same	3	Same	11	Production	
(sp)	2-ocean	as	95	as	71	as	172	releases	
	3-ocean	GRA	5	GRA	9	GRA	9	discontined	

[1] PIT tagged 3-ocean returns to the hatchery racks of migration year 2000 chinook are not available at the time of this report.

What is readily apparent from Table 26 is that a relatively small number of the PIT tagged adults detected at LGR were subsequently detected at the hatchery. This was due to extensive terminal sport and tribal fisheries in recent years, as the number of returning adults has risen. At all hatchery sites, a sport fishery was not allowed in return year 1999 due to the reduced number of adult fish that returned to the Snake River basin. Although a limited tribal fishery was allowed in some regions in 1999, it wasn't until return years 2000 to 2002 that more extensive tribal fisheries were allowed. In return years 2000 through 2002, a sport fishery was allowed to reduce surplus fish that were destined for the CSS hatcheries. In estimating the survival rate of adult fish from LGR to the hatchery of origin, fishery harvest return numbers were reviewed from tribal and sport sources. Note that Imnaha River did not have a sport fishery in these years with exception of a limited one in 2002; however, they do have adults that spawn below the weir based on carcass counts. Likewise, in the South Fork Salmon River, IDFG accounts for about 10% of the total annual McCall hatchery returns on the spawning grounds below the hatchery weir, and a smaller fraction that have strayed into the Secesh River and Johnson Creek. Returning adult salmon that spawn below a hatchery weir or stray into different streams and do not return to the hatchery of origin will lower the perceived survival rate to the hatchery. The level of this impact cannot be determined from the PIT tag data.

A question of interest has been whether straying would be greater in returning adults that had been transported as juvenile migrants through the hydro system rather than migrating through the hydro system. Terminal fishery harvest rates should be similar between adult chinook that were barged or migrated in-river as smolts. We did investigate whether these two groups of returning adults had differences in their proportion returned to the hatchery from what was detected at LGR. In order to increase the numbers of adults available for this investigation, we considered a pooled group of PIT tagged from categories C_0 and C_1 as the in-river group (I) and a pooled group of PIT tagged fish from categories T_0 and T_1 as the transport group (T) for each hatchery and migration year of interest (Table 27). The goal was to determine if prior history as a smolt had any bearing on the proportion of returning adults detected at LGR that ultimately were detected back at the hatchery. If no impacts were found, then we could combine all returning adults for a particular hatchery and migration year into a single group for purpose of estimating survival (harvest adjusted) from LGR back to the hatchery.

Table 27. Number of PIT tagged hatchery chinook adults and jacks combined that are detected at Lower Granite Dam (LGR) and at the hatchery racks (HAT) from smolts migrating in 1997 to 2000 (excludes returning jacks and adults that had an unknown route of passage through the hydro system as smolts).

Hat. (run)	Return status	Migration Year							
		1997		1998		1999		2000[A]	
		HAT	LGR	HAT	LGR	HAT	LGR	HAT	LGR
RAPH	Trans.	13	34	34	279	43	427	36	239
(sp)	Inriver	28	57	21	163	51	426	25	138
MCCA	Trans.	54	98	212	340	149	450	141	469
(su)	Inriver	93	190	121	193	163	499	84	309
DWOR	Trans.	7	17	55	155	23	130	15	96
(sp)	Inriver	9	26	74	289	61	317	14	86
IMNA	Trans.	19	38	34	75	58	178	42	256
(su)	Inriver	27	56	23	49	47	137	21	181

[A] Adults include 2-ocean and 3-ocean returns except for 2000 because only 2-ocean returns are available for both the hatchery rack and Lower Granite Dam at the time of this reporting.

We conducted chi-square tests on a series of 2 by 2 contingency tables (Mantel and Haenszel Test [1959] as shown in Lee 1980) to evaluate whether the proportion of fish returning to the hatchery of those detected at LGR was significantly different between returning adults (including jacks) who had passed as smolts through the hydro system in transportation versus in river. The resulting chi-square values of 1.93, 0.73, 1.83, and 0.08 were obtained for the hatcheries RAPH, MCCA, DWOR, and IMNA, respectively, with the data in Table 4 above. These values are less than the table chi-square value of 3.84 (at 1 degree-of freedom) at the ! = 0.05 significance level. The combined PIT tagged adults and jacks detected at LGR for each separate hatchery did not have subsequent detections at the hatchery that differed greater than could occur by random chance for fish that as smolts had migrated through the hydro system in river versus in a transport vehicle (normally a fish barge) across the four migration years of interest. Based on these findings, we concluded that computing separate survival rates from LGR back to the hatchery based on prior hydro system passage history of the smolts was not necessary. Therefore, for each hatchery and migration year of interest, only a single survival parameter (adjusted for harvest) was needed for the LGR-to-hatchery reach.

Smolt-to-Adult Survival Rates from Hatchery to Hatchery for Migration Years 1997 to 2000

Partition of hatchery-to-hatchery SARs into components

Task 2(a) of Objective 2 (presented in Introduction) aims to estimate hatchery-to-hatchery survival rates and partition these rates into their three survival components, hatchery-to-LGR survival as smolts, LGR (smolts)-to-LGR (adults) SAR, and LGR-to-hatchery survival as adults. This partitioning requires estimates of survival to LGR tailrace (Table 25), estimates of LGR-to-LGR SAR's (see Chapter 1 Tables 14 and 15), and harvest adjusted LGR-to-hatchery survival rates. In estimating the latter two components, it is important to know the efficiency of the PIT tag detection equipment at LGR. In return years 1999, 2001 and 2002, a total of only 18 PIT tagged CSS hatchery chinook were detected at the hatchery that previously were not detected at LGR adult trap (where 984 jacks and adults were detected), giving an overall 98% detection efficiency rate at the dam. In return year 2000, all PIT tagged CSS hatchery chinook detected at the hatchery were also detected at LGR adult trap. Because of the very high PIT tag detection efficiency rate at the dam, we concluded that no adjustments to the number of detected PIT tagged fish at LGR were necessary. Because the 3-ocean returns to the hatchery racks for PIT tagged fish were not available at time of this report, all subsequent analyses utilizing migration year 2000 PIT tagged smolts will only include 2-ocean returns.

Another important consideration is verification that the PIT tag data are representative of the run-at-large (tagged and untagged fish) for each hatchery of interest. This may be evaluated by comparison of hatchery rack counts of the run-at-large and PIT tags to their respective release numbers from the hatchery. In this comparison the PIT tag data at the hatchery must be adjusted to reflect the fact that some PIT tagged fish migrate through the system differently than the run-at-large due to the study requirement of obtaining in-river survival estimates between key dams in the hydro system. In migration years 1998 to 2000, virtually all smolts from the run-at-large collected at LGR, LGS, and LMN were transported, whereas there was a fairly large portion of PIT tagged fish returned to the river each year for survival estimation purposes. In those years, the PIT tagged fish in study categories T_0 and C_0 best represented the run-at-large, rather than any fish in study category C_1. In migration year 1997, a large portion of run-at-large smolts were purposely returned to the river at LGS and LMN, thus making those PIT tagged fish in study category C_1 that were not solely detected at LGR, an additional group that represented the run-at-large in that year. In migration years 1997 to 2000, the total number of PIT tagged smolts that would have been transported from the three Snake River collector dams if we had routed PIT tagged smolts to transportation in the same proportion as the run-at-large is given by the sum $T^* = T_2+T_3/S_2+T_4/(S_2S_3)$ where the Tj's are presented for LGR, LGS, and LMN in Table 11 of Chapter 1, and the Sj;s are presented in Appendix A Tables A-2 to A-6. The study category C_0 PIT tagged fish, which by definition all pass the three Snake River collector dams undetected (by going through either the spillways or turbines), directly mimics run-at-large without the need for any further adjustments. The estimated LGR population of PIT tagged fish in study categories C_0, C_1 and T_0 for a particular hatchery minus the C_0 and estimated T* PIT tagged fish gives an estimate of the number of C_1 category fish that mimic the run at large in 1997, whereas in 1998 to 2000 the number of C_1 category fish that mimic the run-at-large was zero. The proportion of the run-at-large that is represented by each category of PIT tagged fish is then multiplied by the SAR obtained with PIT tagged fish for that particular study category (shown in Table 28) to obtain a weighted LGR-to-LGR SAR that may then be multiplied with the number of smolts estimated at LGR for the run-at-large to obtain the estimated number of adults returning to LGR for each hatchery of interest (shown in Table 29).

Table 28. Proportion of Lower Granite Dam estimated combined tagged and untagged population of each hatchery group in each study category with associated LGR-to-LGR SAR (returning adults age 4 and 5 only) for the respective study category.

Migr. Year	Hatchery[1]	Hat. Prop. Tagged	Total LGR[2] (1000's)	Prop. in study category[3]			SAR for study category[4]		
				T_0	C_0	C_1	SAR(T_0)	SAR(C_0)	SAR(C_1)
1997	DWOR	0.2653	30.8	0.481	0.313	0.205	0.0052	0.0047	0.0036
1997	IMNA	0.2628	31.4	0.516	0.273	0.211	0.0075	0.0086	0.0069
1997	LOOH	0.2608	91.9	0.519	0.268	0.213	0.0040	0.0058	0.0035
1997	MCCA	0.2197	101.8	0.509	0.307	0.184	0.0186	0.0109	0.0110
1997	RAPH	0.4713	33.5	0.539	0.272	0.189	0.0082	0.0046	0.0053
1998	DWOR	0.0490	820.6	0.714	0.286		0.0072	0.0125	
1998	IMNA	0.2129	63.8	0.848	0.152		0.0069	0.0055	
1998	LOOH	0.1497	208.7	0.828	0.172		0.0053	0.0014	
1998	MCCA	0.1202	231.6	0.856	0.144		0.0195	0.0138	
1998	RAPH	0.0539	596.0	0.857	0.143		0.0168	0.0120	
1999	DWOR	0.0458	891.0	0.735	0.265		0.0107	0.0120	
1999	IMNA	0.1079	122.7	0.777	0.223		0.0252	0.0143	
1999	LOOH	0.1427	205.4	0.831	0.169		0.0068	0.0061	
1999	MCCA	0.0420	752.1	0.725	0.275		0.0358	0.0240	
1999	RAPH	0.0168	2,138.3	0.797	0.203		0.0272	0.0237	
2000[5]	DWOR	0.0469	839.7	0.660	0.340		0.0048	0.0051	
2000[5]	IMNA	0.1158	123.2	0.686	0.314		0.0248	0.0191	
2000[5]	MCCA	0.0459	693.6	0.580	0.420		0.0290	0.0144	
2000[5]	RAPH	0.0194	1,814.8	0.679	0.321		0.0130	0.0082	

[1] Hatchery coding: DWOR=Dworshak H; IMNA=Imnaha AP; LOOH=Lookingglass H; MCCA=McCall H; RAPH=Rapid River H.
[2] Estimated total population of smolts (tagged and untagged) at LGR.
[3] Estimated proportion of total smolt population (tagged and untagged) at LGR in each study category.
[4] Estimated SAR for PIT tagged chinook for each hatchery group and migration year – SAR's estimated using the CJS estimates of in-river reach survival.
[5] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Table 29. Estimated number of smolts at Lower Granite Dam and returning adults (age 4 and 5 only) to Lower Granite Dam for each hatchery group used in the CSS for migration years 1997 to 2000.

Migr. Year	Hatchery[1]	Hatchery Release	Survival Hat-to-LGR (S_1)	Estimated # smolts at LGR (in 1000's)	Weighted LGR-to-LGR SAR[2]	Estimated # Adults at LGR
1997	DWOR	53,078	0.581	30.8	0.0047	145
1997	IMNA	50,911	0.617	31.4	0.0077	241
1997	LOOH	153,478	0.599	91.9	0.0044	402
1997	MCCA	239,647	0.425	101.8	0.0148	1,511
1997	RAPH	85,838	0.390	33.5	0.0067	223
1998	DWOR	973,400	0.843	820.6	0.0087	7,153
1998	IMNA	93,108	0.685	63.8	0.0067	426
1998	LOOH	295,559	0.706	208.7	0.0046	966
1998	MCCA	393,872	0.588	231.6	0.0187	4,326
1998	RAPH	896,170	0.665	596.0	0.0161	9,604
1999	DWOR	1,044,511	0.853	891.0	0.0110	9,840
1999	IMNA	184,725	0.664	122.7	0.0228	2,792
1999	LOOH	312,145	0.658	205.4	0.0067	1,372
1999	MCCA	1,143,083	0.658	752.1	0.0326	24,486
1999	RAPH	2,847,283	0.751	2,138.3	0.0265	56,642
2000[3]	DWOR	1,017,873	0.825	839.7	0.0049	4,116
2000[3]	IMNA	179,797	0.685	123.2	0.0230	2,834
2000[3]	MCCA	1,039,930	0.667	693.6	0.0229	15,864
2000[3]	RAPH	2,462,354	0.737	1,814.8	0.0115	20,793

[1] Hatchery coding: DWOR=Dworshak H; IMNA=Imnaha AP; LOOH=Lookingglass H; MCCA=McCall H; RAPH=Rapid River H.
[2] Weighted estimated LGR-to-LGR SAR's are obtained by taking proportion of total population of smolts (tagged and untagged) at Lower Granite Dam in each study category and multiplying by the respective study category's LGR-to-LGR SAR.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

In the hatchery-to-hatchery partitioning, the final reach of interest for the returning adult chinook is from LGR to the hatchery. This includes the hatchery rack counts and adjustments for harvest (and potential adjustments for periods when weirs and adult fish traps are non-operational when adults are returning to the hatchery). The returning jacks and adults counted at the hatchery from each brood year consist of three age classes (3-yr olds [jacks], 4-yr olds and 5-yr olds) that show up over three successive return years. In the estimating of survival of adult chinook from LGR back to the hatchery, only 4-yr olds and 5-yr olds will be included. This is because the computed SARs used to compare between upstream and downstream hatcheries are based on only adult returns. Although only returning adult chinook are included in survival estimation, we include for completeness the jack count data provided by the fishery agencies (and tribes for harvest) in the summary tables below (Tables 30 to 34) for each key hatchery utilized in the CSS in migration years 1997 to 2000. The smolts that migrated in 1997 to 2000 were from the 1995 to 1998 brood stocks, and had returns of jacks and adults in 1998 to 2002. Virtually all of the jacks and adults that arrived at a CSS hatchery were checked for the presence of a PIT tag. However, there was no program for detecting PIT tags in the sport/tribal harvest (IDFG has reported a few PIT tags detections from sport fishermen in the South Fork Salmon River and Little Salmon River fisheries, but this PIT tag detection information is very spotty). The sum of the harvest and rack counts is the total return for a given year.

Table 30. McCall Hatchery production release number and total adult return (including jacks) split into sport/tribal harvests and hatchery escapement for migration years 1997 to 2000 with associated hatchery-to-hatchery SARs of returning age 4 and 5 adults.

Migr. Year	Hatchery Release	Return Year	Sport Harvest	Tribal Harvest[1]	Hatchery Rack	Total Adult Return[1]	Hat-to-hat SAR[1] (%)
1997	239,647	1998	None	N/A	N/A	---	
		1999	None	59	N/A	---	N/A
		2000	6	4	45	54	
1998	393,872	1999	None	N/A	N/A	---	
		2000	648	443	4,780	5,871	1.59 %
		2001	140	41	226	407	
1999	1,143,083	2000	(213 jacks)	N/A	(1,566 jacks)	---	
		2001	5,863	1,754	9,476	17,093	1.64 %
		2002	739	152	807	1,698	
2000[2]	1,039,930	2001	(79 jacks)	N/A	(128 jacks)	---	
		2002	5,888	1,208	6,423	13,519	Incomplete
		2003	---	---	---	---	

[1] Tribal harvest, total adult return and respective SAR estimate exclude returning jacks.
[2] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.
Data source: Sport harvest provided by Kim Apperson (IDFG, McCall, Idaho); Nez Perce and Shoshone-Bannock tribal harvest from Tables 3 and South Fork weir counts from Table 4 in Snake River Fisheries Biological Assessment, Shoshone-Bannock Tribes, April 24, 2003, provided by Keith Kutchins (Fort Hall Indian Reservation, Idaho).

Table 31. Imnaha Acclimation Pond production release number and total adult return (including jacks) split into sport/tribal harvests and hatchery escapement for migration years 1997 to 2000 with associated hatchery-to-hatchery SARs of returning age 4 and 5 adults.

Migr. Year	Hatchery Release	Return Year	Sport & Tribal Harvest	Hatchery Rack	Total Adult Return[1,2]	Hat-to-hat SAR[2] (%)
1997	50,911	1998	None	(73 jacks)	---	
		1999	None	148	585	1.21 %
		2000	None	15	32	
1998	93,108	1999	None	(174 jacks)	---	
		2000	None	254	542	0.76 %
		2001	14	84	162	
1999	184,725	2000	None	(511 jacks)	---	
		2001	218	1,298	2,489	1.53 %
		2002	30	81	342	
2000[3]	179,797	2001	(103 jacks)	(621 jacks)	---	
		2002	280	746	3,151	Incomplete
		2003	---	---	---	

[1] To arrive a total return, ODFW adjusts hatchery rack count for periods when weir is not operating.
[2] Total adult return and respective SAR estimate exclude returning jacks.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.
Data source: Harvest, rack count, and total adult return provided by Pat Keniry (ODFW, Eastern Oregon University, La Grande, Oregon).

Table 32. Dworshak Hatchery production release number and total adult return (including jacks) split into sport/tribal harvests and hatchery escapement for migration years 1997 to 2000 with respective hatchery-to-hatchery SARs of returning age 4 and 5 adults.

Migr. Year	Hatchery Release	Return Year	Sport & Tribal Harvest	Hatchery Rack	Total Adult Return[1]	Hat-to-hat SAR[1] (%)
1997	53,078	1998	(3 jacks)	(11 jacks)	---	
		1999	None	78	78	0.80 %
		2000	240	104	344	
1998	973,400	1999	None	(670 jacks)	---	
		2000	4,606	2,827	7,443	1.02 %
		2001	1,705	747	2,452	
1999	1,044,511	2000	(275 jacks)	(221 jacks)	---	
		2001	7,387	3,235	10,622	1.17 %
		2002	987	645	1,602	
2000[2]	1,017,873	2001	(92 jacks)	(36 jacks)	---	
		2002	2,375	1,480	3,855	Incomplete
		2003	n.a	n.a	n.a	

[1] Total adult return and respective SAR estimate exclude returning jacks.
[2] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.
Data source: Hatchery rack and total adult return from Burge *et al.* (2002) and combined sport & tribal harvest is calculated as the difference between these two quantities.

Table 33. Rapid River NFH production release number and total adult return (including jacks) split into sport/tribal harvests and hatchery escapement for migration years 1997 to 2000 with associated hatchery-to-hatchery SARs of returning age 4 and 5 adults.

Migr. Year	Hatchery Release	Return Year	Sport Harvest	Tribal Harvest[1]	Hatchery Rack	Total Adult Return[1]	Hat-to-hat SAR[1] (%)
1997	85,838	1998	None	N/A	(7 jacks)	---	
		1999	None	87	152	239	0.31 %
		2000	9	10	12	31	
1998	896,170	1999	None	N/A	(639 jacks)	---	
		2000	2,179	2,547	3,086	7,812	0.95 %
		2001	518	105	96	719	
1999	2,847,283	2000	(695 jacks)	N/A	(1,701 jacks)	---	
		2001	14,851	7,362	12,546	34,759	1.23 %
		2002	133	51	157	341	
2000[2]	2,462,354	2001	(117 jacks)	N/A	(128 jacks)	---	
		2002	6,179	2,374	2,872	11,425	Incomplete
		2003	n.a.	n.a.	n.a	n.a.	

[1] Tribal harvest, total adult return and respective SAR estimate exclude returning jacks.
[2] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.
Data source: Sport harvest from Barrett (2002) and Paul Janssen (IDFG, McCall, Idaho); Nez Perce and Shoshone-Bannock tribal harvest from Table 3 in Snake River Fisheries Biological Assessment, Shoshone-Bannock Tribes, April 24, 2003, provided by Keith Kutchins (Fort Hall Indian Reservation, Idaho).

Table 34. Lookingglass Hatchery production release number and total adult return (including jacks) for migration years 1997 to 1999 with associated hatchery-to-hatchery SARs of returning age 4 and 5 adults.

Migr. Year	Hatchery Release	Return Year	Sport/ Tribal Harvest	Collected at LGR for hatchery	Hatchery Rack (swim-in)	Total Adult Return[1,2]	Hat-to-hat SAR[2] (%)
1997	153,478	1998	None	(24 jacks)	(3 jacks)	---	
		1999	None	494	11	507	0.36 %
		2000	None	44	4	49	
1998	295,559	1999	None	(31 jacks)	(17 jacks)	---	
		2000	None	458	203	730	0.30 %
		2001	65	None	6	155	
1999	312,145	2000	None	(56 jacks)	(19 jacks)	---	
		2001	592	None	98	1,405	0.46 %
		2002	n.a	None	13	18	

[1] To arrive a total return, ODFW adjusts hatchery rack count for estimated number of fish not entering hatchery ladder.
[2] Total adult return and respective SAR estimate exclude returning jacks.
Data source: Harvest, rack count, and total adult return provided by Pat Keniry (ODFW, Eastern Oregon University, La Grande, Oregon).

Tables 30 to 34 also shows the estimated hatchery-to-hatchery SAR for the total hatchery production released in 1997 to 2000 (harvest adjusted total return divided by hatchery release) for each CSS hatchery. The SARs are reported for the 1997 through 2000 migration years with the understanding that the 2000 season is preliminary since it only includes 4-year old fish. For migration years 1997 to 1999 that have completed adult returns, the estimated hatchery-to-hatchery SAR ranged from 0.3% to 1.6% across the five CSS hatcheries. For migration year 2000, the hatchery-to-hatchery SAR will be completed once the PIT tagged 3-ocean adult returns at the hatchery racks is available. The SARs for hatchery chinook that migrated in 1997 to 1999 have increased during these three years. This trend has also been observed with the downstream Carson Hatchery stock (presented in Chapter 3).

Agreement between the PIT tagged returning adults and run-at-large returning adults was checked by utilizing two methods for estimating the size of the adult return (age 4 and 5) at Lower Granite Dam for each CSS hatchery group. The first method used the production times the survival components S_1 and $SAR_{LGR\text{-}LGR}$ presented in Table 29. The second method was the Peterson estimator [MC/R] where the number of PIT tagged returning adults for a particular hatchery detected at LGR [C] was expanded by the ratio of PIT tagged chinook detected at the hatchery rack [R] to those previously detected at LGR [M]. The resulting estimates of adult population size LGR based on the two methods are presented in Tables 35 to 38 for the CSS hatcheries. With the exception of Rapid River Hatchery in migration year 2000 (which includes returning 4 year olds only), there was poor agreement between the two methods of estimating the total number of adults (tagged and untagged) passing LGR for each CSS hatchery. The Peterson estimates were a minimum of 25% higher than the estimates using the hatchery release number times the survival components covering the interval between hatchery release as smolts and LGR as adults.

Table 35. Estimation of McCall Hatchery summer chinook adults (age 4 and 5 returns) at Lower Granite Dam by two methods for fish that outmigrated in 1997 to 2000.

		PIT tags		Return	Run-at-large		Estimated total adults at LGR		
Migr Year	Return Year	LGR (M)	Hat. (R)	year ratio (R/M)	Hat. (C)	LGR[1] (MC/R)	Migr Year	Sum of MC/R	Production times S_1 (SAR lgr-lgr)[2]
1997	1999	263	139	0.5285	N/A	N/A	1997	N/A	1,511
	2000	11	6	0.6790	45	66			
1998	2000	394	269		4,780	7,040	1998	7,834	4,326
	2001	37	5	0.2846	226	794			
1999	2001	722	211		9,476	33,298	1999	36,331	24,486
	2002	113	20	0.2660	807	3,033			
2000[3]	2002	635	179		6,423	24,143	2000	24,143	15,864

[1] Expansion of run-at-large rack count by aggregate return-years' proportion of LGR PIT tags detected at hatchery rack.
[2] Hatchery production release multiplied by the "Hatchery-to-LGR" SAR estimates from Table 6.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Table 36. Estimation of Imnaha Acclimation Pond summer chinook adults (age 4 and 5 returns) at Lower Granite Dam by two methods for fish that outmigrated in 1997 to 2000.

		PIT tags		Return	Run-at-large		Estimated total adults at LGR		
Migr Year	Return Year	LGR (M)	Hat. (R)	year ratio (R/M)	Hat. (C)	LGR[1] (MC/R)	Migr Year	Sum of MC/R	Production times S_1 (SAR lgr-lgr)[2]
1997	1999	63	30	0.4762	148	311	1997	344	241
	2000	7	1	0.4474	15	34			
1998	2000	69	33		254	568	1998	756	426
	2001	2	0	0.4474	84	188			
1999	2001	226	102		1298	2,901	1999	3,772	2,792
	2002	12	1	0.0930	81	871			
2000[3]	2002	289	27		746	8,020	2000	8,020	2,834

[1] Expansion of run-at-large rack count by aggregate return-years' proportion of LGR PIT tags detected at hatchery rack.
[2] Hatchery production release multiplied by the "Hatchery-to-LGR" SAR estimates from Table 6.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Table 37. Estimation of Dworshak Hatchery spring chinook adults (age 4 and 5 returns) at Lower Granite Dam by two methods for fish that outmigrated in 1997 to 2000.

		PIT tags		Return	Run-at-large		Estimated total adults at LGR		
Migr Year	Return Year	LGR (M)	Hat. (R)	year ratio (R/M)	Hat. (C)	LGR[1] (MC/R)	Migr Year	Sum of MC/R	Production times S_1 (SAR lgr-lgr)[2]
1997	1999	36	15	0.4167	78	187	1997	667	145
	2000	6	1	0.2169	104	479			
1998	2000	372	81		2827	13,032	1998	16,523	7,153
	2001	23	9	0.2139	747	3,492			
1999	2001	393	80		3235	15,121	1999	19,499	9,840
	2002	44	4	0.1473	645	4,378			
2000[3]	2002	180	29		1480	10,046	2000	10,046	4,116

[1] Expansion of run-at-large rack count by aggregate return-years' proportion of LGR PIT tags detected at hatchery rack.
[2] Hatchery production release multiplied by the "Hatchery-to-LGR" SAR estimates from Table 6.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Table 38. Estimation of Rapid River Hatchery spring chinook adults (age 4 and 5 returns) at Lower Granite Dam by two methods for fish that outmigrated in 1997 to 2000.

		PIT tags		Return	Run-at-large		Estimated total adults at LGR		
Migr Year	Return Year	LGR (M)	Hat. (R)	year ratio (R/M)	Hat. (C)	LGR[1] (MC/R)	Migr Year	Sum of MC/R	Production times S_1 (SAR lgr-lgr)[2]
1997	1999	86	40	0.4651	152	327	1997	433	223
	2000	7	1	0.1134	12	106			
1998	2000	390	44		3086	27,225	1998	28,140	9,604
	2001	23	0	0.1049	96	915			
1999	2001	787	85		12546	119,556	1999	120,574	56,642
	2002	31	2	0.1542	157	1,018			
2000[3]	2002	371	60		2872	18,622	2000	18,622	20,793

[1] Expansion of run-at-large rack count by aggregate return-years' proportion of LGR PIT tags detected at hatchery rack.
[2] Hatchery production release multiplied by the "Hatchery-to-LGR" SAR estimates from Table 6.
[3] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

For the Lookingglass Hatchery spring chinook, the production times the S_1 and $SAR_{LGR\text{-}LGR}$ survival components produced estimates for the run-at-large at LGR that agreed relatively well with the actual numbers of adults returns (Table 39). However, most adults Lookingglass Hatchery chinook were collected and trucked back to the hatchery (the level of swim-ins to the hatchery was low), which was not the situation with the other hatchery groups.

Table 39. Estimation of Lookingglass Hatchery spring chinook adults (age 4 and 5 returns) at Lower Granite Dam for fish that outmigrated in 1997 to 1999.

Migration Year	Estimated total adults at LGR	
	ODFW Total Return[2]	Production times S_1 (SAR lgr-lgr)[3]
1997	584	402
1998	936	966
1999	1,504	1,372

[1] Total return number provided by ODFW and is shown in Table 33.
[2] Hatchery production release multiplied by the "Hatchery-to-LGR" SAR estimates from Table 29.

The ratio R/M based on the PIT tagged adult returns detected at the hatchery rack and at LGR, respectively, is the conversion rate that we hoped would be applicable to the run-at-large for each hatchery group. This conversion rates should be independent of the harvest removal under the assumption that harvest affects equally the run-at-large and PIT tagged fish. Under this assumption, a harvest adjustment based on run-at-large could be applied to the PIT tag hatchery rack counts to estimate the total hatchery return (escapement to hatchery and harvest combined). This harvest adjustment would allow an estimate of the number of PIT tags that would have been detected at the hatchery rack had no harvest taken place by multiplying $1/(1- p_R)$, where p_R is the proportion of total run harvested, with the number of PIT tags detected at the hatchery rack. However, since the conversion rates between the run-at-large and PIT tagged fish do not appear similar, the validity of simply applying the harvest adjustment to the PIT tag data in order to mimic what is happening to the run-at-large returning adults is lost. To investigate this issue further, we look at migration year 1997, which did not have any sport harvest and limited tribal harvest until return year 2000. The conversion rates for migration year 1997 chinook showed that just under half of the 4-yr old adult PIT tagged chinook were detected at the hatchery rack in a year with negligible harvest (Table 40). However, because the flows in 1999 were very high, the installment of hatchery weirs to collect the returning adults was often delayed. For example, the South Fork Salmon River weir was not operation until the second week of July in 1999, which was the latest of any year included in this analysis (see page 42). The recapture problem plus losses due to mortality prior to spawning or straying may also be large impacts that we cannot handle based on simply adjusting for the known harvest. But these impacts should affect the PIT tagged and non-tagged returning adults equally so effects on some comparisons should be negligible. Additionally, delayed mortality from the hooking and handling of fish that are returned to the river nay occur. The numbers of fish that might temporarily or permanently stray into other areas is unknown, but some level of displacement or straying occurs with most stocks of salmon. For example, adult chinook of Dworshak Hatchery origin have been detected outside the Clearwater River basin as far as the Rapid River Hatchery rack (PIT tagged fish) and in the sport fishery in the mainstem Salmon River below Riggins, Idaho (CWT fish) during the study years of the CSS.

Table 40. Conversion factor of PIT tagged returning adults from Lower Granite Dam to hatchery racks in a year of no sport and very limited tribal harvests.

Hatchery	Migration Year	Return Year	Detections of PIT tagged adults (age 4 and 5 fish)		
			Lower Granite (M)	Hatchery rack (R)	Conversion rate (R/M)
McCall H	1997	1999	263	139	0.529
Imnaha AP	1997	1999	63	30	0.476
Dworshak H	1997	1999	36	15	0.417
Rapid River H	1997	1999	86	40	0.465
Geometric Mean					0.470

As an alternative method to estimate the survival component for the final reach from LGR to the respective CSS hatcheries, we attempted to simply take the hatchery-to-hatchery SAR computed for the run-at-large and divide it by the hatchery (smolts)-to-LGR (adults) SAR. The results, presented in Table 41, were above 100% in most cases, indicating limited utility to this simplified approach. However, these results do point to the difficulties in partitioning the hatchery-to-hatchery SAR into three survival components. Since the harvest adjustment cannot account for all fish that are not being collected at the hatchery weirs, the PIT tag survival component from LGR to the hatchery will tend underestimate the “true” survival of the run-at-large.

Table 41. Preliminary estimates of LGR-to-hatchery survival for returning 4- and 5-yr old adult chinook that migrated as smolts in 1997 to 1999 from hatcheries used in the CSS.

Migr. Year	Hatchery[1]	Hatchery-to-hatchery SAR (run-at-large)	Survival Hat-to-LGR (S_1)	Weighted LGR-to-LGR SAR[2] (PIT tagged fish)	Preliminary LGR-to-hat. Survival est.
1997	DWOR	0.0080	0.581	0.0047	2.93
1997	IMNA	0.0121	0.617	0.0077	2.55
1997	LOOH	0.0036	0.599	0.0044	1.37
1997	MCCA	n.a.	0.425	0.0148	n.a.
1997	RAPH	n.a.	0.390	0.0067	n.a.
1998	DWOR	0.0102	0.843	0.0087	1.39
1998	IMNA	0.0076	0.685	0.0067	1.66
1998	LOOH	0.0030	0.706	0.0046	0.92
1998	MCCA	0.0157	0.588	0.0187	1.43
1998	RAPH	n.a.	0.665	0.0161	n.a.
1999	DWOR	0.0117	0.853	0.0110	1.25
1999	IMNA	0.0153	0.664	0.0228	1.01
1999	LOOH	0.0046	0.658	0.0067	1.04
1999	MCCA	0.0164	0.658	0.0326	0.76
1999	RAPH	n.a.	0.751	0.0265	n.a.

[1] Hatchery coding: DWOR=Dworshak H; IMNA=Imnaha AP; LOOH=Lookingglass H; MCCA=McCall H; RAPH=Rapid River H.

<u>Future refinements in the partitioning of hatchery-to-hatchery SARs into components</u>

In years previous to return year 2002, there was limited PIT tag detection capability for returning adult chinook. But with the complete monitoring of all ladders at Bonneville Dam it will be possible in future years to further partition the LGR-to-LGR SAR component into at least two more components, a LGR (smolt)-to-BON (adult) and BON (adult)-to-LGR (adult) partition. We further plan to evaluate the possibly of improving population estimate of smolts at Bonneville Dam by utilizing additional PIT recovery information from the bird colonies on Rice and East Sand islands nearer the mouth of the Columbia River. Using this type of PIT tag recovery data has been successful with the Carson Hatchery PIT tag releases. The goal is to obtain a LGR-to-BON, BON (smolts)–to-BON (adults), and BON-to-LGR survival estimates. This additional level of partitioning the LGR-to-LGR SARs will be very beneficial in the upstream/downstream hatchery comparisons where a BON-to-BON SAR comparison of Carson Hatchery versus the upstream CSS hatcheries would be the most direct evaluation of hydro system effects on migrating smolts. Likewise, for wild chinook, a BON-to-BON SAR comparison of wild spring chinook from John Day River to wild spring/summer chinook originating in tributaries above Lower Granite Dam would be important in the evaluation of hydro system effects on migrating smolts.

SUMMARY AND CONCLUSIONS

- Survival of juvenile spring/summer chinook was estimated from particular CSS hatcheries to the tailrace of LGR for PIT tagged groups marked and released in 1997 to 2000. These estimates ranged from 39 % to 85 %.

- Based on methodology of using PIT recoveries from the bird colonies at East Sands and Rice islands to estimate survival of the Carson Hatchery spring chinook (see Chapter 3), future status reports should explore utilizing recoveries of PIT tags from these bird colonies to improve juvenile fish survival estimates to Bonneville Dam tailrace.

- Weighted LGR (smolts)-to LGR (adults) SARs (weighted to represent the run-at-large in each CSS study category) were higher for the summer chinook stocks than spring chinook stocks. Weighted SARs varied widely among the five hatcheries with the highest SARs going to McCall Hatchery and lowest SARs going to Lookingglass and Dworshak hatcheries. For each chinook race, the weighted SARs followed an increasing trend from migration years 1997 to 1999.

- SARs for chinook from the upriver CSS hatcheries showed a similar increasing trend in recent years to that observed for chinook from the downriver Carson Hatchery (see Chapter 3). Improving ocean conditions may have contributed to higher SARs in both the lower-river and upper-river hatcheries in the CSS.

- For PIT tagged adults detected at LGR, there was no significant difference in proportion detected at the hatchery racks based on their juvenile outmigration experience (in-river versus transported) as smolts.

- With PIT tag detection equipment installed at all BON fish ladders in 2002, detection of adult fish with PIT tags will allow for more reliable estimates of the number of returning adults of upstream and downstream origin that are passing BON. The estimates are needed in the partitioning of the hatchery-to-hatchery SARs further to obtain a key BON-to-BON SARs component for evaluation of hydro system effects between upstream and downstream stocks of yearling chinook.

- Based on PIT tag detections at the hatchery racks, the conversion rate from LGR to the hatchery is approximately 50% after accounting for harvest. However, the SARs estimated from total production release and the PIT tag SARs differed, and the reasons are unresolved.

REFERENCES

Barrett, L. 2002. 2001 Clearwater, Snake, and Salmon River, Idaho, spring chinook salmon (*Oncorhynchus tshawytscha)* sport harvest report. IDFG, Lewiston, Idaho.

Burge, H. L., M. Faler, and R. B. Roseberg. 2002. Appendix A - Adult spring chinook salmon returns to Dworshak and Kooskia National Fish Hatcheries in 2002 and prognosis for 2003. Idaho Fishery Resource Office, Dworshak Fishery Complex, U.S. Fish and Wildlife Service, Ahsahka, Idaho.

CHAPTER 3

Hatchery-to-hatchery smolt-to-adult survival rates for Carson Hatchery spring chinook adjusted for harvest

METHODS AND RESULTS

Notice: In the lower Columbia River basin, the CSS has included PIT tagged spring chinook from Carson Hatchery and in the future will add PIT tagged wild spring chinook from John Day River for the planned upstream/downstream comparison. ODFW has reported a 6% return rate based on detections of 2-ocean returning adults (112 fish) from smolts (1,852 fish) that migrated in 2000 (personal communication, J. Ruzycki and R. Boyce, ODFW, April 2003). The John Day River chinook's SAR was much higher than what was estimated for the 2-ocean returning adults of Snake River basin PIT tagged chinook that also migrated in 2000. The Snake River basin chinook's SAR did not exceed 1% in any study category. As more downriver data becomes available in future years, the CSS will begin to more rigorously compare, as part of Objective 3 task 3(e), the performance of upriver and downriver wild chinook stocks.

Background of Carson NFH spring chinook

Carson NFH released its first brood year spring chinook salmon in 1965 after the Wind River was made passable to adult spring migrants with the installation of fish passage facilities at Shipherd Falls. Carson NFH is operated by the USFWS and is currently funded as part of the Mitchell Act Funding administrated by the NMFS. Annually, Carson NFH releases about 1.5 million yearling spring chinook smolts from raceways and ponds directly into the Wind River. Carson NFH is located at RKm 28 on the Wind River some 279 RKm from the ocean. After release from the hatchery, the yearling chinook swim 28 kilometers in the free-flowing waters of the Wind River and 20 kilometers in the slack waters of the Columbia River before passing BON.

Adult fish from Carson NFH normally return to the Columbia River and migrate to the Wind River after spending from 1 to 3 years in the ocean. Breakdown by brood year will vary considerably, but with the recent upswing in adult returns, the 2-ocean age (4-year old fish) comprising about 90% and 3-ocean age (5-year old fish) about 10% of the adult run. The jack chinook or 3-year old fish may account for about 2% of a brood year. The Carson stock fish normally return to the Columbia River from March through early May and pass Bonneville Dam from Mid-March through Mid-May on an annual basis. The Carson spring chinook pass Bonneville Dam at about the same time frame as other upriver spring chinook stocks from the Snake River, Yakima River, and upper Columbia River based on recent PIT tag data. After passing BON, the adult Carson spring chinook do not enter the Wind River and swim directly upstream to the hatchery, but rather hold up in the vicinity of mouth of the Wind River where sport and tribal fisheries occur. From mid-May through June, these adult chinook begin a mass exodus from the Columbia River up the Wind River to the hatchery. Once these fish near the hatchery, they have the option of entering the small stream to the hatchery ponds or continuing upstream. The Hatchery does not employ a weir across the Wind River.

Carson NFH was selected as the site to release PIT tagged spring chinook for the CSS's upstream-downstream comparison because, of all the spring chinook stocks available in the lower Columbia River, the Carson stock is the most closely related to the hatchery stocks of the Snake River basin. Since 1997 the CSS has PIT tagged a given number of Carson Hatchery production with the goal of assessing smolt-to-adult (SAR) survival rates for comparison with those of the upstream PIT tagged stocks over a series of years. However, an adult PIT tag system was not fully installed at BON until the 2002 return season, so only limited PIT tag detections of adult fish at that dam are available for this status report. In future years the goal will be to fully partition the hatchery-to-hatchery SARs into components of hatchery-to-BON survival, BON-to-BON SARs, and BON-to-hatchery survival rates (adjusted for harvest).

PIT tagging

The USFWS (Columbia River Fishery Program Office, Vancouver WA) was the contracting agency that marked yearling spring chinook at Carson NFH for the CSS from 1997 through 2002. Marking procedures follow standard PIT tag marking protocol set by the PIT Tag Steering Committee and the PIT Tag Marking Procedure Manual published by the PIT Tag Operations Center (PTOC). The USFWS operated a marking trailer that incorporated the PIT tag equipment, generally two marking stations with six personnel completing the work. On average, the PIT marking took about 5 to 7 days to complete each year. The PIT tag marking at Carson NFH was normally accomplished in January of the migration season and tagged fish were placed back into the production raceways after the marking was completed. The release date for yearling chinook was normally set for mid-late April and marking in January allowed sufficient time (3+months) to assess marking mortality from the raceways. Normally this allowed sufficient time to finalize the tagging and release files, and fish release numbers could be accurately assessed prior to the fishes' release from the hatchery.

Table 1 lists the number of Carson Hatchery yearling spring chinook marked with PIT tags for the CSS program from 1997 to 2002. During the initial two seasons of marking, the number of fish PIT tagged were minimal (5,000 and 7,500), rising to 13,000 in 1999, and finally increasing to the full complement of 15,000 fish in 2000. With 15,000 PIT tagged chinook released annually from Carson Hatchery, the goal was to detect adequate numbers of PIT tagged fish for estimating survival for both the juvenile and adult fish through the upcoming years. Pertinent data for the marked release groups are included in Table 42, including hatchery production numbers and the proportion of PIT tags in that production. Lengths of individual PIT tagged fish were taken at Carson NFH at the time of marking and generally did not vary substantially through the study years. Hatchery staff assessed numbers of fish per pound at time of release. Release dates ranged from April 17 to April 21 for the six years. Hatchery managers indicated that the yearling spring chinook were healthy based on records at time of release for all years in the study. Fish that were PIT tagged were marked from and held in raceways that represented most of the production fish. Mortality from time of marking to release was minimal (less than 0.5% of the marked release). Fish in these marked releases were from brood years 1995 through 2000.

Table 42. Carson NFH release numbers and PIT tags used for the Comparative Survival Study in migration years 1997 to 2002.

Migration Year	Dates of Release	Hatchery Release Number	Fish per Pound	Mean Fork Length (mm)	PIT Tag Release Number	PIT Tags to Hatchery Release (%)
1997	4/17/97	907,708	15.5/lb	119	4,983	0.55
1998	4/20/98	1,734,188	16.6/lb	115	7,491	0.43
1999	4/20/99	1,415,744	12.6/lb	120	12,977	0.92
2000	4/20/00	1,430,022	15.6/lb	114	14,992	1.05
2001	4/19-21/01	1,608,684	14.9/lb	107	14,978	0.93
2002	4/16-17/02	1,449,361	15.6/lb	115	14,983	1.03

Juvenile Migration Timing to Bonneville Dam

The juvenile migration of Carson Hatchery spring chinook begins with the release of the fish directly from the hatchery raceways and into the small stream (approximately 100 yards in length) that leads to the Wind River. Although the first Carson Hatchery yearling salmon may reach the Bonneville project in less than 24 hours, the overall passage timing of the middle 80% of the run takes around 2 to 3 weeks (Table 43). The earlier 10% passage dates in 1997 and 2002 coincided with the earlier hatchery release in those two years. The passage timing is based on the PIT tagged fish that pass through the juvenile bypass systems at the old and new powerhouses. A juvenile PIT tag detection system has been fully operational at BON throughout the time frame that Carson Hatchery spring chinook has been PIT tagged for the CSS. Prior to the start of the 2000 migration season, juvenile fish PIT tag detectors at BON were upgraded from the older 400 kHz PIT tag to the newer and more powerful 134 kHz PIT tag that improves detection efficiency at the dam.

Table 43. Yearling spring chinook smolt timing from Carson NFH to Bonneville Dam for migration years 1997 to 2002.

Migration Year	Smolt Passage Timing at BON			Mean Flow and Spill at BON		
	10%	50%	90%	Flow (kcfs)	Spill (kcfs)	Flow Range (kcfs)
1997	4/22	5/4	5/13	430	216	251 – 515
1998	4/25	5/1	5/8	285	103	138 – 420
1999	4/23	4/29	5/11	294	98	186 – 384
2000	4/23	5/2	5/16	286	92	211 – 387
2001	4/26	5/8	5/15	136	16	94 – 180
2002	4/21	5/3	5/14	254	117	198 – 348

We were unable to obtain flow rates in the Wind River for the 6-years of juvenile migrations, but river flow and spill at BON are shown when the Carson spring chinook juveniles would be passing through the project and the lower Columbia River. As shown in Table 43, average river flow in 1997 ranked first, while year 2001 ranked last, in magnitude for the April 15 – May 31 timeframe. Because of lower river flows in 2001, expectations would be that overall travel rates would be slower than in years with more normal river flow. The passage timing for mid-point of arrival at BON was May 8 for the 2001 release group, about 4-days later than the nearest year. Aside from 1998, timing when 90% of the yearling spring chinook from Carson NFH had passed BON was fairly similar (range = May 11-16).

Juvenile Migration Survival Rates

For Carson Hatchery spring chinook, BON is the primary evaluation site. Both powerhouses at BON incorporate PIT tag detection systems in the fish bypass channels that transfer data to the PTAGIS computer system in Portland, OR. Since BON is the only project these fish pass on their way to the ocean, juvenile survival estimates must rely on a recapture site(s) below the project to estimate survival from the hatchery to BON tailrace. NMFS has employed a trawl that is equipped with PIT tag detection equipment on the cod-end of the net. Only a specific amount of sets can be made during the season, and catch rate may vary based on river flow, and debris and other factors that might reduce sampling time during a given year. The NMFS normally operates the trawl near Jones Beach Site (TWX), located close to Clatskanie, OR (Rkm 74). Since these recapture numbers can be minimal, we also began to explore the use of PIT tags that are 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. Primarily, NMFS has employed a detection system to monitor for presence of PIT tags at these two sites in the lower river, and recaptures of PIT tags has been on-going for the time frame these Carson stock fish have been used in this study. NMFS used PIT tag recovery data from the piscivorous bird colonies in the Columbia River to make survival estimates when conducting the survival studies at The Dalles Dam from 1997 through 2000 (Absolon *et al.* 2002). Ryan *et al.* (2001) described PIT tag technology and methodologies for detecting the tags on the islands.

Survival estimates of the six years of data using the CJS estimates of survival from Carson NFH to BON from PIT tags sampled at the trawl as last recovery site, and then using estimates from the trawl plus the PIT recoveries made at Rice and East Sand Island were completed for all years and are presented in Table 44. With minimal release numbers in 1997, it was impossible to obtain a survival estimate based solely on the trawl recoveries, and even with the addition of PIT tag detections from the islands, there were still too few PIT tag recaptures to produce a reasonable survival estimate from the hatchery to BON tailrace. For migration years 1998 to 2002, the use of the trawl detections plus PIT tag detections from the tern and cormorant bird colonies reduced the error bounds about the respective survival estimates. The increase in numbers of total PIT tagged smolts detected below Bonneville Dam when the bird colonies detection data is added is seen in the following example. Of the 7,500 PIT tagged spring chinook released from the hatchery in 1998, there were only 39 fish detected in the trawl, however, a total of 258 detections were possible when the PIT tags from the bird colonies on Rice and East Sand Island were added. In 1999, Carson NFH released 13,000 PIT tagged spring chinook with only 54 detected in the trawl and 355 detected on Rice and

East Sand Islands for a total of 409 detections that could be used for the survival estimate. With the trawl and bird colonies detection data together, the FPC believes that more precise survival estimates can be made for the Carson NFH release groups for the 1998 through 2002 migration years. Using this approach, the estimated survival from Carson NFS to BON tailrace ranged from a low of 81% to a high of 93% for 1998 – 2002 (Table 44). As part of future survival evaluations of the upstream versus downstream originating PIT tagged chinook groups, this approach of including PIT tags recovered from the bird colonies will also need to be explored further for the upstream stocks in future status reports.

Table 44. Estimated chinook survival from Carson NFH to Bonneville Dam tailrace based on either (1) solely trawl detections or (2) trawl detections plus additional detections from bird guano on East Sand and Rice islands for migration years 1997 to 2002.

CARSON YEARLING CHINOOK						
Migration year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
Release dates	4/17/97	4/20/98	4/20/99	4/20/00	4/19/01	4/17/02
PIT tag release number	4,983	7,491	12,977	14,992	14,978	14,983
Below-BON recovery includes trawl detections only						
Survival S_1	NA	0.793	0.975	0.531	0.726	0.871
Standard Error	NA	0.300	0.300	0.114	0.073	0.221
Upper limit of 95% CI	NA	1.381	1.564	0.755	0.870	1.305
Lower limit of 95% CI	NA	0.204	0.387	0.308	0.583	0.438
Below-BON recovery includes trawl and bird guano detections						
Survival S_1	0.524	0.863	0.931	0.862	0.830	0.810
Standard Error	0.146	0.132	0.099	0.086	0.056	0.105
Upper limit of 95% CI	0.809	1.122	1.125	1.031	0.941	1.017
Lower limit of 95% CI	0.238	0.605	0.736	0.693	0.720	0.604

Adult Chinook Migration Timing at Bonneville Dam in Return Year 2002

Because the adult PIT tag system was not fully installed at BON until the 2002 return season, we are able to only present timing information at BON for one return year in this status report. The 2-ocean returning adults of Carson Hatchery origin were passing BON in 2002 at the same time that the returning 2-ocean adults of Dworshak and Rapid River origin were passing that dam (Figure 5).

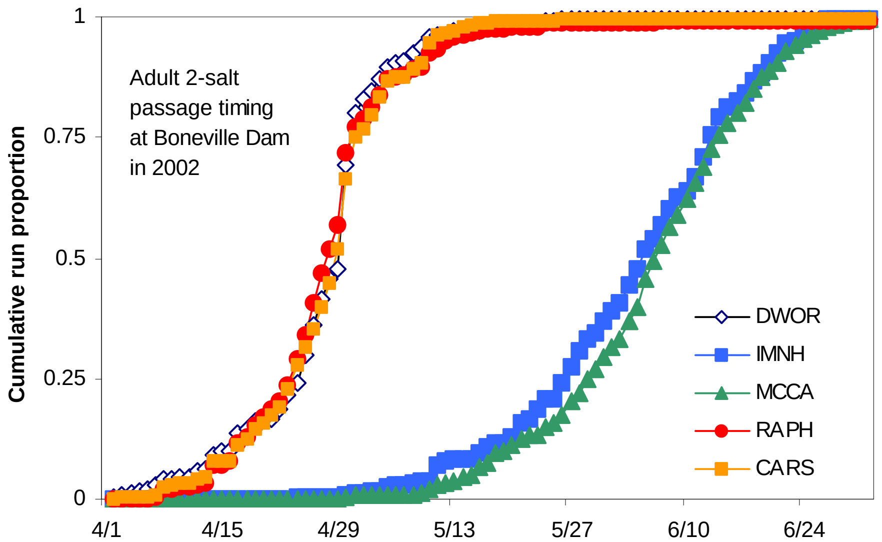

Figure 5. Passage timing at Bonneville Dam of the 2-ocean returning adults for PIT tagged hatchery fish released as smolts in 2000 for the CSS (dwor= Dworshak H, imnh= Imnaha AP, mcca= McCall H, raph= Rapid River H, and cars= Carson H).

Smolt-to-Adult Survival Rates (SARs) for Migration Years 1997 to 2000

Hatchery-to-hatchery SARs

Estimating hatchery-to-hatchery SARs for Carson Hatchery spring chinook requires a valid measure of the harvest of adult fish returning to the hatchery. The returning adults counted at the hatchery from each brood year consist of three age classes (3-yr olds (jacks), 4-yr olds, and 5-yr olds) that show up over three successive return years. To clarify the adult return data for the SAR, the 3-year old fish were not included in the contribution (jacks counted at the hatchery for each migration year were as follows: 14 from 1997; 197 from 1998; 489 from 1999; and 672 from 2000). This is because the computed SARs used to compare between upstream and downstream hatcheries are based on adults returns only (excluded PIT tagged jacks detected at the hatchery for each migration year included 0 for 1997 and 1998, 1 for 1999, and 5 for 2000). The 1995 to 1998 brood stocks outmigrated through the hydro system in 1997 to 2000, the four migration years covered in this status report, and the adults returned in years 1999 to 2002. Table 45 summarizes the harvest on the returning adults from WDFW Columbia River Progress Report 2003-05 (Pettit 2003). This table shows the estimated numbers of adult (no jacks) chinook taken in the tribal and sport fisheries (designated area downstream from the Wind River mouth as well as in the main Wind River), plus adult chinook distributed from the hatchery directly to the tribes the remaining number of adult chinook at the hatchery (net escapement). Almost all adult fish that arrived at Carson NFH were interrogated for presence of PIT tags, regardless of whether the fish were distributed to the tribes or saved for spawning. There was no program for detecting PIT tags in the sport/tribal harvest. The sum of these four categories is the total return for a given year. Because the SARs are computed for each migration year, there is the need to break out the return year data from Table 45 into the respective smolt migration years as shown in Table 46.

Table 45. Carson Hatchery adult spring chinook from sport and tribal catch, tribal distribution, and hatchery escapement by return year[1].

Rtn Yr	Sport Harvest			Tribal Harvest			Tribal Distribution			Hatchery Escapement		
	4-yr	5-yr	Total	4-yr	5-yr	Total	4-yr	5-yr	Total	4-yr	5-yr	Total
1999	1091	26	1117	195	5	200	2152	66	2218	1372	43	1415
2000	9298	156	9454	1095	40	1135	7753	282	8035	2588	94	2682
2001	10874	615	11489	1742	98	1840	9554	852	10406	1343	120	1463
2002	17507	529	18255	680	45	725	5730	72	5802	1673	21	1694

[1] Data Source: WDFW Columbia River Progress Report 2003-05 (Pettit, 2003).

Table 46. Carson Hatchery adult spring chinook from sport and tribal catch, tribal distribution, and hatchery escapement ordered by migration year and return year[1].

Migr. Year	Return Year	Sport Harvest		Tribal Harvest		Tribal Distribution		Hatchery Escapement		Total Run	
		4-yr	5-yr	4-yr	5-yr	4-yr	5-yr	4-yr	5-yr	4-yr	5-yr
1997	1999	1091		195		2152		1372		4810	
	2000		156		40		282		94		572
1998	2000	9298		1095		7753		2588		20734	
	2001		615		98		852		120		1685
1999	2001	10874		1742		9554		1343		23513	
	2002		529		45		72		21		667
2000	2002	17507		680		5730		1673		25590	
	2003		N/A		N/A		N/A		N/A		N/A

[1] Data from Table 45.

Estimates of hatchery-to-hatchery SAR for the total Carson Hatchery production released in 1997 to 2000 were possible by dividing the total run return (return to hatchery rack plus harvest) by the hatchery release (Table 47). The SARs reported for the 1997 through 2000 migration years require the understanding that the 2000 SARs are preliminary since they only include 4-year old fish. For migration years 1997 to 1999 (with completed adult returns), the estimated hatchery-to-hatchery SAR was 0.59%, 1.29%, and 1.71%, respectively. For migration year 2000, the hatchery-to-hatchery SAR for 2-ocean returns is 1.79% (3-ocean returns at the hatchery rack are not available at time of report). Given that Carson Hatchery PIT tagged adults detected at BON in 2003 accounted for 29% (124 of 426 PIT tag adults) of the returning adult chinook from the 2000 migration year, we expect that the harvest adjusted SAR to the hatchery to reach around 2.5% once the final rack return and harvest data is available. The overall trend in hatchery-to-hatchery SARs for Carson Hatchery chinook that migrated in 1997 to 2000 is increasing over the four years of study just as was observed for the upstream spring/summer stocks presented in Chapter 1 of this report.

Table 47. Carson NFH production release number and total adult return number split into sport/tribal harvests and hatchery escapement/tribal distribution for migration years 1997 to 2000.

Migration Year	Hatchery Release	Return Year	Sum of Sport and Tribal Harvest[1]	Hatchry Escapement and Tribal Distribution	Total Run Return	Hatchery-to-hatchery SAR (%)
1997	907,708	1999 2000	1,286 196	3,524 376	4,810 572	0.59 %
1998	1,734,188	2000 2001	10,393 713	10,341 972	20,734 1,685	1.29 %
1999	1,415,744	2001 2002	12,616 574	10,897 93	23,513 667	1.71 %
2000[2]	1,430,022	2002 2003	18,187 N/A	7,403 N/A	25,590 N/A	1.79 % (incomplete)

[1] Sport and tribal harvested adult chinook were not checked for PIT tags.
[2] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.

The adult chinook in the sport and tribal harvest were not checked for PIT tags whereas virtually all fish sampled in the hatchery holding ponds (tribal distribution and escapement) were checked for PIT tags. Once the adult fish enter the hatchery holding pond, the probability of an individual fish being checked for the presence of a PIT tag was very high throughout the season (100% checked in return years 1999 and 2000 and 97% checked in return years 2001 and 2002). However, since approximately 26 to 86 percent of the total run was removed in the sport/tribal harvest and tribal distribution prior to arriving at the hatchery adult pond (Table 48), there was the need to adjust the PIT tag detections at the hatchery to account for the effect of harvest. To estimate the number of PIT tags that would have been detected at the hatchery had no harvest taken place, the factor $1/(1- p_R)$, where p_R is the proportion of total run harvested, was multiplied with the number of PIT tags detected at the hatchery (Table 48). The resulting hatchery-to-hatchery SARs for the PIT tagged chinook after harvest adjustment agreed well with the estimate for migration year 1999, but was one-third to one-half lower than what was estimated with the total population (tagged and untagged fish) for the other three migration years. This impact may be seen in Table 49 where the harvest-adjusted numbers of PIT tags in the total adult return were divided by the proportion of PIT tags placed in production (?) and then compared to the actual number of fish in the adult return (fish to the hatchery plus harvest). It is not clear why fewer than expected PIT tags were detected at the hatchery for all but migration year 1999.

Table 48. Carson NFH PIT tag release, number of returning adults detected at the hatchery with a PIT tag, and estimated number of total PIT tags that would have been detected if no removals of adults prior to PIT tag detection had occurred for migration years 1997 to 2000.

Migration Year	PIT tags released at hatchery	Return Year	PIT tags detected at hatchery	% total run harvested prior to PIT tag detection	Adjust total number of PIT tags destined for hatchery	Hatchery-to-hatchery SAR (%)
1997	4,983	1999	11	26.7 %	15	0.40 %
		2000	3	34.3 %	5	
1998	7,491	2000	22	50.1 %	44	0.63 %
		2001	2	42.3 %	3	
1999	12,977	2001	83	53.7 %	179	1.66 %
		2002	5	86.1 %	36	
2000[1]	14,992	2002	50	71.1 %	173	1.15 %
		2003	N/A		N/A	(incomplete)

[1] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report; so hatchery-to-hatchery SAR is incomplete.

Table 49. Comparison of harvest adjusted total Carson adult returns based on PIT tags to the actual harvest adjusted total Carson adult return for migration years 1997 to 2000.

Juvenile Migration Year	Proportion PIT tags in production (?)	Harvest adjusted total Carson adult return (adj PIT # / ?)	Actual total Carson adult return	% Difference between PIT tag expanded and actual total return
1997	0.0055	3,636	5,382	-32 %
1998	0.0043	10,930	22,419	-51 %
1999	0.0092	23,369	24,180	- 3 %
2000[1]	0.0105	16,476	25,590	-36 %

[1] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Partition of hatchery-to-hatchery SARs into components

The partitioning of the hatchery-to-hatchery SARs into its three components, hatchery-to-BON survival, BON-BON SAR, and BON-to-hatchery survival, requires estimates of survival to BON tailrace and an estimate of the number of PIT tagged adults passing BON. Survival estimates from hatchery-to-BON were presented earlier and are available for migration years after 1997 (reliable estimates were not possible for 1997 due to the low numbers tagged at the hatchery in that year). So the partitioning will be limited to migration years 1998, 1999, and 2000. The total number of tagged and untagged Carson NFH adult chinook passing BON was derived using the PIT tag detection data. Prior to return year 2002 there was limited PIT tag detection capability at BON, whereas starting in return year 2002, the capability of detecting PIT tagged fish passing all three ladders. Even with the detection capability on each ladder, the overall detection of the adult fish at the project will still be less than 100% since a portion of the fish swim over the weir crests and don't pass through the orifices where the detection equipment is installed. However, in return years prior to 2002, the only sampling for PIT tags at BON was at the adult trapping facility located on the Washington shore fish ladder. In those years, PIT tagged fish were diverted from the main fish ladder and into the sampling facility (B2A) where PIT tag detection equipment was installed on the chutes prior to the sampling tanks. The adult sampling facility was operated only a portion of the passage day during the spring migration season, so only a small percentage of the adult chinook run were actually sampled for PIT tags at this site (B2A).

Since adult chinook were further interrogated at Carson NFH for presence of PIT tags, it was possible to calculate what percentage of the marked fish arriving at the hatchery in return years 2000 to 2002 had previously been detected at BON (Table 50). This allowed the estimation of an overall collection efficiency of PIT tag detection at BON for these three return years (return year 1999 is not included because no PIT tagged Carson NFH adult chinook were detected at both the dam and hatchery), and an estimate of population of PIT tagged Carson Hatchery chinook passing the facility as adults in those years (Table 49). The equation for estimating the population of PIT tagged Carson Hatchery adult chinook is $N = m_2 / p_2$. Let Xij denote the number of PIT tagged fish where the i^{th} subscript represents the presence (1) or absence (0) at BON and the j^{th} subscript represents the presence (1) or absences (0) at the hatchery. The parameter $p_2 = X_{11} / (X_{01} + X_{11})$ for a given return year and 2-ocean adult returns. We used only the 2-ocean returns in the computation of p_2 because of larger return numbers in the X_{11} and X_{01} capture histories than occurred with the 3-ocean fish, an age group that was less than 10% of the overall run for these migration years. The very low numbers of 3-ocean fish created unreliable results for p_2 ranging from 0 in return year 2001 to 60-67% in return years 2000 and 2002, so pooling the 2-ocean and 3-ocean data together was not advisable. The BON count $m2 = X_{10} + X_{11}$ was computed separately for each age class within a return year. The ratio of m_2 to p_2 then provided the estimate of the PIT tag population at BON (N) for each age class (migration year) within each return year.

Table 50. Estimated number of PIT tagged Carson Hatchery (CARS) adult chinook passing Bonneville Dam (BON) from smolts that migrated in 1998 – 2000.

Migr. Year	Return Year	Number of PIT tags detected at sites			BON Return Year Collection Efficiency (p_2)	Est. Carson Tags at BON ($N = m_2 / p_2$)	Migr. Year	Sum Carson Tags at BON for Migr. Year
		BON (m_2)	BON &CARS (X_{11})	CARS only (X_{01})				
1997	2000	3	2	1		33		
1998	2000	9	2	20	0.0909	99	1998	106
1998	2001	1	0	2		7		
1999	2001	56	12	71	0.1446	387	1999	391
1999	2002	4	3	2		4		
2000[1]	2002	302	47	3	0.9400	321	2000	321

[1] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

The BON-to-hatchery survival rate (adjusted for harvest) was estimated with the PIT tagged data as follows. Expanding the estimated number of total PIT tagged Carson

NFH adults at BON (from Table 50) by the proportion of PIT tags initially in production, we arrive at the estimated number of total (tagged and untagged) Carson NFH chinook passing the dam. Taking the ratio of the harvest adjusted number at the hatchery (derived in Table 49) to the estimated population number passing BON gives an estimate of the BON-to-hatchery survival rate as shown in Table 51. The low values of survival estimated to the hatchery after adjusting for harvest implies that more fish should be accounted in our removals than currently are being removed based on the harvest adjustment, which is simply the ratio of total harvest to total return from the run-at-large of adults to Carson NFH.

Table 51. Estimated Bonneville Dam to hatchery survival rate for Carson NFH PIT tagged adult chinook for migration years 1998 to 2000.

Juvenile Migration Year	Proportion PIT tags in production (P_h)	Estimated total Carson adult chinook from expanded PIT tag detections		Estimated BON-to-hatchery survival rate
		Number at Bonneville Dam (PIT # / P_h)	Harvest adjusted number at hatchery (adj PIT # / P_h)	
1998	0.0043	24,651	10,930	0.443
1999	0.0092	42,500	23,369	0.550
2000[1]	0.0105	30,571	16,476	0.539

[1] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

Next, the hatchery-to-hatchery SAR for the Carson Hatchery run-at-large (tagged and untagged fish) can be partitioned into three sub-components using the estimates of survival and population sizes at BON obtained with the PIT tag data for migration years 1998 to 2000 (Table 52). Survival from the hatchery to BON has been estimated using PIT tagged fish (results from Table 44) and number of adult fish passing Bonneville Dam has been estimated using PIT tagged fish (results from Table 49). The BON-to-BON SARs for migration years 1999 and 2000 (partial return only) are higher than that of migration year 1998. The extremely low BON-to-hatchery survival rate following the harvest adjustment for the migration year 1999 chinook appears unexpectedly too low, but the reason for this is not clear. It is possible that the harvest adjustment isn't taking into account all losses that are occurring prior to the adults being counted at the hatchery adult pond. If we look at the ratio of PIT tagged adults detected at both BON and the hatchery (X_{11} in Table 50) to PIT tagged adults detected at BON (m_2 in Table 50), we obtain a fairly consistent value for migration years 1998 and 1999 at 0.22 and 0.21, respectively, dropping to 0.16 for migration year 2000. Although the PIT tag numbers are low, the implication is that over 75% of the PIT tagged adult chinook did not reach the hatchery, while the harvest rate accounted for only 44-55% of the 4-yr old returns (see Table 48) that made up over 90% of the run. The harvest adjustment may be too low for these migration years.

Table 52. Partition of Carson NFH survival into three sub-components from hatchery to Bonneville tailrace, Bonneville-to-Bonneville, and Bonneville-to-hatchery (harvest adjusted) for smolts that migrated in 1998 to 2000.

Juvenile Migr. Year	Hatchery Release	Survival Rate from PIT tags (Table 44)	Estimated juvenile number at BON	Est. adult number passing BON (Table 51)	BON-to-BON SAR	Total returm to hatchery (harvest adj) (Table 47)	BON-to-hatchery survival rate
1998	1,734,188	0.863	1,496,604	24,651	0.0165	22,419	0.909
1999	1,415,744	0.931	1,318,058	42,500	0.0322	24,180	0.569
2000[1]	1,430,022	0.862	1,232,679	30,571	0.0248	25,590	0.837

[1] Only 2-ocean returning adults were used in 2000 to match the hatchery rack PIT tag data available at the time of this report.

In addition to losses of adult fish through fisheries, these fish were subjected to delayed mortality due to hooking and handling stress in sport fisheries as well as some natural mortality that would normally occur prior to spawning. At present, numbers of fish that might temporarily or permanently stray into other areas such as Drano Lake, Little White Salmon River and Hatchery, or the Big White Salmon River is unknown, but some level of displacement or straying occurs with most stocks of salmon. A small number of coded wire tags were recovered in the sampling of adult fish at the Little White Salmon Hatchery in 2000 and 2001.

In years previous to 2002, chance for error was increased due to the lack of full detection equipment at BON. In future years, numbers of PIT tagged adult fish returning to BON can be expanded to the population of the hatchery with more confidence if adequate fish escape the fisheries and arrive safely at the hatchery during each brood cycle.

SUMMARY AND CONCLUSIONS

- Survival of juvenile spring chinook was estimated from Carson NFH to the tailrace of BON for PIT tagged groups marked and released in 1998 through 2002. These estimates ranged from 81.0 to 93.1% for those years when based on trawl detections of PIT tags plus additional PIT tags detected at East Sand and Rice islands.

- Based on methodology of using PIT recoveries from the bird colonies at East Sands and Rice islands to estimate survival of these Carson stock, juvenile spring chinook, future status reports for the upstream releases of smolts from CSS or others studies should explore utilizing recoveries of PIT tags from these bird colonies to improve juvenile fish survival estimates to BON tailrace.

- BON-to-BON smolt-to-adult survival rates for Carson Hatchery spring chinook salmon increased through the years of the study with the 1998, 1999, and 2000 juvenile migration season’s adult returns shown respectively to be 1.65%, 3.22%, and 2.48% (migration year lacks 3-ocean returns at this time). The 1997 migration year SAR was likely less than 1% based on limited PIT tagged fish marked and subsequent few adult fish returning to the hatchery with a PIT tag.

- Adult fish returns from Carson NFH show a similar trend as other upriver spring/summer chinook groups with respect to increasing SARs in recent years. Improving ocean conditions may have resulted in higher SARs at the lower river and upper river hatcheries participating in the CSS program.

- Harvest of adult fish from the sport and tribal fisheries from BON to Carson NFH appears to result in over 75% take prior to these fish reaching the hatchery. However, the reported counts used to make our harvest adjustments are much lower. Overall, sufficient numbers of adult returns were available to provide for tribal distribution and spawning escapement in all years of this study.

- With PIT tag detection equipment installed at all BON fish ladders in 2002, detection of adult fish with PIT tags will allow for more reliable estimates of Carson Hatchery PIT tagged adults passing BON. The estimates that are need in the partitioning of the hatchery-to-hatchery SARs into components of BON-to-BON SARs and BON-to-hatchery (harvest adjusted) survival rates for Carson Hatchery spring chinook.

- The SAR for PIT tagged wild chinook migrating from John Day River in 2000 look very promising as 2-ocean returns detected at BON in 2002 showed a 6% survival rate. The SARs for PIT tagged Snake River basin wild chinook that migrated in 2000 did not exceed 1% in any CSS study category as 2-ocean returns detected at LGR.

REFERENCES

Absolon, R. F., E. M. Dawley, B. P. Sandford, J. W. Ferguson, and D. A. Brege. 2002. Relative survival of juvenile salmon passing through the spillway of The Dalles Dam, 1997-2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland, Oregon.

Pettit, R. 2003. WDFW Columbia River Progress Report 2003-05.

Ryan, B., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River Basin. N. Am. J. Fish. Manage. 21: 417 – 421.

CHAPTER 4

Comparison of bootstrap and likelihood-based confidence intervals for selected quantities

INTRODUCTION

The purpose of the bootstrap program is to estimate confidence intervals and probability distributions of various parameters, for use in tests of hypotheses about the relative magnitude of survival rates (e.g. SARs) of different groups. Confidence intervals and probability distributions are needed to place bounds on our beliefs about the values of survival rates and to help determine whether, or by how much, survival rates being compared truly differ. The bootstrap method is a comprehensive approach, which allows confidence intervals to be computed for all of the parameters of interest without requiring assumptions about the form of distribution of the parameter. While the bootstrap program is the primary method we use to develop confidence intervals, other methods can be applied for the same purpose for some parameters, providing estimates independent of the bootstrap program. For instance, likelihood theory can be used with the raw PIT-tag data to derive confidence intervals for several parameters where the random survival and detection process can be described with relatively simple probability distributions. In addition, the processes experienced by PIT tagged fish, such as migration, mortality, detection, and transportation, can be modeled with stochastic simulations. The behavior of these simulated tagged populations can compared to estimates derived from applying the bootstrap program to simulated data "gathered" from these populations, to help determine the accuracy of the methods developed in the CSS to estimate SARs and related quantities.

METHODS

As a test of the performance of nominal confidence intervals from the bootstrap program, we used likelihood functions based on relevant probability distributions to estimate expected confidence intervals (CIs) for several quantities estimated by the bootstrap program. These quantities included those that closely approximate a straightforward, well-studied random process (e.g., a binomial process), as well as others where individual components of the point estimates need themselves to be estimated (e.g. an SAR where the denominator cannot be directly observed and must be estimated). In the latter example, an additional source of estimation error is involved, and the bootstrapped confidence intervals would be expected to be at least as wide as likelihood-based CIs assuming smolt releases are observed.

Confidence intervals are constructed using the profile likelihood (likelihood ratio test) method (Hudson 1971; Venzon and Moolgavkar 1988; Hilborn and Mangel 1997). Profile likelihood has been used to estimate confidence intervals for various quantities estimated from PIT tag data and to compare to bootstrapped confidence intervals (Lowther and Skalski 1996, Townsend and Skalski 2000). The profile likelihood method takes advantage of the fact that twice the logarithm of the ratio of the value of the likelihood function evaluated at the maximum likelihood value of the parameter to the value of the function evaluated at another value, follows a chi-square distribution with one degree of freedom (Hilborn and Mangel 1997). The profile likelihood CI for a parameter *q* can be expressed by the equation (after Townsend and Skalski 2000)

$$CI(q) = \left\{ q : -2\ln\left(\frac{L(\breve{q} \mid D)}{L(\hat{q}_{MLE} \mid D)} \right) \le c^2_{1,1-a} \right\}, \quad (1)$$

where $\hat{q}_{MLE}$ is the maximum likelihood value of the parameter, $\breve{q}$ is the value of the parameter searched for (i.e. the upper or lower bound), *D* represents the data observed in the experiment, and alpha is 1 minus the target confidence coefficient.

The quantities for which profile likelihood CIs were derived are:

1. SAR(T_{LGR})
2. SAR (T_{LGS})
3. SAR(C1) (Denominator estimated)
4. SAR (C0) (Denominator estimated)
5. SAR (T_{LGR}) / SAR(C0)
6. P_2_LGS (estimate of detection probability at LGR from LGS detections)
7. Population (total number of smolts at LGR, estimated from LGS detections)

Some these quantities are not of primary interest in the CSS, but were chosen because of the relative ease with which likelihood CIs can be developed to compare to bootstrapped CIs.

The likelihood function used for SARs (quantities 1-4) is derived from the binomial probability distribution (e.g. Hilborn and Mangel 1997):

$$L(p \mid n, R) = \binom{R}{n} p^n (1-p)^{R-n} \quad (2)$$

where *R* is the number of smolts released or collected in that category, *n* is the number of recovered adults from that group of smolts, and *p* is the probability of smolts in that category returning as adults (i.e., the SAR).

The likelihood function used for a ratio of SARs (quantity 5) is derived from multiplication of the binomial likelihood for the in-river control group (denominator) by the binomial likelihood for the transported group (numerator). Since the parameter of interest is the ratio of SARs (*e.g.*, T/C when one group is transported and the other is not), the *p* value for the numerator SAR is replaced by the product of the denominator *p* and a parameter representing the T/C ratio. The equation for the likelihood function used is a simplified version of equation (14) in Townsend and Skalski (2000), for the case of one cohort (i.e. smolts and adult returns aggregated from one year's migration):

$$L(t\,, p_c \mid n_c, n_t, R_c, R_t) = \binom{R_c}{n_c} p_c^{n_c}(1-p_c)^{R_c-n_c} \bullet \binom{R_t}{n_t} (tp_c)^{n_t}(1-tp_c)^{R_t-n_t} \quad (3)$$

where

R_c = number of control smolt released
R_t = number of transported smolt released
n_c = number of recovered control adults salmon
n_t = number of recovered transported adult salmon
p_c = probably of control fish returning (control SAR)
t = transport-control ratio

The likelihood function for the estimate of detection probability at LGR derived from fish detected at LGS (*P2_LGS*) requires estimation of a parameter representing the probability that fish will survive from LGR to LGS and be detected at LGS and a parameter for the probability of survival from release to LGR. The number of fish removed for transportation (or for other reasons) rather than being released back into the river below LGR dam must be accounted for, as well. The equation uses the product of a multinomial probability distribution (e.g. Burnham et al. 1987, p. 49) and a binomial distribution. It is comparable to the single release likelihood model (Eq. 1) in Skalski et al. (1998), though terminology differs and it has fewer terms, as detection history downstream from LGS is omitted (because separate estimation of survival rate to LGS and detection probability at LGS is not needed for this problem, only the product):

$$L(S_1, p_2, p \mid R_1, R_2, m_{12}, m_{13}, m_{23}) = \binom{R_1}{m_{12}, m_{13}, R_1 - r_1} (S_1 p_2)^{m_{12}} (S_1(1-p_2)p)^{m_{13}} (1-l)^{R_1-r_1} \bullet \binom{R_2}{m_{23}} p^{m_{23}} (1-p)^{R_2-m_{23}} \quad (4)$$

where the first parenthetical term on the right hand size is the multinomial coefficient (e.g. Ross 1988) and

R_1 = number of PIT tagged fish released from hatchery or traps
R_2 = number of PIT tagged fish detected at LGR and released back to river
m_{12} = number of tagged fish detected at LGR = $R_2 + T$, where T is number of fish removed for transportation or other reasons
m_{13} = number of tagged fish undetected at LGR and detected at LGS
m_{23} = number of tagged fish detected at both LGR and LGS
r_1 = number of tagged fish recaptured at either LGR or LGS = $m_{12} + m_{13}$
p_2 = LGR detection probability estimated from LGS detections (*P2_LGS*)
π = probability of smolts surviving from LGR to LGS and being detected at LGS (assumed the same regardless of LGR detection history)

S_1 = survival probability from point of release to tailrace of LGR dam (assumed the same regardless of LGR detection fate)

λ = probability that a fish released from tagging site will be recaptured at LGR or LGS = $S_1 p_2 + S_1(1 - p_2)p$.

The likelihood function for the PIT tagged smolt population arriving at LGR (*A*) is

$$L(S_1, A, p \mid R_1, R_2, m_{12}, m_{13}, m_{23}) = \binom{R_1}{m_{12}, m_{13}, R_1 - r_1} \left(S_1 \frac{m_{12}}{A}\right)^{m_{12}} \left(S_1\left(1 - \frac{m_{12}}{A}\right)p\right)^{m_{13}} (1 - l)^{R_1 - r_1} \bullet \binom{R_2}{m_{23}} p^{m_{23}} (1 - p)^{R_2 - m_{23}}$$

(5)

where the terms are as described above and the likelihood function is identical to (4), except that p_2 is replaced by m_{12}/A.

Bootstrap and profile likelihood confidence intervals for quantities 1-5 were derived from data on total wild PIT-tagged smolts from two migration years, 1996 and 1999. The selection of these two years provided maximum contrast in adult return numbers (1996 low, 1999 high) among available years. Precision of estimates of SAR and ratios of SARs is highly sensitive to the adult return numbers, so the contrast in years allows investigation of the performance of the bootstrap under both favorable and unfavorable conditions. For quantities 6 and 7, it was necessary to use subsets of annual release groups. This was because one or more individual terms in the likelihood functions diminished to numbers too small for the software to represent, when full annual release groups were used. The subsets of PIT tags were chosen (once) from all tagged wild fish in a given year; the criterion was the PIT tag code, with the first 500 in order being chosen. This subset then became the universe of fish that were resampled in the bootstrap (for that year). Because PIT tag codes are not assigned randomly, but in consecutive numbers to a tagging site, subsets weren't necessarily representative of the "true" survival and detection rates for all PIT-tagged fish in that year. This was not of concern for this exercise since the purpose was solely to compare likelihood confidence intervals to confidence intervals generated by the bootstrap program using the same subset of data. The analysis was performed using data from 1999 and 2000 in order to provide contrast in detection probabilities and release-to-LGR survival rate.

Intervals of 80%, 90%, and 95% confidence were estimated using likelihood and compared to the corresponding estimates from the bootstrap program. Parameter values were set at maximum likelihood (point) estimates, and the parameter of interest iteratively reselected away from the MLE value until the likelihood ratio test was rejected at the 20%, 10%, and 5% significance levels, respectively. For likelihood formulas with more than one adjustable parameter (quantities 5-7), the "likelihood profile" tool of PopTools (http://sunsite.univie.ac.at/Spreadsite/poptools/) was used for this procedure. Bootstrap program confidence intervals are from the "first percentile" method of Efron (Manly 1998, pg. 41) with 5000 valid iterations (unless otherwise indicated).

RESULTS

For SARs and a ratio of SARs (quantities 1-5), the degree to which the bootstrap-generated confidence intervals coincided with those derived from profile likelihood depended on which year's data was used (Tables 53-57). In 1999, when smolt release numbers and SARs were at their highest overall, the bootstrap CIs were usually very similar to likelihood-based CIs. However, within 1999, the extent to which bootstrap CIs equaled or exceeded likelihood-based CIs varied according to the release number in the group, and particularly on the number of adults returning to be detected (compare Tables 54 and 55). When few adult returns are recorded for SAR of interest, the bootstrap program generated CIs that were shifted downward relative to those from likelihood, though the widths of the CIs were similar (Table 54). The bootstrap average estimate was also slightly lower than the maximum likelihood (point) estimate (2.80% vs. 2.82%).

Using data from 1996, the bootstrapped confidence intervals were similar to the likelihood CIs for some quantities, and significantly narrower than likelihood-based CIs for other quantities. The discrepancy was large for SARs where only one adult return was detected, with the upper bootstrap confidence limit consistently below the likelihood-based upper limit (Tables 53 and 54). The discrepancy in CI widths for transport-control ratio was much less, however, even though the SAR of the numerator was the SAR of fish transported from LGR, with only one adult return (Table 57).

Table 53. Comparison of confidence intervals using likelihood and bootstrap methods for SAR(T_{LGR}) of PIT tagged wild chinook migrating in 1996 (R = 268, n = 1, p_{mle} = 0.37%) and 1999 (R = 1107, n = 28, p_{mle} = 2.53%).

Migration year	Confidence Coefficient	Likelihood Lower (%)	Likelihood Upper (%)	Bootstrap Lower (%)	Bootstrap Upper (%)
1996	80%	0.07	1.07	0.00	0.81
1996	90%	0.04	1.35	0.00	1.11
1996	95%	0.02	1.63	0.00	1.19
1999	80%	1.97	3.18	1.94	3.15
1999	90%	1.83	3.38	1.80	3.33
1999	95%	1.71	3.57	1.67	3.51

Table 54. Comparison of confidence intervals using likelihood and bootstrap methods for SAR(T_{LGS}) of PIT tagged wild chinook migrating in 1996 (R = 85, n = 1, p_{mle} = 1.18%) and 1999 (R = 319, n = 9, p_{mle} = 2.82%).

Migration year	Confidence Coefficient	Likelihood Lower (%)	Likelihood Upper (%)	Bootstrap Lower (%)	Bootstrap Upper (%)
1996	80%	0.23	3.35	0.00	2.67
1996	90%	0.13	4.22	0.00	3.41
1996	95%	0.07	5.08	0.00	3.85
1999	80%	1.79	4.17	1.66	4.02
1999	90%	1.55	4.62	1.36	4.44
1999	95%	1.37	5.03	1.19	4.83

Table 55. Comparison of confidence intervals using likelihood and bootstrap methods for SAR(C_1) of PIT tagged wild chinook migrating in 1996 (R_{est} = 5209, n = 9, p_{mle} = 0.17%) and 1999 (R_{est} = 26138, n = 497, p_{mle} = 1.90 %).

Migration year	Confidence Coefficient	Likelihood Lower (%)	Likelihood Upper (%)	Bootstrap Lower (%)	Bootstrap Upper (%)
1996	80%	0.11	0.26	0.10	0.25
1996	90%	0.09	0.29	0.08	0.27
1996	95%	0.08	0.31	0.07	0.29
1999	80%	1.79*	2.01*	1.79	2.01
1999	90%	1.76*	2.05*	1.76	2.04
1999	95%	1.74*	2.07*	1.74	2.07

*Bounds were estimated by the "exact" (Clopper-Pearson) method (Brown et al. 2001) instead of profile likelihood, due to large R_{est}.

Table 56. Comparison of confidence intervals using likelihood and bootstrap methods for SAR(C_0) of PIT tagged wild chinook migrating in 1996 (R_{est} = 1917, n = 5, p_{mle} = 0.26%) and 1999 (R_{est} =4469, n = 95, p_{mle} = 2.13%).

Migration year	Confidence Coefficient	Likelihood Lower (%)	Likelihood Upper (%)	Bootstrap Lower (%)	Bootstrap Upper (%)
1996	80%	0.15	0.44	0.11	0.42
1996	90%	0.11	0.50	0.10	0.47
1996	95%	0.09	0.56	0.05	0.52
1999	80%	1.86	2.41	1.85	2.41
1999	90%	1.79	2.50	1.77	2.48
1999	95%	1.73	2.58	1.71	2.56

Table 57. Comparison of confidence intervals using likelihood and bootstrap methods for SAR(T_{LGR}) / SAR(C0) of PIT tagged wild chinook migrating in 1996 ($?_{mle}$ = 1.43) and 1999 ($?_{mle}$ = 1.19).

Migration year	Confidence Coefficient	Likelihood Lower	Likelihood Upper	Bootstrap Lower	Bootstrap Upper
1996	80%	0.264	4.94	0.000	4.54
1996	90%	0.140	6.76	0.000	6.88
1996	95%	0.075	8.83	0.000	8.23
1999	80%	0.900	1.55	0.905	1.56
1999	90%	0.829	1.67	0.834	1.68
1999	95%	0.770	1.78	0.765	1.79

Estimates of confidence intervals for detection probability at LGR from LGS recaptures were similar between the two methods, for both years examined (Table 58). The P_2_*LGS* estimate was considerably higher for the 2000 subset, and the bootstrap CIs slightly exceeded the likelihood CIs (Table 58).

Table 58. Comparison of confidence intervals using likelihood and bootstrap methods for *P_2_LGS* estimates generated from subset of release data (R_1 = 500) of PIT tagged wild chinook migrating in 1999 ($P_2\_LGS_{mle}$ = 0.216) and 2000 ($P_2\_LGS_{mle}$ = 0.484).

Migration year	Confidence Coefficient	Likelihood Lower	Likelihood Upper	Bootstrap Lower	Bootstrap Upper
1999	80%	0.162	0.276	0.159	0.273
1999	90%	0.148	0.294	0.143	0.290
1999	95%	0.137	0.310	0.133	0.306
2000	80%	0.393	0.576	0.393	0.576
2000	90%	0.368	0.601	0.365	0.604
2000	95%	0.346	0.623	0.343	0.630

Confidence intervals for the population of smolts arriving at LGR, calculated from LGS detections (*A*) were different between the two methods, with bootstrap intervals consistently narrower than likelihood-based intervals (Table 59). The discrepancy was very small for the 2000 subset of data (point estimate of 107 smolts), and larger for 1999 (point estimate of 195 smolts). In 1999, the upper limit of the bootstrap was 6-7.5% lower than the likelihood upper limit, for all confidence coefficients, while the lower limit was 5-6 % higher than the likelihood lower limit (Table 59). In practice, however, the number of PIT tagged smolts in the population passing Lower Granite Dam used in the CSS analyses were much higher, exceeding 7,500 smolts in all but one case (wild chinook in 1997). Larger population sizes may provide closer agreement in confidence interval coverage between the likelihood and bootstrap methods.

Table 59. Comparison of confidence intervals using likelihood and bootstrap methods for estimate of *A* (number of smolts in population passing Lower Granite Dam) generated from subset of release data (R_1 = 500) of PIT tagged wild chinook migrating in 1999 (A_{mle} = 195) and 2000 (A_{mle} = 107).

Migration year	Confidence Coefficient	Likelihood Lower	Likelihood Upper	Bootstrap Lower	Bootstrap Upper
1999	80%	152	259	159	244
1999	90%	143	283	151	265
1999	95%	136	307	144	284
2000	80%	90	132	90	130
2000	90%	86	141	85	137
2000	95%	83	150	81	145

DISCUSSION

The bootstrapped confidence intervals generally agreed well with those estimated from the profile likelihood approach for SARs except when there were extremely low adult returns. In the case of low adult returns, the probability distribution of the SAR parameter is highly skewed, and the discrete nature of bootstrap results limits its ability to mimic these skewed distributions. For instance, in 1996, the numerator of a realization of the bootstrapped SAR value may take the value of 0, 1, 2, 3, 4 and so on, while the likelihood-based CIs assume a continuous probability distribution. It's not possible to match exactly likelihood bounds, particularly the lower bound, with the bootstrap in the case of low adult returns and release numbers. The extreme skewness seen in the likelihood profile may be better approximated by the bootstrap in the future through use of bias-corrected percentile confidence limits (Manly 1998).

Despite the significant underperformance of bootstrap limits for the LGR SAR in 1996 (since only one adult return was available in this study group), the coverage for the transport-control ratio estimated using LGR SAR was much less sensitive to the low adult return numbers. This is encouraging, since ratios of SARs are the primary metric for inference in the CSS (e.g. *T*/*C* ratios, *D*). However, since the true upper limit on this ratio for wild releases in 1996 still appears to be underestimated by the bootstrap, inferences on these SAR ratios using bootstrap results will be made only after conducting sensitivity analyses on the variance for the ratio estimate in that year.

The bootstrap appears able to reproduce the uncertainty in LGR detection probability well, as judged by the comparison to likelihood-based CIs. It's unclear, however, why the bootstrap program does not seem to reproduce the probability distribution of population arriving at LGR as well. As stated earlier, the small population sizes used to create the likelihood-based CIs were only a fraction of the actual PIT tag population sizes that occurred. With the larger population numbers that actually occurred each year, closer agreement may occur between the two methods of computing confidence intervals.

Another important point is that in the CSS report, estimates of detection probability, arriving population, and survival rates and SARs derived from these values are calculated from the full juvenile capture history. Detections of smolts first seen at LMN, MCN, JDA, BON, and the lower Columbia River trawl, as well as those seen at LGR, are used in addition to captures at LGS in order to get the most precise estimate of LGR detection probability (and hence, of total arriving smolt population). Therefore, the comparison presented here is not a true test of the primary CSS method, but rather of a similar, but less comprehensive method. This simpler method was used for this comparison because of the relative ease of deriving and solving the likelihood function, which quickly becomes impractical to use with multiple downstream detection sites added. A more exact test of the full method, along with an alternative test of the reduced method, could be made with the population simulation method mentioned earlier. Simulation will also allow tests of other quantities, including several which aren't susceptible to profile-likelihood treatment.

REFERENCES

Brown, L.D., T. Cai, and A. DasGupta. 2001. Interval estimation for a binomial proportion. *Statistical Science* 16: 101-133.

Burnam, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. Am. Fish. Soc. Monogr. No. 5.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Mongr. Pop. Biol. No. 28. Princeton University Press, Princeton, N.J.

Hudson, D. J. 1971. Interval estimation from the likelihood function. *Journal of the Royal Statistical Society Series B* 33:256-262.

Lowther, A. B. and J. R. Skalski. 1996. School of Fisheries, University of Washington, The Design and Analysis of Salmonid Tagging Studies in the Columbia Basin - Volume VII: Monte-Carlo Comparison of Confidence Interval Procedures for Estimating Survival in a Release-Recapture Study, with Applications to Snake River Salmonids, Report to Bonneville Power Administration, Contract No. 1990BP02341, Project No. 198910700, 42 electronic pages (BPA Report DOE/BP-02341-5)

Manly, B.F.J. 1998. Randomization, bootstrap, and Monte Carlo methods in biology. 2nd edition, Chapman & Hall, London.

Ross, S. 1988. A first course in probability. 3rd edition, Macmillan, New York.

Skalski, J.R., S.G. Smith, R.N. Iwamoto, J.G. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. *Can. J. Fish. Aquat. Sci.* 55: 1484-1493.

Townsend, R. L. and J. R. Skalski. 2000. School of Aquatic & Fishery Sciences, University of WA, The Design and Analysis Of Salmonid Tagging Studies In The Columbia Basin Volume IX, A Comparison of Statistical Methods of Estimating Treatment-Control Ratios (Transportation Benefit Ratios) Using Coded Wire Tags, Based on Spring Chinook Salmon on the Columbia River, 1986-1988, Technical Report 2000, Report to Bonneville Power Administration, Contract No. 1990BI023410, Project No. 198910700, 44 electronic pages (BPA Report DOE/BP-02341-11)

Venzon, D. J. and S. H. Moolgavkar. 1988. A method for computing profile-likelihood based confidence intervals. *Applied Statistics* 37:87-94.