MONITORING AND EVALUATION OF SMOLT MIGRATION IN THE COLUMBIA BASIN VOLUME XVIII

Survival and Transportation Effects for Migrating Snake River Wild Chinook Salmon and Steelhead: Historical Estimates From 1996-2004 and Comparison to Hatchery Results

DRAFT

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Preface

Project 91-051 was initiated in response to the Endangered Species Act (ESA) and the subsequent 1994 Council Fish and Wildlife Program (FWP) call for regional analytical methods for monitoring and evaluation. This project supports the need to have the "best available" scientific information accessible to the BPA, fisheries community, decision-makers, and public by analyzing historical tagging data to investigate smolt outmigration dynamics, salmonid life histories and productivity, and providing real-time analysis to monitor outmigration timing for use in water management and fish operations of the hydrosystem. Primary objectives and management implications of this project include: (1) to address the need for further synthesis of historical tagging and other biological information to improve understanding and identify future research and analysis needs; (2) to assist in the development of improved monitoring capabilities, statistical methodologies and software tools to aid management in optimizing operational and fish passage strategies to maximize the protection and survival of listed threatened and endangered Snake River salmon populations and other listed and non-listed stocks in the Columbia River Basin; (3) to develop better analysis tools for monitoring evaluation programs; and (4) to provide statistical support to the Bonneville Power Administration and the Northwest fisheries community.

The following report presents historical estimates of survival and transportation effects for wild PIT-tagged salmon released in the Snake River Basin from 1996 to 2004. Reported measures are calculated on an annual basis for basin-wide release groups. Estimates of the overall smolt-to-adult return ratio (SAR) are reported, as well as of juvenile inriver survival from Lower Granite Dam to Bonneville Dam, survival from Bonneville back to Bonneville, and adult survival from Bonneville to Lower Granite. Transportation effects are reported in two ways: the transport-inriver (T/I) ratio, and differential post-Bonneville mortality (D). Estimates of T/I and D are reported on a dam-specific basis. For a given release group, transportation effects are estimated only for transportation from dams where at least 1,000 smolts from the release group were transported.

Abstract

The combined juvenile and adult detection histories of PIT-tagged wild salmonids migrating through the Federal Columbia River Power System (FCRPS) were analyzed using the ROSTER (River-Ocean Survival and Transportation Effects Routine) statistical release-recapture model. This model, implemented by software Program ROSTER, was used to estimate survival on large temporal and spatial scales for PIT-tagged wild spring and summer Chinook salmon and steelhead released in the Snake River Basin upstream of Lower Granite Dam from 1996 to 2004. In addition, annual results from wild salmonids were compared with results from hatchery salmonids, which were presented in a previous report in this series (Buchanan, R. A., Skalski, J. R., Lady, J. L., Westhagen, P., Griswold, J., and Smith, S. 2007, "Survival and Transportation Effects for Migrating Snake River Hatchery Chinook Salmon and Steelhead: Historical Estimates from 1996 - 2003," Technical report, Bonneville Power Administration, Project #1991-051-00). These results are reported here. Annual estimates of the smolt-to-adult return ratio (SAR), juvenile inriver survival from Lower Granite to Bonneville, the ocean return probability from Bonneville to Bonneville, and adult upriver survival from Bonneville to Lower Granite are reported. Annual estimates of transport-inriver (T/I) ratios and differential post-Bonneville mortality (D) are reported on a dam-specific basis for release years with sufficient numbers of wild PIT-tagged smolts transported. Transportation effects are estimated only for dams where at least 1,000 tagged wild smolts were transported from a given upstream release group. Because few wild Chinook salmon and steelhead tagged upstream of Lower Granite Dam were transported before the 2003 release year, T/I and D were estimated only for the 2003 and 2004 release years. Performance measures include age-1-ocean adult returns for steelhead, but not for Chinook salmon. Spring and summer Chinook salmon release groups were pooled across the entire Snake River Basin upstream of Lower Granite Dam for this report.

Annual estimates of SAR from Lower Granite back to Lower Granite averaged 0.92% with an estimated standard error ($\widehat{SE}$) of 0.25% for wild spring and summer Chinook salmon for tagged groups released from 1996 through 2004, omitting age-1-ocean (jack) returns. Only for the 1999 and 2000 release years did the wild Chinook SAR approach the target value of 2%, identified by the NPCC as the minimum SAR necessary for recovery. Annual estimates of SAR for wild steelhead from the Snake River Basin averaged 0.63% ($\widehat{SE} = 0.15\%$), including age-1-ocean returns, for release years 1996 through 2004. For release years when the ocean return probability from Bonneville back to Bonneville could be estimated (i.e., 1999 through 2004), it was estimated that on average approximately 83% of the total integrated mortality for nontransported, tagged wild spring and summer Chinook, and 78% for steelhead (omitting the 2001 release year), occurred during the ocean life stage (i.e., from Bonneville to Bonneville). This suggests that additional monitoring and research efforts should include the ocean and estuary environment.

Annual estimates of the dam-specific T/I for Lower Granite Dam were available for the 2003 and 2004 release years for both wild Chinook salmon and wild steelhead. The estimated T/I for Lower

Granite was significantly > 1.0 for Chinook in 2004 ($P < 0.0001$) and for steelhead in both 2003 ($P < 0.0001$) and 2004 ($P < 0.0001$), indicating that for these release years, wild fish transported at Lower Granite returned there in higher proportions than fish that were returned to the river at Lower Granite, or that passed Lower Granite without detection as juveniles. Annual estimates of the dam-specific T/I for Little Goose Dam were available for wild Chinook salmon for both 2003 and 2004. The estimated T/I for Little Goose was significantly > 1.0 for wild Chinook in 2004 ($P = 0.0024$), but not in 2003 ($P = 0.1554$).

Differential post-Bonneville mortality (D) is the ratio of post-Bonneville survival to Lower Granite Dam of transported fish to that of nontransported ("inriver") fish. Estimates of D were available for transportation from Lower Granite and Little Goose dams in 2003 and 2004 for wild Chinook, and from Lower Granite Dam in 2003 and 2004 for wild steelhead. Point estimates ranged from 0.74 ($\widehat{SE} = 0.29$) for transportation of wild Chinook salmon from Lower Granite Dam in 2003 to 1.91 ($\widehat{SE} = 0.61$) for transportation of wild steelhead from Lower Granite Dam in 2003. Small transport groups resulted in high uncertainty on the point estimates, and only for 2003 steelhead transported from Lower Granite Dam did transported fish have significantly greater post-Bonneville survival than nontransported fish ($P = 0.0213$).

The trends observed in survival and mortality estimates for wild Snake River spring and summer Chinook and steelhead agree well with the trends observed for hatchery Chinook and steelhead presented in Buchanan et al. (2007). In general, wild and hatchery estimates track each other well, with high correlations between wild and hatchery estimates for SAR ($r = 0.9517$), juvenile inriver survival ($r = 0.7916$), and ocean return probability ($r = 0.9879$) for Chinook, and for SAR ($r = 0.8654$), ocean return probability ($r = 0.9943$), and adult upriver survival ($r = 0.9637$) for steelhead. For steelhead, the estimated SAR for wild fish was often greater than the estimated SAR for hatchery fish, suggesting that the hatchery SAR may be a reasonable surrogate, providing a minimum estimate of SAR for wild fish. A similar pattern is seen for SAR and ocean return probability estimates between wild Chinook and hatchery spring Chinook, juvenile inriver survival for steelhead, and for adult upriver survival for both Chinook and steelhead.

Executive Summary

Objectives

We present historical annual estimates of the following performance measures for wild spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2004:

- Inriver survival between Lower Granite Dam and Bonneville Dam for smolts ("juveniles");
- Inriver survival between Bonneville Dam and Lower Granite Dam for adults, categorized in two ways:
  - For all adults returning from a given release group ("By release group");
  - For all adults migrating upstream in a given calendar year ("By return year").
- Ocean return probability (i.e., probability of returning from Bonneville as a juvenile to Bonneville as an adult) for nontransported ("inriver") and transported fish separately;
- Smolt-to-adult return ratio (SAR) from Lower Granite as a juvenile to Lower Granite as an adult for a given release group (transported and nontransported fish combined);
- Transportation effects, including
  - Dam-Specific transport-inriver ratio (T/I);
  - Differential post-Bonneville mortality, D, the ratio of survival from Bonneville as a juvenile to Lower Granite as an adult of transported smolts to that of nontransported smolts, measured on a dam-specific basis.

Estimates are made on large temporal and spatial scales. Annual estimates are based on regional release groups of PIT-tagged salmonids composed of individual releases of wild fish tagged in the Snake River Basin upstream of Lower Granite Dam, including the Clearwater Basin. Wild spring and summer Chinook salmon releases are pooled for this analysis. Inference from the results reported here is to the wild populations studied, and should not be used to make inference to species and runs not explicitly included. Performance measures that relate to adult returns (i.e., SAR, the ocean return probability, adult upriver survival, T/I, and D) are reported here only for age-2-ocean and older age classes for Chinook salmon, because the age-1-ocean age class is typically very small for Chinook salmon. Performance measures are reported for all returning age classes (including age-1-ocean) for steelhead, because the age-1-ocean age class is usually large for steelhead. A further objective is to compare estimates from wild fish to previous annual estimates from hatchery fish, as reported in Buchanan et al. (2007).

Methods

Data Methods

Tagging and detection data were downloaded from the PTAGIS database for wild spring and summer Chinook salmon and steelhead tagged and released as smolts in the Snake River Basin upstream of Lower Granite Dam, with migration years ranging from 1996 to 2004. Data were downloaded in late August and early September 2008. Release groups were defined by species, run, release area, and migration year (hereafter referred to as "release year"). For each release group, transportation effects were analyzed for dams where at least 1,000 tagged smolts were transported. Detection histories combining juvenile and adult detections were compiled using University of Washington software PitPro, publicly available online at
`http://www.cbr.washington.edu/paramest/pitpro/`.

Statistical Methods

The statistical methods implemented were described in detail in a previous report in this series (Buchanan et al. 2007). Each set of PIT-tag detection data with sufficient juvenile and adult detections was analyzed using the statistical software Program ROSTER (River-Ocean Survival and Transportation Effects Routine), developed by the University of Washington and publicly available at `http://www.cbr.washington.edu/paramest/roster/`. Program ROSTER implements a statistical release-recapture likelihood model that jointly analyzes juvenile and adult PIT-tag data to estimate inriver juvenile survival, ocean return probabilities, adult upriver survival, transportation rates, and transportation effects on survival. The model has been peer-reviewed and appears in Buchanan and Skalski (2007). This statistical model incorporates PIT-tag detection and juvenile transportation, and accounts for known removals of tagged fish from the migrating population. Unique adult survival probabilities are estimated for transported and nontransported fish, and for adults returning in different calendar years. Program ROSTER fits the likelihood model using numerical estimation techniques, and provides maximum likelihood estimates and associated estimated standard errors of model parameters and performance measures.

Performance measures of interest are defined in terms of the model parameters. Estimated performance measures are calculated from estimates of model parameters, and uncertainty measures on the performance measure estimates (i.e., standard errors) are estimated from the variancecovariance matrix generated by the model-fitting process. Consequently, all performance measures are maximum likelihood estimators (MLEs) based on the invariance property of MLEs (Norden 1972). Performance measures of transportation effects (e.g., transport-inriver ratios) were peer-reviewed in Buchanan, Skalski, and Smith (2006), and performance measures of survival were peer-reviewed in Buchanan and Skalski (2007). Several annual release groups had insufficient detections to implement the full ROSTER model. In these cases, alternative estimates of SAR and adult upriver survival were estimated using the Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965) and ratio estimators.

Data Summary

A total of 637,551 tagged fish were included in the 18 release groups analyzed here, with release groups ranging in size from 5,393 for steelhead migrating in 1996 to 92,304 Chinook salmon migrating in 2003. A total of 16,764 transported fish were analyzed, with transport groups ranging in size from 1,000 for steelhead transported from Lower Granite Dam (LGR) in 2003 to 6,175 for Chinook salmon transported from LGR in 2004. Transport groups of Chinook were also analyzed for Little Goose Dam (LGS) in 2003 and 2004. No release years prior to 2003 had sufficient numbers of wild fish transported (from the release groups analyzed) to estimate transportation effects.

Results

Wild Spring and Summer Chinook

Estimated SAR from Lower Granite to Lower Granite, including both transported fish (as available) and nontransported fish but excluding jacks, ranged from 0.15% ($\widehat{SE} = 0.05\%$) for 1996 to 2.26% ($\widehat{SE} = 0.13\%$) for 2000, and averaged 0.92% ($\widehat{SE} = 0.25\%$) over release years 1996 to 2004 for wild spring and summer Chinook salmon. Estimates of SAR for wild Chinook tracked well with SAR estimates for hatchery fish as reported in Buchanan et al. (2007) (Figure 1). Point estimates of SAR for wild Chinook salmon were typically greater than point estimates of SAR for hatchery spring Chinook, and had greater uncertainty arising from the smaller samples sizes available for wild fish.

Juvenile inriver survival was estimated for all release years from 1998 to 2004. Neither the 1996 nor the 1997 release had sufficient adult detections to estimate juvenile inriver survival for those release years. For the 7 years with estimates, the average of the juvenile inriver survival estimate from Lower Granite to Bonneville was 53.2% ($\widehat{SE} = 3.8\%$), with a range from 36.1% ($\widehat{SE} = 12.5\%$) in 2001 to 66.3% ($\widehat{SE} = 16.5\%$) in 1998. The ocean return probability (i.e., survival from Bonneville back to Bonneville, O_{NT}) was estimated for release years 1999 to 2004. The average estimated ocean return probability for nontransported wild Chinook salmon (excluding jacks) was

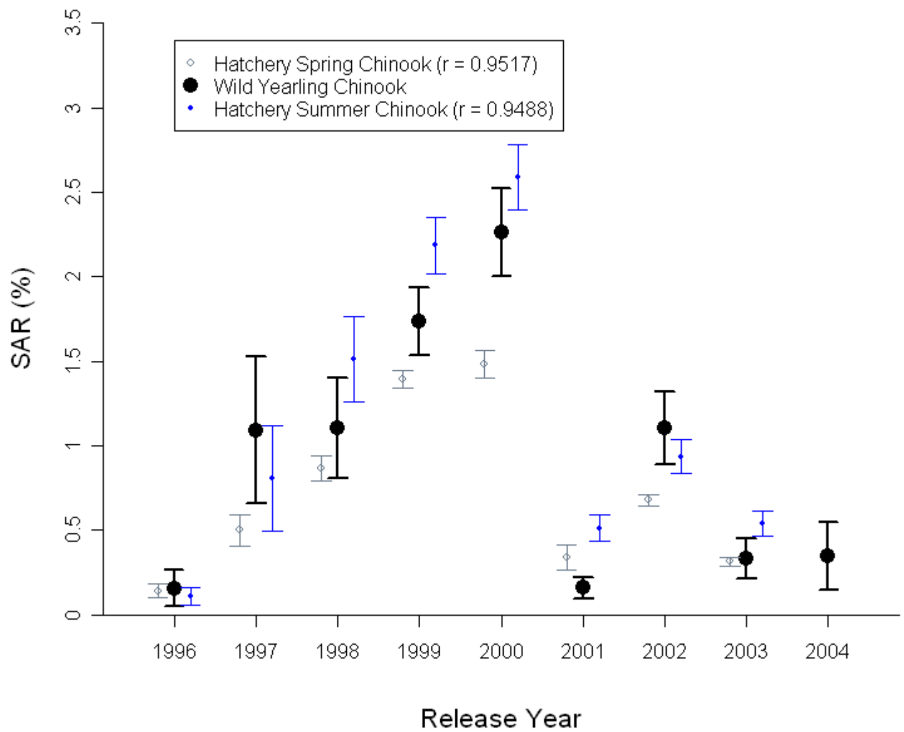

Figure 1: Estimated SAR for tagged wild and hatchery yearling Chinook salmon from the Snake River Basin ($\widehat{SAR}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Both transported and nontransported fish are represented in SAR estimates for hatchery Chinook, and in the 2003 and 2004 estimates for wild Chinook. Other estimates represent only nontransported Chinook. Estimates do not include the age-1-ocean age class.

2.06% ($\widehat{SE} = 0.72\%$), with a range from 0.49% ($\widehat{SE} = 0.20\%$) for 2001 to 4.72% ($\widehat{SE} = 0.45\%$) for 2000.

Wild Chinook transported from either Lower Granite Dam or Little Goose Dam in 2003 and 2004 were analyzed. For both Lower Granite and Little Goose, the estimated T/I value was significantly greater than 1.0 for 2004 ($P < 0.0001$ for Lower Granite; $P = 0.0024$ for Little Goose), but not for 2003. For Lower Granite, the geometric average T/I was 1.74 ($\widehat{SE} = 0.54$) for 2003 and 2004. For Little Goose, the average T/I was 1.80 ($\widehat{SE} = 0.39$). Point estimates of D for Lower Granite and Little Goose transport Chinook were lower than the T/I estimates for both 2003 and 2004, and in no case were they significantly > 1.0 ($P > 0.4$ for each case). The geometric average D estimate for Lower Granite for 2003 and 2004 was 0.89 ($\widehat{SE} = 0.16$), while the average D estimate for Little Goose was 1.00 ($\widehat{SE} = 0.07$).

Wild Steelhead

The average SAR estimate for wild steelhead was 0.63% ($\widehat{SE} = 0.15\%$) over release years 1996 to 2004, with a range from 0.16% ($\widehat{SE} = 0.08\%$) for 1997, to 1.70% ($\widehat{SE} = 0.11\%$) for 2000. The trend in SAR estimates for wild steelhead followed the trend for hatchery steelhead in general ($r = 0.8654$), with significantly higher SAR for wild steelhead in 2000, 2001, and 2003 (Figure 2).

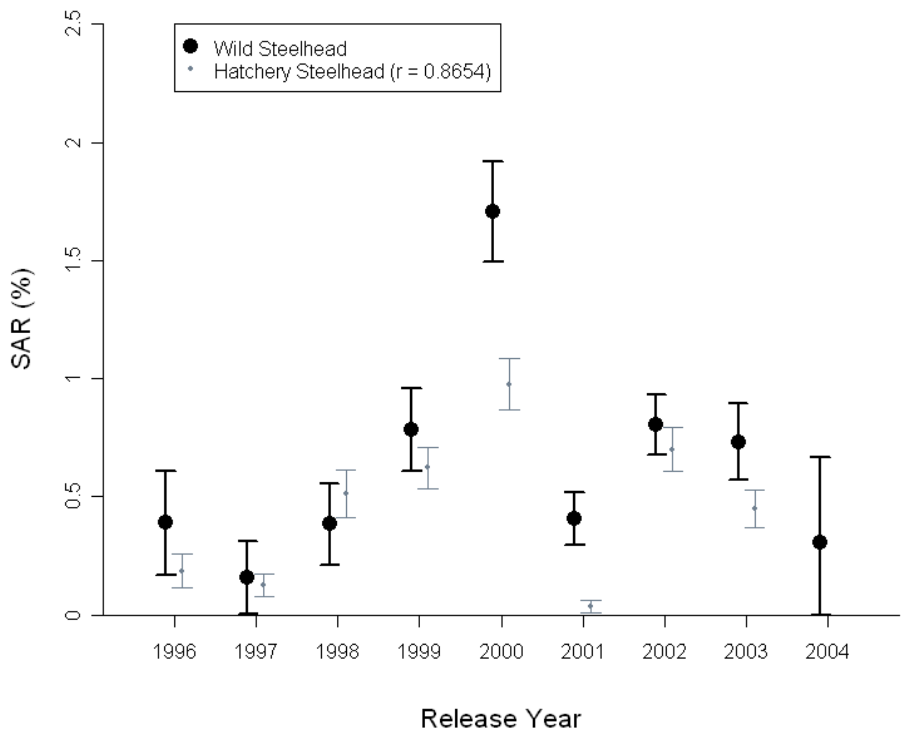

Figure 2: Estimated SAR for wild and hatchery steelhead from the Snake River Basin ($\widehat{SAR}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Both transported and nontransported fish are represented in SAR estimates for 2003 and 2004 wild steelhead. All other estimates represent only nontransported steelhead. Estimates include the age-1-ocean age class.

Juvenile inriver survival was estimated for all release years from 1999 through 2004, excluding the 2001 release year. The 1996, 1997, 1998, and 1999 had too few adult detections to estimate juvenile inriver survival for those release years. For the 5 years with estimates, the average of the juvenile inriver survival estimates from Lower Granite to Bonneville was 40.1% ($\widehat{SE} = 6.9\%$) for wild steelhead. The ocean return probability (i.e., survival from Bonneville back to Bonneville) was estimated for release years 1999, 2000, and 2002 to 2004. There were insufficient data to estimate the ocean return probability for the 2001 release group. For the 5 years with estimates, the average estimated ocean return probability for nontransported wild steelhead was 2.21% ($\widehat{SE} = 0.56\%$), with a range from 1.25% ($\widehat{SE} = 1.68\%$) for 2004, to 4.29% ($\widehat{SE} = 0.58\%$) for 2000.

Wild steelhead transported from Lower Granite Dam in 2003 and 2004 were analyzed, resulting in T/I estimates significantly greater than 1.0 ($P < 0.0001$) for both years (geometric average 4.68, $\widehat{SE} = 1.32$). The point estimate of D for Lower Granite transport steelhead was significantly greater than 1.0 only for 2003 ($P = 0.0213$). The geometric average estimate of D was 1.33 ($\widehat{SE} = 0.48$) for 2003 and 2004. Too few tagged wild steelhead were transported from Little Goose Dam to analyze for transportation effects.

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Acknowledgments

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We especially thank Dr. Al Giorgi for his suggestions on appropriate data to use in this report. Funding support for this work came from the Pacific Northwest region's electrical rate-payers through the Columbia River Fish and Wildlife Program administered by the Bonneville Power Administration, project number 199105100 (contract 35477).

Chapter 1

Introduction

1.1 Background

Information on the migratory life stages of Chinook salmon and steelhead from the Snake River Basin is routinely available from large annual PIT-tag studies and the region-wide system of PIT-tag detectors. The availability of detection data from both the juvenile and adult life stages over multiple years makes it possible to use a cohesive modeling framework to estimate important performance measures such as juvenile, ocean, and adult survival, and transportation effects. The River-Ocean Survival and Transportation Effects Routine (ROSTER) modeling software (`http://www.cbr.washington.edu/paramest/roster/`) was developed by the University of Washington for this estimation purpose. A previous report (Buchanan et al. 2007) gave an in-depth description of the ROSTER model and presented estimation results for eight consecutive years of release groups of hatchery spring and summer Chinook salmon and steelhead. This report extends these results to release groups of wild spring and summer Chinook salmon and steelhead that were released in the Snake River Basin from 1996 through 2004. Estimates are presented of SAR (smolt-to-adult return ratio) and juvenile, ocean, and adult survival for large-scale annual release groups of wild Chinook and steelhead. In addition to survival and mortality components, estimates of transportation effects are presented as available.

Numerous populations of wild salmonids are listed as endangered or threatened under the Endangered Species Act (1973). Nevertheless, it is more feasible to study hatchery stocks, and more hatchery smolts are PIT-tagged annually than wild smolts. A primary question is how representative are the hatchery stocks of the wild populations, and whether survival and transportation estimates from tagged hatchery fish may be used to make inference to wild stocks. To address this question, this report compares estimates of survival and transportation effect measures from large-scale regional release groups of wild and hatchery Chinook and steelhead. Estimates from wild stocks are first presented in this report, while estimates from hatchery fish are taken from Buchanan et al. (2007).

Chapter 2 describes how release groups were identified, and how the data were acquired and formatted for analysis. Details on data collection and preparation for each release group are provided in Appendix C. Statistical methods are also briefly described in Chapter 2. A description of the statistical model used (i.e., the ROSTER model) is available in Buchanan et al. (2007). Details on the composition of the release groups and the model-fitting are provided in Chapter 3 and Appendix D, respectively. Descriptions of observed patterns in estimated SAR, survival, and transportation effects, as well as comparisons with results for hatchery fish, are in Chapter 4. Point estimates and standard errors are provided in Appendix E.

1.2 Objectives

We will present historical annual estimates of the following performance measures for wild spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2004:

- Inriver survival between Lower Granite Dam and Bonneville Dam for smolts ("juveniles");
- Inriver survival between Bonneville Dam and Lower Granite Dam for adults, categorized in two ways:
  - For all adults returning from a given release group ("By release group");
  - For all adults migrating upstream in a given calendar year ("By return year").
- Ocean return probability (i.e., probability of returning from Bonneville as a juvenile to Bonneville as an adult) for nontransported ("inriver") and transported fish separately;
- Smolt-to-adult return ratio (SAR) from Lower Granite as a juvenile to Lower Granite as an adult for a given release group (transported and nontransported fish combined);
- Transportation effects, including
  - Dam-Specific transport-inriver ratio (T/I);
  - Differential post-Bonneville mortality, D, the ratio of survival from Bonneville as a juvenile to Lower Granite as an adult of transported smolts to that of nontransported smolts, measured on a dam-specific basis.

Annual estimates will be based on regional pooled release groups of PIT-tagged salmonids composed of individual releases of wild fish in the Snake River Basin, including the Clearwater Basin. Wild spring and summer Chinook salmon releases will be pooled for this analysis. Inference from the results reported here is to the wild populations studied; results from the wild fish analyzed here should not be used to make inference to species and runs not explicitly included. Performance measures that relate to adult returns (i.e., SAR, the ocean return probability, adult upriver survival, T/I, and D) will be reported here only for age-2-ocean and older age classes for Chinook salmon, because the age-1-ocean age class is typically very small for Chinook salmon. Performance measures will be reported for all returning age classes (including age-1-ocean) for steelhead, because the age-1-ocean age class is usually large for steelhead. A further objective is to compare estimates from wild fish to previous annual estimates from hatchery fish, as reported in Buchanan et al. (2007).

Chapter 2

Methods

2.1 Data Collection and Preparation Methods

2.1.1 Data Used

We analyzed annual PIT-tagged release groups composed of wild fish tagged and released in the Snake River Basin upstream of Lower Granite Dam, with migration year ranging from 1996 to 2004. We followed the common approach of pooling releases spring and summer Chinook salmon. We also pooled all release groups across the Snake River Basin by species for each migration year, and did not distinguish between releases from the Clearwater River Basin and those from the rest of the Snake River Basin. We omitted release groups that were tagged and released at Lower Granite Dam because of potential bias caused by tagging effects.

The release groups analyzed were categorized by species and migration year, hereafter referred to as “release year” (defined below, Section 2.1.2). The data requirements of the ROSTER model demand large release groups because of low return rates from the ocean. Consequently, it was necessary to pool fish from individual releases made at separate release sites to form the annual release groups.

Annual transport groups within each release group were composed of all fish transported from a particular dam within the release year, regardless of transport date. Low return rates from the ocean precluded analysis of small transport groups. Transportation effects can be reasonably estimated only if sufficient adults return from both the transport and the nontransport groups. For the hatchery analysis in Buchanan et al. (2007), transport groups of 5,000 or more fish were analyzed. Because fewer wild fish are tagged upstream of Lower Granite Dam, and fewer tagged wild fish are transported than hatchery fish, we lowered the minimum transport group size to 1,000 for analysis of wild release groups. Smaller transport groups were treated as known removals, and their detection histories were censored at their transport dam (i.e., these fish were not used to estimate survival after passing the transport dam). Transportation effects were not estimated for dams with transport groups smaller than 1,000.

Juvenile PIT-tag detection was available at four detection sites in all years: Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMO), and McNary (MCN). Additionally, detections at Bonneville (BON) were available starting in 1997, and detections at John Day (JD) were available starting in 1998. Adult PIT-tag detection became available at an increasing number of dams during the study period. Until 2000, only LGR had reliable adult detection. From 2000 to 2002, both BON and LGR had adult detection capability; after 2002, BON, MCN, Ice Harbor (IH), and LGR all had adult PIT-tag detection capability. Thus, the number of adult detection sites modeled increased throughout the study (Table C.3). Detections of PIT tags from the towed PIT-tag detection array operated by the National Marine Fisheries Service (NMFS) in the Columbia River estuary were not used in this analysis (Buchanan et al. 2007).

Detections of all returning adults were used in estimating parameters of the release-recapture model, including age-1-ocean fish but not age-0-ocean fish. The performance measures presented here are reported for age-2-ocean and older adults for Chinook salmon, and for all adults (including age-1-ocean fish) for steelhead. This mirrors the approach taken elsewhere (e.g., Schaller et al. 2007), and is based on observations that age-1-ocean fish do not contribute largely to Chinook salmon returns, but do contribute heavily to overall steelhead returns.

2.1.2 Acquiring Data

PIT-tag release and recapture data for release years 1996 - 2004 were downloaded in late August and early September 2008 from the PTAGIS database, maintained by the Pacific States Marine Fisheries Commission. We used the criteria outlined in Schaller et al. (2005) to define release groups for a given migration year. For Chinook salmon, the release group for a given migration year consisted of wild spring and summer Chinook tagged from July 25 of the previous calendar year through May 20 of the migration year. For steelhead, the release group for a given migration year consisted of wild steelhead tagged from July 1 of the previous calendar year through June 30 of the migration year, with fork length at tagging between 130 and 299 mm (inclusive).

In addition to tagging date and fork length (for steelhead), appropriate tagged smolts were identified by their species, run, and rearing type (wild vs. hatchery); migration year; and release site (EPA reach; Table 2.1). Because both juvenile and adult PIT-tag detections were required, we did not restrict the observation dates in the Interrogation Summary from PTAGIS (see the CBR webpage for PTAGIS queries), but instead used all observations of each PIT-tagged fish.

Table 2.1: EPA reaches (Hydrologic Unit Codes, HUCs) used in the Tagging Details and Interrogation Details queries in PTAGIS. Not all EPA reaches had release groups.

Hydrologic Unit Codes				
17060101	17060102	17060103	17060104	17060105
17060106	170602*	17060201	17060202	17060203
17060204	17060205	17060206	17060207	17060208
17060209	17060210	170603*	17060301	17060302
17060303	17060304	17060305	17060306	17060308

2.1.3 Preparing Data for Analysis

The University of Washington software used to analyze the data, Program ROSTER, requires data in the form of detection histories. A detection history is a sequence of codes indicating the nature of the observation of a tagged fish at each detection site, combining both juvenile and adult detection sites. Each detection site in the study is represented by a single field in the detection history. The detection history indicates the sites where the fish was detected and where it was not detected, where the fish was transported (if at all), and the fish's ocean age class if it was detected as an adult. Each fish in the release group has its own detection history.

The raw PIT-tag detection data downloaded from PTAGIS must be converted to joint juvenile and adult detection histories. This was done using University of Washington software PitPro, which determines the appropriate detection history for each fish based on release information, observed PIT-tag detections, any tag-recovery or mortality information, and decision rules regarding disposition after detection. The decision rules used by PitPro are described briefly in Buchanan et al. (2007), and in more detail at
`http://wiki.cbr.washington.edu/pittag/index.php/PitPro_Manual`. PitPro is publicly available online at `http://www.cbr.washington.edu/paramest/pitpro/`.

A difference between the decision rules described in Buchanan et al. (2007) and those used for this report is that, in agreement with the methods used by NMFS and the Comparative Survival Study (Schaller et al. 2007), we defined the steelhead return year to run from July 1 through the following June 30, to accommodate residualization of steelhead adults during their upriver migration. In Buchanan et al. (2007), a calendar return year was used for hatchery steelhead, because residualization typically occurs in transported steelhead (Doug Marsh, personal communication) and no transported hatchery steelhead were analyzed in Buchanan et al. (2007).

In addition to the decision rules used by PitPro described above, specialized processing of the data was sometimes necessary to deal with anomalous or problematic data. In particular, because we cannot estimate transportation effects from small transport groups, we censored all detection histories for transport groups composed of fewer than 1,000 tagged smolts at the transport site. Censoring smaller transport groups means that we treated these small transport groups as known removals at the transport site. We were unable to estimate transportation effects or adult upriver survival for censored transport groups. Additionally, detection histories for fish from very small adult age classes were censored at their final juvenile detection, because reliable ocean and adult survival cannot be estimated based on only a few fish.

Some adult steelhead were observed to pass one or more dams in the lower river before June 30, and pass upriver dams after July 1, resulting in a detection history with multiple adult age classes. Because the ROSTER model requires that all adult upriver migration for a given fish be limited to a single age class, the records of adult steelhead with multiple age classes were censored at the last detection in the earlier age class. This practice does not bias estimation of SAR if the ROSTER model is used for analysis.

2.2 Statistical Methods

The statistical methods used for estimation of performance measures are described in Buchanan et al. (2007). Briefly, the ROSTER model was used to generate maximum likelihood estimates (MLEs; Norden 1972) of the various parameters: survival, transportation effects (by transport site and adult age class), detection probability, transportation probability, and censoring (i.e., known removal) probability. Model selection was performed using likelihood ratio rests and AIC (Burnham and Anderson 2002). The performance measures are defined in terms of these model parameters, and were estimated using the MLEs of the model parameters. Standard errors were estimated using the matrix of second derivatives of the likelihood estimated during the numerical fitting process, in combination with the Delta Method (Seber 1982, pp. 7-9).

We compared results from releases of wild fish generated for this report with results from releases of hatchery fish as presented in Buchanan et al. (2007). Comparisons were made between wild and hatchery results for release years in common. Because hatchery spring and summer Chinook salmon were analyzed separately in Buchanan et al. (2007), separate comparisons were made between wild Chinook and both spring and summer Chinook. Additionally, only the results for hatchery spring Chinook salmon from the Snake River Basin (release area SNB; Buchanan et al. 2007) were used in the spring Chinook comparisons. We used estimates for tagged fish for both wild and hatchery fish, without attempting to make inference to untagged fish for these comparisons. Comparisons were made for all measures of survival, including SAR, and for the proportions of integrated mortality. No formal comparisons were made for either T/I or D, because only two years of estimates of these measures were available for wild fish.

Wild and hatchery results were compared in several ways. For each performance measure, the correlation between wild and hatchery estimates was estimated for the release years in common. Because the estimated correlation values are based on estimates of performance measures, rather than on their true values, the correlations reported here include measurement error. This means that the correlation between actual values of the performance measures (rather than their estimates) will generally be higher than the values reported here. The small sample sizes available for wild fish prevented removal of measurement error from the correlation estimates.

In addition to simple correlation, we tested for the effect of rearing type (i.e., wild or hatchery) on estimated values for each performance measure using weighted analysis of variance (WANOVA). We used a 2-way classification of year by rearing type. In each case, we removed the effect of release year before testing for rearing type via F-tests. The weights used in the WANOVA depended on the performance measure, and were selected to stabilize the variance across release years. The appropriate weight depended on the variance structure of the performance measure estimate. For SAR, the proportions of integrated mortality, and all measures of survival except ocean survival, we used weights inversely proportional to the square of the coefficient of variation. For ocean survival, we used weights inversely proportional to the variance.

Chapter 3

Description of PIT-Tag Release Groups Used in Analysis

The annual regional release groups are composed of multiple smaller releases (Tables C.1 and C.2). Spring and summer Chinook salmon release groups were pooled. A total of 637,551 tagged fish were included in the 18 release groups analyzed here, with release groups ranging in size from 5,393 for steelhead migrating in 1996 to 92,304 Chinook salmon migrating in 2003.

Size-at-tagging (i.e., fork length) of Chinook salmon ranged from 31 mm in 1999, 2002, and 2004 to 298 mm in 2001 (Figure 3.1). Median fork length at tagging for Chinook salmon ranged from 72 mm in 2003 to 88 mm in 1998 and 2001. Size-at-tagging information was not available for all Chinook salmon, in particular for the 2003 releases (Figure 3.1). Size-at-tagging for steelhead ranged from 130 mm to 300 mm, according to the data selection criteria. Median fork length at tagging for steelhead ranged from 162 mm in 1997, 2001, 2002, and 2003 to 171 mm in 1998 (Figure 3.2).

For most release years, transport numbers were low at each dam (Table 3.1). While transportation occurred at each of Lower Granite, Little Goose, Lower Monumental, and McNary dams, only Lower Granite and Little Goose transported enough tagged smolts ($\geq 1,000$) to be analyzed for transportation effects (Table 3.1). Detection histories of smaller transport groups were censored at the transport dam. Censoring the detection histories of small transport groups enables us to use previous detections of those fish to estimate survival to the transport dams, without overfitting the model in an attempt to estimate transportation effects from small transport groups. The result of this censoring is that for each release group, transportation effects are estimated only for Lower Granite or Little Goose dams.

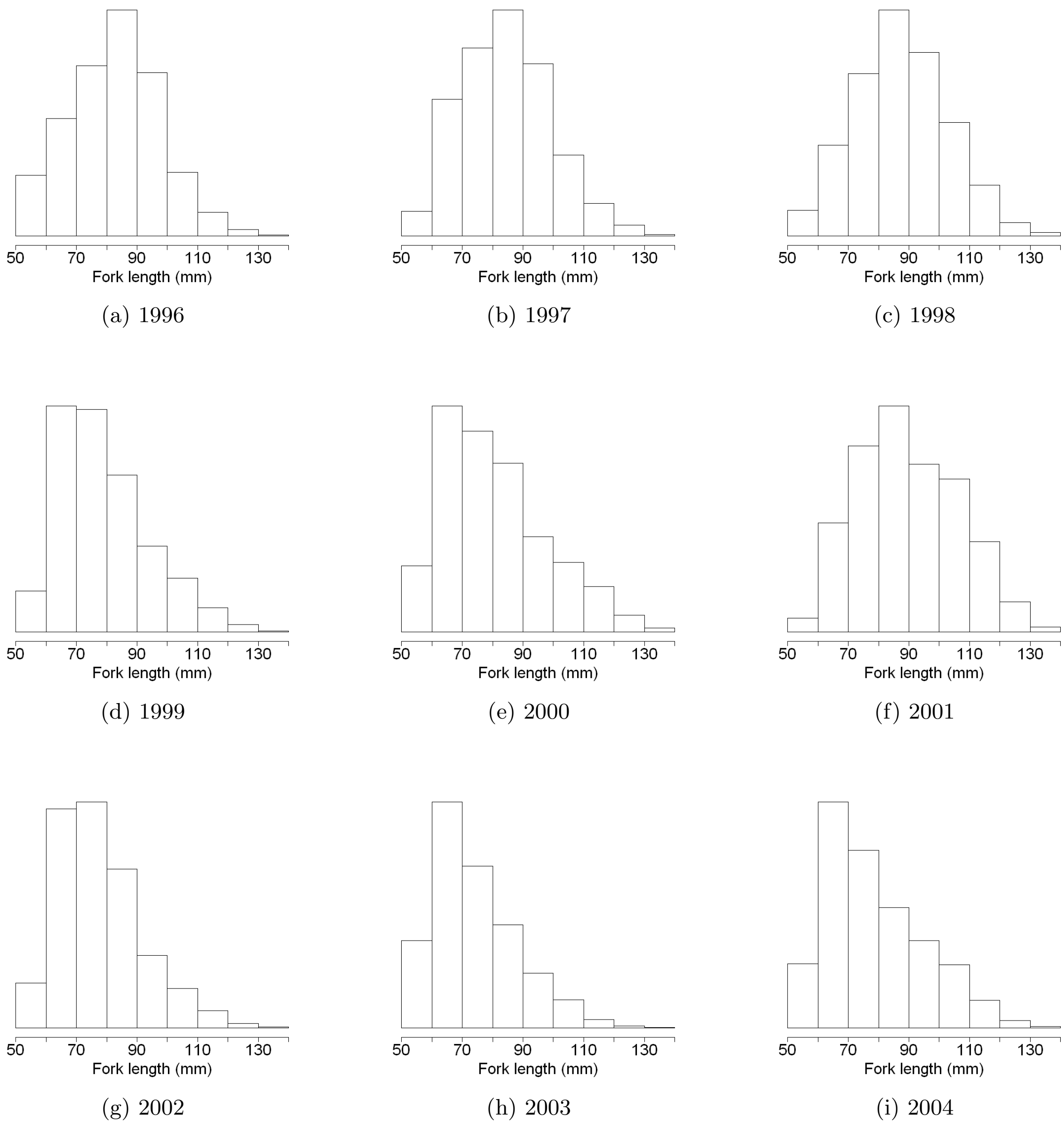
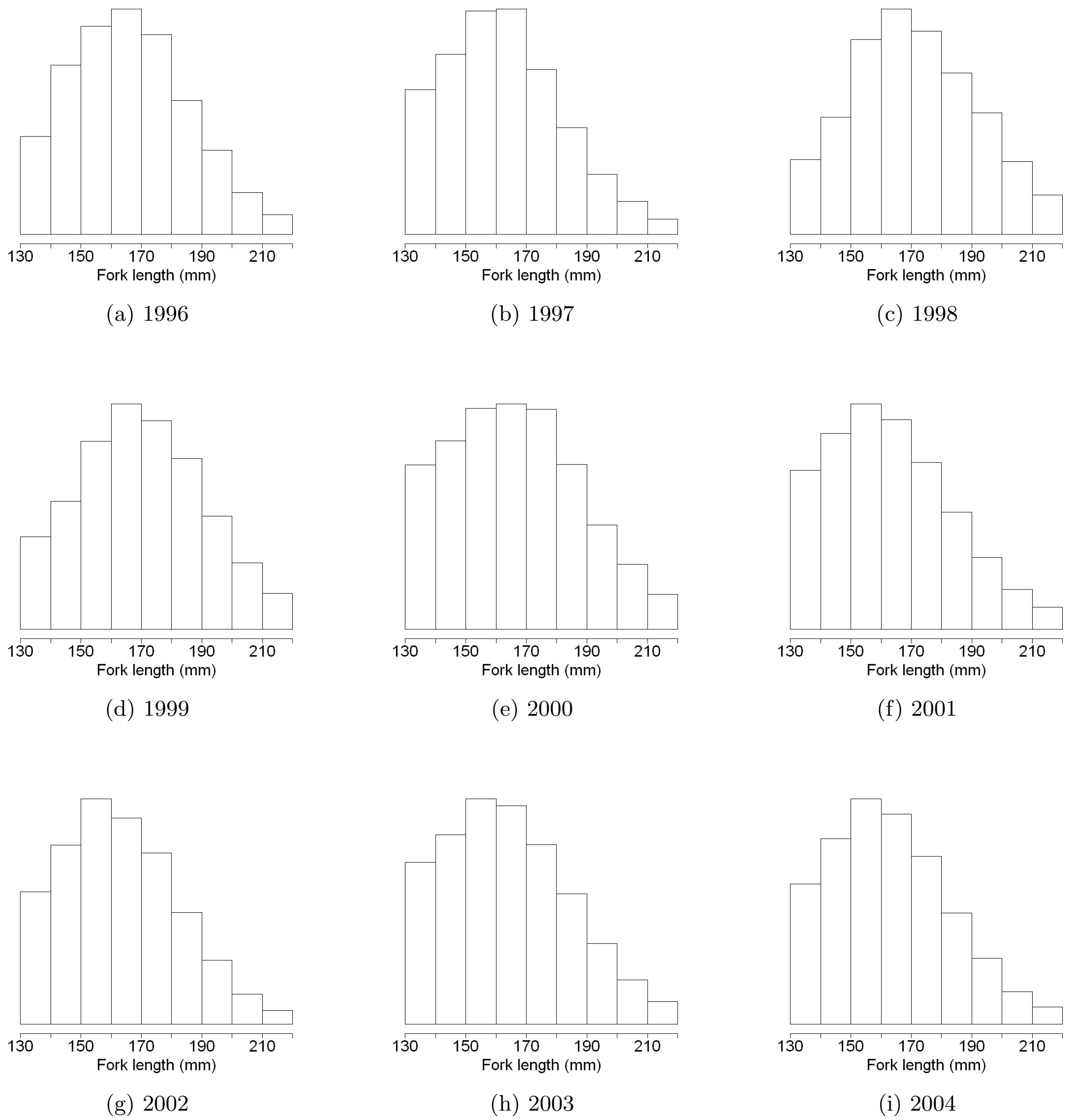


Figure 3.1: Fork length (mm) at tagging for wild spring and summer Chinook salmon releases. Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent the following proportions of annual release groups: 1996, 1999, 2000, 2002 (99.8%); 1997, 1998 (99.9%); 2001 (99.1%); 2003 (97.3%); 2004 (97.4%).



(a) 1996 (b) 1997 (c) 1998

(d) 1999 (e) 2000 (f) 2001

(g) 2002 (h) 2003 (i) 2004

Figure 3.2: Fork length (mm) at tagging for wild steelhead releases. Size-at-tagging data were not available for all tagged fish in all years. Frequency distributions represent 100% of each annual release group.

Table 3.1: Number transported at each transport dam. Bolded transport groups were analyzed, while all others were censored at transport dam because of small group size ($< 1,000$).

		Number Transported			
Release Year	**Species**	**LGR**	**LGS**	**LMO**	**MCN**
1996	Chinook	93	51	34	5
1997		140	25	21	0
1998		471	391	174	21
1999		635	152	382	9
2000		132	148	213	48
2001		108	34	62	78
2002		791	947	140	105
2003		**2,805**	**1,665**	470	87
2004		**6,175**	**2,221**	771	78
1996	Steelhead	41	37	26	1
1997		129	22	69	1
1998		156	139	234	4
1999		161	96	151	0
2000		123	139	314	17
2001		60	39	130	11
2002		73	30	336	38
2003		**1,000**	657	239	26
2004		**2,898**	957	293	18

After removing erroneous tags (Tables C.5 and C.6) as described in Section 2.1.3, annual release groups ranged in size from 5,393 for the 1996 release of wild steelhead to 92,304 for the 2003 release of wild Chinook (Table 3.2). Transport group size ranged from 1,000 steelhead transported from Lower Granite in 2003, to 6,173 Chinook salmon transported from Lower Granite in 2003 (Table 3.2).

Table 3.2: Size of release groups after removing erroneous tags, percent of release group identified in PTAGIS as "spring run" (for Chinook), size of transport groups analyzed, and number of adults detected at Lower Granite by juvenile migration method (not transported, LGR transport, or LGS transport). Chinook adult counts do not include age-1-ocean fish; steelhead adult counts include age-1-ocean fish.

			Number of Smolts			Number of Adults at LGR			
Release Year	Species	Percent Spring	Release Group	LGR Transp.	LGS Transp.	Not Transp.	LGR Transp.	LGS Transp.	Total
1996	Chinook	62.1	18,908	0	0	8	-	-	8
1997		59.6	9,601	0	0	27	-	-	27
1998		54.7	30,615	0	0	130	-	-	130
1999		53.7	73,319	0	0	405	-	-	405
2000		51.4	62,780	0	0	507	-	-	507
2001		33.7	44,372	0	0	29	-	-	29
2002		60.4	59,025	0	0	188	-	-	188
2003		55.2	92,304	2,805	1,665	57	12	9	78
2004		64.3	89,077	6,173	2,220	43	48	17	108
1996	Steelhead		5,393	0	0	12	-	-	12
1997			6,409	0	0	4	-	-	4
1998			8,003	0	0	19	-	-	19
1999			15,632	0	0	63	-	-	63
2000			24,712	0	0	242	-	-	242
2001			23,384	0	0	53	-	-	53
2002			25,524	0	0	126	-	-	126
2003			23,809	1,000	0	71	30	-	101
2004			24,688	2,897	0	14	43	-	57

Chapter 4

Results

The focus of the results is on comparisons between estimates of performance measures for wild and hatchery yearling Chinook salmon and steelhead (Buchanan et al. 2007). Appendix E provides tables of yearly point estimates and standard errors for the performance measures for wild fish. Confidence intervals on the plots of wild and hatchery results have width equal to $\pm 1.96 \times SE$. Correlation values between wild and hatchery results refer to the estimates of the performance measures, rather than to the actual performance of the wild and hatchery groups, per se. The presence of sampling error in the estimates means that the correlation between actual (unknown) values of the performance measures will be higher than the correlations shown here. The P-values used to compare wild and hatchery results come from F-tests and analysis of variance.

Wild results for Chinook salmon are based on pooled release groups of spring and summer Chinook salmon, whereas hatchery results are available for spring Chinook salmon and summer Chinook salmon separately. Thus, wild Chinook results are compared with both spring and summer hatchery Chinook results. All results presented here refer to release groups composed of fish from the Snake River Basin, including the Clearwater Basin when applicable. More information on the release areas is given in Appendix C.

Estimates of performance measures for Chinook salmon do not include age-1-ocean fish (i.e., jacks). Estimates for steelhead include the age-1-ocean age class. Reported means (averages) of survival estimates (e.g., SAR, S_J, O_{NT}, etc.) and estimates of the integrated mortality measures (μ_J, μ_O, and μ_A) are unweighted arithmetic means across release years. Only two years had sufficient transport numbers of wild fish to yield estimates of transport performance measures, so no mean is reported for either T/I or D.

4.1 Smolt-to-Adult Return Rate (SAR)

Estimates of the smolt-to-adult return ratio (SAR) for wild Chinook salmon ranged from 0.0015 ($\widehat{SE} = 0.0005$) for the 1996 release group to 0.0226 ($\widehat{SE} = 0.0013$) for the 2000 release group, with a mean of 0.0092 ($\widehat{SE}$ = 0.0025) over the years 1996 to 2004 (Table E.1). These values do not include the age-1-ocean age class. There was high correlation ($r > 0.90$) between estimated SAR values for the annual release groups of wild and hatchery Chinook salmon (Figure 4.1). Estimated SAR for both wild and hatchery Chinook salmon peaked for the 2000 release groups, with low estimates for the 1996, 2001, 2003, and 2004 release groups (Figure 4.1). Although the estimate of SAR was often higher for wild Chinook than for hatchery spring Chinook, and lower for wild Chinook than for hatchery summer Chinook, in neither case was the difference significant at the 90% level ($P = 0.1218$ for spring Chinook, and $P = 0.6631$ for summer Chinook). In general, standard errors were higher on the wild estimates because of lower tagging numbers of wild fish.

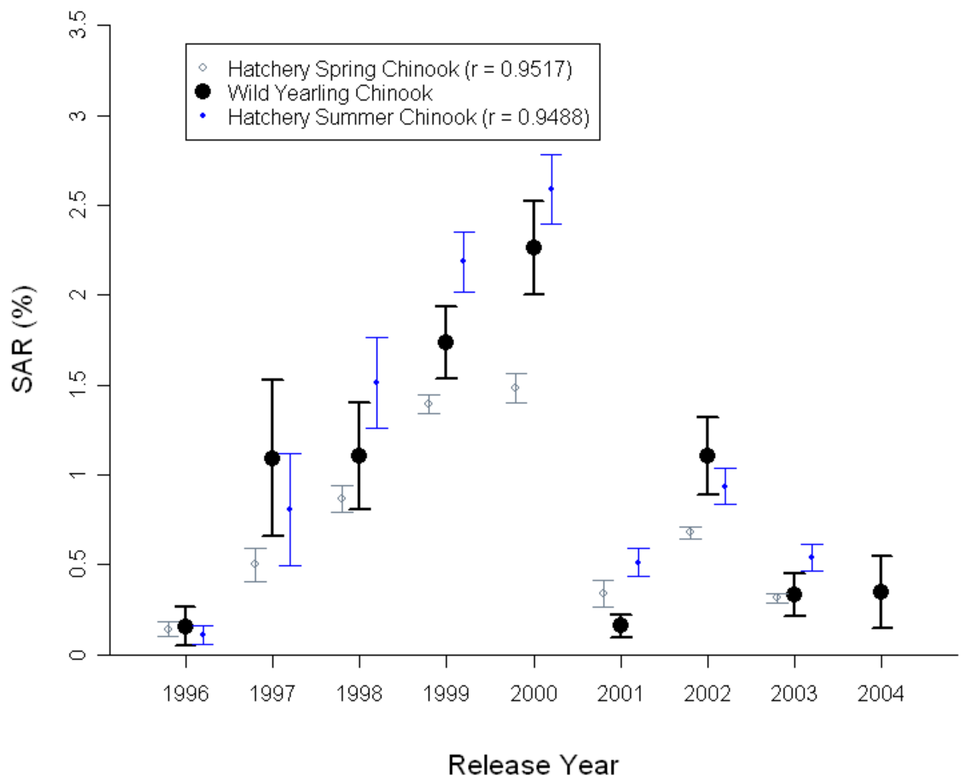


Figure 4.1: Estimated SAR for tagged wild and hatchery yearling Chinook salmon from the Snake River Basin ($\widehat{SAR}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Both transported and nontransported fish are represented in SAR estimates for hatchery Chinook, and in the 2003 and 2004 estimates for wild Chinook. Other estimates represent only nontransported Chinook. Estimates do not include the age-1-ocean age class.

Estimates of SAR for wild steelhead ranged from 0.0016 ($\widehat{SE}$ = 0.0008) for the 1997 release group to 0.0170 ($\widehat{SE}$ = 0.0011) for the 2000 release group, with a mean of 0.0063 ($\widehat{SE}$ = 0.0015) over the years 1996 to 2004 (Table E.1); these estimates include the age-1-ocean age class. There was high correlation between SAR estimates for annual release groups of wild and hatchery steelhead ($r = 0.87$; Figure 4.2). Analysis of variance found a significant difference between estimated SAR for wild and hatchery steelhead ($P = 0.0745$), with wild SAR greater than hatchery SAR on average. The largest differences were for the 2000 and 2001 release groups (Figure 4.2). Again, standard errors were generally higher on the wild estimates because of smaller wild release groups.

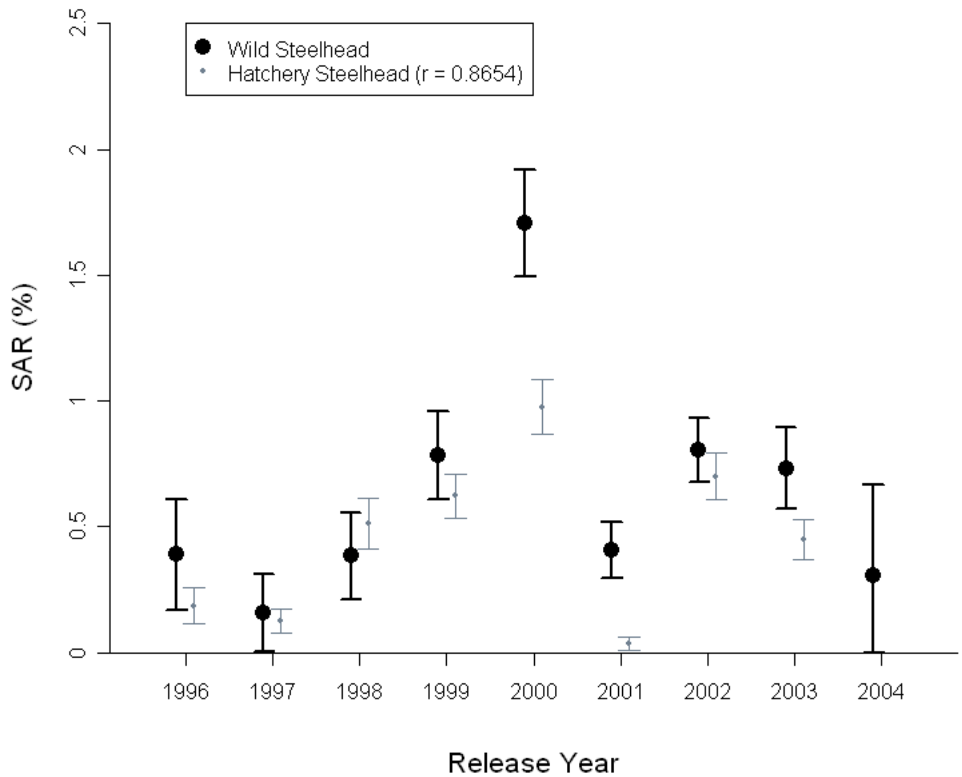


Figure 4.2: Estimated SAR for wild and hatchery steelhead from the Snake River Basin ($\widehat{SAR}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Both transported and nontransported fish are represented in SAR estimates for 2003 and 2004 wild steelhead. All other estimates represent only nontransported steelhead. Estimates include the age-1-ocean age class.

4.2 Juvenile Inriver Survival (S_J)

Estimates of survival (S_J) of nontransported wild Chinook salmon from Lower Granite Dam to Bonneville Dam ranged from 0.3610 ($\widehat{SE} = 0.1245$) for the 2001 release group, to 0.6628 ($\widehat{SE} = 0.1650$) for the 1998 release group, with a mean of 0.5323 ($\widehat{SE} = 0.0375$) over the years 1998 to 2004 (Table E.2). No estimates of S_J were available for the 1996 or 1997 release groups of wild Chinook because of small release groups and low detection probabilities at Bonneville. There was high correlation between estimates of juvenile inriver survival from wild and hatchery Chinook ($r > 0.70$; Figure 4.3). Analysis of variance found a significant difference in juvenile survival estimates between wild Chinook and hatchery spring Chinook ($P = 0.0059$), with juvenile survival lower for wild Chinook than for hatchery Chinook on average. Survival for wild Chinook was not significantly different than survival for hatchery summer Chinook ($P = 0.5014$).

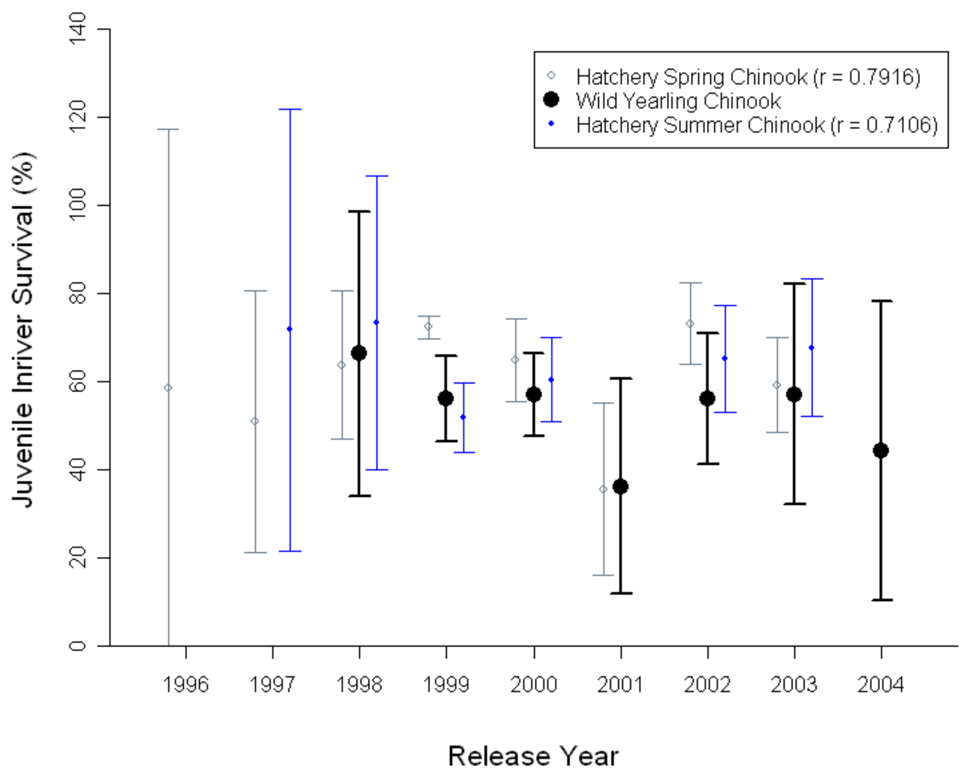


Figure 4.3: Estimated juvenile inriver survival for nontransported wild and hatchery yearling Chinook salmon from the Snake River Basin ($\widehat{S_J}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r.

Estimates of S_J for wild steelhead ranged from 0.1478 ($\widehat{SE} = 0.1865$) for the 2004 release group, to 0.5297 ($\widehat{SE}$ = 0.1107) for the 2003 release group, with a mean of 0.4096 ($\widehat{SE}$ = 0.0693) over the years 1999 and 2000 to 2004 (Table E.2). No estimates of S_J were available for the 1996, 1997, or 1998 release groups for wild steelhead because of small release groups and low detection probabilities at Bonneville Dam. No estimate is available for 2001 because of low ocean return probabilities. Estimates of juvenile inriver survival for steelhead were available for both wild and hatchery releases in only four years (1999, 2000, 2002, and 2003), and for each year, the point estimate for wild steelhead was higher than for hatchery steelhead (Figure 4.4). However, large standard errors meant that only in 2000 was the estimate for wild steelhead significantly greater, and analysis of variance found no significant difference between wild and hatchery estimates across the four years ($P = 0.1182$).

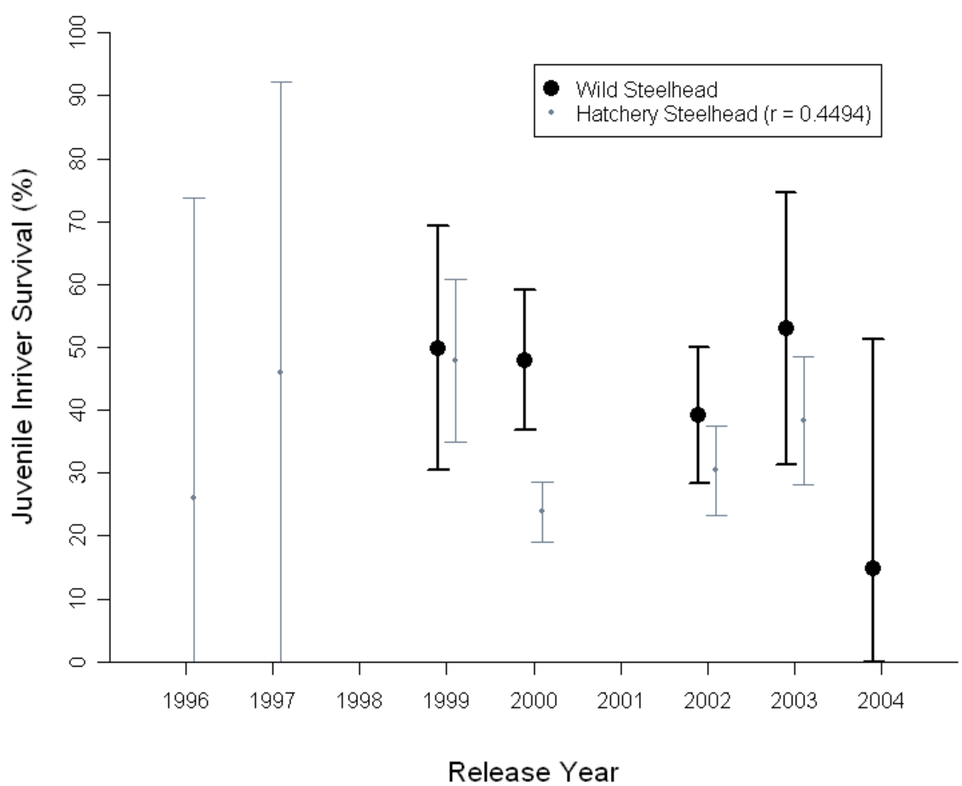


Figure 4.4: Estimated juvenile inriver survival for nontransported wild and hatchery steelhead from the Snake River Basin ($\widehat{S_J}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r.

4.3 Ocean Return Probability (O_{NT})

Estimates of the ocean return probability from Bonneville back to Bonneville (O_{NT}) for wild Chinook salmon ranged from 0.0049 ($\widehat{SE} = 0.0020$) for the 2001 release group, to 0.0472 ($\widehat{SE} = 0.0045$) for the 2000 release group, with a mean of 0.0206 ($\widehat{SE} = 0.0072$) over the release years 1999 to 2004 (Table E.3). These values do not include the age-1-ocean age class. Estimates of the ocean return probability were not available for Chinook salmon for release years prior to 1999 because there were no adult PIT-tag detection facilities at Bonneville Dam before then.

There was high correlation between estimates of the ocean return probability for wild and hatchery spring Chinook ($r = 0.9879$), and slightly lower correlation between wild and hatchery summer Chinook ($r = 0.8656$; Figure 4.5). Point estimates of the ocean return probability are often greater for wild Chinook than for either spring or summer hatchery Chinook, but there is no significant difference between the wild and hatchery estimates overall ($P = 0.5763$ for hatchery spring Chinook, and $P = 0.7092$ for hatchery summer Chinook). Confidence intervals tend to be greater for estimates for wild fish, because of the smaller release groups.

Estimates of the ocean return probability (O_{NT}) for wild steelhead ranged from 0.0125 ($\widehat{SE} = 0.0168$) for the 2004 release group, to 0.0429 ($\widehat{SE} = 0.0058$) for the 2000 release group, with a mean of 0.0221 ($\widehat{SE} = 0.0056$) over the years 1999 to 2004, omitting 2001 (Table E.3). These estimates include the age-1-ocean age class. Insufficient detections of wild adult steelhead from the 2001 release group prevented estimation of the ocean return probability for that year, but suggested that ocean survival was very small. Across the four years with available data, estimates of the ocean return probability from wild steelhead were highly correlated with those from hatchery steelhead ($r = 0.9943$; Figure 4.6). There was no significant difference between wild and hatchery estimates of ocean return probability over those four years ($P = 0.9351$).

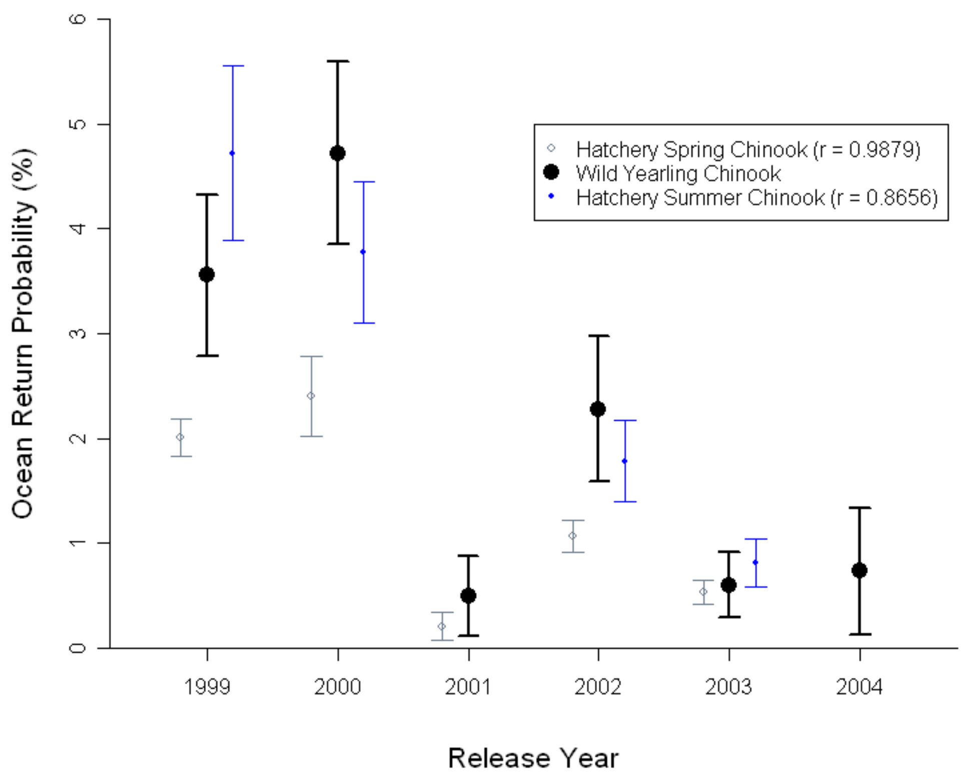


Figure 4.5: Estimated ocean return probability for nontransported wild and hatchery Chinook salmon from the Snake River Basin ($\widehat{O_{NT}}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Estimates do not include the age-1-ocean age class.

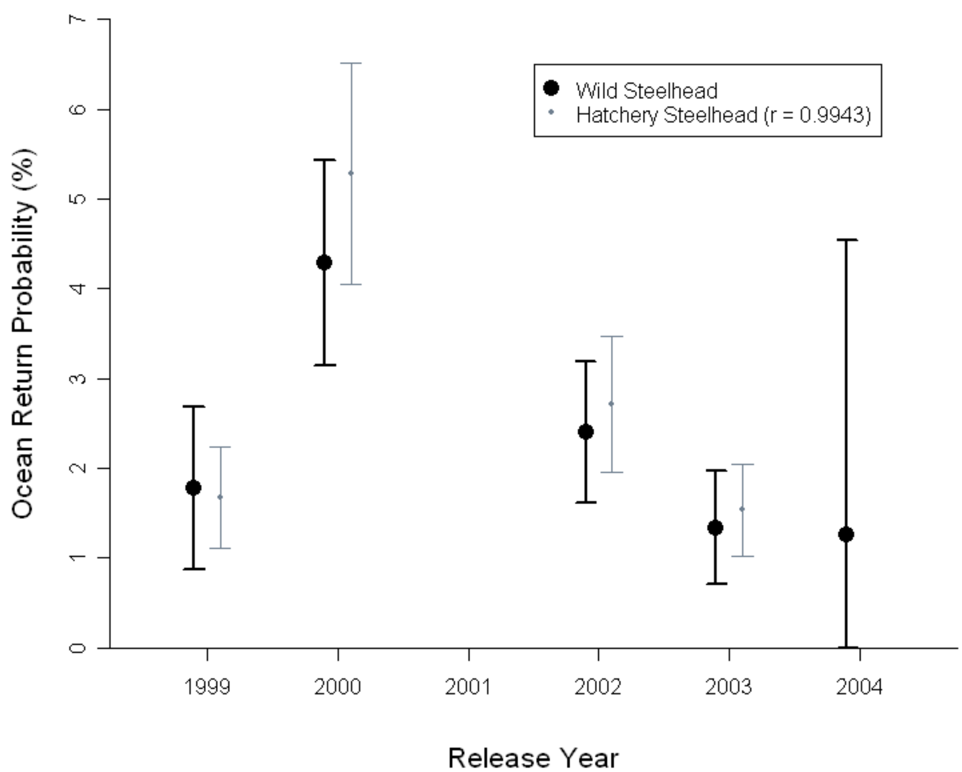


Figure 4.6: Estimated ocean return probability for nontransported wild and hatchery steelhead from the Snake River Basin ($\widehat{O_{NT}}$), with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Estimates include the age-1-ocean age class.

4.4 Adult Upriver Survival ($S_{A_{Rel}}$ and $S_{A_{Ret}}$)

Average perceived adult upriver survival ("adult upriver survival") from Bonneville to Lower Granite was estimated both on a release group basis ($S_{A_{Release}}$, abbreviated $S_{A_{Rel}}$), and also for all tagged adults present at Bonneville in a given calendar year ($S_{A_{Return}}$, abbreviated $S_{A_{Ret}}$). The two measures are complementary, providing estimates of adult upriver survival through the hydrosystem from two alternative viewpoints, with $S_{A_{Rel}}$ useful for relating adult survival back to a brood year, and with $S_{A_{Ret}}$ useful for assessing effects of annual operations and the river environment directly on migrating adults. Both measures represent "perceived" survival because their complements include both straying and harvest, in addition to natural mortality.

Estimates of adult upriver survival by release year ($S_{A_{Rel}}$) for wild Chinook salmon ranged from 0.7228 ($\widehat{SE} = 0.444$) for the 2004 release group, to 0.8986 ($\widehat{SE} = 0.0363$) for the 2003 release group, with a mean of 0.8486 ($\widehat{SE} = 0.0265$) over the years 1999 to 2004 (Table E.4). These values do not include the age-1-ocean age class. Estimates of adult upriver survival were not available for release groups prior to the 1999 release group because there were no PIT-tag detectors in the adult fishways at Bonneville Dam.

Correlation between wild and hatchery estimates of adult upriver survival by release year ($S_{A_{Rel}}$) was low for both spring and summer Chinook ($|r| < 0.4$; Figure 4.7). There was little variation over time in estimates for both wild and hatchery Chinook. Analysis of variance found a significant difference between wild and hatchery spring Chinook estimates of adult upriver survival ($P = 0.0053$), with higher estimates for wild fish. No significant difference was found in adult upriver survival between wild and hatchery summer Chinook salmon ($P = 0.5974$).

Estimates of adult upriver survival by release year ($S_{A_{Rel}}$) for wild steelhead ranged from 0.6000 ($\widehat{SE} = 0.2098$) for the 2001 release group, to 0.8833 ($\widehat{SE} = 0.1147$) for the 1999 release group, with a mean of 0.7694 ($\widehat{SE} = 0.0496$) over the years 1999 to 2004; these estimates include the age-1-ocean age class. There was high correlation between estimates for wild steelhead and those for hatchery steelhead ($r = 0.9637$; Figure 4.8), with no significant difference between wild and hatchery estimates overall ($P = 0.3189$).

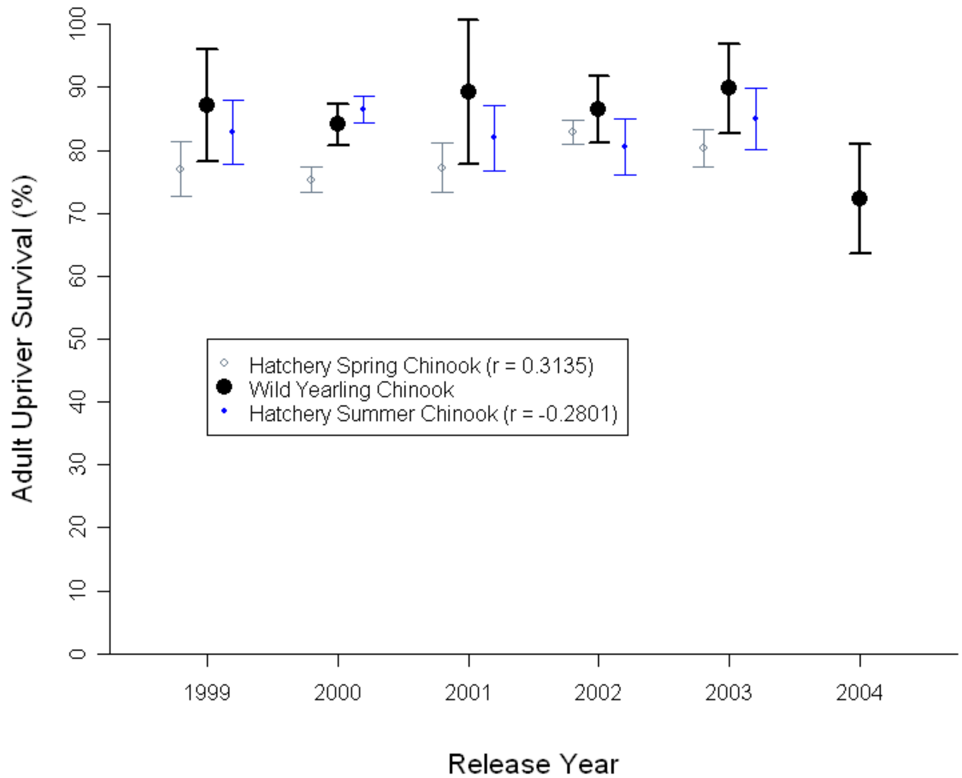


Figure 4.7: Estimated perceived adult upriver survival by release year ($\widehat{S_{A_{Rel}}}$) for wild and hatchery Chinook salmon from the Snake River Basin, with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Estimates incorporate adult detections from multiple return years, and do not include the age-1-ocean age class. Both transported and nontransported fish are represented in estimates for hatchery Chinook, and in the 2003 and 2004 estimates for wild Chinook. Other estimates represent only nontransported Chinook.

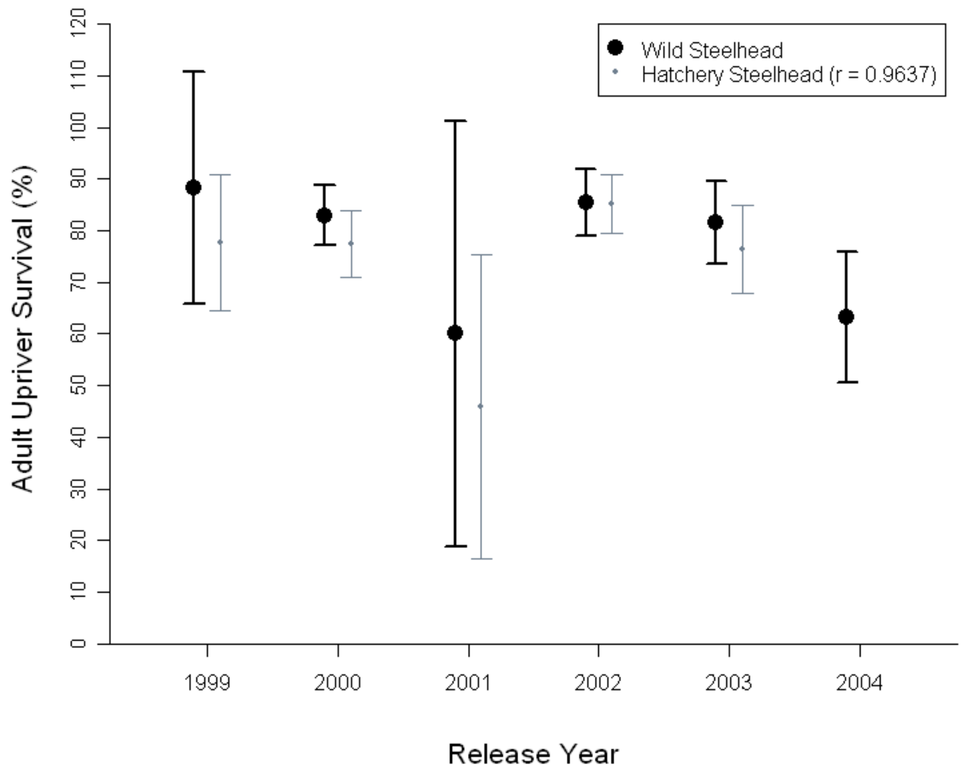


Figure 4.8: Estimated perceived adult upriver survival by release year ($\widehat{S_{A_{Rel}}}$) for wild and hatchery steelhead from the Snake River Basin, with 95% confidence intervals. Estimated correlation between wild and hatchery estimates $= r$. Estimates incorporate adult detections from multiple return years, including the age-1-ocean age class. Both transported and nontransported fish are represented in estimates for 2003 and 2004 wild steelhead. All other estimates represent only nontransported steelhead.

Estimates of adult upriver survival by return year ($S_{A_{Ret}}$) for wild Chinook salmon ranged from 0.7929 ($\widehat{SE}$ = 0.0459) for 2006, to 0.8837 ($\widehat{SE}$ = 0.0489) for 2001, with a mean of 0.8518 ($\widehat{SE}$ = 0.0152) over the years 2001 to 2006 (Table E.5). These estimates do not include the age-1-ocean age class. The estimate for 2001 is based solely on the 1999 release group (age-2-ocean fish).

There was moderate correlation (non-significant at the 90% level) between the estimates of survival by return year for wild Chinook and both hatchery spring Chinook (r = 0.7171) and hatchery summer Chinook (r = 0.6739) over the six years of available data (Figure 4.9). Wild Chinook estimates were significantly greater than hatchery spring Chinook estimates (P = 0.0622), but there was no significant difference between wild and hatchery summer Chinook estimates (P = 0.8310).

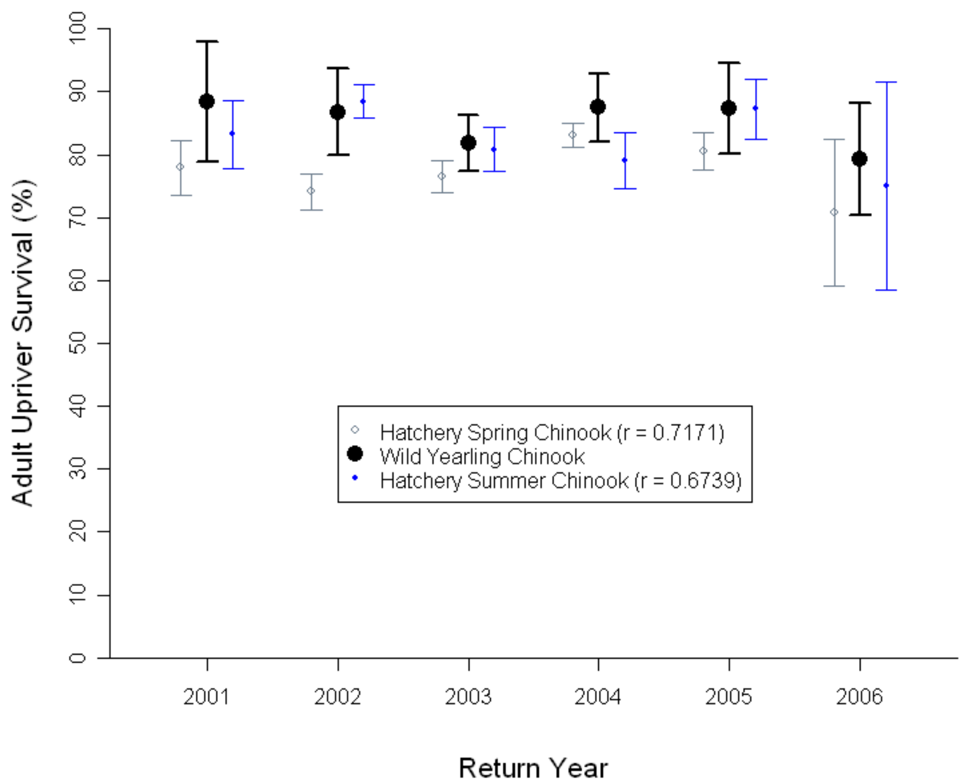


Figure 4.9: Estimated perceived adult upriver survival by return year ($\widehat{S_{A_{Ret}}}$), for wild and hatchery Chinook salmon from the Snake River Basin, with 95% confidence intervals. Estimated correlation between wild and hatchery estimates = r. Estimates incorporate adult detections from multiple release years from both transported and nontransported fish, and do not include the age-1-ocean age class.

Estimates of adult upriver survival by return year ($S_{A_{Ret}}$) for wild steelhead ranged from 0.5272 ($\widehat{SE} = 0.0988$) for 2006, to 0.8924 ($\widehat{SE} = 0.0353$) for 2001, with a mean of 0.7712 ($\widehat{SE} = 0.0453$) over the years 2000 to 2004 (Table E.5). These estimates include the age-1-ocean age class. The estimate for 2000 is based solely on the 1999 release group (age-1-ocean fish). There was moderate correlation (non-significant at the 90% level) between wild and hatchery steelhead estimates of adult upriver survival ($r = 0.5363$; Figure 4.10). There was no significant difference between the wild and hatchery estimates for steelhead ($P = 0.3568$).

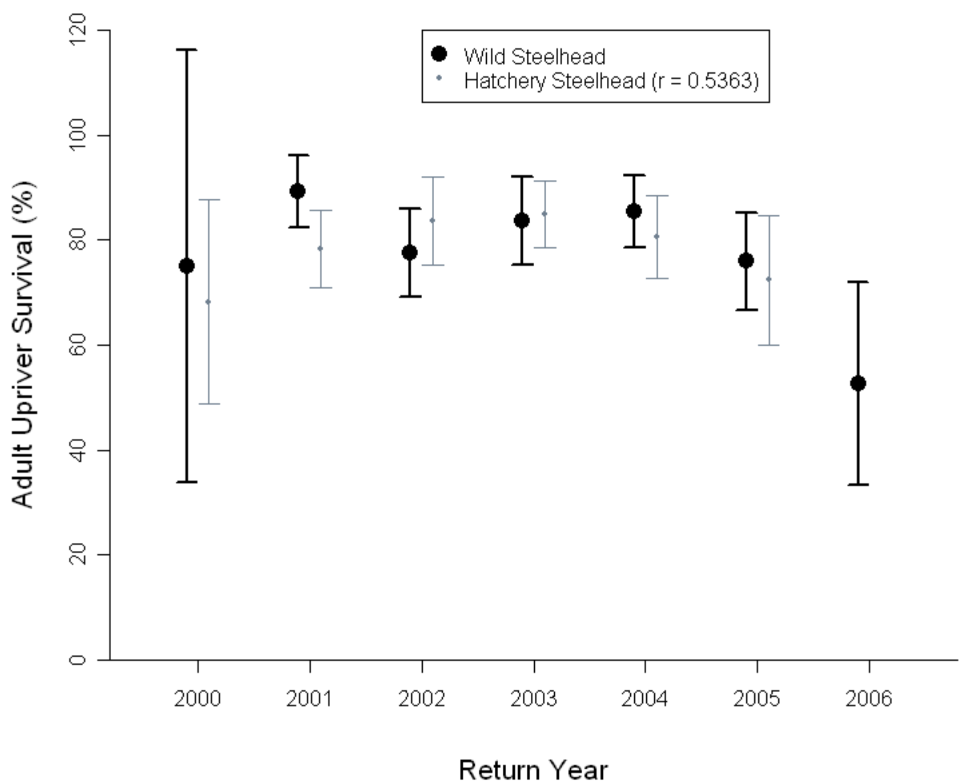


Figure 4.10: Estimated perceived adult upriver survival by return year ($\widehat{S_{A_{Ret}}}$) for wild and hatchery steelhead from the Snake River Basin, with 95% confidence intervals. Estimated correlation between wild and hatchery estimates $= r$. Estimates incorporate adult detections from multiple release years from both transported and nontransported fish, including the age-1-ocean age class.

4.5 Proportion of Total Integrated Mortality

The total integrated mortality of nontransported fish, between passing Lower Granite as a smolt and returning to Lower Granite as an adult, was partitioned into juvenile inriver, ocean, and adult upriver components for each release group that had available estimates of juvenile inriver survival, ocean return probability, and adult upriver survival. Integrated mortality throughout a given life stage incorporates both the instantaneous mortality rate during the life stage and the total time spent during the life stage. Assessing the relative contribution of the three migratory life stages (juvenile inriver, ocean, and adult upriver stages) to total integrated mortality removes confounding with the order of the life stages. The age-1-ocean age class was included in results for steelhead, but not for Chinook. Furthermore, results are available only for release years for which each of S_J, O_{NT}, and $S_{A_{Rel}}$ are estimable. Thus, estimates of the total integrated mortality proportions are available for release years 1999 through 2004 for wild Chinook salmon, and for release years 1999, 2000, and 2002 through 2004 for wild steelhead.

The largest contribution to total integrated mortality for nontransported wild Chinook salmon from the Snake River Basin from 1999 to 2004 came from the ocean life stage (Figures 4.11 and 4.12; Tables E.6 - E.8). On average, the ocean life stage accounted for approximately 0.8318 ($\widehat{SE} = 0.0114$) of the total integrated mortality between passing LGR as a smolt and returning to LGR as an adult (non-jack) for the release years 1999 through 2004 (Table E.7). This integrated mortality proportion corresponded to an average ocean return probability of 0.0206 ($\widehat{SE} = 0.0072$) from 1999 to 2004 for nontransported wild Chinook (Table E.3). On average, the juvenile migration from LGR to BON accounted for approximately 0.1350 ($\widehat{SE} = 0.0087$) of the total integrated mortality(Table E.6), corresponding to an average juvenile inriver survival of 0.5105 ($\widehat{SE} = 0.0362$) from 1999 to 2004 (Table E.2). The adult migration from BON to LGR accounted for an average of 0.0331 ($\widehat{SE} = 0.0055$) of the total integrated mortality from 1999 to 2004 (Table E.8), corresponding to an average adult upriver survival of 0.8486 ($\widehat{SE} = 0.0265$) from 1999 to 2004 (Table E.4). These estimates do not include the age-1-ocean age class.

Analysis of variance found a significant difference between wild and hatchery spring Chinook estimates of the juvenile proportion of total integrated mortality ($P = 0.0014$), with wild Chinook experiencing higher relative mortality during their juvenile migration compared to hatchery spring Chinook (Figure 4.13). Wild Chinook also had a lower ocean proportion of their total mortality compared to hatchery spring Chinook ($P = 0.0149$), but there was no significant difference between wild and hatchery spring Chinook in their adult proportions of total mortality ($P = 0.7125$). Comparisons between wild Chinook and hatchery summer Chinook followed a different pattern, with analysis of variance showing a significant interaction between release year and stock (i.e., wild versus hatchery summer Chinook; $P = 0.0444$) in estimates of the juvenile proportion of total mortality, but no significant difference between stocks for ocean ($P = 0.6398$) or adult ($P = 0.9731$) proportions of total mortality (Figure 4.13).

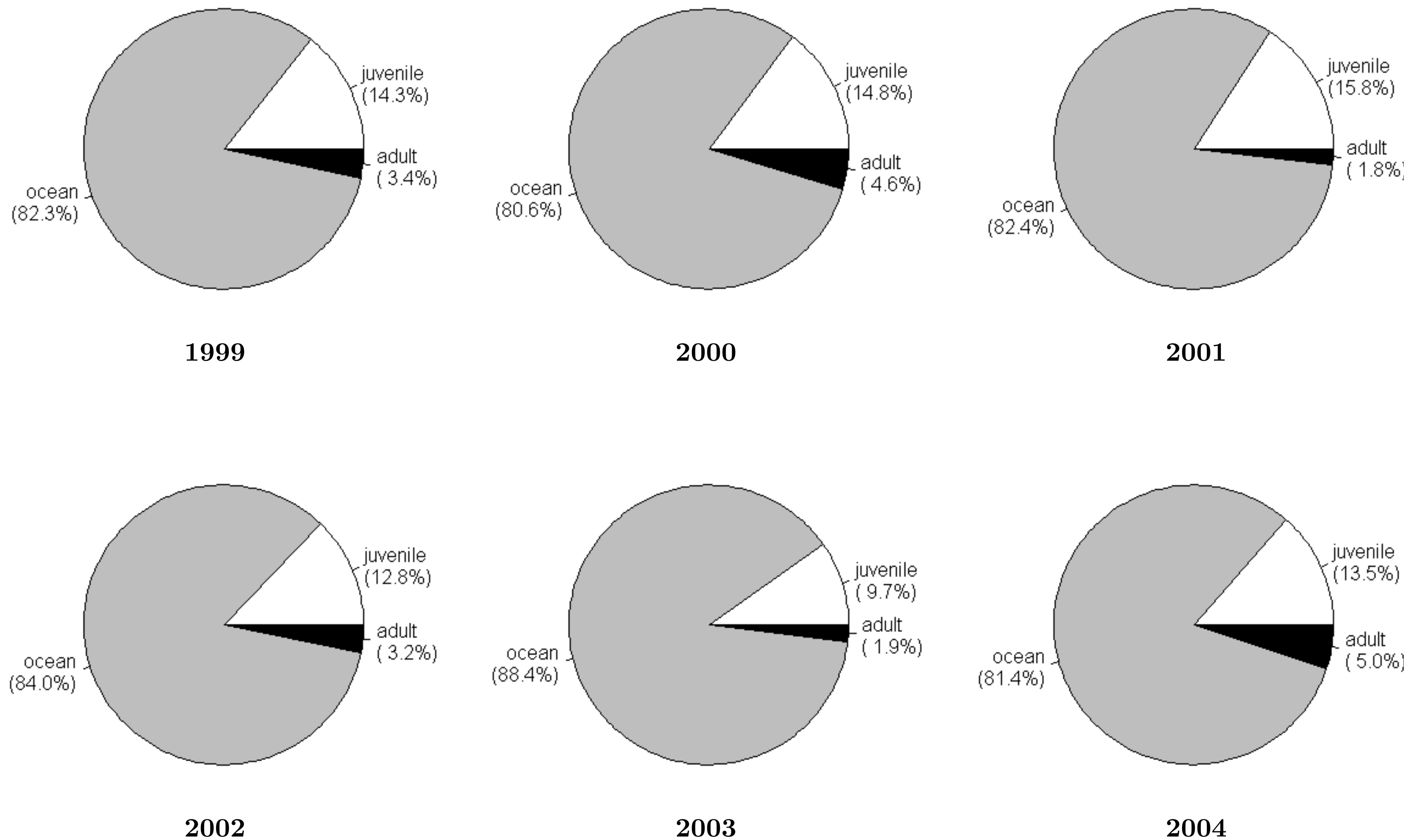


Figure 4.11: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for nontransported wild Chinook salmon from the Snake River Basin, 1999 to 2004. Estimates do not include the age-1-ocean age class.

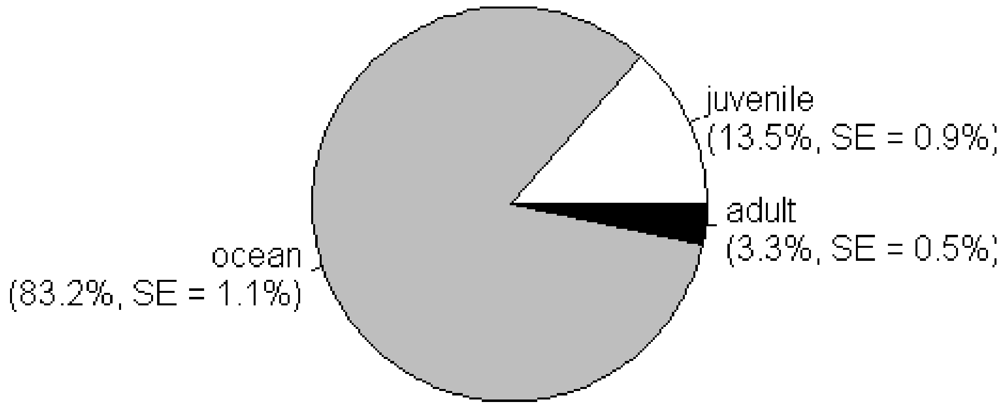


Figure 4.12: The average estimated components of total integrated mortality for the 1999 to 2004 release groups of wild Chinook salmon from the Snake River Basin, with standard error (SE). The average is the arithmetic average, and does not include the age-1-ocean age class.

Estimates of the mortality proportions were available for wild steelhead for release years 1999, 2000, and 2002 through 2004. No estimate was available for 2001 because the ocean return probability could not be estimated for that release year due to low numbers of both juvenile and adult detections at Bonneville Dam. For nontransported wild steelhead, the largest component of mortality between passing LGR as a smolt and returning to LGR as an adult (including age-1-ocean fish) came from the ocean life stage (Figure 4.14; Tables E.6 - E.8) for release years 1999, 2000, and 2002 through 2004. On average, the ocean life stage accounted for approximately 0.7780 ($\widehat{SE} = 0.0314$) of total integrated mortality over these years (Table E.7), corresponding to an average ocean return probability of 0.0221 ($\widehat{SE} = 0.0056$; Table E.3). The juvenile migration from LGR to BON accounted for approximately 0.1868 ($\widehat{SE} = 0.0289$) of total integrated mortality on average (Table E.6), corresponding to an average juvenile inriver survival of 0.4096 ($\widehat{SE} = 0.0693$) over these years (Table E.2). On average, the adult migration from BON to LGR accounted for approximately 0.0352 ($\widehat{SE} = 0.0038$) of total integrated mortality for nontransported steelhead (Table E.8), corresponding to an average adult upriver survival of 0.7800 ($\widehat{SE} = 0.0538$) for release years 1999, 2000, and 2002 through 2004 (Table E.4). These estimates include age-1-ocean fish.

Although the average proportion of total integrated mortality for the juvenile stage was higher for wild steelhead than for hatchery steelhead (Figure 4.15), the difference was not significant ($P = 0.1757$). There was also no significant difference between the wild and hatchery proportions of total integrated mortality for the ocean life stage ($P = 0.2388$) or the adult life stage ($P = 0.2011$).

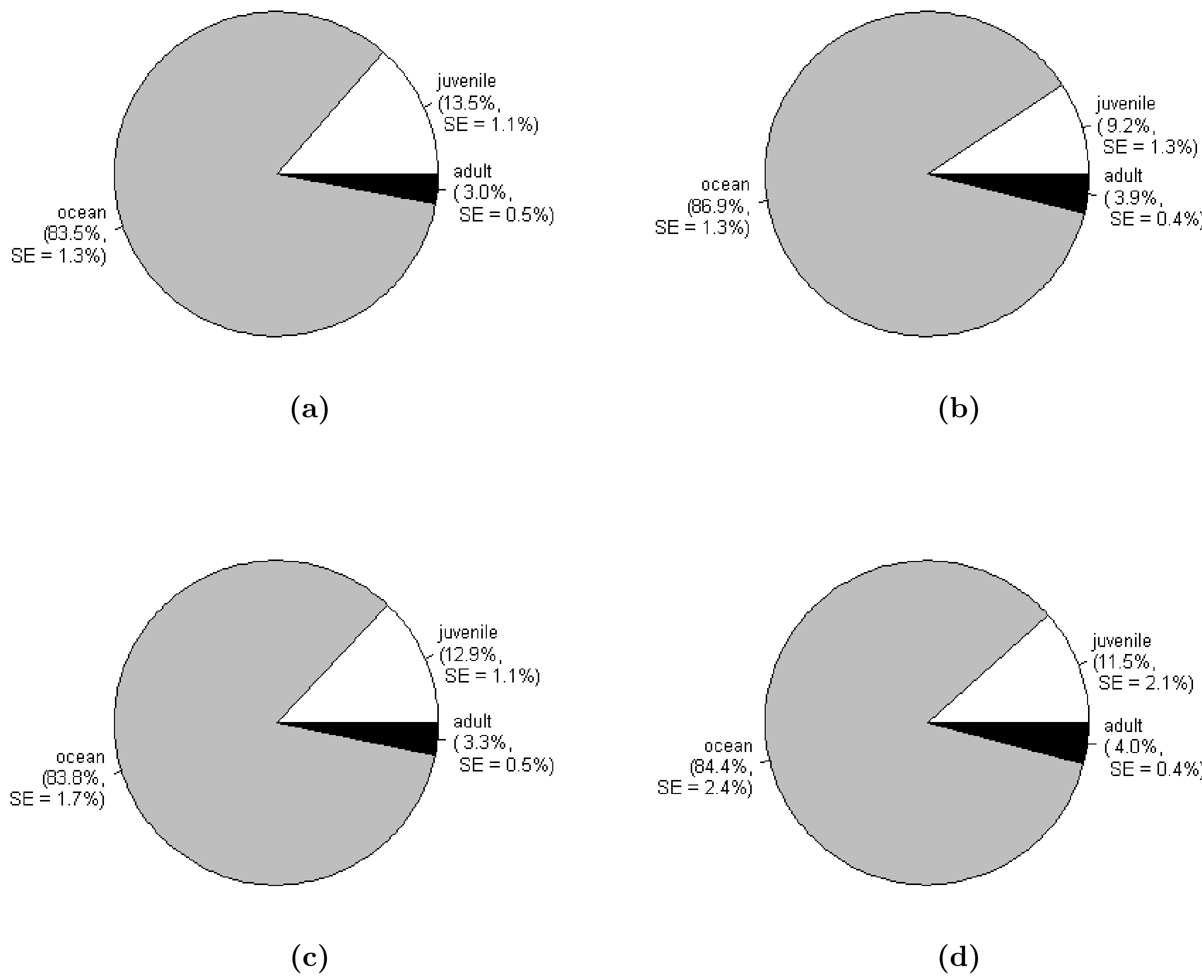


Figure 4.13: The average estimated components of total integrated mortality with standard error (SE), for wild and hatchery Chinook salmon. Wild Chinook results refer to spring and summer release groups, pooled. Wild Chinook (a) and hatchery spring Chinook (b) are compared over 5 years of results (1999 - 2003). Wild Chinook (c) and hatchery summery Chinook (d) are compared over 4 years of results (1999, 2000, 2002, and 2003). The average is the arithmetic average, and does not include the age-1-ocean age class.

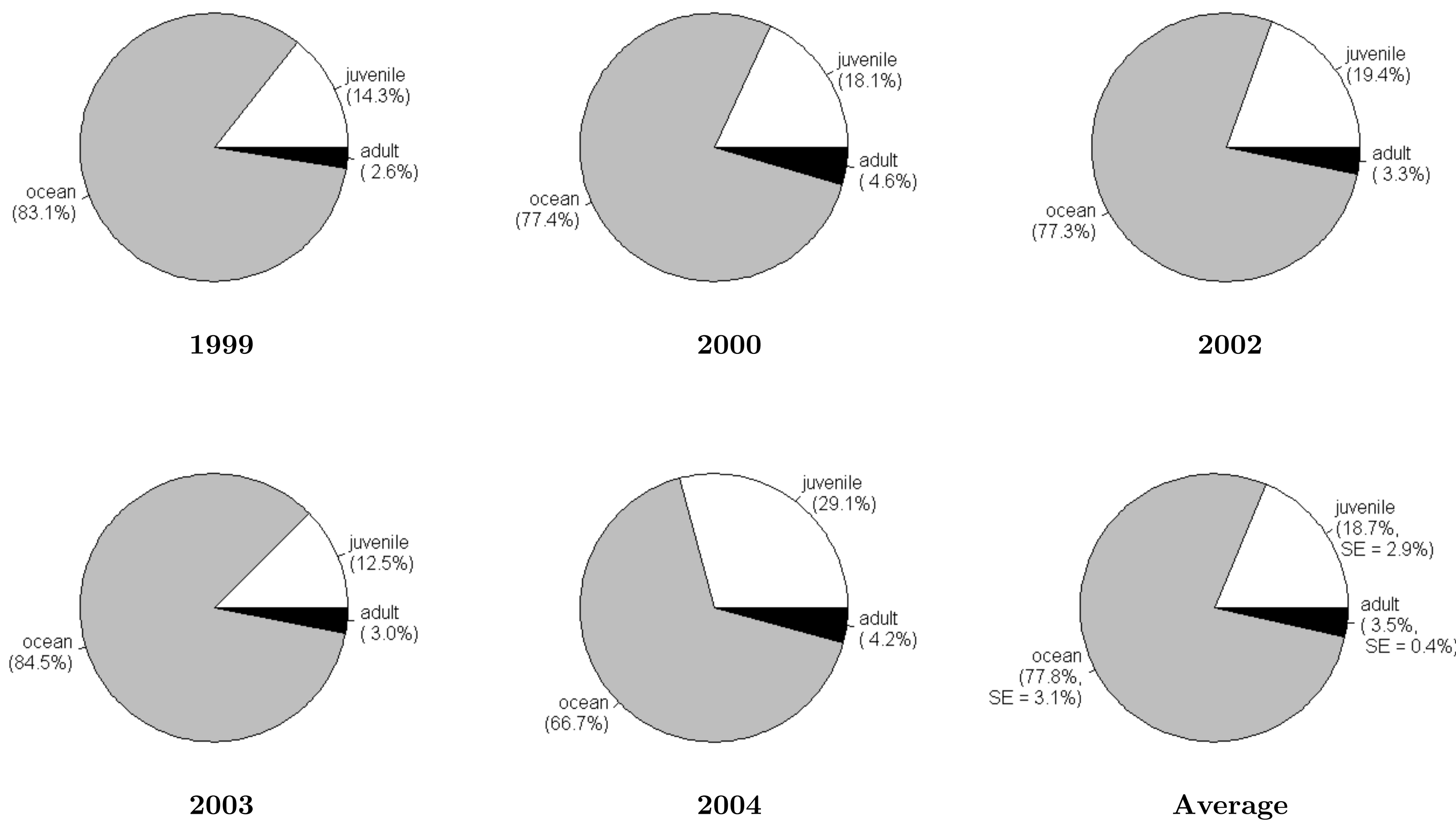
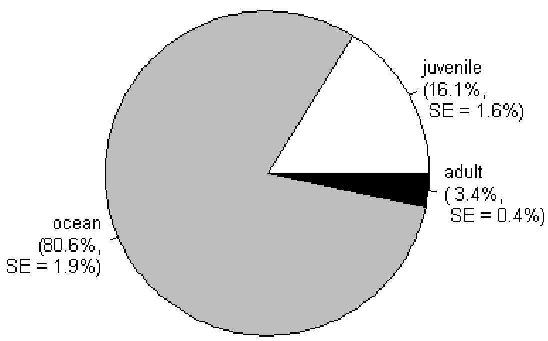
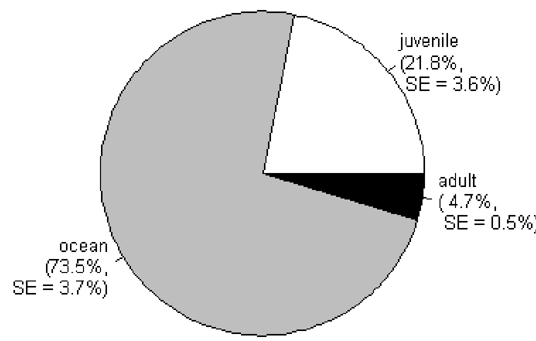


Figure 4.14: The estimated proportion of total integrated mortality accounted for by the juvenile inriver migration, ocean life stage, and adult upriver migration for nontransported wild steelhead from the Snake River Basin, 1999 to 2004 (excluding 2001). The last chart shows the average components of total integrated mortality for the 1999 to 2004 release groups, with standard error (SE). Estimates were unavailable for the 2001 release group because there were too few adult detections of nontransported steelhead from that release year. The average is the arithmetic average. Estimates include the age-1-ocean age class.



(a)



(b)

Figure 4.15: The average estimated components of total integrated mortality with standard error (SE), for wild (a) and hatchery (b) steelhead, over the release years 1999, 2000, 2002, and 2003. The average is the arithmetic average, and includes the age-1-ocean age class.

4.6 Transport-Inriver Ratios (T/I)

Wild Chinook salmon in the release groups analyzed here were transported in numbers sufficient to estimate transportation effects (i.e., at least 1,000 transported) only in 2003 and 2004 at both Lower Granite and Little Goose dams. Estimates of the dam-specific transport/inriver ratio (T/I) for wild Chinook at Lower Granite Dam (R_{LGR}) were 1.2715 ($\widehat{SE} = 0.4043$) for the 2003 release group, and 2.3714 ($\widehat{SE} = 0.5055$) for the 2004 release group (Table E.9). For Little Goose Dam, estimates of the dam-specific T/I (R_{LGS}) were 1.4549 ($\widehat{SE} = 0.5383$) for the 2003 release group of wild Chinook salmon, and 2.2314 ($\widehat{SE} = 0.6349$) for the 2004 release group (Table E.10).

Only the 2003 release year had T/I estimates for both wild and hatchery Chinook salmon. For this release year, the point estimate of the T/I for Lower Granite for wild Chinook salmon ($\widehat{R}_{LGR} = 1.27$, $\widehat{SE} = 0.40$) was lower than both the hatchery estimates of 1.71 ($\widehat{SE} = 0.15$) for hatchery spring Chinook and 1.74 ($\widehat{SE} = 0.23$) for hatchery summer Chinook (Buchanan et al. 2007), but in neither case was the difference significant (z-test, $P = 0.3732$ for hatchery spring Chinook, and $P = 0.3620$ for hatchery summer Chinook). For Little Goose transportation, the point estimate for wild Chinook ($\widehat{R}_{LGS} = 1.45$, $\widehat{SE} = 0.54$) was higher than the corresponding point estimate for hatchery spring Chinook salmon ($\widehat{R}_{LGS} = 1.16$, $\widehat{SE} = 0.14$), but the difference was not significant (z-test, $P = 0.5530$). No estimate of R_{LGS} was available for hatchery summer Chinook for 2003.

Analysis of transport groups of wild steelhead was also limited to 2003 and 2004, and only for Lower Granite Dam, because of low numbers of transported PIT-tagged steelhead. Point estimates of the dam-specific T/I for Lower Granite (R_{LGR}) were 3.5266 ($\widehat{SE} = 0.8378$) for the 2003 release group, and 6.1973 ($\widehat{SE} = 2.0061$) for the 2004 release group (Table E.9). No transport groups of wild steelhead from Little Goose Dam were large enough for analysis. Also, no transportation results for hatchery steelhead were available for a comparison with wild steelhead results.

4.7 Differential Post-Bonneville Mortality (D)

Differential post-Bonneville mortality, D, is the ratio of survival from passing Bonneville as a juvenile to returning to Lower Granite as an adult for transport fish relative to that of non-transported fish. Dam-specific results are available here for wild Chinook for transportation from Lower Granite (D_{LGR}) and from Little Goose (D_{LGS}) for the 2003 and 2004 release groups. For wild Chinook salmon, the dam-specific D from Lower Granite (D_{LGR}) was estimated at 0.7399 ($\widehat{SE} = 0.2900$) for the 2003 release group, and at 1.0672 ($\widehat{SE} = 0.4811$) for the 2004 release group. The dam-specific D from Little Goose (D_{LGS}) was estimated at 0.9302 ($\widehat{SE} = 0.4056$) for the 2003 release group of wild Chinook, and at 1.0744 ($\widehat{SE} = 0.5237$) for the 2004 release group of wild Chinook.

Only the 2003 release year had D estimates for both wild and hatchery Chinook salmon. In this case, the wild estimate of the D for Lower Granite ($\widehat{D}_{LGR} = 0.74$, $\widehat{SE} = 0.29$) was lower than the estimates of D_{LGR} for both hatchery spring Chinook ($\widehat{D}_{LGR} = 1.03$, $\widehat{SE} = 0.13$) and hatchery summer Chinook ($\widehat{D}_{LGR} = 1.20$, $\widehat{SE} = 0.22$) (Buchanan et al. 2007). In neither case was the difference significant (z-test, $P = 0.4221$ for hatchery spring Chinook, and $P = 0.2594$ for hatchery summer Chinook). For Little Goose, the results were reversed, with the point estimate for wild Chinook ($\widehat{D}_{LGS} = 0.93$, $\widehat{SE} = 0.41$) greater than the corresponding point estimate for hatchery Chinook salmon ($\widehat{D}_{LGS} = 0.78$, $\widehat{SE} = 0.12$). Again, the difference between the wild and hatchery estimate was not significant (z-test, $P = 0.6958$). No estimate of D_{LGS} was available for hatchery summer Chinook salmon.

For wild steelhead, estimates are available for transportation from Lower Granite for 2003 and 2004, with estimates of D_{LGR} equal to 1.9063 ($\widehat{SE} = 0.6064$) for the 2003 release group, and equal to 0.9345 ($\widehat{SE} = 1.2639$) for the 2004 release group. No transportation results for hatchery steelhead were available for a comparison with wild steelhead results.

Chapter 5

Discussion

In general, the estimates from wild release groups of spring and summer Chinook salmon and steelhead from the Snake River correlate with analogous estimates from hatchery release groups, reported in Buchanan et al. (2007). In particular, wild and hatchery estimates of SAR have high correlation for both Chinook ($r = 0.9517$) and steelhead ($r = 0.8654$), as do estimates of the ocean return probability for both Chinook ($r = 0.9879$) and steelhead ($r = 0.9943$), juvenile inriver survival for Chinook ($r = 0.7916$), and adult upriver survival (by release year) for steelhead ($r = 0.9637$). For Chinook, no effect of rearing type (i.e., wild or hatchery) was detected for SAR ($P > 0.10$) or the ocean return probability ($P > 0.10$), suggesting that estimates of these measures for hatchery spring and summer Chinook salmon may be used as surrogate estimates for wild Chinook salmon. Steelhead showed a significant effect of rearing type on SAR ($P = 0.0745$), with the mean SAR estimate greater for wild steelhead than for hatchery steelhead. Consequently, it may be reasonable to use estimates of SAR for hatchery steelhead as surrogate minimum estimates of SAR for wild steelhead.

For both Chinook and steelhead, wild fish tended to have higher point estimates of adult upriver survival than hatchery fish, regardless of whether adult upriver survival was estimated for a given release group or for a given return year (Figures 4.7 - 4.10). Only for spring Chinook salmon was the difference between wild and hatchery fish statistically significant ($P < 0.10$). The persistent pattern of higher estimates for wild fish suggests that the findings are likely real. There are several possible explanations for such a finding. First, the measures of adult upriver survival are not adjusted for harvest mortality, so it is reasonable that hatchery fish, which are subject to harvest pressure upriver of Bonneville Dam, will have lower survival than wild fish between Bonneville and Lower Granite Dam. Second, adult upriver survival is more correctly termed "perceived adult upriver survival," because it does not account for straying or fallback. Higher straying rates among hatchery fish would produce lower perceived adult upriver survival estimates for hatchery fish. The Chinook hatchery release groups analyzed in Buchanan et al. (2007) included more transported fish than the wild release groups analyzed in this report, primarily because of the relative sizes of the available wild and hatchery release groups. If transported adults experience higher straying rates during their upriver migration, as has been suggested by Chapman et al. (1997), then the Chinook hatchery results in Buchanan et al. (2007) would represent higher perceived adult straying rates than the wild results presented here. This would be reflected in lower adult upriver survival estimates for hatchery fish compared with wild fish. If increased straying among transported fish and the higher representation of transported fish in the hatchery release groups were the only factors producing the difference in perceived adult upriver survival between wild and hatchery fish, then we would expect that this difference would disappear for release years when both wild and hatchery fish had transported fish, and also when neither had transported fish. The only release year with both wild and hatchery transport groups analyzed was 2003 for Chinook. For this release year, point estimates of adult upriver survival (by release year) were greater for wild Chinook than for hatchery Chinook. For steelhead, no transport groups were analyzed for the 1999 - 2002 release years for either wild or hatchery fish. For 3 of these 4 years (1999, 2000, and 2001), the point estimate of perceived adult upriver survival was higher for wild steelhead than for hatchery steelhead (Figure 4.8). These findings suggest that the observed pattern of higher estimates of adult upriver survival for wild fish compared to hatchery fish is not merely an artifact of the different transport composition of the release groups. Instead, some combination of higher harvest and higher straying may produce lower perceived adult upriver survival for hatchery fish.

One difference between the methods used for the wild analysis and those used for the hatchery analysis is the definition of the steelhead return year. Some adult steelhead have been observed to residualize during their adult upriver migration through the hydrosystem, passing downriver dams in summer or fall and upriver dams the following spring. Thus, for the wild steelhead results presented here, we defined the return year in this report to be from July 1 through June 30, to coincide with the approach used by the Comparative Survival Study (Schaller et al. 2007) and NOAA Fisheries (Doug Marsh, personal communication). The steelhead return year was defined to be the calendar year for the hatchery steelhead analyses in Buchanan et al. (2007), because adult residualization has been detected mostly among transported fish, and the hatchery analyses did not analyze transport groups. Thus, the calendar return year was expected to produce the same results as the July-June return year for the hatchery steelhead release groups analyzed in Buchanan et al. (2007). For both definitions of return year, records with one or more adult detections in one ocean age class and later detections in the next ocean age class were censored at the final adult detection in the earlier age class. Thus, fish that appeared to have residualized during their upriver migration, either by delaying over winter for hatchery fish (using the calendar return year) or migrating both before and after July in a given calendar year for wild fish (using the July 1 - June 30 return year) were not used to estimate adult upriver survival or SAR, although they were used to estimate juvenile inriver survival and the ocean return probability. When SAR was estimated with a simplified tagging model (i.e., the Cormack-Jolly-Seber model; Cormack 1964; Jolly 1965; Seber 1965), any detections at Lower Granite of these censored fish were returned to the data set. Thus, any perceived residualization not accounted for by the selected return year definition did not bias the age-specific estimates of upriver adult survival.

We observed high correlation between wild and hatchery estimates of SAR over time for both Chinook ($r = 0.9517$) and steelhead ($r = 0.8654$), with wild SAR estimates often (though not always) greater than the analogous hatchery SAR estimates (Figures 4.1, 4.2). This finding agrees with the patterns found by the Comparative Survival Study (Schaller et al. 2007) and NOAA Fisheries (Williams et al. 2005). We also observed that juvenile inriver survival from Lower Granite to Bonneville was correlated between wild and hatchery estimates, especially for Chinook ($r = 0.7916$; Figure 4.3), with wild survival estimates often slightly lower than corresponding hatchery estimates. This general pattern also agrees with findings of the CSS (Berggren et al. 2007).

The sample sizes available for wild fish are generally considerably smaller than sample sizes available for hatchery fish. For this report, sample sizes ranged from 5,393 for the 1996 release group of wild steelhead to 92,304 for the 2003 release group of wild Chinook. Small sample size makes analysis difficult if survival or detection probabilities are also low. Thus, it was not possible to use the ROSTER model to analyze detection data in the early release years, when low detection capabilities at John Day and Bonneville dams was combined with small release groups. The 1998 and 2001 steelhead release groups also required analysis using a simplified tagging model, because of small sample sizes combined with low ocean return probabilities and low detection probabilities at Bonneville. In the remaining years, however, the ROSTER model was capable of estimating survival over various spatial scales for the available sample sizes for wild fish. It was less able to estimate transportation effects for wild fish, because of the low number of transport fish in the release groups (Table 3.1). We recommend using the Ricker relative recovery model (Ricker 1975) to estimate dam-specific transportation effects (e.g., T/I ratio) for small transport groups.

We chose not to pool wild fish tagged upstream of Lower Granite Dam with those tagged at Lower Granite, even though large numbers of wild yearling Chinook and steelhead were tagged at Lower Granite and transported in most of the release years studied here. Our primary concern with pooling fish tagged at Lower Granite with those tagged upstream was that the two groups of fish would experience handling and tagging effects over different stretches of river. In particular, for fish tagged upstream of Lower Granite, it may be expected that tagging and handling effects would have ended by the time they reached Lower Granite. Fish that were tagged at Lower Granite, however, would experience tagging and handling effects downstream of Lower Granite. This would result in biased estimates of survival, SAR, and possibly transportation effects if LGR-tagged fish were pooled with fish tagged upstream. For this reason, fish tagged at Lower Granite were not included in this report.

Chapter 6

Conclusions

We used a combination of the ROSTER release-recapture model and a simplified tagging model, based on the CJS model and the Ricker model (Ricker 1975), to analyze PIT-tag detection data large-scale regional release groups of wild spring and summer Chinook salmon and steelhead from the Snake River Basin for release years 1996 - 2004. The primary focus was on estimation of survival of juveniles through the hydrosystem (juvenile inriver survival), survival through the ocean (from Bonneville back to Bonneville, i.e., the ocean return probability), survival of adults through the hydrosystem (adult upriver survival), and the smolt-to-adult return ratio (SAR). A secondary focus was to estimate dam-specific transportation effects (i.e., T/I ratio and D), but low numbers of transported smolts resulted in transportation effect estimates for only the last two release years for both Chinook and steelhead.

For wild Chinook, estimates of SAR ranged from less than 0.5% for the 1996, 2001, 2003, and 2004 release groups, to a high of 2.3% ($\widehat{SE} = 0.1\%$) for the 2000 release group (Figure 4.1; Table E.1). Only the 2000 release group had SAR over the minimum 2% SAR suggested by the NPCC as a minimum requirement for stock sustainability. Wild steelhead SAR estimates were generally lower, ranging from less than 0.5% for the 1997, 1998, 2001, and 2004 release groups to a high of 1.7% ($\widehat{SE} = 0.1\%$) for the 2000 release group (Figure 4.2, Table E.1). No estimate of SAR was greater than 2% for wild steelhead.

One advantage of the ROSTER model is that it produces estimates of the ocean return probability for nontransported fish, which is essentially survival in the ocean and estuary, including harvest mortality. Release groups with ocean return probabilities less than 2% cannot yield SAR estimates greater than 2%, so the ocean life stage is a limiting factor on recovery of endangered populations. The estimated ocean return probabilities for Chinook ranged from a low of approximately 0.5% in 2001 to a high of 4.7% ($\widehat{SE} = 0.5\%$) in 2000, and was less than 2% in 3 of the 6 years with available data (Figure 4.5, Table E.3). For steelhead, the ocean return probability was estimated at less than 2% in 3 of the 5 years with available data (Figure 4.6, Table E.3). As with Chinook, the estimated ocean return probability for steelhead was highest (4.3%, $\widehat{SE} = 0.6\%$) for the 2000 release year (Figure 4.6, Table E.3).

For both wild Chinook and wild steelhead, the ocean life stage accounted for the large majority of mortality of nontransported fish, as shown by the estimated proportions of integrated mortality for each life stage (Figures 4.11, 4.12, 4.14, and Tables E.6-E.8). For Chinook, the ocean life stage accounted for an average of 83% ($\widehat{SE} = 1.1\%$) of the total mortality for release years 1999 - 2004 (Table E.7). For steelhead, the ocean life stage accounted for approximately 78% ($\widehat{SE} = 3.1\%$) of the total mortality for release years 1999, 2000, and 2002 - 2004. The low numbers of adult detections of steelhead from the 2001 release group prevented estimation of the ocean return probability and the proportions of total integrated mortality, but it is likely that the ocean life stage accounted for a high percentage of total mortality for steelhead in 2001 as well.

There was a high level of correlation between the estimates of survival and mortality observed here for wild Chinook and those observed for hatchery Chinook presented in Buchanan et al. (2007). There was significant correlation (at the 90% level) between wild Chinook and hatchery spring Chinook estimates of juvenile survival through the hydrosystem (S_J; $r = 0.7916$), SAR ($r = 0.9517$), and the ocean return probability (O_{NT}; $r = 0.9879$) (Table 6.1; Figures 4.1, 4.3, and 4.5). Estimates of SAR were significantly correlated between wild Chinook and hatchery summer Chinook, as well ($r = 0.9488$; Table 6.1; Figure 4.1). The high correlations between wild and hatchery estimates for many peformance measures are mirrored by the finding that in most cases, there was no significant interaction between year and stock (i.e., wild versus hatchery) for Chinook. The only significant interaction effect between release year and stock was for the juvenile proportion of overall mortality in comparisons between wild and hatchery summer Chinook ($P = 0.0444$; Table 6.1). No other difference was detected between wild Chinook and hatchery summer Chinook performance (Table 6.1). More differences were detected between wild Chinook and hatchery spring Chinook, with wild Chinook showing a significantly lower juvenile inriver survival ($P = 0.0059$) and higher adult upriver survival ($P = 0.0053$) than hatchery spring Chinook (Table 6.1). Similarly, wild Chinook experienced a higher proportion of their total integrated mortality during their juvenile migration compared to hatchery spring Chinook ($P = 0.0014$; Table 6.1).

There was high correlation between wild and hatchery estimates of SAR ($r = 0.8654$), ocean return probability ($r = 0.9943$), and adult upriver survival by release year ($r = 0.9637$) for steelhead (Table 6.2; Figures 4.2, 4.6, and 4.8). The only significant difference between estimates of performance for wild and hatchery steelhead was for SAR, where wild steelhead were found to have higher SAR estimates than hatchery steelhead ($P = 0.0745$; Table 6.2).

The high correlation between estimated performance of wild and hatchery fish suggests that in many cases, hatchery fish may be used to make inference to wild populations, at least over the broad regional and temporal (i.e., annual) scales used to define release groups in this analysis. In particular, with no significant differences in estimated SAR or ocean return probability between wild Chinook and either spring or summer hatchery Chinook, the hatchery estimates may serve as surrogates for wild Chinook. Similarly, estimates of ocean return probability from hatchery steelhead may be used as surrogates for wild steelhead. With SAR estimates significantly greater for wild steelhead than for hatchery steelhead, it is reasonable to use the hatchery estimates as minimum surrogate estimates of SAR for wild fish.

There were too few fish transported from the wild release groups analyzed here to make a multi-year comparison of transportation effects between wild and hatchery fish. Only two years had sufficient numbers of wild tagged fish transported for estimation of T/I and D, and the transport groups analyzed here for wild fish were small (1,000 - 6,175), resulting in low precision on performance estimates. Thus, for both wild and hatchery populations, continued tagging and detection of smolts and adults are required for necessary monitoring and evaluation of population survival and transport performance.

Table 6.1: Comparison of estimated performance measures over common years between wild and hatchery Chinook salmon release groups, 1996 - 2003. Number of years depends on available data. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Correlation coefficient between estimates = r; bolded values of r are significant at the 10% level. P-value from F-test for effect of rearing type (wild vs. hatchery) = P. Values of P marked with an asterisk (*) refer to interaction effect between year and rearing type; otherwise, P refers to main effect of rearing type. Bolded P-values indicate a significant difference between wild and hqatchery means at the 10% level. Wild results are based on pooled release groups of spring and summer Chinook salmon. Hatchery results are available for spring and summer Chinook salmon separately (Buchanan et al. 2007). All release groups are pooled from the Snake River Basin. Chinook results do not include the age-1-ocean are class.

Compare:	**Hatchery Spring Chinook Salmon**					**Hatchery Summer Chinook Salmon**				
Measure	**Number of Years**	r	**Wild Mean**	**Hatchery Mean**	**Test of Means P**	**Number of Years**	r	**Wild Mean**	**Hatchery Mean**	**Test of Means P**
S_J	6	**0.7916**	0.5475	0.6146	**0.0059**	5	0.7106	0.5848	0.6370	0.5014
			(0.0406)	(0.0562)				(0.0196)	(0.0363)	
SAR	8	**0.9517**	0.0099	0.0071	0.1218	8	**0.9488**	0.0099	0.0115	0.6631
			(0.0027)	(0.0018)				(0.0027)	(0.0031)	
O_{NT}	5	**0.9879**	0.0233	0.0124	0.5763	4	0.8656	0.0279	0.0277	0.7092
			(0.0083)	(0.0042)				(0.0088)	(0.0090)	
$S_{A_{Rel}}$	5	0.3135	0.8737	0.7857	**0.0053**	5	-0.2801	0.8737	0.8339	0.5974
			(0.0104)	(0.0136)				(0.0104)	(0.0107)	
$S_{A_{Ret}}$	6	0.7171	0.8518	0.7717	**0.0622**	6	0.6739	0.8518	0.8232	0.8310
			(0.0152)	(0.0181)				(0.0152)	(0.0208)	
μ_J	5	0.4816	0.1350	0.0921	**0.0014**	4	0.8133	0.1292	0.1153	**0.0444***
			(0.0106)	(0.0131)				(0.0115)	(0.0211)	
μ_O	5	0.4625	0.8354	0.8692	**0.0149**	4	0.7676	0.8381	0.8443	0.6398
			(0.0133)	(0.0129)				(0.0168)	(0.0242)	
μ_A	5	0.7127	0.0297	0.0387	0.7125	4	0.4279	0.0327	0.0404	0.9731
			(0.0052)	(0.0040)				(0.0055)	(0.0044)	

Table 6.2: Comparison of estimated performance measures over common years between wild and hatchery steelhead release groups, 1996 - 2003. Number of years depends on available data. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Correlation coefficient between estimates = r; bolded values of r are significant at the 10% level. P-value from F-test for main effect of rearing type (wild vs. hatchery) = P; bolded P-values indicate a significant difference between wild and hqatchery means at the 10% level. All release groups are pooled from the Snake River Basin. Steelhead results include the age-1-ocean are class.

Measure	**Number of Years**	r	**Wild Mean**	**Hatchery Mean**	**Test of Means** P
S_J	4	0.4494	0.4750	0.3510	0.1182
			(0.0295)	(0.0518)	
SAR	8	**0.8654**	0.0067	0.0045	**0.0745**
			(0.0017)	(0.0011)	
O_{NT}	4	**0.9943**	0.0245	0.0280	0.9351
			(0.0065)	(0.0087)	
$S_{A_{Rel}}$	5	**0.9637**	0.7969	0.7250	0.3189
			(0.0505)	(0.0685)	
$S_{A_{Ret}}$	6	0.5363	0.8119	0.7803	0.3568
			(0.0237)	(0.0268)	
μ_J	4	0.7529	0.1607	0.2180	0.1757
			(0.0161)	(0.0363)	
μ_O	4	0.8014	0.8058	0.7352	0.2388
			(0.0189)	(0.0369)	
μ_A	4	0.3268	0.0335	0.0467	0.2011
			(0.0043)	(0.0050)	

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Appendix A

Glossary

ADULT: Returning migrant. In general, any fish that is detected moving upstream after the presumed outmigration year. Includes age-1-ocean fish.

ADULT AGE CLASS: Category of returning migrants identified by the number of winters spent in the ocean. Ignores number of years spent in freshwater before juvenile outmigration. Also referred to as "ocean age class."

ADULT UPRIVER SURVIVAL: S_A; see Perceived Adult Upriver Survival.

ADULT UPRIVER SURVIVAL BY RELEASE GROUP: $S_{A_{Rel}}$, average perceived adult upriver survival for tagged fish in a given release group. Combines adult data from multiple return years, and includes both transported and nontransported fish. Includes the age-1-ocean age class for steelhead, but not for Chinook.

ADULT UPRIVER SURVIVAL BY RETURN YEAR: $S_{A_{Ret}}$, average perceived adult upriver survival for tagged adults that are migrating upriver in a given calendar (return) year. Combines adult data from multiple release groups, and includes both transported and nontransported fish. Includes the age-1-ocean age class for steelhead, but not for Chinook.

AGE-J-OCEAN: Classification of returning migrants by the number (J) of winters spent in the ocean.

ANNUAL TRANSPORT GROUP: Collection of tagged fish from a single release group that were transported from a particular dam during the release year. Only annual transport groups of at least 5,000 fish are used to estimate transportation effects. Specific to individual dams.

DAM-SPECIFIC DIFFERENTIAL POST-BONNEVILLE MORTALITY: D_i, the ratio of the SAR from Bonneville to Lower Granite for dam-i transport fish relative to that of nontransported fish. Assumes 98% survival of transport fish during transportation. In general, may include the age-1-ocean age class (jacks); values reported here for Chinook salmon do not include jacks.

DAM-SPECIFIC T/I RATIO: R_i, the ratio of the SAR from dam i to Lower Granite for dam-i transport fish relative to fish that were inriver immediately downstream of dam i. R_i isolates the effect of transportation from dam i on SAR, removing the effect of any transportation from downstream dams on the nontransported (inriver) return probability to Lower Granite. In general, may include the age-1-ocean age class (jacks); values reported here for Chinook salmon do not include jacks.

DETECTION SITE: River location or structure where PIT-tagged fish may be detected. For this report, detection sites are restricted to dams. Classified as "juvenile" or "adult," according to when the tagged fish is detected. All detection coils within a dam are considered to be the same detection site for fish passing in a given life stage (juvenile or adult).

DIFFERENTIAL POST-BONNEVILLE MORTALITY: D, the ratio of SAR from Bonneville to Lower Granite of transported fish to that of non-transported fish. See Dam-Specific Differential Post-Bonneville Mortality.

INRIVER GROUP: Nontransported fish. Includes detected and nondetected tagged fish.

INTEGRATED MORTALITY: For migratory stage i, equal to the negative log of the conditional survival probability through stage i: $\gamma_i = -\ln S_i$.

JACK: For Chinook salmon, a male fish that returns to freshwater after a single winter in the ocean, i.e., an age-1-ocean fish. Not used for steelhead.

JBS: Juvenile Bypass System at a dam.

JUVENILE INRIVER SURVIVAL: S_J, the probability of surviving inriver (nontransported) as a smolt from Lower Granite Dam to Bonneville Dam. Direct inference is to all nontransported, tagged juveniles.

MIGRATION YEAR: Assumed calendar year of smolt outmigration to seawater. Also referred to as "release year."

MINIJACK: Any fish that returns to freshwater to migrate upstream in the same year as its presumed outmigration. Age-0-ocean fish.

NONTRANSPORTED FISH: Any fish from the release group that was not transported as a juvenile.

OCEAN AGE CLASS: See Adult Age Class.

OCEAN RETURN PROBABILITY: The probability of returning to Bonneville as an adult, conditional on reaching Bonneville as a smolt. Estimated separately for nontransported fish (O_{NT}) and for transported fish (O_i for fish transported from dam i, $i = LGR$ or $i = LGS$). Includes survival in the river between Bonneville and the river mouth for both juveniles and adults, in addition to ocean survival. Includes the age-1-ocean age class for steelhead, but not for Chinook.

PERCEIVED ADULT UPRIVER SURVIVAL: Probability of reaching Lower Granite Dam as an adult, conditional on reaching Bonneville Dam as an adult. Includes the joint probability of migrating upriver, surviving, and reascending all dams after any fallback. The complement includes straying, fallback without reascension, natural mortality, and harvest mortality. Also referred to as "adult upriver survival." Includes the age-1-ocean age class for steelhead, but not for Chinook.

PERFORMANCE MEASURE: (1) A number relating to the migration or survival of a particular group of fish; (2) the estimator of that number.

PROPORTION OF TOTAL INTEGRATED MORTALITY: μ_i for migratory stage i, equal to the ratio of the negative log of survival through stage i to the negative log of SAR for nontransported fish. Reflects the relative contribution of stage i to overall mortality compared to other stages, irrespective of the order in which the stages occur.

REACH: Stretch of river or river and ocean between two adjacent detection sites. The "reach" between the juvenile Bonneville detection site and the adult Bonneville detection site includes the ocean.

RELEASE GROUP: Collection of fish PIT-tagged and released as smolts with a single migration year, for which estimates of performance measures are reported. Restricted to a single species.

RELEASE YEAR: Calendar year during which tagged release group is assumed to migrate downstream as smolts. Migration year.

RETURN RATE: Probability of returning from an identified juvenile detection site (dam) to an identified adult detection site (dam). Unless otherwise specific, the adult detection site is Lower Granite Dam.

RIGHT-CENSORING: Intentional removal from detection history of any subsequent observations. Applied when fish are treated as known removals at a detection site. A censored detection history is not used to estimate survival over subsequent reaches.

ROSTER: River-Ocean Survival and Transportation Effects Routine. The name of the statistical model and software used to analyze most data sets. The software was developed by the University of Washington and is available at `http://www.cbr.washington.edu/paramest/roster/`.

SITE: Detection site, categorized as either juvenile or adult. Alternatively, location of release of PIT-tagged fish, identified by river kilometer.

Smolt-to-adult return ratio: SAR, the probability of returning to Lower Granite Dam as an adult. May be estimated for different treatment groups (e.g., nontransported or transported) and for different initial dams (e.g., probability of returning from Bonneville as a juvenile, or probability of returning from Lower Granite as a juvenile). If not otherwise specified, SAR refers to the entire release group, conditional on reaching Lower Granite as a juvenile. The estimator for tagged fish in the release group is SAR. Includes the age-1-ocean age class for steelhead, but not for Chinook.

Tagged performance measure: A performance measure with direct inference limited to the tagged release group, reflecting the transportation probabilities experienced by tagged smolts. Applies to SAR, T/I, and D.

Total integrated mortality: The negative log of SAR for nontransported fish from Lower Granite to Lower Granite: $\gamma = -\left(\ln S_J + \ln O_{NT} + \ln S_{A_{NT}}\right)$.

Transport dam: A dam at which transportation operations occurred during a given release year, such that 1,000 or more tagged fish of a given release group were transported there during the release year. Designation as "transport dam" is specific to a release group.

Transport group: The fish from a particular release group that were transported from a particular dam. The dam must be specified. Only transport groups of 1,000 or more fish were analyzed here.

Transport-inriver ratio: T/I, the ratio of SAR of transported fish to the SAR of nontransported fish. See Dam-Specific T/I Ratio.

Transportation probability: t_i, probability of being transported at dam i, conditional on (1) reaching the dam inriver, (2) being detected there, and (3) not being censored there. Typically differs for tagged and untagged fish.

Appendix B

List of Symbols

$\widehat{\theta}$: The maximum likelihood estimate (MLE) of parameter or performance measure θ.

μ_A: Proportion of total integrated mortality accounted for by the adult migration from Bonneville to Lower Granite for nontransported fish.

μ_J: Proportion of total integrated mortality accounted for by the juvenile migration from Lower Granite to Bonneville for nontransported fish.

μ_O: Proportion of total integrated mortality accounted for by the ocean life stage from Bonneville to Bonneville for nontransported fish.

BON: Bonneville Dam.

D: Differential Post-Bonneville Mortality.

D_{LGR}: D specific to Lower Granite transportation.

D_{LGS}: D specific to Little Goose transportation.

JD: John Day Dam.

LGR: Lower Granite Dam.

LGS: Little Goose Dam.

LMO: Lower Monumental Dam.

MCN: McNary Dam.

N: Size of a release group.

O_{NT}: Ocean return probability from Bonneville back to Bonneville for nontransported fish.

R_{LGR}: T/I ratio specific to Lower Granite transportation.

R_{LGS}: T/I ratio specific to Little Goose transportation.

S_A: Perceived adult upriver survival.

$S_{A_{REL}}$: Average perceived adult upriver survival by release group.

$S_{A_{RET}}$: Average perceived adult upriver survival by return year.

S_J: Juvenile inriver survival from Lower Granite to Bonneville.

SAR: Smolt-to-adult return ratio (conceptual).

SAR: Tagged SAR measure.

SE: Standard error.

T/I: Transport-inriver ratio.

Appendix C

Data Collection and Preparation

C.1 Release Sites

Tables C.1 and C.2 give details of the smaller release groups that comprise the pooled regional release groups used in the analysis. River kilometers (RKMs) from the confluence of the Snake River into the Columbia River (i.e., from RKM 522 from the mouth of the Columbia River) are reported using the convention that a dot (.) separates distances on different rivers, with downstream reaches (i.e., higher order streams and rivers) listed fish. For example, RKM 224.65 represents the North Fork of the Clearwater River, which is located 65 RKM upstream from the confluence of the Clearwater River into the Snake River; the confluence of the Clearwater River is located 224 RKM upstream on the Snake River from the confluence of the Snake River into the Columbia River. Thus, to reach the North Fork of the Clearwater River from the confluence of the Snake River into the Columbia River, it is necessary to travel 224 RKM up the Snake River from the Columbia, and then 65 RKM up the Clearwater from the Snake. As another example, the Grande Ronde River has RKM address 271; to reach the Grande Ronde River from the mouth of the Snake River, travel 271 RKM up the Snake River from the Columbia to the Grande Ronde.

Table C.1: Release sites of the spring and summer Chinook salmon release groups. River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM. Abbreviations: EF = East Fork, SF = South Fork, WF = West Fork, NF = North Fork, R = River.

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1996	Frenchman Creek	303.647	500	2.6
	Sawtooth Trap	303.617	796	4.2
	EF Salmon R. Weir	303.552.030	259	1.4
	Marsh Creek Trap	303.319.170.011	274	1.4
	Pahsimeroi R. Trap	303.489.002	297	1.6
	Lemhi River Weir	303.416.049	216	1.1
	SF Salmon R. Trap	303.215.115	1,286	6.8
	Secesh R.	303.215.059	569	3.0
	SF Salmon R.	303.215	660	3.5
	Catherine Creek	271.232	1,621	8.6
	Crooked Fork Creek Trap	224.120.037.113.003	371	2.0
	Red River Trap	224.120.101.006	781	4.1
	Lostine River	271.131.042	977	5.2
	Crooked River	224.120.094	488	2.6
	Minam River	271.131.016	996	5.3
	Meadow Creek, Selway R.	224.120.037.031	219	1.2
	Lookingglass Creek	271.137	2,008	10.6
	Imnaha River Weir	308.074	958	5.1
	SF Wenaha R.	271.073.035	825	4.4
	Imnaha Trap	308.007	2,271	12.0
	Lolo Creek	224.087	183	1.0
	Imnaha R.	308	960	5.1
	Salmon R.	303	441	2.3
	Grande Ronde R.	271	326	1.7
	Other		626	3.2
	Total		18,908	100.0
1997	Pahsimeroi R. Trap	303.489.002	118	1.2
	Lemhi R. Weir	303.416.049	271	2.8
	SF Salmon R. Trap	303.215.115	1,771	18.4

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1997	Lake Creek	303.215.059.045	392	4.1
	Secesh R.	303.215.059	259	2.7
	SF Salmon R.	303.215	669	7.0
	Catherine Creek	271.232	1,198	12.5
	Crooked Fork Creek Trap	224.120.037.113.003	574	6.0
	Lostine R.	271.131.042	1,854	19.3
	Minam R.	271.131.016	589	6.1
	Imnaha Trap	308.007	680	7.1
	Imnaha R.	308	1,009	10.5
	Other		217	2.2
	Total		9,601	99.9
1998	Sawtooth Trap	303.617	336	1.1
	Marsh Creek Trap	303.319.170.011	952	3.1
	Bear Valley Creek	303.319.170	426	1.4
	Lemhi R. Weir	303.416.049	824	2.7
	SF Salmon R. Trap	303.215.115	2,099	6.9
	Lake Creek	303.215.059.045	695	2.3
	Secesh R.	303.215.059	1,240	4.1
	Lower SF Salmon R. Trap	303.215.000	1,325	4.3
	SF Salmon R.	303.215	927	3.0
	Catherine Creek	271.232	2,049	6.7
	Crooked Fork Creek Trap	224.120.037.113.003	1,264	4.1
	Red R. Trap	224.120.101.006	1,653	5.4
	Lostine R.	271.131.042	1,214	4.0
	Crooked R. Trap	224.120.094.001	462	1.5
	Minam R.	271.131.016	996	3.3
	Lookingglass Creek	271.137	2,054	6.7
	Imnaha R. Weir	308.074	1,856	6.1
	Clear Creek	224.120.004	344	1.1
	Imnaha Trap	308.007	5,387	17.6
	Lolo Creek	224.087	850	2.8
	Imnaha R.	308	946	3.1

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1998	Grande Ronde R.	271	1,877	6.2
	Other		839	2.7
	Total		30,615	100.2
1999	Valley Creek	303.609	1,000	1.4
	West Fork Yankee Fork	303.591.011	1,293	1.8
	Herd Creek	303.552.014	957	1.3
	Elk Creek	303.319.170.014	699	1.0
	Marsh Creek Trap	303.319.170.011	1,527	2.1
	Pahsimeroi R. Trap	303.489.002	1,331	1.8
	Bear Valley Creek	303.319.170	817	1.1
	Marsh Creek	303.319.170	744	1.0
	Lemhi R. Weir	303.416.049	3,380	4.6
	Loon Creek	303.319.073	1,027	1.4
	Big Creek, MF Salmon R.	303.319.029	1,426	1.9
	SF Salmon R. Trap	303.215.115	3,273	4.5
	Lake Creek	303.215.059.045	4,784	6.5
	Johnson Creek Trap	303.215.060.024.007	7,674	10.5
	Johnson Creek	303.215.060.024	1,060	1.4
	Secesh R.	303.215.059	3,134	4.3
	Lower SF Salmon R. Trap	303.215.000	2,403	3.3
	SF Salmon R.	303.215	916	1.2
	Catherine Creek	271.232	2,055	2.8
	Crooked Fork Creek Trap	224.120.037.113.003	3,121	4.3
	Papoose Creek	224.120.037.105	833	1.1
	Red R. Trap	224.120.101.006	1,633	2.2
	American R.	224.120.101	839	1.1
	Lostine R.	271.131.042	1,801	2.5
	Crooked R. Trap	224.120.094.001	737	1.0
	Newsome Creek	224.120.084	2,017	2.8
	Minam R.	271.131.016	1,002	1.4
	Lookingglass Creek	271.137	3,135	4.3
	Imnaha R. Weir	308.074	1,974	2.7
	Clear Creek	224.120.004	815	1.1

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1999	Imnaha Trap	308.007	7,160	9.8
	Lolo Creek	224.087	2,170	3.0
	Imnaha R.	308	990	1.4
	Grande Ronde R.	271	2,656	3.6
	Other		2,936	4.0
	Total		73,319	100.2
2000	Sawtooth Trap	303.617	1,519	2.4
	Valley Creek	303.609	1,008	1.6
	WF Yankee Fork	303.591.011	1,173	1.9
	EF Salmon R.	303.552	1,024	1.6
	Elk Creek	303.319.170.014	659	1.0
	Marsh Creek Trap	303.319.170.011	1,824	2.9
	Pahsimeroi R. Trap	303.489.002	1,211	1.9
	Bear Valley Creek	303.319.170	834	1.3
	Sulphur Creek, MF Salmon R.	303.319.150	837	1.3
	Lemhi R. Weir	303.416.049	1,689	2.7
	Loon Creek	303.319.073	719	1.1
	Camas Creek, MF Salmon R.	303.319.057	762	1.2
	Big Creek, MF Salmon R.	303.319.029	1,088	1.7
	SF Salmon R. Trap	303.215.115	5,983	9.5
	Lake Creek	303.215.059.045	1,985	3.2
	Johnson Creek Trap	303.215.060.024.007	5,377	8.6
	Johnson Creek	303.215.060.024	770	1.2
	Secesh R.	303.215.059	2,581	4.1
	Lower SF Salmon R. Trap	303.215.000	3,367	5.4
	SF Salmon R.	303.215	916	1.5
	Catherine Creek	271.232	2,030	3.2
	Crooked Fork Creek Trap	224.120.037.113.003	1,380	2.2
	Red R. Trap	224.120.101.006	2,074	3.3
	American R.	224.120.101	1,700	2.7
	Lostine R.	271.131.042	1,641	2.6
	Newsome Creek	224.120.084	1,998	3.2
	Minam R.	271.131.016	990	1.6

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2000	Imnaha R. Weir	308.074	1,932	3.1
	Imnaha Trap	308.007	5,636	9.0
	Lolo Creek	224.087	726	1.2
	Imnaha R.	308	1,414	2.3
	Grande Ronde R.	271	2,641	4.2
	Other		3,292	5.2
	Total		62,780	99.9
2001	Sawtooth Trap	303.617	1,112	2.5
	Valley Creek	303.609	1,001	2.3
	Pahsimeroi R. Trap	303.489.002	1,630	3.7
	Bear Valley Creek	303.319.170	581	1.3
	Lemhi R. Weir	303.416.049	1,341	3.0
	SF Salmon R. Trap	303.215.115	1,767	4.0
	Lake Creek	303.215.059.045	1,647	3.7
	Johnson Creek Trap	303.215.060.024.007	5,439	12.3
	Johnson Creek	303.215.060.024	505	1.1
	Secesh R.	303.215.059	3,909	8.8
	SF Salmon R.	303.215	864	1.9
	Catherine Creek	271.232	1,777	4.0
	Crooked Fork Creek Trap	224.120.037.113.003	465	1.0
	Red R. Trap	224.120.101.006	541	1.2
	Lostine R.	271.131.042	1,835	4.1
	Minam R.	271.131.016	1,797	4.0
	Meadow Creek, Selway R.	224.120.037.031	728	1.6
	Imnaha R. Weir	308.074	1,735	3.9
	Imnaha Trap	308.007	11,680	26.3
	Lolo Creek	224.087	1,295	2.9
	Imnaha R.	308	959	2.2
	Grande Ronde R.	271	719	1.6
	Other		1,045	2.4
	Total		44,372	99.8

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2002	Sawtooth Trap	303.617	2,465	4.2
	Valley Creek	303.609	1,495	2.5
	Elk Creek	303.319.170.014	1,519	2.6
	Marsh Creek Trap	303.319.170.011	1,405	2.4
	Pahsimeroi R. Trap	303.489.002	812	1.4
	Bear Valley Creek	303.319.170	1,495	2.5
	Marsh Creek	303.319.170	940	1.6
	Lemhi R. Weir	303.416.049	1,397	2.4
	SF Salmon R. Trap	303.215.115	1,598	2.7
	Lake Creek	303.215.059.045	2,441	4.1
	Johnson Creek Trap	303.215.060.024.007	6,416	10.9
	Secesh R.	303.215.059	3,991	6.8
	SF Salmon R.	303.215	1,432	2.4
	Lower SF Salmon R. Trap	303.215.000	578	1.0
	Catherine Creek	271.232	1,618	2.7
	Crooked Fork Creek Trap	224.120.037.113.003	1,662	2.8
	Colt Kill Creek	224.120.037.113	783	1.3
	Papoose Creek	224.120.037.105	746	1.3
	Red R. Trap	224.120.101.006	756	1.3
	Lostine R.	271.131.042	1,921	3.3
	Crooked R. Trap	224.120.094.001	855	1.4
	Newsome Creek	224.120.084	1,973	3.3
	Minam R.	271.131.016	1,901	3.2
	Minam R.	271.131.016	1,901	3.2
	Meadow Creek, Selway R.	224.120.037.031	2,549	4.3
	Lookingglass Creek	271.137	2,023	3.4
	Imnaha R. Weir	308.074	1,187	2.0
	Clear Creek	224.120.004	920	1.6
	Imnaha Trap	308.007	4,283	7.3
	Lolo Creek	224.087	2,654	4.5
	Imnaha R.	308	977	1.7
	Grande Ronde R. Trap	271.002	2,085	3.5
	Other		2,148	3.5
	Total		59,025	99.9

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2003	Sawtooth Trap	303.617	5,159	5.6
	Valley Creek	303.609	2,265	2.5
	Elk Creek	303.319.170.014	975	1.1
	Marsh Creek Trap	303.319.170.011	2,569	2.8
	Pahsimeroi R. Trap	303.489.002	3,734	4.0
	Lemhi R. Weir	303.416.049	2,069	2.2
	Camas Creek, MF Salmon R.	303.319.057	976	1.1
	Big Creek, MF Salmon R.	303.319.029	1,729	1.9
	SF Salmon R. Trap	303.215.115	2,737	3.0
	Lake Creek	303.215.059.045	3,709	4.0
	Johnson Creek Trap	303.215.060.024.007	9,843	10.7
	Johnson Creek	303.215.060.024	891	1.0
	Secesh R.	303.215.059	5,255	5.7
	Lower SF Salmon R. Trap	303.215.000	2,029	2.2
	SF Salmon R.	303.215	888	1.0
	Catherine Creek	271.232	3,694	4.0
	Crooked Fork Creek Trap	224.120.037.113.003	2,792	3.0
	Papoose Creek	224.120.037.105	1,026	1.1
	American R.	224.120.101	1,057	1.1
	Lostine R.	271.131.042	3,131	3.4
	Newsome Creek	224.120.084	2139	2.3
	Minam R.	271.131.016	2,338	2.5
	Meadow Creek, Selway R.	224.120.037.031	2,207	2.4
	Imnaha Trap	308.007	12,145	13.2
	Lolo Creek	224.087	2,958	3.2
	Imnaha R.	308	984	1.1
	Grande Ronde R. Trap	271.002	3,631	4.0
	Other		9,374	10.1
	Total		92,304	100.2
2004	Sawtooth Trap	303.617	5,855	6.6
	Valley Creek	303.609	2,495	2.8
	Herd Creek	303.552.014	968	1.1
	Elk Creek	303.319.170.014	1,520	1.7

Table C.1 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2004	Marsh Creek Trap	303.319.170.011	5,298	5.9
	Pahsimeroi R. Trap	303.489.002	1,666	1.9
	Marsh Creek	303.319.170	1,372	1.5
	Sulphur Creek, MF Salmon R.	303.319.150	1,048	1.2
	Lemhi R. Weir	303.416.049	4,020	4.5
	Loon Creek	303.319.073	860	1.0
	Camas Creek, MF Salmon R.	303.319.057	1,009	1.1
	Big Creek, MF Salmon R.	303.319.029	2,401	2.7
	SF Salmon R. Trap	303.215.115	4,394	4.9
	Lake Creek	303.215.059.045	1,018	1.1
	Johnson Creek Trap	303.215.060.024.007	9,068	10.2
	Secesh R.	303.215.059	1,627	1.8
	SF Salmon R.	303.215	1,334	1.5
	Catherine Creek	271.232	2,581	2.9
	Red R. Trap	224.120.101.006	2,641	3.0
	American R.	224.120.101	1,885	2.1
	Lostine R.	271.131.042	2,289	2.6
	Newsome Creek	224.120.084	3,178	3.6
	Minam R.	271.131.016	1,904	2.1
	Meadow Creek, Selway R.	224.120.037.031	1,067	1.2
	Imnaha Trap	308.007	12,716	14.3
	Lolo Creek	224.087	3,998	4.5
	Imnaha R.	308	981	1.1
	Grande Ronde R. Trap	271.002	4,599	5.2
	Other		5,285	5.9
	Total		89,077	100.0

Table C.2: Release sites of the steelhead release groups. River kilometer (RKM) is measured from the confluence of the Snake River with the Columbia River (i.e., RKM 522 from the mouth of the Columbia River). Release sites are ordered by total RKM. Abbreviations: EF = East Fork, SF = South Fork, WF = West Fork, NF = North Fork, R = River.

Release Year	**Release Site**	**RKM**	**Number Released**	**Percentage**
1996	Pahsimeroi R. Trap	303.489.002	103	1.9
	Running Creek	224.120.037.253	223	4.1
	Johnson Creek	303.215.060.024	61	1.1
	Chamberlain Creek	303.282	135	2.5
	East Fork SF Salmon R.	303.215.060	74	1.4
	Crooked Fork Creek Trap	224.120.037.113.003	249	4.6
	Rapid R. Hatchery	303.140.007.006	191	3.5
	Crooked R.	224.120.094	113	2.1
	Fish Creek Trap	224.120.037.039.002	487	9.0
	Fish Creek	224.120.037.039	521	9.7
	Gedney Creek	224.120.037.029	360	6.7
	Salmon Trap	303.103	251	4.7
	Kooskia NFH	224.120.004.001	139	2.6
	Imnaha Trap	308.007	1,493	27.7
	Grande Ronde R.	271	82	1.5
	Snake Trap	225	679	12.6
	Other		232	4.2
	Total		5,393	99.9
1997	Pahsimeroi R.	303.489	530	8.3
	Running Creek	224.120.037.253	128	2.0
	Crooked Fork Creek Trap	224.120.037.113.003	143	2.2
	Rapid R., Little Salmon R.	303.140.007	350	5.5
	Crooked R.	224.120.094	193	3.0
	Fish Creek Trap	224.120.037.039.002	2,436	38.0
	Fish Creek	224.120.037.039	649	10.1
	Gedney Creek	224.120.037.029	274	4.3
	Clear Creek	224.120.004	131	2.0
	Imnaha Trap	308.007	778	12.1
	Grande Ronde R.	271	378	5.9

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1997	Snake Trap	225	146	2.3
	Other		273	4.0
	Total		6,409	99.7
1998	Marsh Creek Trap	303.319.170.011	85	1.1
	Pahsimeroi R. Trap	303.489.002	185	2.3
	Pahsimeroi R.	303.489	254	3.2
	SF Salmon R. Trap	303.215.115	78	1.0
	Lick Creek	303.215.059.008	395	4.9
	Crooked Fork Creek Trap	224.120.037.113.003	658	8.2
	Rapid R., Little Salmon R.	303.140.007	211	2.6
	Fish Creek	224.120.037.039	306	3.8
	WF Gedney Creek	224.120.037.029.005	81	1.0
	Gedney Creek	224.120.037.029	152	1.9
	Salmon Trap	303.103	112	1.4
	Imnaha Trap	308.007	3,068	38.3
	Grande Ronde R.	271	887	11.1
	Snake Trap	225	1,084	13.5
	Other		447	5.1
	Total		8,003	99.4
1999	Pahsimeroi R. Trap	303.489.002	949	6.1
	Johnson Creek Trap	303.215.060.024.007	171	1.1
	Chamberlain Creek	303.282	795	5.1
	Lick Creek	303.215.059.008	656	4.2
	Secesh R.	303.215.059	414	2.6
	Bargamin Creek	303.225	1,053	6.7
	Crooked Fork Creek Trap	224.120.037.113.003	298	1.9
	White Sand Creek	224.120.037.113	304	1.9
	Warm Springs Creek	224.120.037.092	505	3.2
	Three Links Creek	224.120.037.051	474	3.0
	Fish Creek Trap	224.120.037.039.002	2,381	15.2

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
1999	Fish Creek	224.120.037.039	243	1.6
	Gedney Creek	224.120.037.029	331	2.1
	Slate Creek	303.106	352	2.3
	Lookingglass Creek	271.137	183	1.2
	Salmon Trap	303.103	226	1.4
	Clear Creek	224.120.004	234	1.5
	Imnaha Trap	308.007	2,436	15.6
	Grande Ronde R.	271	1,444	9.2
	Snake Trap	225	886	5.7
	Other		1,293	8.3
	Total		15,628	99.9
2000	Pahsimeroi R. Trap	303.489.002	483	2.0
	Johnson Creek Trap	303.215.060.024.007	443	1.8
	Horse Creek	303.301	397	1.6
	Chamberlain Creek	303.282	1,904	7.7
	Lick Creek	303.215.059.008	436	1.8
	Bargamin Creek	303.225	441	1.8
	Lower SF Salmon R. Trap	303.215.000	272	1.1
	Storm Creek	224.120.037.113.016	587	2.4
	Catherine Creek	271.232	626	2.5
	Crooked Fork Creek Trap	224.120.037.113.003	272	1.1
	White Sand Creek	224.120.037.113	329	1.3
	Wind R.	303.177	302	1.2
	Lostine R.	271.131.042	1,010	4.1
	Fish Creek Trap	224.120.037.039.002	6,101	24.7
	Fish Creek	224.120.037.039	243	1.0
	Gedney Creek	224.120.037.029	314	1.3
	Slate Creek	303.106	480	1.9
	Lookingglass Creek	271.137	260	1.1
	Salmon Trap	303.103	333	1.3
	Imnaha Trap	308.007	4,423	17.9
	Lolo Creek	224.087	384	1.6

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2000	Grande Ronde R.	271	1,504	6.1
	Snake Trap	225	1,279	5.2
	Other		1,889	7.6
	Total		24,712	100.1
2001	Pahsimeroi R. Trap	303.489.002	499	2.1
	Johnson Creek Trap	303.215.060.024.007	1,421	6.1
	Horse Creek	303.301	610	2.6
	Chamberlain Creek	303.282	1,804	7.7
	Bargamin Creek	303.225	412	1.8
	Storm Creek	224.120.037.113.016	313	1.3
	Brushy Fork Creek	224.120.037.113.011	380	1.6
	Catherine Creek	271.232	546	2.3
	Lostine R.	271.131.042	336	1.4
	Boulder Creek	224.120.037.042	394	1.7
	Fish Creek Trap	224.120.037.039.002	4,244	18.1
	Minam R.	271.131.016	420	1.8
	Gedney Creek	224.120.037.029	344	1.5
	Slate Creek	303.106	787	3.4
	Lookingglass Creek	271.137	689	2.9
	Salmon Trap	303.103	471	2.0
	O'Hara Creek	224.120.037.012	313	1.3
	Whitebird Creek	303.086	713	3.0
	Imnaha Trap	308.007	3,537	15.1
	Lolo Creek	224.087	922	3.9
	Grande Ronde R.	271	998	4.3
	Snake Trap	225	862	3.7
	Other		2,369	10.4
	Total		23,384	100.0
2002	Sawtooth Trap	303.617	353	1.4
	Pahsimeroi R. Trap	303.489.002	551	2.2
	Johnson Creek Trap	303.215.060.024.007	1,033	4.0
	Horse Creek	303.301	290	1.1

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2002	Chamberlain Creek	303.282	774	3.0
	Lick Creek	303.215.059.008	305	1.2
	Bargamin Creek	303.225	644	2.5
	Brushy Fork Creek	224.120.037.113.011	615	2.4
	Catherine Creek	271.232	755	3.0
	Crooked Fork Creek Trap	224.120.037.113.003	1,182	4.6
	Colt Kill Creek	224.120.037.113	332	1.3
	NF Moose Creek, Selway R.	224.120.037.065.006	643	2.5
	Lostine R.	271.131.042	643	2.5
	Boulder Creek	224.120.037.042	256	1.0
	Fish Creek Trap	224.120.037.039.002	5,324	20.9
	Fish Creek	224.120.037.039	300	1.2
	Gedney Creek	224.120.037.029	430	1.7
	Clear Creek	224.120.004	273	1.1
	Lookingglass Creek	271.137	746	2.9
	Salmon Trap	303.103	382	1.5
	Imnaha Trap	308.007	4,584	18.0
	Grande Ronde R. Trap	271.002	597	2.3
	Grande Ronde R.	271	503	2.0
	Snake Trap	225	2,497	9.8
	Other		1,512	5.7
	Total		25,524	99.8
2003	Sawtooth Trap	303.617	482	2.0
	Marsh Creek Trap	303.319.170.011	285	1.2
	Pahsimeroi R. Trap	303.489.002	750	3.2
	Loon Creek	303.319.073	307	1.3
	Camas Creek, MF Salmon R.	303.319.057	468	2.0
	Big Creek, MF Salmon R.	303.319.029	285	1.2
	Horse Creek	303.301	334	1.4
	Chamberlain Creek	303.282	920	3.9
	Lick Creek	303.215.059.008	355	1.5
	Bargamin Creek	303.225	528	2.2
	Brushy Fork Creek	224.120.037.113.011	333	1.4

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2003	Catherine Creek	271.232	890	3.7
	Crooked Fork Creek Trap	224.120.037.113.003	373	1.6
	NF Moose Creek, Selway R.	224.120.037.065.006	671	2.8
	Lostine R.	271.131.042	839	3.5
	Fish Creek Trap	224.120.037.039.002	2,765	11.6
	Minam R.	271.131.016	501	2.1
	Lookingglass Creek	271.137	891	3.7
	Salmon Trap	303.103	305	1.3
	Clear Creek	224.120.004	585	2.5
	Imnaha Trap	308.007	5,959	25.0
	Grande Ronde R. Trap	271.002	566	2.4
	Grande Ronde R.	271	561	2.4
	Clearwater Trap	224.010	451	1.9
	Snake Trap	225	1,195	5.0
	Other		2,210	9.2
	Total		23,809	100.0
2004	Sawtooth Trap	303.617	432	1.7
	Marsh Creek Trap	303.319.170.011	310	1.3
	Pahsimeroi R. Trap	303.489.002	239	1.0
	Lemhi R. Weir	303.416.049	662	2.7
	Rapid R., MF Salmon R.	303.319.124	372	1.5
	Yellowjacket Creek	303.319.057.007	677	2.7
	Camas Creek, MF Salmon R.	303.319.057	702	2.8
	SF Salmon R. Trap	303.215.115	254	1.0
	Johnson Creek Trap	303.215.060.024.007	335	1.4
	Horse Creek	303.301	476	1.9
	Chamberlain Creek	303.282	865	3.5
	Lick Creek	303.215.059.008	287	1.2
	Bargamin Creek	303.225	377	1.5
	Catherine Creek	271.232	572	2.3
	NF Moose Creek, Selway R.	224.120.037.065.006	1,103	4.5
	Fish Creek Trap	224.120.037.039.002	4,013	16.3
	Lookingglass Creek	271.137	881	3.6

Table C.2 (continued)

Release Year	Release Site	RKM	Number Released	Percentage
2004	Whitebird Creek	303.086	276	1.1
	Clear Creek	224.120.004	528	2.1
	Imnaha Trap	308.007	5,500	22.3
	Grande Ronde R. Trap	271.002	747	3.0
	Grande Ronde R.	271	388	1.6
	Clearwater Trap	224.010	987	4.0
	Snake Trap	225	1,920	7.8
	Other		1,785	6.9
	Total		24,688	99.7

C.2 Detection Sites

Table C.3 identifies the detection sites used for each release group.

Table C.3: Detection sites used for each release group by year of release and species.

Release		Juvenile Sites						Adult Sites			
Year	Species	LGR	LGS	LMN	MCN	JD	BON	BON	MCN	IH	LGR
1996[a]	Chinook	X	X	X	X	-	-	-	-	-	X
1997[a]		X	X	X	X	-	X	-	-	-	X
1998		X	X	X	X	X	X	-	-	-	X
1999		X	X	X	X	X	X	X	-	-	X
2000		X	X	X	X	X	X	X	-	-	X
2001		X	X	X	X	X	X	X	-	-	X
2002		X	X	X	X	X	X	X	X	X	X
2003		X	X	X	X	X	X	X	X	X	X
2004		X	X	X	X	X	X	X	X	X	X
1996[a]	Steelhead	X	X	X	X	-	-	-	-	-	X
1997[b]		X	X	X	X	-	X	-	-	-	X
1998[a]		X	X	X	X	X	X	-	-	-	X
1999		X	X	X	X	X	X	X	-	-	X
2000		X	X	X	X	X	X	X	-	-	X
2001[b]		X	X	X	X	X	X	X	-	-	X
2002		X	X	X	X	X	X	X	X	X	X
2003		X	X	X	X	X	X	X	X	X	X
2004		X	X	X	X	X	X	X	X	X	X

[a] Performance measures were estimated using a reduced tagging model.

[b] There were too few adult detections to use the ROSTER model. Instead, juvenile detection sites LGR and LGS were used, and all later detections were pooled. Detection histories were analyzed using a reduced tagging model (i.e., the CJS model with removals, combined with ratio estimators).

C.3 PitPro Error Summaries

PitPro performs error checking while converting the raw release and observation data to detection histories. Tags flagged as errors are removed from the data set. PitPro searches for 14 types of errors, but only 5 error types were found in the data analyzed in this report. Tables C.5 and C.6 summarize the errors found for these data, using error codes defined in Table C.4. Some tags have multiple errors.

Table C.4: Descriptions and codes for data errors detected by PitPro for the spring and summer Chinook salmon and steelhead releases analyzed in this report.

Error Code	**Error Description**
A	Observation on known juvenile detector outside of migration year.
B	Observations are out of sequence.
C	Fish observed before release date.
D	Fish removed before first capture history site.
E	Fish detected as jack (i.e., before start of adult return year, for steelhead).

Table C.5: PitPro error summary for the Chinook salmon release groups. Error codes are defined in Table C.4. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	10	0	0	262	0	272	18,908
1997	11	0	0	174	0	185	9,601
1998	15	0	0	849	0	864	30,615
1999	0	0	5	1,420	0	1,423	73,319
2000	40	0	1	1,464	0	1,505	62,781
2001	19	0	0	1,575	0	1,594	44,374
2002	13	0	2	1,220	0	1,234	59,027
2003	40	0	118	2,255	0	2,305	92,304
2004	33	0	11	977	0	1,019	89,081

Table C.6: PitPro error summary for the steelhead release groups. Error codes are defined in Table C.4. Final N is the size of the release group after removing tags with errors.

Release	**Error Type**					**Total**	**Final**
Year	A	B	C	D	E	**Errors**	N
1996	59	2	1	49	1	110	5,393
1997	76	0	0	151	4	227	6,409
1998	55	0	1	165	3	221	8,003
1999	0	0	2	110	0	112	15,632
2000	463	0	4	526	20	1,002	24,712
2001	357	2	8	311	34	679	23,384
2002	256	1	3	378	19	644	25,524
2003	274	0	14	213	12	504	23,809
2004	227	0	14	178	10	421	24,688

Appendix D

Notes on Fitting the Model

Tables D.1 and D.2 identify certain key notes about fitting the model to the various data sets. In particular, survival parameters that were fixed (instead of estimated) are identified, as well as the effect of this practice on interpreting results. Also, any age classes or records that were omitted are identified as well.

Table D.1: Notes on fitting model to data sets for the wild Chinook salmon release groups.

Release Year	Notes
1996	No JD or BON juvenile detection site, so S_4 is survival in last juvenile reach. $\widehat{S}_4 >> 1$, a simplified tagging model was used for analysis. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1997	Too few adult detections for full ROSTER analysis. A simplified tagging model was used for analysis. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1998	
1999	
2000	Censored records of two age-4-ocean fish at their final juvenile detection.
2001	Censored records of one age-1-ocean fish and one age-4-ocean fish at their final detection; fixed S_{C71} to 0.000001, fixed λ_{C1} and p_{C71} to 1 to fit ROSTER model.
2002	Censored records of two age-4-ocean fish at their final juvenile detection. Fixed S_{C81}, S_{C91}, S_{C92}, and S_{C93} to 0.99999; standard error on SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2004, 2005) will be underestimated.
2003	Fixed S_{C81}, S_{C92}, and S_{C93} to 0.99999; standard error on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2005, 2006),R_{LGR}, D_{LGR}, R_{LGS}, and D_{LGS} will be underestimated.
2004	Censored records of 5 age-1-ocean fish and 3 age-4-ocean fish at their final juvenile detection; fixed S_{C71}, S_{C81}, S_{C91} to 0.00001, λ_{C1}, p_{C71}, p_{C81}, and p_{C91} to 1. Fixed S_{C92} to 0.9999; standard error on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2006),R_{LGR}, D_{LGR}, R_{LGS}, and D_{LGS} will be underestimated.

Table D.2: Notes on fitting model to data sets for the wild steelhead release groups.

Release Year	Notes
1996	No JD or BON juvenile detection site, so S_4 is survival in last juvenile reach. $\widehat{S}_4 >> 1$, so a simplified tagging model was used for analysis. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1997	Too few adults for ROSTER analysis. A simplified tagging model was used for analysis. Fit CJS model (with removals) to reduced data set including juvenile sites LGR, LGS, and all later detections pooled (3 fields in detection history). Used UW software USER to estimate S_1, p_1, and c_1.

Table D.2 continued

Release Year	Notes
1998	Too few adult detections for full ROSTER analysis. A simplified tagging model was used for analysis. Model parameters S_1, p_1, and c_1 were estimated using the ROSTER model.
1999	Censored 4 age-3-ocean fish, because low adult detection probability at BON prevented estimation of age-3 adult parameters; fixed S_{C73} to 0.00001 and p_{C73} to 1 to fit model.
2000	
2001	Too few adults for ROSTER analysis. A simplified tagging model was used for analysis. Fit CJS model (with removals) to reduced data set including juvenile sites LGR, LGS, and all later detections pooled (3 fields in detection history). Used UW software USER to estimate S_1, p_1, and c_1.
2002	Censored 1 age-3-ocean fish and 1 age-4-ocean fish. Fixed S_3 and S_{C92} to 0.99999; standard error on S_J, SAR, $S_{A_{Rel}}$, and $S_{A_{Ret}}$ (for 2004, 2005) will be underestimated.
2003	Fixed S_{C91} to 0.99999, fixed S_{T911}, S_{T921} to 1; standard errors on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2004, 2005), R_{LGR}, and D_{LGR} will be underestimated.
2004	Censored 1 age-3-ocean fish. Fixed S_{C91}, S_{C92}, and S_{T911} to 0.99999; standard errors on SAR, $S_{A_{Rel}}$, $S_{A_{Ret}}$ (for 2005, 2006), R_{LGR}, and D_{LGR} will be underestimated.

Appendix E

Tables of Estimated Performance Measures

E.1 SAR

Table E.1: Estimated smolt-to-adult return ratios from Lower Granite to Lower Granite for wild PIT-tagged fish (i.e., "tagged SAR," SAR). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook SAR does not include the age-1-ocean age class ("jacks"), while steelhead SAR does include the age-1-ocean age class.

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.0015	0.0109	0.0111	0.0173	0.0226	0.0016	0.0111	0.0033	0.0035	0.0092
	(0.0005)	(0.0022)	(0.0015)	(0.0010)	(0.0013)	(0.0003)	(0.0011)	(0.0006)	(0.0010)	(0.0025)
Steelhead	0.0039	0.0016	0.0038	0.0078	0.0170	0.0041	0.0081	0.0073	0.0030	0.0063
	(0.0011)	(0.0008)	(0.0009)	(0.0009)	(0.0011)	(0.0006)	(0.0007)	(0.0008)	(0.0018)	(0.0015)

E.2 Juvenile Inriver Survival

Table E.2: Estimated juvenile inriver survival from Lower Granite to Bonneville (S_J). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean.

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	-	-	0.6628	0.5597	0.5701	0.3610	0.5611	0.5703	0.4410	0.5323
	(-)	(-)	(0.1650)	(0.0496)	(0.0478)	(0.1245)	(0.0759)	(0.1279)	(0.1734)	(0.0375)
Steelhead	-	-	-	0.4989	0.4792	-	0.3922	0.5297	0.1478	0.4096
	(-)	(-)	(-)	(0.0995)	(0.0570)	(-)	(0.0550)	(0.1107)	(0.1865)	(0.0693)

E.3 Ocean Return Probabilities

Table E.3: Estimated ocean return probabilities for nontransported fish (O_{NT}). Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook ocean return probability does not include the age-1-ocean age class ("jacks"), while steelhead ocean return probability does include the age-1-ocean age class.

	Release Year						
Species	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.0356	0.0472	0.0049	0.0228	0.0060	0.0073	0.0206
	(0.0039)	(0.0045)	(0.0020)	(0.0035)	(0.0016)	(0.0031)	(0.0072)
Steelhead	0.0178	0.0429	-	0.0240	0.0134	0.0125	0.0221
	(0.0047)	(0.0058)	(-)	(0.0040)	(0.0033)	(0.0168)	(0.0056)

E.4 Adult Upriver Survival by Release Group

Table E.4: Estimated average adult upriver survival from Bonneville to Lower Granite, by release group ($S_{A_{Rel}}$). Estimates include both transported and nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks"), while steelhead adult upriver survival does include the age-1-ocean age class.

	Release Year						
Species	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.8716	0.8408	0.8927	0.8651	0.8986	0.7228	0.8486
	(0.0457)	(0.0166)	(0.0587)	(0.0268)	(0.0363)	(0.0444)	(0.0265)
Steelhead	0.8833	0.8300	0.6000	0.8547	0.8164	0.6318	0.7694
	(0.1147)	(0.0302)	(0.2098)	(0.0326)	(0.0409)	(0.0649)	(0.0496)

E.5 Adult Upriver Survival by Return Year

Table E.5: Estimated average adult upriver survival from Bonneville to Lower Granite, by return year ($S_{A_{Ret}}$). Estimates include both transported and nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook adult upriver survival does not include the age-1-ocean age class ("jacks"), while steelhead adult upriver survival does include the age-1-ocean age class.

	Release Year							
Species	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**Average**
Chinook	-	0.8837	0.8675	0.8179	0.8751	0.8735	0.7929	0.8518
	(-)	(0.0489)	(0.0353)	(0.0226)	(0.0275)	(0.0367)	(0.0459)	(0.0152)
Steelhead	0.7500	0.8924	0.7766	0.8373	0.8554	0.7598	0.5272	0.7712
	(0.2108)	(0.0353)	(0.0430)	(0.0431)	(0.0351)	(0.0475)	(0.0988)	(0.0453)

E.6 Proportion of Total Integrated Mortality

Table E.6: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the juvenile inriver migration (μ_J) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	Release Year						
Species	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.1431	0.1483	0.1580	0.1283	0.0970	0.1354	0.1350
	(0.0217)	(0.0222)	(0.0539)	(0.0301)	(0.0389)	(0.0652)	(0.0087)
Steelhead	0.1434	0.1807	-	0.1941	0.1245	0.2911	0.1868
	(0.0410)	(0.0293)	(-)	(0.0281)	(0.0411)	(0.1947)	(0.0289)

Table E.7: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the ocean life stage (μ_O) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	Release Year						
Species	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.8230	0.8059	0.8244	0.8396	0.8840	0.8142	0.8318
	(0.0263)	(0.0226)	(0.0548)	(0.0307)	(0.0395)	(0.0658)	(0.0114)
Steelhead	0.8310	0.7735	-	0.7733	0.8454	0.6668	0.7780
	(0.0500)	(0.0305)	(-)	(0.0287)	(0.0421)	(0.1957)	(0.0314)

Table E.8: Estimated proportion of total integrated mortality between Lower Granite and Lower Granite accounted for by the adult upriver migration (μ_A) for tagged nontransported fish. Values in parentheses are the standard errors of the point estimates above. Average is unweighted arithmetic mean. Chinook measures do not include the age-1-ocean age class ("jacks"), while steelhead measures do include the age-1-ocean age class.

	Release Year						
Species	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	0.0339	0.0458	0.0176	0.0322	0.0190	0.0503	0.0331
	(0.0133)	(0.0050)	(0.0100)	(0.0067)	(0.0070)	(0.0095)	(0.0055)
Steelhead	0.0256	0.0458	-	0.0326	0.0301	0.0422	0.0352
	(0.0272)	(0.0088)	(-)	(0.0078)	(0.0095)	(0.0128)	(0.0038)

E.7 Dam-Specific Transport-Inriver Ratios

Table E.9: Estimated T/I specific to Lower Granite Dam (R_{LGR}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	-	-	-	-	-	-	-	1.2715	2.3714	1.7364
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.4043)	(0.5055)	(0.5411)
Steelhead	-	-	-	-	-	-	-	3.5266	6.1973	4.6750
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.8378)	(2.0661)	(1.3178)

Table E.10: Estimated T/I specific to Little Goose Dam (R_{LGS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook T/I does not include the age-1-ocean age class ("jacks").

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	-	-	-	-	-	-	-	1.4549	2.2314	1.8018
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.5383)	(0.6349)	(0.3853)
Steelhead	-	-	-	-	-	-	-	-	-	-
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)

E.8 Dam-Specific Differential Post-Bonneville Mortality (D)

Table E.11: Estimated D specific to Lower Granite Dam (D_{LGR}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook estimates do not include the age-1-ocean age class ("jacks").

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	-	-	-	-	-	-	-	0.7399	1.0672	0.8886
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.2900)	(0.4811)	(0.1627)
Steelhead	-	-	-	-	-	-	-	1.9063	0.9345	1.3347
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.6064)	(1.2638)	(0.4758)

Table E.12: Estimated D specific to Little Goose Dam (D_{LGS}). Values in parentheses are the standard errors of the point estimates above. Average is the unweighted geometric mean including the 2001 estimate. Chinook estimates do not include the age-1-ocean age class ("jacks").

	Release Year									
Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Average**
Chinook	-	-	-	-	-	-	-	0.9302	1.0744	0.9997
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.4056)	(0.5237)	(0.0720)
Steelhead	-	-	-	-	-	-	-	-	-	-
	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)