

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

Ten-year Retrospective Summary Report

**Project #1996-020-00
BPA Contract #s 25634, 25264, 20620**

**Project #1994-033-00
BPA Contract #25247**

Prepared by

Comparative Survival Study Oversight Committee and Fish Passage Center:

Howard Schaller, Paul Wilson, and Steve Haeseker, U.S. Fish and Wildlife Service
Charlie Petrosky, Idaho Department of Fish and Game
Eric Tinus and Tim Dalton, Oregon Department of Fish and Wildlife
Rod Woodin, Washington Department of Fish and Wildlife
Earl Weber, Columbia River Inter-Tribal Fish Commission
Nick Bouwes, EcoLogic
Thomas Berggren, Jerry McCann, Sergei Rassk, Henry Franzoni, and Pete McHugh,
Fish Passage Center

Project Leader:
Michele DeHart, Fish Passage Center

FINAL

8/31/2007

Table of Contents

List of Tables	iv
List of Figures	xx
Executive Summary	xxix
Chapter 1: A Retrospective Summary of Ten Years of the Comparative Survival Study – Methods, Analyses, and Interpretation of Data	1
Chapter 2: Travel Time, Survival, and Instantaneous Mortality Rates of Yearling Chinook and Steelhead through the Lower Snake and Columbia Rivers, and their Associations with Environmental Variables	11
Chapter 3: Annual SAR by Study Category, <i>TIR</i> , <i>S_R</i> , and <i>D</i> for Hatchery and Wild Spring/Summer Chinook Salmon and Steelhead: Patterns and Significance.	67
Chapter 4: Estimating Environmental Stochasticity in SARs, <i>TIR</i> s and <i>D</i> s	100
Chapter 5: Evaluation and Comparison of Overall SARs.....	129
Chapter 6: Partitioning Survival Rates – Hatchery Release to Return.....	178
Chapter 7: Simulation Studies to Explore Impact of CJS Model Assumption Violations on parameter estimation	192
Chapter 8: Conclusion and Future Direction.....	212
References	221
Glossary	230
Appendix A: Logistical Methods.....	A-1
Appendix B: Analytical Methods: Statistical Framework and Equations of Study Parameters	B-1
Appendix C: 2006 Design and Analysis Report.....	C-1
Appendix D: Supporting Tables of PIT-Tag Marking Data and Estimates of Survival and Major CSS Parameters.....	D-1
Appendix E: Tables for 61 Groups of Upriver PIT-tagged Chinook and Steelhead Analyzed for SARs and Related Parameters	E-1

Appendix F: Cumulative passage distributions (timing plots)at Lower Granite and Bonneville dams for PIT-tagged juvenile wild and hatchery Chinook (1997-2004) and steelhead (1997-2003)F-1

Appendix G: Comments and Response from ISRP/ISAB..... G-1

Appendix H: Response to Comments on the DRAFT CSS 10 Year Report..... H-1

List of Tables

Table 2.1. Mean and median of the \hat{Z}_i across cohorts and years for wild yearling Chinook, hatchery yearling Chinook and combined hatchery and wild steelhead in the LGR-MCN reach, and combined hatchery and wild yearling Chinook and steelhead in the MCN-BON reach.	32
Table 2.2. Daily percent mortality rates based on the mean and median of the \hat{Z}_i reported in Table 2.1. ...	32
Table 2.3. Proportion of variation explained (R^2 values) for the models characterizing yearling Chinook and steelhead survival, instantaneous mortality (Z), and median FTT in the LGR-MCN and MCN-BON reaches. The survival results reported here utilized the variable Z approach.	33
Table 2.4. Performance of the three survival modeling approaches for wild Chinook (CHW), hatchery Chinook (CHH), hatchery and wild steelhead (STH&W) and hatchery and wild Chinook (CHH&W) for the LGR-MCN and MCN-BON reaches. AIC is Akaike’s Information Criterion, RMSE is the root mean squared error of the survival predictions, K is the number of parameters requiring estimation, and R^2 is the coefficient of determination.	41
Table 2.5. Across-cohort averages of LGR-MCN median fish travel times (d) for wild yearling Chinook during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.	45
Table 2.6. Across-cohort averages of LGR-MCN median fish travel times (d) for hatchery and wild steelhead during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.....	46
Table 2.7. Across-cohort averages of LGR-MCN median fish travel times (d) for wild yearling Chinook, hatchery yearling Chinook, and hatchery and wild steelhead for average percent spill ranges of < 2%, 20-29%, 30-39%, and 40-51%, 1998-2006. There were no observations of percent spill in the 2-20% range.	46
Table 2.8. Across-cohort averages of LGR-MCN survival rates for wild yearling Chinook during the early, middle, and late periods of their outmigration, when average flows were 50-100, 100-150, and 150-200 kcfs.....	53
Table 2.9. Across-cohort averages of LGR-MCN survival rates for hatchery and wild steelhead during the early, middle, and late periods of their outmigration, when average flows were 50-100, 100-150, and 150-200 kcfs.....	53
Table 2.10. Across-cohort averages of LGR-MCN survival rates for wild yearling Chinook, hatchery yearling Chinook, and hatchery and wild steelhead for average percent spill ranges of < 2%, 20-29%, 30-39%, and 40-51%, 1998-2006. There were no observations of percent spill in the 2-20% range.	53
Table 2.11. Squared correlation coefficients (r^2 values) for associations between instantaneous mortality rates estimates (\hat{Z}_i) and estimates of LGR-MCN survival, median FTT^{-1} , and WTT across cohorts of wild Chinook and hatchery and wild steelhead, 1998-2006.	55

Table 2.12. Parameter estimates and equations characterizing median fish travel time (<i>FTT</i>) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.	56
Table 2.13. Parameter estimates for equations characterizing instantaneous mortality rates (<i>Z</i>) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.	57
Table 2.14. Parameter estimates for equations characterizing survival rates (<i>S</i>) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.	57
Table 2.15. CHW <i>FTT</i> , LGR-MCN, $\log_e(FTT)$, unweighted.	58
Table 2.16. CHH <i>FTT</i> , LGR-MCN, $\log_e(FTT)$, unweighted.	59
Table 2.17. STH&W <i>FTT</i> , MCN-BON, $\log_e(FTT)$, unweighted.	60
Table 2.18. CHH&W <i>FTT</i> , MCN-BON, $\log_e(FTT)$, unweighted.	60
Table 2.19. STH&W <i>FTT</i> , MCN-BON, $\log_e(FTT)$, unweighted.	61
Table 2.20. CHW <i>Z</i> , LGR-MCN, $\log_e(Z)$, inverse-CV weighting.	61
Table 2.21. CHH <i>Z</i> , LGR-BON, $\log_e(Z)$, inverse-CV weighting.	62
Table 2.22. STH&W <i>Z</i> , LGR-BON, <i>Z</i> , inverse-variance weighting.	63
Table 2.23. CHH&W <i>Z</i> , MCN-BON, <i>Z</i> , inverse-CV weighting.	63
Table 2.24. STH&W <i>Z</i> , MCN-BON, <i>Z</i> , inverse-variance weighting.	64
Table 2.25. CHW <i>S</i> , LGR-MCN, $\log_e(S)$, inverse-variance weighting.	64
Table 2.26. CHH <i>S</i> , LGR-MCN, $\log_e(S)$, inverse-variance weighting.	65
Table 2.27. STH&W <i>S</i> , LGR-MCN, $\log_e(S)$, inverse-variance weighting.	65
Table 2.28. CHH&W <i>S</i> , MCN-BON, $\log_e(S)$, inverse-CV weighting.	66
Table 2.29. STH&W <i>S</i> , MCN-BON, $\log_e(S)$, inverse-CV weighting.	66
Table 3.1. Estimated $SAR_{LGR-to-LGR}$ (%) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2004 (with 90% confidence intervals).	76
Table 3.2. Estimated <i>TIR</i> and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating <i>TIR</i> > 1 are highlighted in bold (red).	77

Table 3.3. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).....	78
Table 3.4. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....	81
Table 3.5. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....	82
Table 3.6. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 1997 to 2004 (with 90% confidence intervals).....	83
Table 3.7. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from McCall Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....	84
Table 3.8. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Imnaha River AP for each study category from 1997 to 2004 (with 90% confidence intervals).....	85
Table 3.9. Estimated TIR and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook.....	87
Table 3.10. Estimated TIR and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery summer Chinook. Point estimates and lower limits indicating $TIR > 1$ are highlighted in bold (red).....	88
Table 3.11. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).....	88
Table 3.12. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery summer Chinook. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).....	89
Table 3.13. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).....	91
Table 3.14. Estimated TIR and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. Point estimates and lower limits indicating $TIR > 1$ are highlighted in bold (red).....	92

Table 3.15. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).....	93
Table 3.16. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).....	95
Table 3.17. Estimated TIR and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. $TIR > 1$ is highlighted in red and TIR lower limit > 1 is highlighted in yellow.....	97
Table 3.18. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. $D > 1$ is highlighted in red and D lower limit > 1 is highlighted in yellow.....	97
Table 4.1. Effect of CV of 4% in C_0 estimate on sampling variance of $SAR(C_0)$, for different correlations and mean smolt number. SAR assumed = 1%. Binomial variance was assumed in Chapter 4 analyses. CV of SAR is $\sqrt{\text{variance}} / 1\%$	109
Table 4.2. Effect of variance of two C_0 estimates, on actual sampling variance of $SAR(C_0)$, compared to assumed binomial sampling variance. In first row, C_0 , CV, and SAR estimates are from wild steelhead in 2001; second is from wild Chinook in 2003. Correlation (ρ) between C_0 adults and smolts is estimated through simulation as described in Methods. Binomial variance was assumed in Chapter 4 analyses. CV of SAR is $\sqrt{\text{variance}} / SAR$ est.	109
Table 4.3. Parameters of SAR distributions for wild spring/summer Chinook and Steelhead, and observed correlation coefficient between point estimates of annual T and C_0 SARs. Migration years 1994-2003 for Chinook; 1997-2002 for steelhead.	109
Table 4.4. Species- and project-specific parameters of lognormal TIR distributions for implementation of the hypothesis, with mean and median of distributions. Lognormal fit to output from 25000 iterations. SAR data from 1994-2003 migration years (Chinook); 1997-2002 migration years (steelhead).	112
Table 4.5. Weighted mean, estimated standard deviation of environmental variance, and parameters of beta distribution, reach survival rates used to calculate D . Spring/summer Chinook data from 1994-2003 migration years; steelhead data from 1997-2002 migration years.	116
Table 4.6. Species- and project-specific parameters of lognormal D distributions for implementation of the hypothesis. Lognormal fit to output from 25000 iterations. SAR data from 1994-2003 migration years (Chinook); 1997-2002 migration years (steelhead).	116
Table 4.7. Estimated pathway probability (π_i) for different routes of passage for wild spring/summer Chinook, and for transport as a whole (π_T). Subscripts 1-3 represent the three Snake River transport projects; subscript R is the in-river route.	120

Table 4.8. Estimated pathway probability (π_i) for different routes of passage for wild steelhead, and for transport as a whole. Subscripts 1-3 represent the three Snake River transport projects; subscript <i>R</i> is the in-river route.	120
Table 4.9. Mean SARs and variances for early, mid and late periods, for migrating wild Chinook from LGR dam. Data from migration years 1998-2003.	123
Table 4.10. Mean SARs and variances for early, mid and late periods, for migrating wild steelhead from LGR dam. Data from migration years 1997-2002.	123
Table 5.1. Number of PIT-tagged wild Chinook parr/smolts from the four subbasins above Lower Granite Dam and Snake River trap used in the CSS analyses for migration years 1994 to 2004.	132
Table 5.2. Number of PIT-tagged wild Chinook adults (2-ocean and older) detected in Lower Granite Dam adult fish ladder from aggregate of fish tagged in 10-month period between July 25 and May 20 and classified into each of the three study categories from 1994 to 2004. Cells with >15 fish are bolded; cells with >15 fish in each of 4 drainages are highlighted in red.	133
Table 5.3. Number of PIT-tagged wild Chinook released in John Day River basin, estimated survival and resulting smolt population arriving John Day Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.	141
Table 5.4. Number of PIT-tagged Carson Hatchery Chinook released in the Wind River, estimated survival and resulting smolt population arriving Bonneville Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.	142
Table 5.5. PIT-tag detections of returning adult Chinook (ages 2- and 3-ocean) at Bonneville and Lower Granite dams with percentage of fish undetected at Bonneville Dam – returns from smolts that outmigrated in 2001 to 2004.	143
Table 5.6. Correlation matrices for monthly environmental variables for the years 1964-2004. A is monthly Pacific Decadal Oscillation indices. B is monthly Bacun Upwelling indices at 45 degrees North.	154
Table 5.7. Bi-variate selection results for LN (SAR)-environmental variable (PDO) regressions using long time series (1964-1984, 1992-2004) of data and current time series (1994-2004).	155
Table 5.8. Bi-variate selection results for LN(SAR)-environmental variable (Upwelling) regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).	156
Table 5.9. Model selection results for LN(SAR)-environmental variable regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).	157
Table 5.10. Estimates of SAR from first dam encountered as smolts to Bonneville Dam (BOA) as adults for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.	158

Table 5.11 Conversion of estimated upriver/downriver ratios to differential mortality rates for comparison to differential mortality rates computed by spawner-recruit analyses, 95% confidence intervals shown with each method.	159
Table 5.12. Estimates of SAR from first dam encountered as smolts to Bonneville Dam (BOA) as adults for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.	161
Table 5.13. Summary statistics for wild Chinook salmon smolts captured, tagged, and released at CSS trap sites between March 15 th and May 20 th during migration years 2000-2005.	163
Table 5.14. Results from an ANCOVA-based comparison of smolt size across upriver and downriver release sites, using redd density as a covariate.	164
Table 5.15. Results from an ANOVA evaluating smolt size variation across release sites and migration years.	166
Table 5.16. Dates of 50% passage (i.e., median emigration date) for Chinook salmon captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.	166
Table 5.17. Median estuary arrival (i.e., BON detection) dates for Chinook salmon smolts captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.	169
Table 5.18 Number of smolts and adult returns for Snake River wild spring/summer Chinook by group (C ₀ , C ₁ , T ₀) and for John Day River wild spring Chinook for smolts passing Bonneville Dam during biweekly periods smolt migration years 2000-2003.	172
Table 6.1. Counts of hatchery Chinook salmon adults that failed ('F') or were successful ('S') in surviving their BON-LGR migration in return years 2002-2006, grouped by migration year and outmigration experience (see Methods for group definitions). There was evidence for a significant association between transport history and migration success where sufficient observations-per-cell were available (see Table 6.3 for details).	180
Table 6.2. Counts of wild Chinook salmon adults that failed ('F') or were successful ('S') in surviving their BON-LGR migration in return years 2002-2006. There was evidence for a significant association between transport history and migration success where sufficient observations-per-cell were available (i.e., ≥ 5 ; MY2002: $\chi^2 = 8.74$, $df = 2$, $P = 0.013$; Combined: $\chi^2 = 7.94$, $df = 2$, $P = 0.019$; MY2001, MY2003-4, not applicable).....	180
Table 6.3. Summary of MY-, RY-, and hatchery-specific χ^2 -tests for hatchery Chinook salmon. The <i>P</i> -values listed are not corrected for multiple tests. The success rate ranking corresponds to the ordering of % successful upstream migrants by juvenile outmigration history. The entry 'NA' corresponds to table values that are not applicable because either a test was not performed due to low cell counts (i.e., RY2002) or the resulting test statistic was not significant ($\alpha = 0.05$). $df = 2$ for all tests.....	182

Table 6.4. Logistic regression model-selection results for CSS hatchery Chinook salmon. Note, $Y = P(\text{Success} X)$, where X is the variable in question. The bold-faced model was the one most supported by the data, however those with a $\Delta\text{AIC} \leq 2$ can be considered nearly equivalent. K is the number of estimated parameters (inclusive of variance).....	186
Table 6.5. Parameter estimates for the top logistic regression model describing BON-LGR migration success for CSS hatchery Chinook salmon returning in 2002-2006.	187
Table 6.6. Logistic regression model-selection results for CSS wild Chinook salmon. Note, $Y = P(\text{Success} X)$, where X is the variable in question. The bold-faced model was the one most supported by the data, however those with a $\Delta\text{AIC} \leq 2$ were viewed as equivalent. K is the number of estimated parameters (inclusive of variance)..	187
Table 6.7. Parameter estimates for the top logistic regression model describing BON-LGR migration success for CSS wild Chinook salmon returning from 2002-2006.	188
Table 7.1. Comparison of smolt numbers and the relative percent differences estimated for each study category using the computational and expectation formulas, across the twelve scenarios investigated. Reported smolt numbers are averages across the 1,000 simulated data sets.....	205
Table 7.2. Comparison of smolt numbers and the relative percent differences estimated for each study category using the computational formulas, across the twelve scenarios investigated. Reported smolt numbers are averages across the 1,000 simulated data sets.	207
Table 7.3. Comparison of estimated SARs for each study category with the known simulated values across the twelve scenarios investigated. The SAR values are averages across the 1,000 simulated data sets. Differences $\leq \pm 0.0001$ are considered trivial, and denoted with “=”.	208
Table 7.4. Comparison of estimated TIR (i.e., $\text{sar}T_0/\text{sar}C_0$), S_R , and D values with the known simulated values across the twelve scenarios investigated. Parameter values are averages across the 1,000 simulated data sets.....	211
Table A-1. Progression of study design logistics changes through the series of annual reports prepared by the CSS in 2000 to 2006..	A-2
Table B-1. Progression of methods of estimating study-specific SARs and D through the series of annual reports and design & analysis technical documents prepared by the CSS in 2000 to 2006 (see definitions of symbols in text).....	B-15
Table D-1. Number of PIT-tagged wild Chinook parr/smolts from the four tributaries above Lower Granite Dam and Snake River trap used in the CSS analyses for migration years 1994 to 2004.	D-1
Table D-2. Number of PIT-tagged hatchery Chinook parr/smolts from key hatcheries located above Lower Granite Dam used in the CSS analyses for migration years 1997 to 2004.	D-2

Table D-3. Number of PIT-tagged wild steelhead smolts from the four tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS for migration years 1997 to 2003.....	D-2
Table D-4. Number of PIT-tagged hatchery steelhead smolts from the four tributaries above Lower Granite Dam (plus mainstem Snake River) used in the CSS for migration years 1997 to 2003.	D-2
Table D-5. Estimated number of PIT-tagged wild Chinook (aggregate of fish tagged in 10-month period between July 25 and May 20) arriving Lower Granite Dam in each of the three study categories from 1994 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.....	D-3
Table D-6. Estimated number of PIT-tagged spring Chinook from Rapid River Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.....	D-4
Table D-7. Estimated number of PIT-tagged spring Chinook from Dworshak Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.....	D-5
Table D-8. Estimated number of PIT-tagged spring Chinook from Catherine Creek Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 2001 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.....	D-6
Table D-9. Estimated number of PIT-tagged summer Chinook from McCall Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.	D-7
Table D-10. Estimated number of PIT-tagged summer Chinook from Imnaha River Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.	D-8
Table D-11. Estimated number of PIT-tagged wild steelhead (aggregate of tagged fish >130 mm released in 12-month period between July 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) adult ladders.	D-9
Table D-12. Estimated number of PIT-tagged hatchery steelhead (aggregate of tagged fish released in 3-month period between April 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) adult ladders.	D-10
Table D-13. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2004 (with 90% confidence intervals).....	D-11
Table D-14. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....	D-11

Table D-15. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....D-12

Table D-16. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 2001 to 2004 (with 90% confidence intervals).....D-12

Table D-17. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged summer Chinook from McCall Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).....D-12

Table D-18. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged summer Chinook from Imnaha River AP for each study category from 1997 to 2004 (with 90% confidence intervals).....D-13

Table D-19. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).....D-13

Table D-20. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).....D-13

Table D-21. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged wild Chinook for migration years 1994 to 2004 (with 90% confidence intervals).....D-14

Table D-22. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged Rapid River Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).....D-14

Table D-23. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged Dworshak Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).....D-15

Table D-24. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged Catherine Creek AP spring Chinook for 2001 to 2004 (with 90% confidence intervals).....D-15

Table D-25. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged McCall Hatchery summer Chinook for 1997 to 2004 (with 90% confidence intervals).....D-16

Table D-26. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged Imnaha AP summer Chinook for 1997 to 2004 (with 90% confidence intervals).....D-16

Table D-27. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged wild steelhead for migration years 1997 to 2003 (with 90% confidence intervals).....D-16

Table D-28. Estimated in-river survival LGR to BON (S_R), TIR , and D of PIT-tagged hatchery steelhead for migration years 1997 to 2003 (with 90% confidence intervals).....D-16

Table D-29. Annual wild Chinook pathway survival estimates (S) and contributions to overall SAR (Path $S_i * \pi_i$), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate in-river. The resulting covariances used to estimate parameters for Figure 3.3 are $Cov(1,2) = 2.59E-06$; $Cov(1+2,3) = 2.75E-06$; and $Cov(1+2+3,4) = 7.07E-06$D-17

Table D-30. Annual wild steelhead pathway survival estimates (S) and contributions to overall SAR (Path $S_i * \pi_i$), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate

in-river. The resulting covariances used to estimate parameters for Figure 3.4 are $Cov(1,2) = -5.86E-06$; $Cov(1+2,3) = 6.72E-06$; and $Cov(1+2+3,4) = 1.86E-06$D-17

Table D-31. In-river smolt survival rate estimates through hydrosystem for the PIT-tag aggregate of wild spring/summer Chinook in migration years 1994 to 2004.....D-18

Table D-32. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Rapid River Hatchery spring Chinook in migration years 1997 to 2004....D-19

Table D-33. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Dworshak Hatchery spring Chinook in migration years 1997 to 2004.....D-20

Table D-34. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Catherine Creek Acclimation Pond spring Chinook in migration years 2001 to 2004.D-21

Table D-35. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged McCall Hatchery summer Chinook in migration years 1997 to 2004.D-22

Table D-36. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Imnaha Acclimation Pond summer Chinook in migration years 1997 to 2004.D-23

Table D-37. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of wild summer steelhead in migration years 1997 to 2003.....D-24

Table D-38. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of hatchery summer steelhead in migration years 1997 to 2003.D-25

Table D-39. Age composition of returning PIT-tagged wild Chinook jacks and adults detected at Lower Granite Dam that were PIT-tagged during the 10-month period from July 25 to May 20 for each migration year between 1994 and 2004.....D-26

Table D-40. Age composition of returning PIT-tagged John Day River wild Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.D-26

Table D-41. Number of returning PIT-tagged hatchery Chinook adults and jacks detected at Lower Granite Dam that migrated as smolts in 1997 to 2004 and percent of total return.D-27

Table D-42. Age composition of returning PIT-tagged Carson NFH Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.D-28

Table D-43. Age composition of returning PIT-tagged wild steelhead adults detected at Lower Granite Dam that were PIT-tagged during the 12-month period from July 1 to June 30 for each migration year between 1997 and 2003.D-28

Table D-44. Age composition of returning PIT-tagged hatchery steelhead adults detected at Lower Granite Dam that migrated as smolts in 1997 to 2003.....D-28

Table D-45. Actual number of PIT-tagged juvenile hatchery spring Chinook transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in

creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.D-29

Table D-46. Actual number of PIT-tagged juvenile hatchery summer Chinook transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.D-30

Table D-47. Actual number of PIT-tagged juvenile wild Chinook and wild/hatchery steelhead transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.D-31

Table E-1. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1994.E-2

Table E-2. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1995.E-3

Table E-3. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1996.E-4

Table E-4. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1997.E-5

Table E-5. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1998.E-6

Table E-6. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1999.E-7

Table E-7. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2000.E-8

Table E-8. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2001.E-9

Table E-9. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2002.E-10

Table E-10. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2003. E-11

Table E-11. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2004.E-12

Table E-12. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1997.E-13

Table E-13. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1998.E-14

Table E-14. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1999.E-15

Table E-15. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2000.E-16

Table E-16. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2001.E-17

Table E-17. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2002.E-18

Table E-18. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2003.E-19

Table E-19. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1997.E-20

Table E-20. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1998.E-21

Table E-21. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1999.E-22

Table E-22. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2000.E-23

Table E-23. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2001.E-24

Table E-24. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2002.E-25

Table E-25. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2003.E-26

Table E-26. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1997.E-27

Table E-27. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1998.E-28

Table E-28. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1999.E-29

Table E-29. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2000.E-30

Table E-30. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2001.E-31

Table E-31. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2002.E-32

Table E-32. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2003.E-33

Table E-33. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2004.E-34

Table E-34. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1997.E-35

Table E-35. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1998.E-36

Table E-36. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1999.E-37

Table E-37. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2000.E-38

Table E-38. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2001.E-39

Table E-39. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2002.E-40

Table E-40. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2003.E-41

Table E-41. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2004.E-42

Table E-42. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2001.....E-43

Table E-43. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2002.....E-44

Table E-44. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2003.....E-45

Table E-45. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2004.....E-46

Table E-46. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1997.....E-47

Table E-47. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1998.....E-48

Table E-48. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1999.....E-49

Table E-49. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2000.....	E-50
Table E-50. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2001.....	E-51
Table E-51. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2002.....	E-52
Table E-52. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2003.....	E-53
Table E-53. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2004.	E-54
Table E-54. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1997.....	E-55
Table E-55. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1998.....	E-56
Table E-56. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1999.....	E-57
Table E-57. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2000.....	E-58
Table E-58. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2001.....	E-59
Table E-59. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2002.....	E-60
Table E-60. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2003.....	E-61

Table E-61. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2004.....E-62

Table F-1. Proportion of flow passing through powerhouse at Lower Granite Dam. Daily PIT-tag detection tallies are divided by this proportion to produce daily PIT-tag passage index values, which in turn are used in the cumulative passage distributions.F-3

Table F-2. Proportion of flow passing through combined powerhouses at Bonneville Dam. Daily PIT-tag detection tallies are divided by this proportion to produce daily PIT-tag passage index values, which in turn are used in the cumulative passage distributions.F-5

Table F-3. Proportion of Chinook hatchery production PIT-tagged for the CSS in 1997 to 2004.F-7

Table F-4. Hatchery Chinook PIT-tagged and released in Snake River basin specifically for CSS, 1997-2004.F-8

Table F-5. Carson NFH Chinook PIT-tagged and released in lower Columbia River basin specifically for CSS, 1997-2004.F-8

List of Figures

Figure 1.1. Salmonid life cycle in the Snake River and lower Columbia River basins (Source: Marmorek et al. 2004).....	2
Figure 1.2. CSS PIT-tag release locations and PIT-tag detection sites in the Columbia River Basin.	3
Figure 1.3. CSS PIT-tag release watersheds and PIT-tag detection sites in the Columbia River Basin.	4
Figure 2.1. Boxplots of flow (left column, kcfs), water transit time (center column, days) and average percent spill (right column, %) experienced by cohorts of wild yearling Chinook (top row) and hatchery and wild steelhead (bottom row) in the LGR-MCN reach during 1998-2006. The box ends correspond to the first and third quartiles of the data, the filled square corresponds to the median, the whiskers correspond to the least and greatest observations within the first quartile minus, and the third quartile plus, 1.5 times the inter-quartile range, and the asterisks correspond to observations beyond the whisker limits.....	20
Figure 2.2. Boxplots of flow (left column, kcfs), water transit time (center column, days) and average percent spill (right column, %) experienced by cohorts of hatchery and wild yearling Chinook (top row) and steelhead (bottom row) in the MCN-BON reach during 1999-2006. See Figure 2.1 for a description of boxplots.	21
Figure 2.3. Estimates of median <i>FTT</i> , survival rates and instantaneous mortality rates for wild yearling Chinook in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.	23
Figure 2.4. Estimates of median <i>FTT</i> , survival rates and instantaneous mortality rates for hatchery yearling Chinook in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.	24
Figure 2.5. Estimates of median <i>FTT</i> , survival rates and instantaneous mortality rates for combined hatchery and wild steelhead in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.	25
Figure 2.6. Boxplots of LGR-MCN estimates of median fish travel time (left column, days), survival (middle column) and instantaneous mortality (<i>Z</i>) (right column, d^{-1}) for cohorts of wild yearling Chinook (upper row), hatchery and wild steelhead (lower row) for migration years 1998-2006. See Figure 2.1 for a description of boxplots.....	26
Figure 2.7. Estimates of median <i>FTT</i> , survival rates and instantaneous mortality rates for wild (open squares) and hatchery (closed diamonds) yearling Chinook in the LGR-MCN reach, 1998-2006.	27
Figure 2.8. Estimates of MCN-BON median <i>FTT</i> (d) with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006.	29

Figure 2.9. Estimates of MCN-BON survival with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006. 30

Figure 2.10. Estimates of MCN-BON Z with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006. 31

Figure 2.11. Observed LGR-MCN median FTT (d) (filled diamonds, with 95% confidence intervals) and model predictions for median FTT (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006. 34

Figure 2.12. Observed MCN-BON median FTT (d) (closed diamonds) with 95% confidence intervals and predicted median FTT (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006. 35

Figure 2.13. LGR-MCN \hat{Z}_i (d^{-1}) (filled diamonds, with 95% confidence intervals) and model predictions for Z_i (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006. 37

Figure 2.14. MCN-BON \hat{Z}_i (d^{-1}) (closed diamonds, with 95% confidence intervals) and predicted Z_i (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel) cohorts, 1999-2006. 39

Figure 2.15. Observed LGR-MCN survival (filled diamonds, with 95% confidence intervals) and model predictions for survival (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006. Survival estimates were made using the variable Z approach. 42

Figure 2.16. Observed MCN-BON survival (closed diamonds, with 95% confidence intervals) and model predictions of survival (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel) across cohorts, 1999-2006. Survival predictions were made using the variable Z approach. 43

Figure 2.17. Model predictions of LGR-MCN median fish travel time (FTT) versus flow (kcfs) for 0% and 40% average spill levels (left panels) and observed median fish travel time versus flow (right panels), during early, mid, and late periods of the outmigration. Model predictions for scenarios with 0% average spill were limited to flows at or below 120 kcfs, the approximate hydraulic capacity of the Snake River projects. 45

Figure 2.18. Model predictions of LGR-MCN Z for wild yearling Chinook as a function of Julian day and LGR-MCN water transit times of 5-, 10-, 15-, and 20-d (top panel) and LGR-MCN Z for hatchery and wild steelhead as a function of Julian day, flow (75, 150, and 200 kcfs), and average percent spill (0%, 40%, and 45%). 47

Figure 2.19. Model predictions of LGR-MCN survival for wild yearling Chinook (upper panel) and hatchery and wild steelhead (lower panel) versus flow (kcfs) at two average percent spill levels (0%, 40%), during early, mid, and late outmigration periods (early, mid, late). Model predictions for scenarios with 0% average spill were limited to flows at or below 120 kcfs, the approximate hydraulic capacity of the Snake River projects. Survival predictions utilized the variable Z approach. 50

Figure 2.20. Estimates of LGR-MCN survival versus flow for wild yearling Chinook (left) and hatchery and wild steelhead (right) during the early (upper panels), middle (center panels) and late (lower panels) portions of the migration period, with their 95% confidence intervals.....	51
Figure 2.21. Estimates of LGR-MCN survival versus flow for wild yearling Chinook across all portions of the migration period, 1998-2006.	52
Figure 2.22. Estimates of LGR-MCN survival versus flow for hatchery and wild steelhead across all portions of the migration period, 1998-2006.	53
Figure 2.23. Estimates of LGR-MCN instantaneous mortality rates (Z_i) versus median fish travel time (FTT , d) for wild yearling Chinook and hatchery and wild steelhead during the early, mid, and late migration periods. Horizontal lines denote the period-specific averages of the Z_i	55
Figure 3.1. Estimated LGR-LGR SAR for PIT-tagged wild Chinook aggregate in transport [$SAR(T_0)$] and in-river [$SAR(C_0)$] study categories for migration years 1994 to 2004 (incomplete adult returns for 2004).	76
Figure 3.2. Trend in $SAR(C_0)$ (top plot) and $SAR(T_0)$ (bottom plot) for PIT-tagged Snake River wild and hatchery spring/summer Chinook in migration years 1994 to 2004 (see Tables D-13 to D-18 tables for 90% confidence intervals).	80
Figure 3.3. Trend in estimated transport and in-river SARs for Rapid River Hatchery spring Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).....	81
Figure 3.4. Estimated transport and in-river SARs for PIT-tagged Dworshak Hatchery spring Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).....	82
Figure 3.5. Estimated transport and in-river SARs for PIT-tagged Catherine Creek Acclimation Pond spring Chinook for migration years 2001 to 2004 (incomplete adult returns for 2004).	83
Figure 3.6. Estimated transport and in-river SARs for PIT-tagged McCall Hatchery summer Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).	84
Figure 3.7. Estimated transport and in-river SARs for PIT-tagged Imnaha River Acclimation Pond summer Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).	85
Figure 3.8. Trend in in-river survival (S_R) for PIT-tagged Snake River wild and hatchery spring/summer Chinook in migration years 1994 to 2004 (see tables D-21 to D-26 for 90% confidence intervals).	86
Figure 3.9. Trend in TIR (log-transformed) for PIT-tagged Snake river hatchery and wild Chinook for migration years 1994 to 2004 (see Tables D-21 to D-26 90% confidence intervals).	87
Figure 3.10. Trend in D (log-transformed) for PIT-tagged Snake River hatchery and wild Chinook in migration years 1994-2004 (see Tables D-21 to D-26 for 90% confidence intervals).	89

Figure 3.11. Estimated transport and in-river SARs (with 90% confidence intervals) for PIT-tagged wild steelhead aggregate for migration years 1997 to 2003 (incomplete 2003 returns).	91
Figure 3.12. Trend in in-river survival (S_R) for PIT-tagged Snake River wild steelhead and wild Chinook for migration years 1997 to 2003 (see Tables D-21 and D-27 for 90% confidence intervals).	92
Figure 3.13. Trend in TIR (log transformed) for PIT-tagged wild steelhead and wild Chinook from migration years 1997 to 2003 (see Tables D-21 and D-27 for 90% confidence intervals).	93
Figure 3.14. Trend in D (log-transformed) for PIT-tagged Snake River wild steelhead and wild Chinook in migration years 1997-2003 (see Tables D-21 and D27 for 90% confidence intervals).	94
Figure 3.15. Estimated transport and in-river SARs for PIT-tagged hatchery steelhead aggregate for migration years 1997 to 2003 (incomplete adult returns for 2003).	95
Figure 3.16. Trend in TIR (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997 to 2003 (see Tables D-27 and D-28 for 90% confidence intervals).	96
Figure 3.17. Trend in TIR (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997 to 2003 (see Tables D-27 and D-28 for 90% confidence intervals).	98
Figure 3.18. Trend in D (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997-2003 (see Tables D-27 and D-28 for 90% confidence intervals).	98
Figure 4.1. Probability density functions (PDFs) across migration years 1994 – 2003, for SARs of wild Chinook transported from LGR, LGS, and LMN dams, and for true in-river (C_0) Chinook. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Also shown is NPCC 2-6% SAR target range.	110
Figure 4.2. PDFs across migration years 1997-2002, for SARs of wild steelhead transported from LGR, LGS, and LMN dams, and for true in-river (C_0) steelhead. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Also shown is NPCC 2-6% SAR target range.	111
Figure 4.3. Exact probability density function of ratio of beta random variables, based on parameters of steelhead SARs from LMN (dashed line); lognormal approximation using values for μ and σ fit to 25000 values of simulated TIR (solid red line).	112
Figure 4.4. Estimated lognormal distribution of TIR for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.	113
Figure 4.5. Estimated lognormal distribution of TIR for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.	113

Figure 4.6. Estimated lognormal distribution of <i>TIR</i> for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.....	114
Figure 4.7. Estimated lognormal distribution of <i>TIR</i> for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.....	114
Figure 4.8. Estimated lognormal distribution of <i>TIR</i> for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.....	115
Figure 4.9. Estimated lognormal distribution of <i>TIR</i> for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.....	115
Figure 4.10. Estimated lognormal distribution of <i>D</i> for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.....	117
Figure 4.11. Estimated lognormal distribution of <i>D</i> for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.....	117
Figure 4.12. Estimated lognormal distribution of <i>D</i> for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.....	118
Figure 4.13. Estimated lognormal distribution of <i>D</i> for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.....	118
Figure 4.14. Estimated lognormal distribution of <i>D</i> for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.....	119
Figure 4.15. Estimated lognormal distribution of <i>D</i> for wild steelhead transported from LMN. Data from 1997 – 2002 migration years.....	119
Figure 4.16. Distribution of overall wild Chinook SAR; data from migration years 1994 – 2003. Mean = 0.82%.....	121
Figure 4.17. Distribution of overall wild steelhead SAR; data from migration years 1997 – 2002. Mean = 1.95%.....	122
Figure 4.18. PDFs for SAR of wild Chinook transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1998-2003.....	123
Figure 4.19. PDFs for SAR of wild Chinook migrating in-river (C_1) from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1998-2003.....	124
Figure 4.20. PDFs for SAR of wild steelhead transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.....	124
Figure 4.21. PDFs for SAR of wild steelhead migrating in-river (C_1) from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.....	125

Figure 4.22. Distributions of SAR for true controls (C_0) and smolts detected at Lower Granite and returned to the river (C_1), 1994-2002 migration years.	125
Figure 5.1. Percentage of PIT-tags in wild Chinook aggregate from Clearwater (CLW), Grande Ronde (GRN), Salmon (SAL), and Imnaha (IMN) rivers, plus Snake River trap at Lewiston, Idaho, for migration years 1998, 1999, 2000, and 2002.	134
Figure 5.2. Preharvest smolt-to-adult returns for Snake River wild spring/summer Chinook, migration years 1964-2004.	135
Figure 5.3. Preharvest smolt-to-adult returns for Snake River spring/summer Chinook, migration years 1994-2004 (open squares are run reconstruction wild, solid squares are CSS wild, and open triangles are CSS hatchery).	136
Figure 5.4. Water travel time(d) experienced by juvenile spring Snake River migrants, 1964-2004.	137
Figure 5.5. Monthly CUI indices (45N 125W) for April, October and November, 1964-2004 migration years. April, October and November indices were frequently incorporated in multiple regression models describing SAR.	138
Figure 5.6. Monthly PDO indices for May and September, 1964-2004 migration years. May and September indices were frequently incorporated in multiple regression models describing SAR.	138
Figure 5.7. Bootstrapped SAR and upper and lower CI for wild aggregate Snake River spring/summer Chinook, migration years 1994-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.	147
Figure 5.8. SARs and 90% CI for wild aggregate Snake River spring/summer Chinook, and four subbasins above LGR (Clearwater, Grande Ronde, Salmon and Imnaha), 1998-2004.	148
Figure 5.9. Bootstrapped SAR for aggregate wild and five hatchery populations of Snake River spring/summer Chinook, 1994-2004. Migration year 2004 is complete through 2-ocean returns only.	149
Figure 5.10. Bootstrapped SAR and upper and lower CI for wild aggregate Snake River spring/summer Chinook, migration years 1994-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.	150
Figure 5.11. Bootstrapped SAR and upper and lower CI for aggregate wild and aggregate hatchery Snake River steelhead, migration years 1997-2003. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.	154
Figure 5.12. SARs (90% CI) for Snake River and John Day River wild stream-type Chinook from smolts at first dam encountered to adult returns to Bonneville Dam. The NPCC interim SAR goal for listed Snake and upper Columbia River salmon and steelhead is shown for reference.	158

Figure 5.13. Differential mortality from SR data through migration year 2000 (Schaller and Petrosky 2007) compared to estimates based on SARs of wild Snake River and John Day River stream-type Chinook, smolt migration years 2000-2004.....	159
Figure 5.14. Differential mortality of Snake River wild and hatchery populations of spring/summer Chinook 2000-2004 migration years.....	162
Figure 5.15. Wild Chinook salmon smolt size (mean fork length +/- 1 SD) for fish tagged and released during migration years 2000-2005 (between 15 March and 20 May). From left to right, trap sites are: CLWTRP = Clearwater R., GRNTRP = Grande Ronde R., IMNTRP = Imnaha R., JDAR1 = John Day R., SALTRP = Salmon R., SNKTRP = Snake R. <i>Note:</i> there were no wild Chinook smolt size data available for CLWTRP prior to 2002.....	164
Figure 5.16 Scatter plot of mean fork length (mm) against redd density (redds / km) for wild Chinook salmon smolts collected, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 5.18 caption for release site abbreviation definitions.	165
Figure 5.17. 6-year mean trap passage (i.e., emigration) distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. <i>Note:</i> Julian date 75 is March 16 th , 100 is April 10 th , 125 is May 5 th , and 150 is May 30 th . See Figure 5.18 caption for release site abbreviation definitions.	167
Figure 5.18. Wild Chinook salmon smolt downriver migration rates (km / d, +/- 1 SD) for those fish captured, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 5.18 caption for release site abbreviation definitions. <i>Note,</i> CLWTRP operations did not begin until 2002; also, too few tags were available for SNKTRP estimation in 2001, 2004-2005.	168
Figure 5.19 Scatter plot of first-to-third dam migration duration as a function of water travel time. Each dot reflects the mean value for a year-site combination. See Figure 5.18 caption for release site abbreviation definitions.....	169
Figure 5.20. 6-year mean estuary arrival (measured at BON) timing distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. <i>Note:</i> Julian date 100 is April 10 th , 125 is May 5 th , 150 is May 30 th , and 175 is June 24 th . See Figure 5.18 caption for release site abbreviation definitions.	170
Figure 5.21. SAR and 90% binomial confidence intervals for Snake River wild spring/summer Chinook by group (C0, C1, T0) and for John Day River wild spring Chinook (JD) for smolts passing Bonneville Dam during the period April 16 – May 31, migration years 2000-2003.....	171
Figure 5.22. SARs from Lower Granite Dam smolts and adults based on run reconstruction (Williams et al. 2005) and SARs and 90% confidence limits from CSS PIT-tags.	173
Figure 6.1. Survival from hatchery release to Lower Granite Dam for Rapid River Hatchery, Dworshak Hatchery, Catherine Creek AP, McCall hatchery, and Imnaha AP, migration years 1997 – 2004.	183

Figure 6.2. Proportion (and 90% CI) of PIT-tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks (pooled across hatcheries), by juvenile passage route (in-river or transport) and smolt migration year (1997-2000).....	184
Figure 6.3. Proportion of PIT-tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks, expanded for estimated harvest rate, smolt migration year (1997-2002).....	184
Figure 6.4. Bar chart of the percent of hatchery (left) and wild (right) Chinook salmon that were successful in migrating from BON to LGR for in-river, LGR, and LGS-down outmigration histories across return years 2002-2006 (i.e., combined counts). Error bars correspond 95% confidence intervals.....	185
Figure 6.5. Box-and-whisker plot of BON-LGR travel times for hatchery (left) and wild (right) Chinook salmon, by outmigration experience (pooled across RYs 2002-2006). Lower and upper box bounds correspond to 25 th and 75 th percentiles, respectively; the mid line represents the median; the upper and lower whiskers encompass 1.5 times the inter-quartile range (IQR); values beyond 3 times the IQR appear as circles, those within as asterisks.	189
Figure 7.1. First simulator input screen – initial settings including release number and survival to LGR, travel time related parameters, and assumed SAR levels.	194
Figure 7.2. Second simulator input screen – arrival population characteristics, collection efficiency and removal rates at LGR, and smolt travel time and survival to LGS.	194
Figure 7.3. Third simulator input screen – collection efficiency and removal rates at LGS, and smolt travel time and survival to LMN.....	195
Figure 7.4. Fourth simulator input screen – collection efficiency and removal rates at LMN, and smolt travel time and survival to MCN.....	195
Figure 7.5. Fifth simulator input screen – collection efficiency and removal rates at MCN, and smolt travel time and survival to JDA.....	196
Figure 7.6. Sixth simulator input screen – collection efficiency and removal rates at JDA, and smolt travel time and survival to BON.	196
Figure 7.7. Seventh simulator input screen – collection efficiency and removal rates at BON, smolt travel time to trawl site, and trawl collection rate (joint survival-collection efficiency).	197
Figure 7.8. Default base parabola of collection probabilities compared to linear trend of increasing (top plot) and decreasing (bottom plot) collection probabilities used at LGR with corresponding fish passage timing. Linear trend lines will be similar at LGS and LMN and shifted slightly lower at MCN; corresponding fish passage distributions will shift later at these downstream dams as a function of fish travel time.	202

Figure 7.9. Default base parabola of survival rates compared to linear trend of increasing (top plot) and decreasing (bottom plot) survival rates from LGR to LGS with corresponding fish passage timing at LGR. Linear trend lines will be similar for the LGS to LMN reach and shifted slightly lower for the LMN to MCN reach; corresponding fish passage distributions will shift later at these downstream dams as a function of fish travel time..... 203

Figure 7.10. Average percent difference in smolt numbers estimated in LGR-equivalents using the computational formula relative to the expectation formula for each CSS study category (wild Chinook [WC] is average of 1994-2004; hatchery Chinook [HC] from Dworshak [dwor], Rapid River [raph], McCall [mcca], and Imnaha [imna] hatcheries are average of 1997-2004, and Catherine Ck is average of 2001-2004; wild [WS] and hatchery [HS] steelhead are average of 1997-2003). 206

Figure 7.11. Estimated daily LGR collection probabilities for combined PIT-tagged hatchery and wild Chinook for five migration years, along with simulated trends (default parabola and lines of -0.006 and +0.006 slope). 210

Figure 7.12. Estimated survival rates from LGR tailrace to MCN tailrace for combined PIT-tagged hatchery and wild Chinook during weekly intervals for 7 migration years; comparison with simulated trends (default parabola and lines of -0.005 and +0.005 slope) for LGR to LGS reach extrapolated on a per mile basis to MCN. 210

Figure B-1. Schematic of key part of reduced M-matrix used in estimation of CJS survival rates and CSS study category smolt numbers – complete reduced M-matrix of CSS includes three more sites (JDA, BON, and TWX) and three more cohorts (#5,6, and 7).....B-3

Figure B-2. Schematic of bootstrap program for estimating initial values, averages, and confidence intervals for study parameter.....B-14

Figures F-1a – F – 10 B Passage Timing at various locationsF9 – F41

Executive Summary

The Comparative Survival Study (CSS) Oversight Committee prepared this report to address the recommendation provided by the Independent Scientific Advisory Board (ISAB) to prepare a retrospective synthesis of the methods and results to date on spring/summer Chinook and steelhead in the Columbia Basin. This ten-year summary report describes study methods, results and conclusions based on ten years of monitoring efforts. The Passive Integrated Transponder (PIT) data used in the CSS are analyzed retrospectively, incorporating all juvenile and adult recovery data available for the period 1996 through 2006.

The Ten-Year Retrospective Summary Report analyzes the available PIT-tag data within- and across-years, assessing the effects of migration routes, environmental conditions and migration timing on juvenile reach survival rates and Smolt-to-Adult Return rates (SAR). These analyses provide for improved understanding of survival rates and the effects of various environmental conditions and management actions on those rates.

Synopsis of Key Findings

- Juvenile travel times, instantaneous mortality rates and survival rates through the hydrosystem are strongly influenced by managed river conditions including flow, water travel time and spill levels.
- Statistical relationships were developed that can be used to predict the effects of environmental factors and management strategies on migration and survival rates of juvenile yearling Chinook and steelhead.
- The CSS results indicate that the SAR of transported fish relative to in-river migrants (*TIR*) varied across species and between wild and hatchery origins. Wild spring/summer Chinook on average showed no benefit from transportation, except in the severe drought year (2001). Hatchery spring/summer Chinook responded to transportation with higher *TIR* averages across hatcheries than wild Chinook. Wild and hatchery steelhead responded to transportation with the highest *TIR*. Substantial differential delayed transport mortality ($D < 1.0$) was evident for both species and across wild and hatchery groups for each species.
- Overall SARs for wild spring/summer Chinook and wild steelhead fell short of the Northwest Power and Conservation Council (NPCC) SAR objectives (2% minimum, 4% average for recovery).
- SAR values for these Snake River Basin groups were only one quarter those of similar downriver populations that migrated through a shorter segment of the Federal Columbia River Power System (FCRPS).
- The above lines of evidence for Snake River reach survivals, SARs by passage route, overall SARs, and downriver SARs relative to the NPCC objectives, indicate that collecting and transporting juvenile spring/summer Chinook and steelhead at Snake River Dams did not compensate for the effects of the FCRPS.
- The overall SARs are also insufficient to meet broad sense recovery goals that include providing harvestable surplus for wild Snake River Basin spring/summer Chinook and steelhead.

- Adult upstream migration survival is affected by the juvenile migration experience. Adults that were transported from Lower Granite Dam as smolts exhibited a 10% lower adult upstream survival rate than either in-river migrants or those transported from Little Goose or Lower Monumental Dams.
- Simulations results indicate that Cormack-Jolly-Seber parameter estimates are robust in the presence of temporal changes in survival or detection probabilities.
- Given the different responses of wild Chinook and wild steelhead to transportation, it would seem that maximization of survival of both species cannot be accomplished by transportation as currently implemented.
- Our analyses on in-river survival rates indicate that improvements in in-river survival can be achieved through management actions that reduce the water travel time or increase the average percent spilled for Snake River yearling Chinook and steelhead in the Lower Granite to McNary reach. The effectiveness of these actions varies over the migration season.
- Higher SARs of Snake River wild yearling Chinook were associated with faster water travel times during juvenile migration through the FCRPS, cool broad-scale ocean conditions, and near-shore downwelling during the fall of the first year of ocean residence.

Chapter 1.

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

Introduction

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

The CSS began in 1996 with the objective of establishing a long-term dataset of the survival rate of annual generations of salmon from their outmigration as smolts to their return to freshwater as adults to spawn (smolt-to-adult return rate; SAR). The study was implemented with the express need to address the question whether collecting juvenile fish at dams and transporting them downstream in barges and trucks and releasing them downstream of Bonneville Dam was compensating for the effect of the Federal Columbia River Power System (FCRPS) on survival of Snake Basin spring/summer Chinook salmon migrating through the hydrosystem.

All of the Chinook salmon evaluated in the CSS study exhibit a stream-type life history. All study fish used in this report were uniquely identifiable based on a PIT-tag implanted in the body cavity during the smolt life stage and retained through their return as adults. These tagged fish can then be detected as juveniles and adults at several locations of the Snake and Columbia Rivers. Reductions in the number of individuals detected as the tagged fish grow older provide estimates of survival. This allows comparisons of survival over different life stages between fish with different experiences in the hydrosystem (e.g. transportation vs. in-river migrants and migration through various numbers of dams) as illustrated in Figure 1.1.

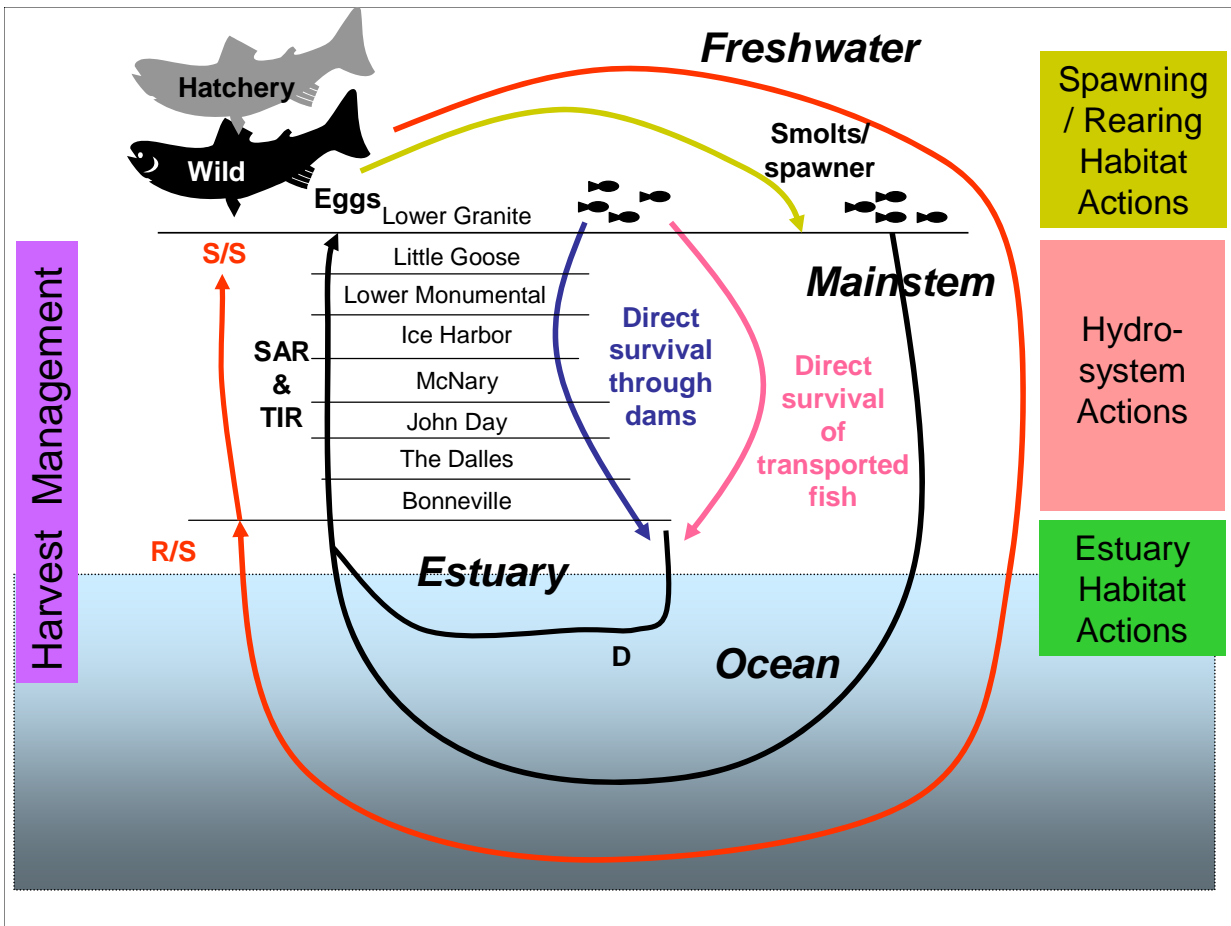


Figure 1.1. Salmonid life cycle in the Snake River and lower Columbia River basins (Source: Marmorek et al. 2004).

The CSS is a long-term study within the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program (NPCC FWP) and is funded by Bonneville Power Administration (BPA). Study design and analyses are conducted through a CSS Oversight Committee (CSSOC) with representation from Columbia River Inter-Tribal Fish Commission (CRITFC), Idaho Department of Fish and Game (IDFG), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), and Washington Department of Fish and Wildlife (WDFW). The Fish Passage Center (FPC) coordinates the PIT-tagging efforts, data management and preparation, and CSSOC work. The location of all tagging sites is identified in Figures 1.2 and 1.3. All draft and final written work products are subject to regional technical and public review and are available electronically on FPC and BPA websites (FPC: <http://www.fpc.org/documents/CSS.html> BPA: <http://www.efw.bpa.gov/searchpublications/index.aspx?projid=+>).

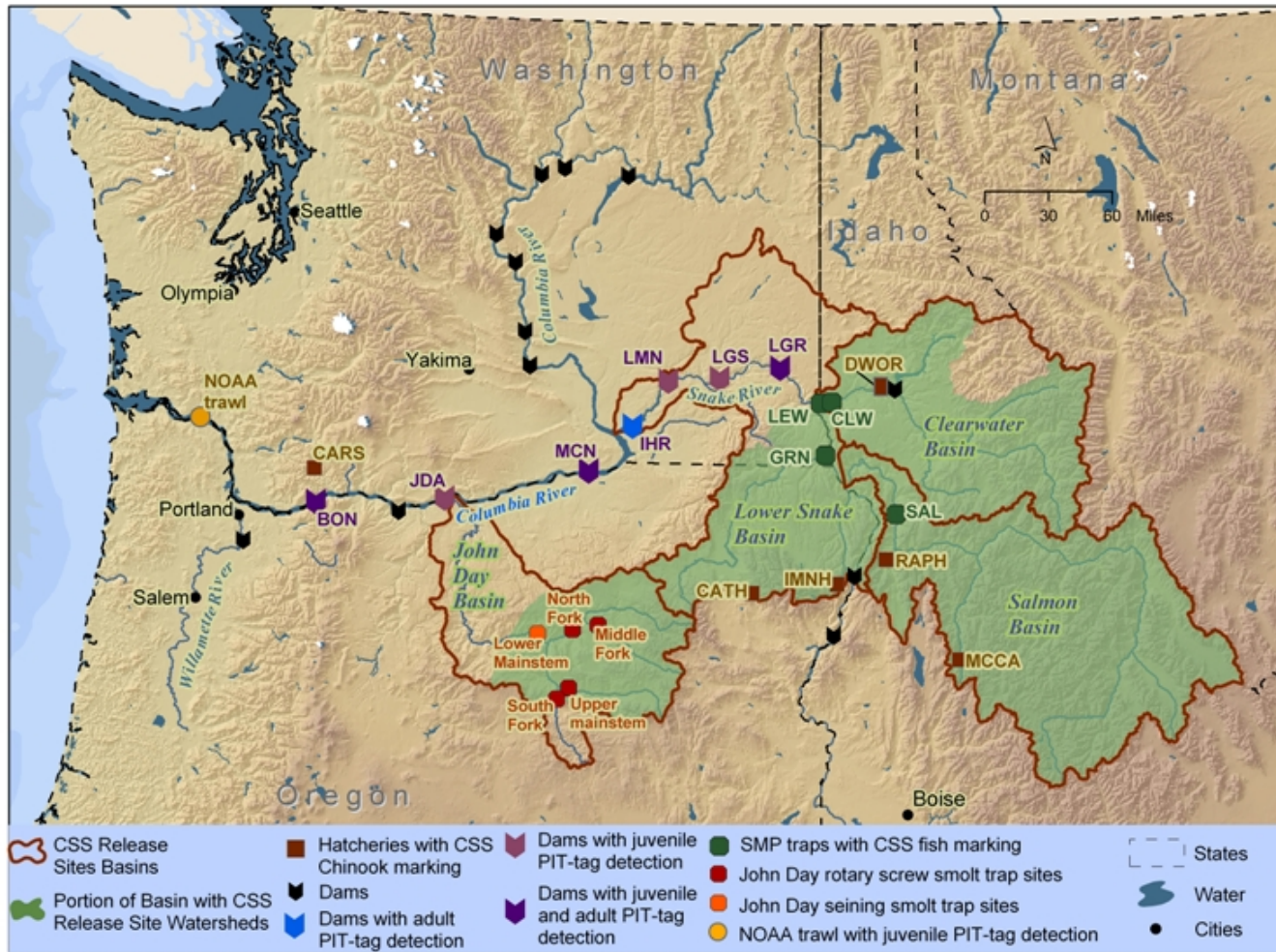
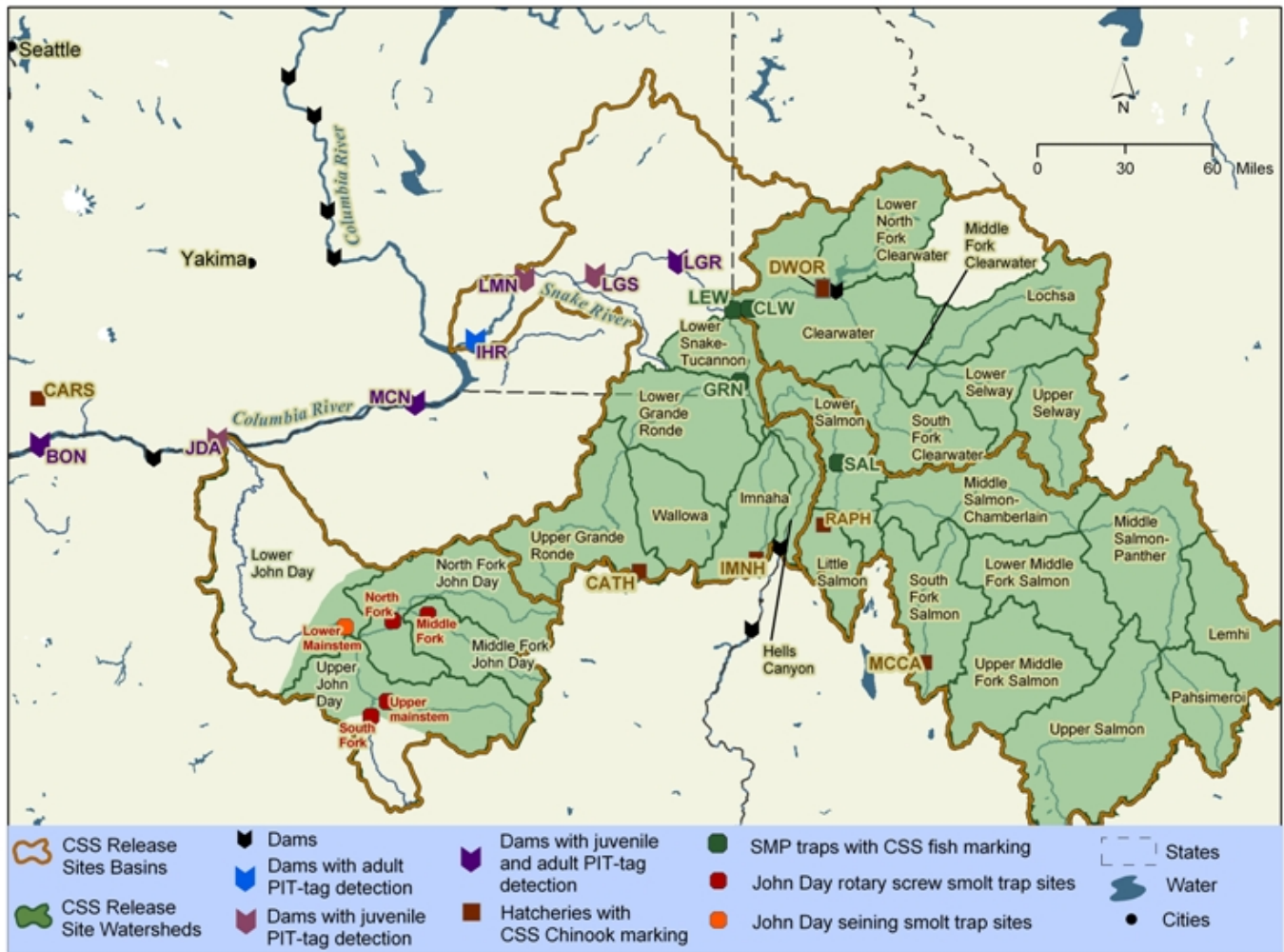


Figure 1.2. CSS PIT-tag release locations and PIT-tag detection sites in the Columbia River Basin.



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

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

Scientific Review

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

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

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

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

Development of the Comparative Survival Study

Beginning in 1981, collection of fish at lower Snake River dams and transportation to below Bonneville dam was institutionalized as an operational program by the U.S. Army Corps

of Engineers (USACE). The intention was to mitigate for mortality impacts associated with the FCRPS, and thus to increase survival of spring/summer Chinook salmon. However, abundance of Snake River spring/summer Chinook salmon continued to decline. Fisheries that had been conducted at moderate levels in the Columbia River main stem during the 1950s and 1960s were all but closed by the mid 1970s. In 1992, the Snake River spring/summer Chinook salmon Evolutionarily Significant Unit (ESU) was listed under the federal Endangered Species Act (ESA). Spawning ground survey results in the mid-1990's indicated virtually complete brood year failure for some wild populations. For hatchery fish, low abundance was a concern as the Lower Snake River Compensation Plan (LSRCP) hatcheries began to collect program brood stock and produce juveniles.

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

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

The objectives of the CSS design translate these issues about the efficacy of transportation into key response variables. The CSS uses the following two aspects for evaluating the efficacy of transportation: 1) empirical SARs compared to those needed for survival and recovery of the ESU; and 2) SAR comparisons between transport and in-river migration routes. In this broader context, the primary objective is to answer: "Are the direct and delayed impacts of the operation and configuration of the FCRPS sufficiently low to ensure that cumulative life-cycle survival is high enough to recover threatened and endangered populations?" Therefore we measure SARs against the regional management goal to maintain SARs between 2-6%, where 2% is a minimum requirement and an average of 4% is maintained over multiple generations (NPCC 2003; *see* Chapter 5). The secondary objective is to answer: "is the survival of transported fish (SAR) higher than the survival (SAR) of fish migrating in-river (*see* Chapters 3 and 4)?" Combining these objectives, effectiveness of transportation is assessed by whether 1) the survival (SAR) of fish collected at Snake River dams and diverted into barges is higher than the SAR of fish that migrate through reservoirs and pass these dams via the spillways and turbines; and 2) the SAR meets the regional objective (2-6%) for the ESU.

Another objective of the CSS study has been to evaluate the impact of the hydrosystem on the Snake River populations by comparing overall survival for Snake River spring/summer Chinook with those from downriver populations which are less influenced by the hydrosystem. The upriver/downriver population comparison was initiated primarily to provide information relevant to patterns observed in comparisons of spawner-recruit (S-R) relationships between upriver and downriver stream-type Chinook (e.g. Petrosky and Schaller 1992, Schaller et al. 1999, Deriso et al. 2001, Schaller and Petrosky 2007). These comparisons indicated productivity and survival rates of Snake River populations declined more than those of downriver

populations, coincident with development and operation of the FCRPS. The S-R comparisons also provided evidence of delayed mortality of in-river migrants from the Snake River (Peters and Marmorek 2001; CSS Delayed Mortality Workshop proceedings, Marmorek et al. 2004; Schaller and Petrosky 2007). Our specific interest through the CSS was whether upriver/downriver differences in overall survival for wild and/or hatchery stream-type Chinook (with more precise estimates from PIT-tagged groups) were consistent with the differential mortality estimated from S-R models for wild populations. We also compared biological characteristics (smolt fork length, migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation.

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

All CSS study fish are uniquely identified with a PIT-tag, and the use of this new technology has provided substantial improvements in the evaluation of the efficacy of transportation. To ensure that all CSS study fish transported or migrating in-river experience the same effects from handling (thus improving the utility of an in-river control group relative to transportation), fish are tagged at hatcheries and wild fish are tagged at subbasin and main stem outmigrant traps upstream of the FCRPS (Figures 1.2 and 1.3). PIT-tagged juveniles are released near their marking station, allowing the numbers of fish and distribution across subbasins of origin to be predetermined. Recapture information can be collected without sacrificing each fish, and lower impacts due to trapping and handling occur where automated detection stations exist.

Within the Columbia and Snake River main stems, PIT-tag detectors at the dams now allow passage dates and locations to be recorded for both juvenile and adult PIT-tagged fish and provide the ability to link that information to the characteristics of each fish at time and location of release (Figures 1.2 and 1.3). Given sufficient numbers of fish among release groups and appropriate distribution across subbasins, ESUs, hatchery vs wild, and outmigration season, survival rates of subgroups of fish with unique life history experience, or aggregate groups with common life history experiences, can be estimated at discrete or combined life-stages throughout

their life cycle. The CSS PIT-tagging design and application allows the use of the Cormack-Jolly-Seber (CJS) method with multiple mark-recapture information to estimate survival of the total number of fish estimated to approach the upper most dam (Lower Granite Dam), thus representing the conditions that the majority of fish migrating through the hydrosystem experience.

The CSS has provided time-series of fish travel times, instantaneous mortality rates, reach survival and SARs. This information allows for the examination of effects of hydrosystem, in-river, climatic and ocean indices on these variables of management interest (see Chapter 2).

Report Organization

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

Chapter 2 summarizes and synthesizes the results that have been obtained to date through the CSS on the responses of juvenile yearling Chinook salmon and steelhead to conditions experienced within the hydrosystem. First, we develop and summarize seasonal travel time and survival rate estimates for juvenile yearling Chinook and steelhead. Second, we develop and summarize estimates of their instantaneous (daily) mortality rates. Third, we develop models for characterizing the associations between environmental factors and fish travel time and survival. In our examination of survival, we compare three analytical approaches for characterizing temporal variation in survival rates. This analysis provides an example of how the CSS PIT-tag results could be used in a predictive fashion to characterize the influence of management strategies on fish travel times and in-river juvenile survival rates, while directly accounting for measurement uncertainty and environmental variability.

Chapter 3 documents the estimation and comparison of annual SARs for hatchery and wild groups of smolts with different hydrosystem experiences between common start and end points. The SARs for fish that are collected at Snake River dams and transported (T_0), collected and returned to the river (C_1), or never collected or transported (C_0) are examined in Chapter 3. To evaluate one component of the effectiveness of transportation relative to in-river migration, annual SAR ratios between T_0 and C_0 fish are compared, both from their passage at Lower Granite Dam as smolts until their return as adults to that dam (TIR , representing the direct effects of transportation versus in-river migration on survival in the freshwater migration corridor as well as the indirect, or delayed, effects in the estuary and ocean), and from their seaward migration from below Bonneville Dam until their return to Lower Granite Dam (D , representing only delayed differential survival effects in the estuary and ocean for transported fish).

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

in order to assess the trend in survival rates over the season, the probability distributions of SARs are derived by dividing the entire juvenile migration season into three periods (early, middle, and late).

Chapter 5 presents overall SAR trends for the PIT-tagged wild and hatchery Chinook and steelhead used in the CSS and examines the extent to which wild SARs meet the regional objectives of maintaining levels from 2 to 6% (NPCC 2003) across years. These SARs represent the type of data required to evaluate the overall effectiveness of the hydrosystem mitigation strategy and to assess the efficacy of the transportation program. Short- and long-term trends in wild Chinook SARs are compared to indices of environmental conditions in the main stem and during early ocean life stages. Wild SARs in aggregate are also compared across broad geographic scales within the Interior Columbia Domain from the Mid-Columbia to Snake River ESUs where fish experience different outmigration conditions, yet share a common environment in the estuary and during early ocean life stages. Biological characteristics (smolt fork length (FL), migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations are also compared, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation. Relationships of annual SARs of the run-at-large with management and environmental variables in the migration corridor, as well as with oceanic/climatic conditions, are examined in Chapter 5; comparisons between upriver and downriver populations can also be found in this chapter.

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

Chapter 7 investigates the impact that violations of assumptions of the Cormack-Jolly-Seber (CJS) model may have on the ability to obtain accurate estimates of reach survival rates and other study parameters, through simulations. In particular, the simulations directly address the assumption that “all fish in a release group have equal detection and survival probabilities”. In the simulations, the emphasis was on the population characteristics of survival rates and collection probabilities that could change over time at the dams where transportation was taking place. These are parameters that will affect how many smolts are estimated within each of the CSS’s three study categories (detected and transported, detected and bypassed, or undetected at the Snake River collector dams) and thus affect estimates of SARs, *TIR*, and *D*.

Chapter 8 concludes the report by presenting accomplishments, key findings, and guidance for future study designs to address critical uncertainties.

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

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

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

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

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

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

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

Appendix H presents responses to the regional review on the first draft of the Ten Year report for the CSS

Chapter 2

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

Introduction

The yearling Chinook and steelhead that have been PIT-tagged through the CSS and other marking efforts allow for monitoring of the effects of environmental factors and hydrosystem management actions during the juvenile life stage on these two species of management concern. Two key fish responses that can be monitored using mark-recapture methods are the rate or amount of time taken to travel through various points along the migration corridor (Raymond 1968, Raymond 1969, Berggren and Filardo 1993, Smith et al. 2002) and survival rates (Burnham et al. 1987, Smith et al. 2002).

Previous research on juvenile Snake River yearling Chinook and steelhead has identified strong associations between flow variables and migration rates (Raymond 1968, Raymond 1969, Raymond 1979, Sims and Ossiander 1981, Berggren and Filardo 1993, Smith et al. 2002, Zabel 2002, Plumb et al. 2006). While associations between migration rates and flow variables have been well-established, several different approaches have been used to characterize the flow variables themselves: flow (Raymond 1968, Raymond 1969, Simms and Ossiander 1981, Smith et al. 2002), flow^{-1} (Berggren and Filardo 1993), water travel time (FPC 2006), and flow variability (Berggren and Filardo 1993, Smith et al. 2002). Although flow variables appear to be a primary driver of migration rates, associations with other factors such as temperature, seasonality (e.g., Julian date) and spill have also been identified (Simms and Ossiander 1981, Berggren and Filardo 1993, Smith et al. 2002, Williams et al. 2005, FPC 2006).

Research on the factors influencing survival rates has been somewhat less conclusive. Raymond (1979) found that survival of Snake River smolts was much lower in years of low river flows and spills than in years of higher river flows and spills. Simms and Ossiander (1981) concluded that flow and spill were positively correlated with yearling Chinook and steelhead survival, and that the relationship between survival and spill had a faster rate of change than the relationship between survival and flow. However, they noted that when Snake River flows exceeded 100,000 ft^3/s , the survival of yearling Chinook salmon and steelhead remained somewhat constant. Using Snake River PIT-tag data collected between 1995 and 1999, Smith et al. (2002) concluded that correlations between river discharge and survival, and between fish travel time and survival, were neither strong nor consistent across years for yearling Chinook and steelhead. However, Smith et al. (2002) did develop a model that included flow, temperature, date, and year effects for characterizing steelhead survival. Williams et al. (2005) fit threshold models relating survival and flow for yearling Chinook and steelhead, with survival increasing with flow up to an estimated threshold flow level, and constant survival for flows beyond that level.

The long-term implementation of the CSS has allowed for the monitoring of migration and survival rates of juvenile salmonids both within-years and across-years. During the 1998-2006 implementation of the CSS, there has been a large degree of contrast in migration and survival rates, along with the variables that may influence those rates through the hydrosystem. Having greater contrast in the environmental and management factors, along with replication

within-years and across-years, should assist in the identification of the important factors that influence migration and survival rates. For yearling Chinook, tagging levels have been large enough to allow for comparisons between hatchery and wild rearing types, providing opportunity to investigate the importance of rearing type on their responses to environmental conditions during their juvenile migrations.

In 2003, the Independent Scientific Advisory Board (ISAB) conducted a review of flow augmentation (ISAB 2003-1). They noted that many questions remained in regard to the relationships between river flows and salmonid production. Some of these questions included “whether instantaneous mortality rates are increased in a given reach as a result of low flow (or other factors such as temperature, particle travel time, turbidity and calendar date), and whether decreased travel time through a reach results in decreased mortality rates measured downstream.” Similarly, they commented that “the debate over a flow survival relationship has failed to distinguish between (1) the possible role of flow in governing the speed of smolt outmigration, and (2) the possible role of flow in affecting the mortality rate experienced by migrating smolts.” While it can be argued whether past and ongoing research has adequately answered the first of these two topics (see references above), research on the effects of flow on mortality rates has not been actively pursued. A notable exception is the analysis conducted by Williams et al. (2005), where daily mortality rates (estimates of mortality per day) were plotted against water travel time and relationships were fit using Lowess smoothes.

In the ISAB’s review of the CSS 2005 Annual Report (ISAB 2006-3), several comments reflected an interest in finer-scale analyses of the PIT-tag data utilized within the CSS. In particular:

- “Although the project is making good progress at addressing such issues as the value of transportation and the relative survival from different passage routes, many relationships between survival and specific operational alternatives or environmental features during migration cannot be resolved when data are aggregated simply by year of migration. For this information to be most useful for making management decisions, aggregations of data within years and across years for different operational options and environmental constraints should be pursued. We encourage the project to move in that direction.”
- “The data could be aggregated to more closely meet the needs of hydrosystem managers. Whether by design or implementation, the aggregation of data simply by year of outmigration is insufficient to resolve many of the important issues related to environmental influences and hydrosystem operations. The numbers of fish tagged may never be sufficient for resolving in-season patterns of survival. However, as data are accumulated over more years, it may be feasible to partition analyses into environmental or operational categories across years to obtain more functional correlations.”

The CSS Oversight Committee wholly agrees that finer-scale analyses of relationships between survival and specific operational alternatives or environmental features during migration would be a logical and useful evolution for the CSS project. Towards that goal, and with the questions and comments outlined in the ISAB (2003-1) report in mind, the CSS Oversight Committee has developed this chapter.

In this chapter, we summarize and synthesize the results that have been obtained to date through the CSS on the in-river responses of juvenile yearling Chinook salmon and steelhead to conditions experienced within the hydrosystem. First, we develop and summarize within-year travel time and survival rate estimates for juvenile yearling Chinook and steelhead across years of the CSS. Second, we develop and summarize estimates of within-year instantaneous (daily) mortality rates across years. Third, we develop models for characterizing the associations between environmental factors and fish travel time, instantaneous mortality rates, and survival. In our examination of survival, we compare three analytical approaches for characterizing temporal variation in survival rates: 1) using multiple linear regression techniques to examine the associations between survival rates and mainstem environmental variables; 2) integrating multiple linear regressions of fish travel time and average instantaneous mortality rates (mortality per day); and 3) integrating multiple linear regressions of fish travel time and instantaneous mortality rates that are both allowed to vary in response to mainstem environmental variables. In addition to these primary objectives, we also examined the three ways that have been used to characterize river flows (i.e., flow, flow⁻¹, and water travel time) in terms of their associations with fish travel time, survival, and instantaneous mortality rates. Finally, we were interested in exploring whether the abundance of salmonids in the hydrosystem may be influencing their mortality rates (i.e., density-dependent effects). Therefore we also conducted a preliminary analysis on whether density-dependent factors, in addition to environmental factors, may be influencing instantaneous mortality rates.

Methods

PIT-tagged fish

Yearling Chinook and steelhead used in this analysis consisted of fish PIT-tagged both at hatcheries and fish traps upstream of Lower Granite Dam (LGR) and those tagged and released at LGR. In this analysis, we define the hydrosystem as the overall reach between Lower Granite Dam and Bonneville (BON) Dam. There are six dams between LGR and BON: Little Goose (LGO), Lower Monumental (LMN), Ice Harbor (IHR), McNary (MCN), John Day (JDA), and The Dalles (TDA). We divided the hydrosystem into two reaches for summarizing fish travel time and survival: LGR-MCN and MCN-BON. Due to sufficient numbers of PIT-tagged hatchery and wild yearling Chinook available, analyses on the LGR-MCN reach were conducted separately for hatchery and wild yearling Chinook. Due to the limited number of PIT-tagged steelhead available, hatchery and wild steelhead were combined for analyses in the LGR-MCN reach. Analyses on the MCN-BON reach included hatchery and wild yearling Chinook and steelhead from the Snake River, hatchery-marked fish from the Mid-Columbia River, and fish marked and released at MCN.

Fish travel time

We define fish travel time (FTT) as the number of days spent migrating each of the two reaches, LGR-MCN and MCN-BON. We utilized a cohort-based approach for characterizing fish travel times for weekly groups of fish. Individual fish detected at LGR with PIT-tags were assigned to a weekly cohort group (*i*) according to the week of their detection. Cohorts were identified by the Julian day of the midpoint of the weekly cohort. For example, the April 1-7 release cohort was identified by Julian day = 94 (April 4). We calculated the number of days

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

For yearling Chinook, we calculated median FTT_i for eight weekly cohorts from April 1 through May 26 in the LGR-MCN reach. Separate estimates were developed for hatchery and wild rearing types of yearling Chinook. In the MCN-BON reach, hatchery and wild yearling Chinook were combined and we calculated median FTT_i for six weekly cohorts from April 26 through June 5. For steelhead, we calculated median FTT_i for six weekly cohorts from April 17 through May 28 in the LGR-MCN reach. Hatchery and wild rearing types of steelhead were combined for both reaches. In the MCN-BON reach, we calculated median FTT_i for six weekly cohorts of steelhead from April 27 through June 7.

Survival

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

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

correlation between \hat{S} and $\text{var}(\hat{S})$ (Burnham et al. 1987:211-212). For lognormally distributed random variables, the variance of $\log_e(x)$ is (Blumenfeld 2001):

$$\text{var}[\log_e(x)] = \log_e(1 + [cv(x)]^2). \quad [2.1]$$

Instantaneous mortality rates

In 2003, the ISAB offered the suggestion that “an interpretation of the patterns observed in the relation between reach survival and travel time or flow requires an understanding of the relation between reach survival, instantaneous mortality, migration speed, and flow” (ISAB 2003-1). Consistent with that suggestion, Ricker (1975) provides a numerical characterization of survival, also known as the exponential law of population decline (Quinn and Deriso 1999):

$$S = \frac{N_t}{N_0} = e^{-Zt}, \quad [2.2]$$

where S is a survival rate, N_t is the number of individuals alive at time t , N_0 is the number of individuals alive at time $t = 0$, and Z is the total instantaneous mortality rate, in units of t^{-1} . Eqn. 2.2 is the solution to the differential equation

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

and the instantaneous mortality rate Z is interpreted as the rate of exponential population decline. Eqn. 2.2 has been called the “first principle” or “first law” of population dynamics (Turchin 2003), and serves as a foundational basis for most fisheries population assessment models (Quinn and Deriso 1999).

The exponential law of population decline provides a useful framework for understanding the interrelationships between instantaneous mortality rates, time, and survival. Over a fixed period of time, an increase in Z will result in lower survival over that time period. Similarly, for a fixed Z , survival will decrease with increasing time. At time $t = 0$, survival is 1.0 and survival declines toward zero as t increases. If instantaneous mortality rates vary over time, Z represents the arithmetic mean mortality rate over the time period (Keyfitz 1985:18-19). This property of Z may be useful for capturing mortality rates for smolts in the Columbia Basin, which may experience different mortality rates over time. For example, if mortality rates experienced through a reservoir differ from mortality experienced through a dam, then the instantaneous mortality rate Z represents the arithmetic mean mortality rate over that period of migration through the reservoir and dam combination. Rearranging Eqn. 2.2, Z can be estimated as

$$\hat{Z} = \frac{-\log_e(\hat{S})}{t}, \quad [2.4]$$

which is the maximum-likelihood estimate of Z (Seber 1982:216).

In our application, we calculated instantaneous mortality rates (in units of d^{-1}) for each survival cohort using Eqn. 2.4. We used the CJS estimates of survival for each cohort (\hat{S}_i) in the numerator and used the median \hat{FTT}_i in the denominator of Eqn. 2.4. While individuals in each release cohort have variable individual FTT 's, we used the median \hat{FTT}_i 's in the denominator of Eqn. 2.4 to characterize the cohort-level central tendency in the amount of time required to travel

a reach. Combining the cohort-level survival rate estimates (\hat{S}_i) with the cohort-level median $F\hat{T}T_i$ estimates, we estimated the cohort-level instantaneous mortality rates (\hat{Z}_i) using Eqn. 2.4.

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

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

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

Environmental variables

The environmental variables associated with each cohort were generated based on fish travel time and conditions at each dam along the reaches. Travel time for each group between dams was estimated, and we calculated the average flow, flow^{-1} , water travel time, spill percentage, temperature (based on tailwater total dissolved gas monitoring data, downloaded from the COE website <http://www.nwd-wc.usace.army.mil/perl/dataquery.pl>) and turbidity values (also downloaded from the COE website) as indicators of conditions each group experienced while passing through the reach. Water travel time was calculated by dividing the total volume of reservoirs by the flow rate, and with adjustments in McNary pool to account for Columbia River versus Snake River flows. Conditions at downstream dams were averaged over a seven-day window around the median passage date at each dam and the travel time to the next dam was used to adjust the start date of the calculations. For example, steelhead travel time from LGR to LGO for the earliest release cohort in 2005 (detected at LGR from 4/17 to 4/23) was estimated to be 5.0 days based on 378 detections. Average environmental variables over the time period of April 22 to April 28 at LGO were then calculated. At each downstream dam, environmental variables were calculated in a similar manner. Since no PIT-tag detection data were available until 2005 at IHR, travel time to IHR was estimated as 43% of the total travel time from LMN to MCN (corresponding to the distance to IHR relative to the distance to MCN). The overall reach environmental variables were the average of these dam-specific calculated values for flow, flow^{-1} , spill percentage, temperature and turbidity, whereas for water travel time the sub-reach values were summed for a reach water travel time. In addition to these environmental predictor variables, we also used Julian date as a predictor variable to help capture seasonal effects not represented by these environmental variables. We use Julian date of release to characterize effects such as degree of smoltification, photoperiod, predator abundance/activity, or fish length that may demonstrate a consistent pattern within- and across-years, but is not already captured by the other environmental variables. The use of Julian date of release as an attempt to capture seasonal effects is a common modeling strategy for these data (Berggren and Filardo 1993, Smith et al. 2002, Williams et al. 2005).

In addition to calculating physical environmental variables associated with each cohort, we also calculated several biological variables to characterize the seasonal relative abundance of various smolt categories. The Smolt Monitoring Program passage index at each of the dams provides information on the timing and relative abundance of smolts (FPC 2006). For the LGR-MCN reach, we calculated the total of the daily passage index estimates at LGR of combined

(hatchery and wild) yearling Chinook and steelhead for each release cohort. These cohort-specific relative abundance estimates were then standardized across the season to have a mean of zero and a standard deviation of one. The same methods were used to derive standardized relative abundance estimates for the yearling Chinook cohorts in the MCN-BON reach, using the passage index values at MCN. For steelhead in the MCN-BON reach, because only two, three-week cohorts were analyzed, we calculated the relative abundances as the proportion of the three-week passage index totals passing in each cohort. For example, if the sum of the passage index at MCN for the first three-week cohort was 400,000 steelhead smolts and the sum for the second three-week cohort was 600,000 smolts, the relative abundance proportions would have been 0.4 and 0.6.

Variable selection and model building

We used linear regression techniques to evaluate the associations between the environmental variables and median FTT , survival (S), and instantaneous mortality (Z). Because preliminary bivariate plots indicated that median \hat{FTT}_i 's and \hat{S}_i 's may be exponential functions of the environmental variables, we modeled median $\log_e(\hat{FTT}_i)$ and $\log_e(\hat{S}_i)$ as the dependent variables. The \log_e transformations were also implemented to help reduce heteroscedasticity and to better approximate normality in the regressions. These regressions were of the form:

$$\log_e(S_i) = \beta_0 + \beta_1 \cdot X_{1,i} + \beta_2 \cdot X_{2,i} + \dots + \varepsilon_i, \text{ and} \quad [2.6]$$

$$\text{median}FTT_i = \beta_0 + \beta_1 \cdot X_{1,i} + \beta_2 \cdot X_{2,i} + \dots + \varepsilon_i, \quad [2.7]$$

where $\beta_0, \beta_1, \dots, \beta_n$ are estimated parameters used to describe the relationship between environmental variables X_1, X_2, \dots, X_n and $\log_e(S_i)$ or median FTT , and $\varepsilon_i \sim N(0, \sigma^2)$.

It was unclear whether \hat{Z}_i should be log-transformed, therefore we evaluated modeling both \hat{Z}_i and $\log_e(\hat{Z}_i)$ as the dependent variables. Our determination of whether to model \hat{Z}_i or $\log_e(\hat{Z}_i)$ as the dependent variable was based on the method that maximized the adjusted R^2 values for the predictions on the arithmetic scale. These regressions were of the form:

$$\log_e(Z) = \beta_0 + \beta_1 \cdot X_{1,i} + \beta_2 \cdot X_{2,i} + \dots + \varepsilon_i. \quad [2.8]$$

With Eqn. 2.8, we attempt to characterize how instantaneous mortality rates may reflect environmental and/or seasonal conditions experienced during migration through the reaches.

To account for potential differences in the precision of the dependent variable estimates, we evaluated both weighted and unweighted regressions. There were substantial differences among the variance estimates for the \hat{S}_i and \hat{Z}_i across cohorts and years, but the median \hat{FTT}_i 's were generally quite precise (CV's typically less than 2%). For the weighted regressions, we examined weighting by the inverse-variance, inverse-CV, and inverse-CV². As with the decision to model \hat{Z}_i or $\log_e(\hat{Z}_i)$ as the dependent variable, our selection of weighting scheme was based on the approach that maximized the adjusted R^2 values for the predictions on the arithmetic scale.

We adopted an information-theoretic paradigm for examining the degree of association between environmental variables and the dependent variables (Burnham and Anderson 2002). For each regression that was fit, we calculated the Akaike's Information Criterion for small sample sizes (AICc) and the Bayesian Information Criterion (BIC). The AICc and BIC scores were used to evaluate the relative degree of fit for the combinations of explanatory variables

examined. Combinations of explanatory variables were evaluated by their resulting AICc- and BIC-values, with lower values indicating better fits to the data. Both the AICc and BIC measure the likelihood of an approximating model, while accounting for the number of parameters estimated within the model. Our process for model building began by examining AICc and BIC scores for each variable, one at a time. Based on the results of this exercise, we then examined multiple-variable models using the top-ranked variables identified in the first round of fitting. Combinations of the top-ranked variables were incorporated until the AICc and BIC scores indicated that adding additional variables did not improve model fit. We calculated AICc differences (Burnham and Anderson 2002:71) between the models evaluated and the model that was selected as the best-fit model based on the AICc score. We also calculated the AICc weights (w_i) for the each of models evaluated, which represent the weight of evidence in favor of model i being the best model, amongst a set of R models (Burnham and Anderson:75). While not used as the primary means of selecting variables during the model building process, we calculated the coefficient of determination (R^2) and the adjusted coefficient of determination (R^2_{adjust}) to quantify the relative amount of the variation explained by the various candidate models.

Comparing survival modeling approaches

We evaluated three approaches for modeling survival rates. The first approach was to develop multiple linear regressions with $\log_e(\hat{S}_i)$ as the dependent variable using Equation 2.6 above. We refer to this approach as the “standard survival approach” because it has frequently been utilized by Columbia Basin researchers for evaluating the effects of various environmental and management factors on salmonid survival (Simms and Ossiander 1981, Smith et al. 2002, Williams et al. 2005). As described above, individual variables were fit and ranked according to their AICc scores, and combinations of the top-ranked variables were incorporated until the AICc and BIC scores indicated that adding additional variables did not improve model fit.

Our second approach was to utilize the exponential mortality model (Eqn. 2.2), assuming that the instantaneous mortality rate Z was constant, and that any changes in survival were due to changes in fish travel time. To implement this approach, we estimated the overall mean instantaneous mortality rate \bar{Z} across cohorts and years for each species and in each reach. Then using our best-fit models for predicting median FTT_i (Eqn. 2.7), survival rates were estimated as:

$$S^*_i = e^{-\bar{Z} \cdot FTT^*_i}, \quad [2.9]$$

where \bar{Z} is the mean instantaneous mortality rate for the species/reach combination being evaluated, FTT^*_i is the predicted median fish travel time for period i , and S^*_i is predicted survival rate for period i , calculated by exponentiating the negative product of \bar{Z} and FTT^*_i .

We refer to this approach as the “constant Z survival approach.” This approach effectively implements the null model of no flow (or other variable) effects on instantaneous mortality rates suggested by the ISAB (2003-1).

Our third approach also utilized the exponential mortality model (Eqn. 2.2), but allowed the instantaneous mortality rates Z_i to vary in response to environmental factors. Using our best-fit models for predicting Z^*_i (Eqn. 2.8), survival rates were estimated as:

$$S^*_i = e^{-Z^*_i \cdot FTT^*_i}, \quad [2.10]$$

where Z_i^* is the predicted instantaneous mortality rate, FTT_i^* is the predicted median FTT_i , and S_i^* is the predicted survival rate for period i , calculated by exponentiating the negative product of Z_i^* and FTT_i^* . We refer to this approach as the “variable Z survival approach.”

We used several performance measures to evaluate the accuracy of the three survival modeling approaches. Each modeling approach provided a prediction of S_i^* that could be compared with the observed \hat{S}_i . We calculated the AIC scores for each approach, accounting for the number of parameters estimated (Burnham and Anderson 2002:63). We also calculated the root mean squared error of the predictions and the coefficient of determination (r^2) for each species and reach.

Preliminary assessment of density-dependent effects

Following the model-building exercise to determine which environmental variables best characterized the variation in \hat{Z}_i , we then added the passage-index-derived biological variables to the regressions and tabulated the resulting AICc scores and adjusted R^2 values. Changes in AICc scores or the adjusted R^2 values were used to evaluate whether there was evidence for or against density-dependent changes in instantaneous mortality rates.

Results

Environmental conditions across years

The environmental conditions experienced by cohorts of juvenile yearling Chinook and steelhead have varied considerably over the period of 1998-2006 (Figures 2.1 and 2.2). Over this time period in the LGR-MCN reach, flows generally decreased, water travel times generally increased, and the average percent spilled generally decreased (Figure 2.1). Exceptions to these generalizations are years 2001 and 2006. In 2001, flows were low, water travel times were high, and no spill was provided at the dams. In 2006, flows were high and water travel times were low, but the average percent spill was at an intermediate level. The average percent spill across cohorts during 1998-2000 was 40%, and during 2002-2006 the average was 35%. Over the 1999-2006 time period in the MCN-BON reach, flows generally decreased, water travel times generally increased, and the average percent spilled has not changed appreciably. Similar to the LGR-MCN reach, exceptions to these generalizations are years 2001 and 2006. In 2001, flows were low and water travel times were high, and a small amount of spill was provided at the dams. In 2006, flows were high and water travel times were low, but average percent spill remained similar to past years.

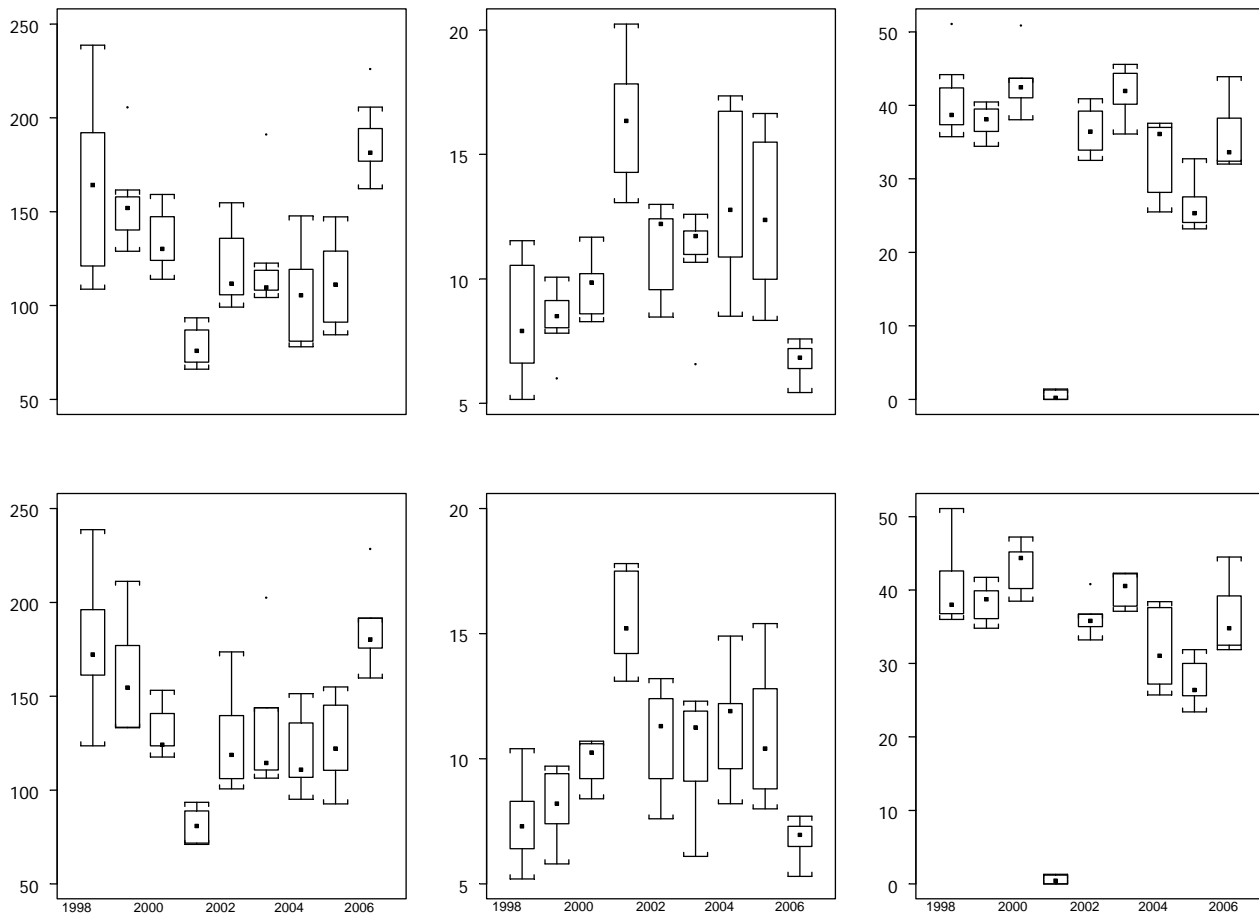


Figure 2.1. Boxplots of flow (left column, kcfs), water travel time (center column, days) and average percent spill (right column, %) experienced by cohorts of wild yearling Chinook (top row) and hatchery and wild steelhead (bottom row) in the LGR-MCN reach during 1998-2006. The box ends correspond to the first and third quartiles of the data, the filled square corresponds to the median, the whiskers correspond to the least and greatest observations within the first quartile minus, and the third quartile plus, 1.5 times the inter-quartile range, and the asterisks correspond to observations beyond the whisker limits.

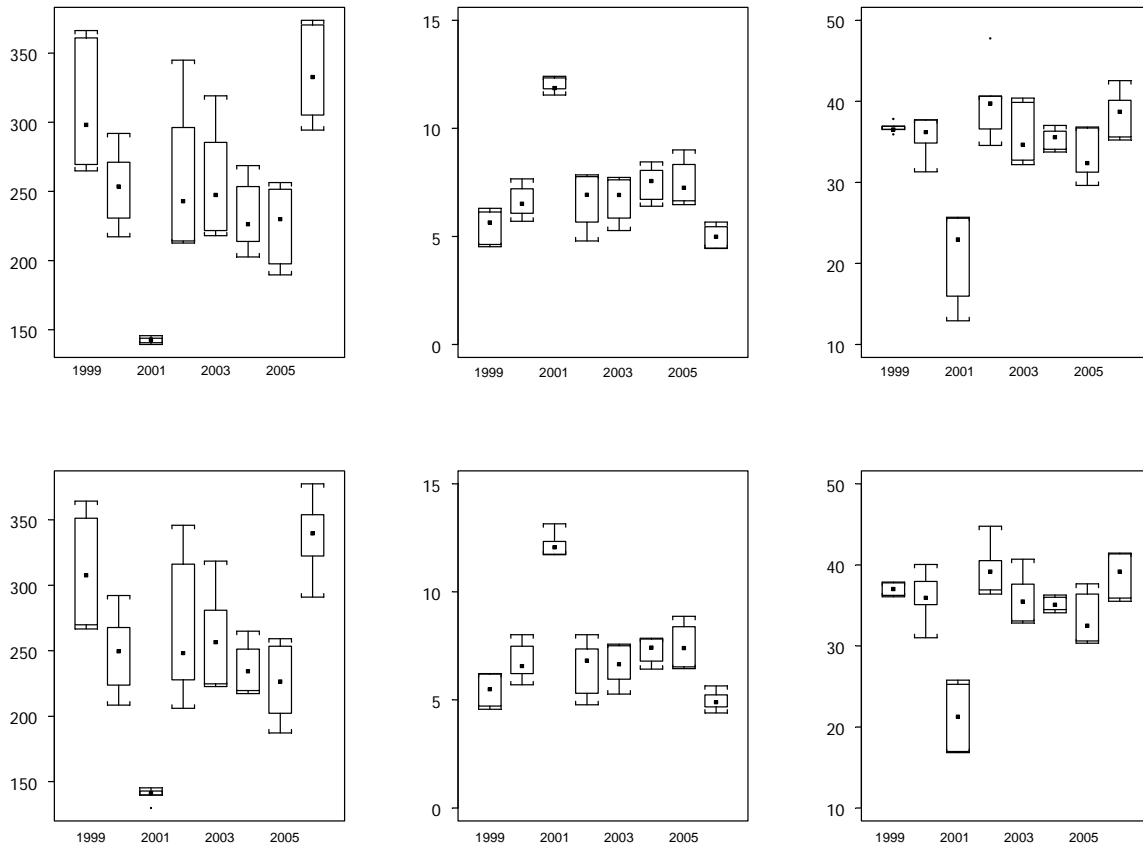


Figure 2.2. Boxplots of flow (left column, kcms), water travel time (center column, days) and average percent spill (right column, %) experienced by cohorts of hatchery and wild yearling Chinook (top row) and steelhead (bottom row) in the MCN-BON reach during 1999-2006. See Figure 2.1 for a description of boxplots.

Fish travel time, survival, and instantaneous mortality rates over time
LGR-MCN reach

The median $F\hat{T}T_i$, \hat{S}_i , and \hat{Z}_i of cohorts of juvenile yearling Chinook and steelhead varied considerably over the period of 1998-2006 in the LGR-MCN reach, both within- and across-years (Figures 2.3-2.5). While there were some special cases, median $F\hat{T}T_i$ generally decreased over the season, \hat{S}_i either increased or decreased over the season, and \hat{Z}_i increased over the season. Within-year estimates of \hat{S}_i varied by up to 39 percentage points for both wild Chinook and steelhead, and by up to 32 percentage points for hatchery Chinook. Across all years and cohorts, estimates of \hat{S}_i varied by up to 64 percentage points for Chinook and 76 percentage points for steelhead. The large within- and across-year variation in \hat{S}_i demonstrates a high degree of contrast in \hat{S}_i over this 1998-2006 timeframe. Across years, median $F\hat{T}T_i$ generally did not change, \hat{S}_i generally decreased, and \hat{Z}_i generally increased (Figure 2.6). Figures 2.5 and 2.6 suggest that within-year variation in \hat{Z}_i may be increasing over time for hatchery and wild steelhead.

Sufficient numbers of PIT-tags were available to compare median $F\hat{T}T_i$, \hat{S}_i , and \hat{Z}_i expressed by wild versus hatchery yearling Chinook (Figure 2.7). When aligned by release cohort, wild and hatchery yearling Chinook expressed similar median $F\hat{T}T_i$, \hat{S}_i , and \hat{Z}_i . There were cases where the rates differed substantially between rearing-types (e.g., \hat{S}_i and \hat{Z}_i for the last cohort in 1998), but these differences were typically associated with imprecise estimates for one of the rearing types.

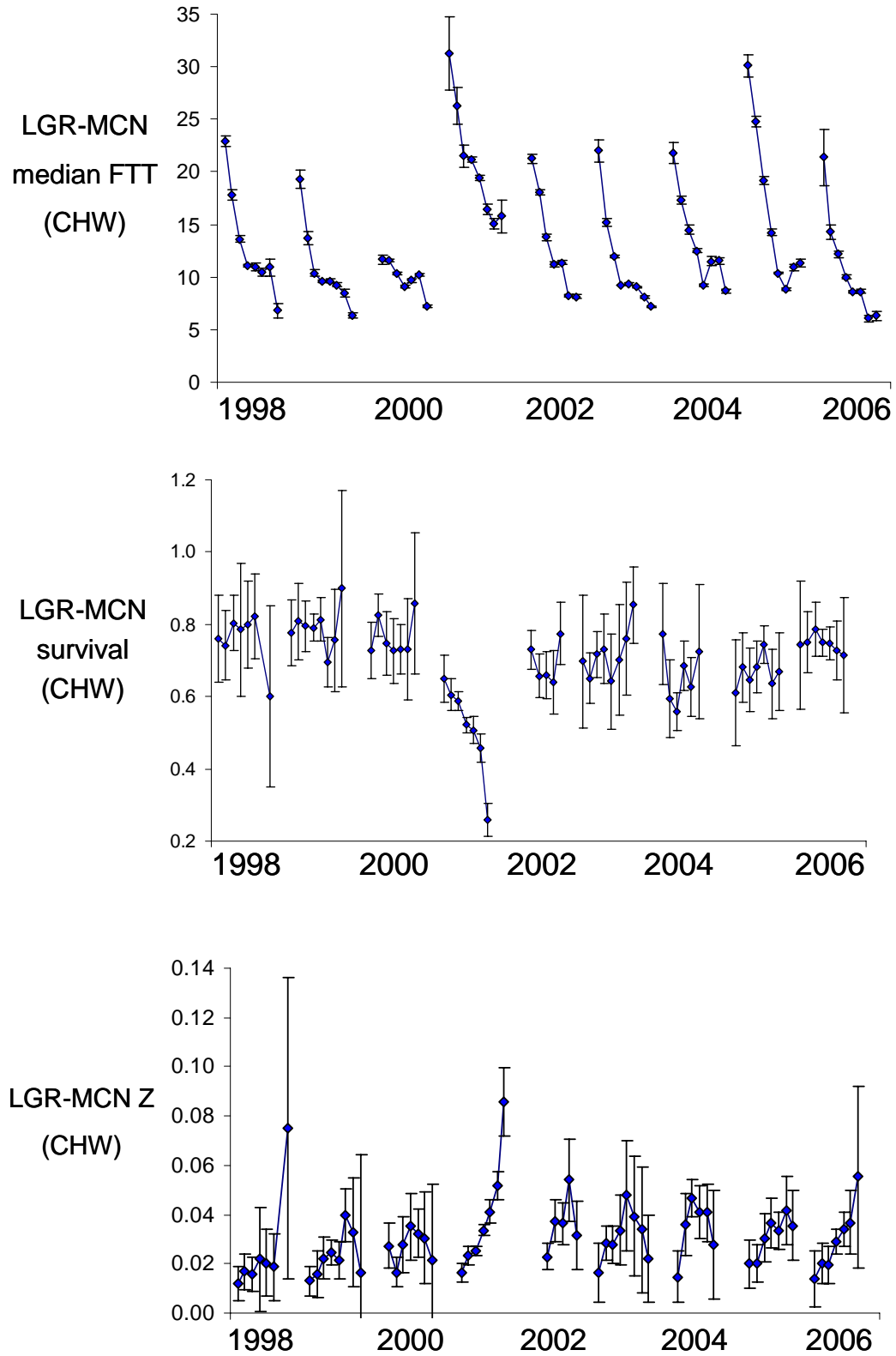


Figure 2.3. Estimates of median *FTT*, survival rates and instantaneous mortality rates for wild yearling Chinook in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.

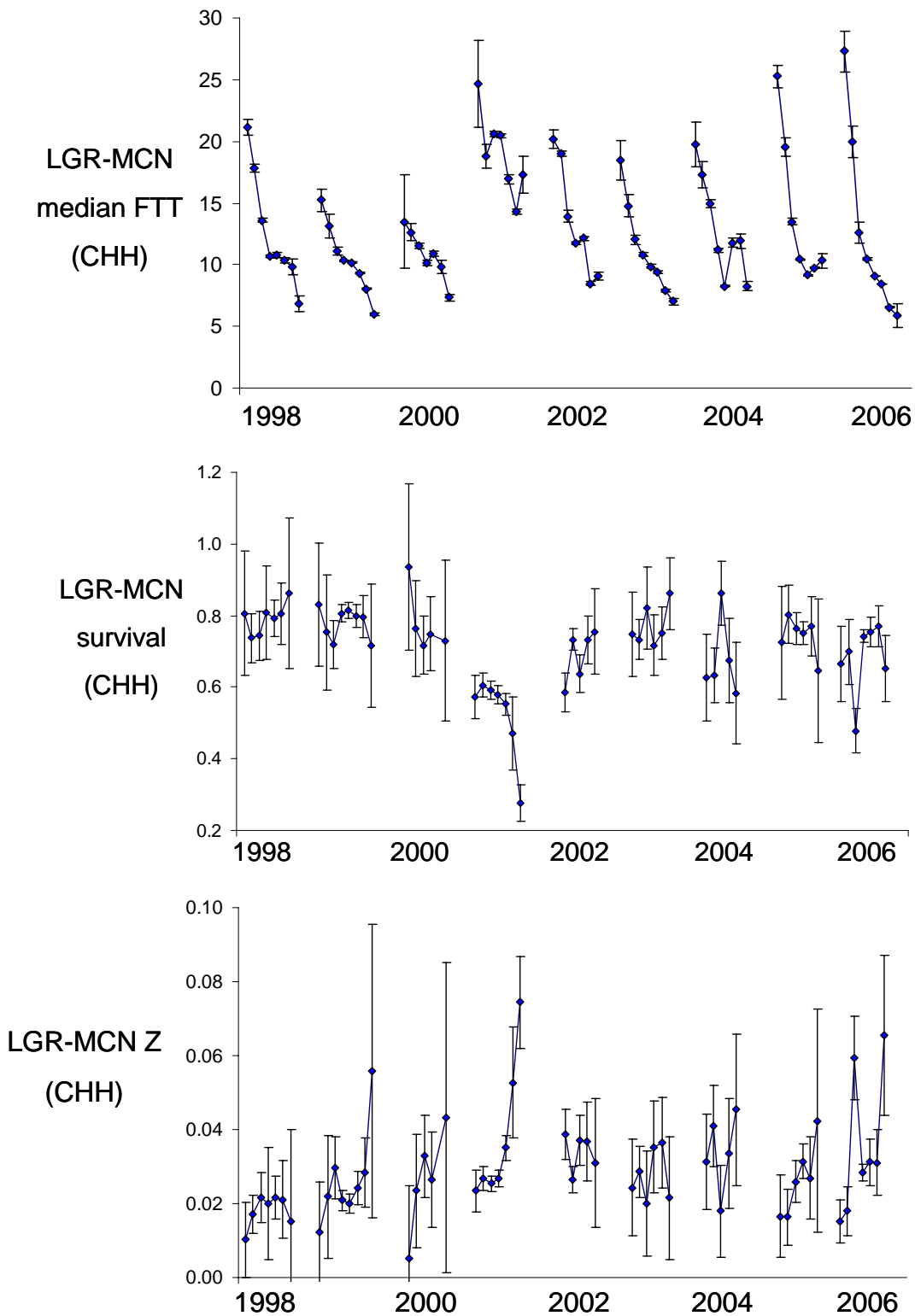


Figure 2.4. Estimates of median *FTT*, survival rates and instantaneous mortality rates for hatchery yearling Chinook in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.

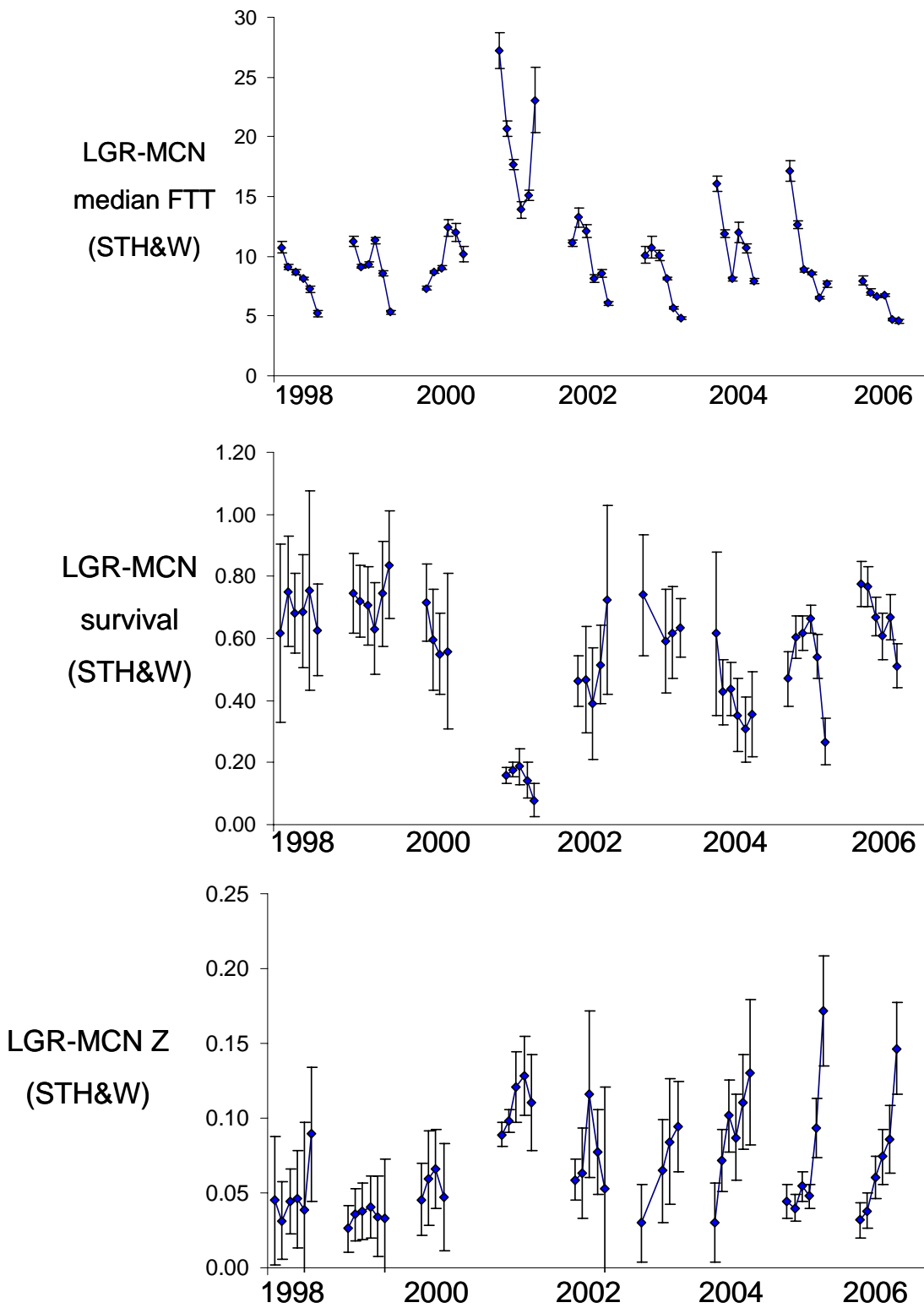


Figure 2.5. Estimates of median *FTT*, survival rates and instantaneous mortality rates for combined hatchery and wild steelhead in the LGR-MCN reach, 1998-2006. Estimates are plotted with their corresponding 95% confidence intervals.

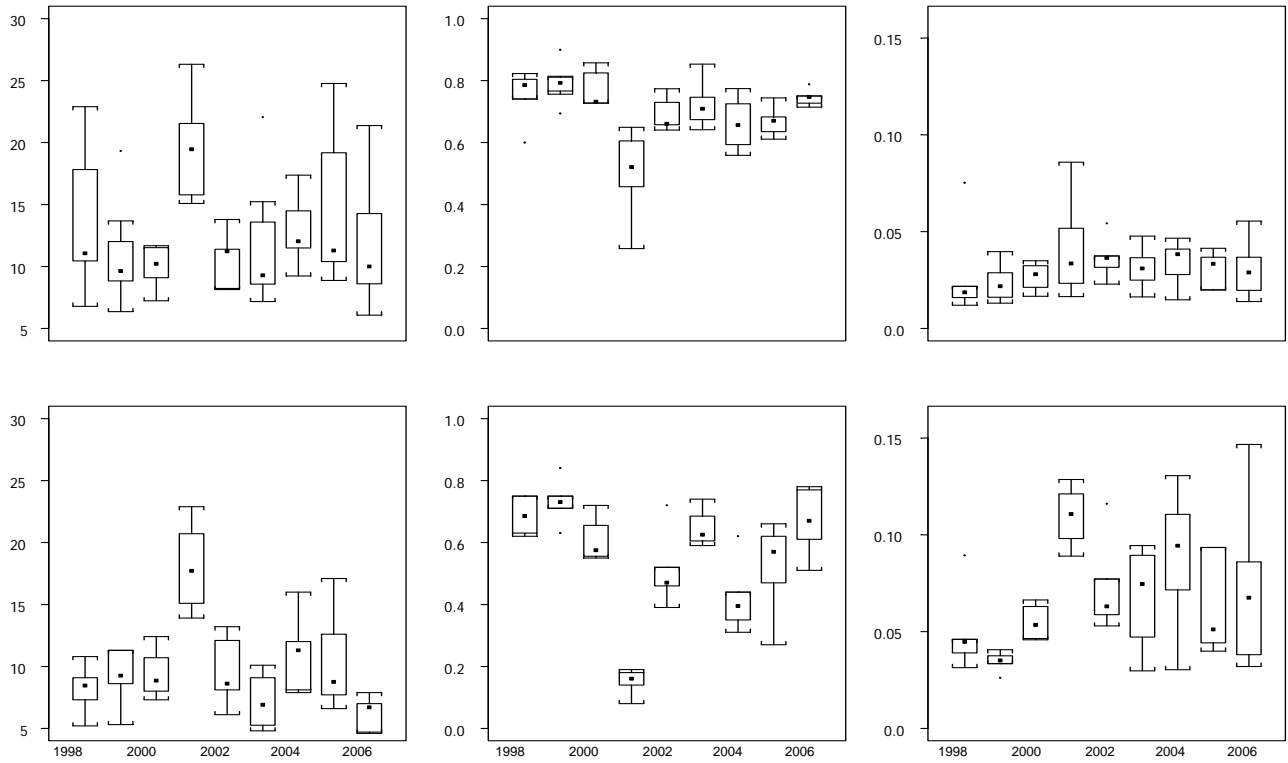


Figure 2.6. Boxplots of LGR-MCN estimates of median fish travel time (left column, days), survival (middle column) and instantaneous mortality (Z) (right column, d^{-1}) for cohorts of wild yearling Chinook (upper row), hatchery and wild steelhead (lower row) for migration years 1998-2006. See Figure 2.1 for a description of boxplots.

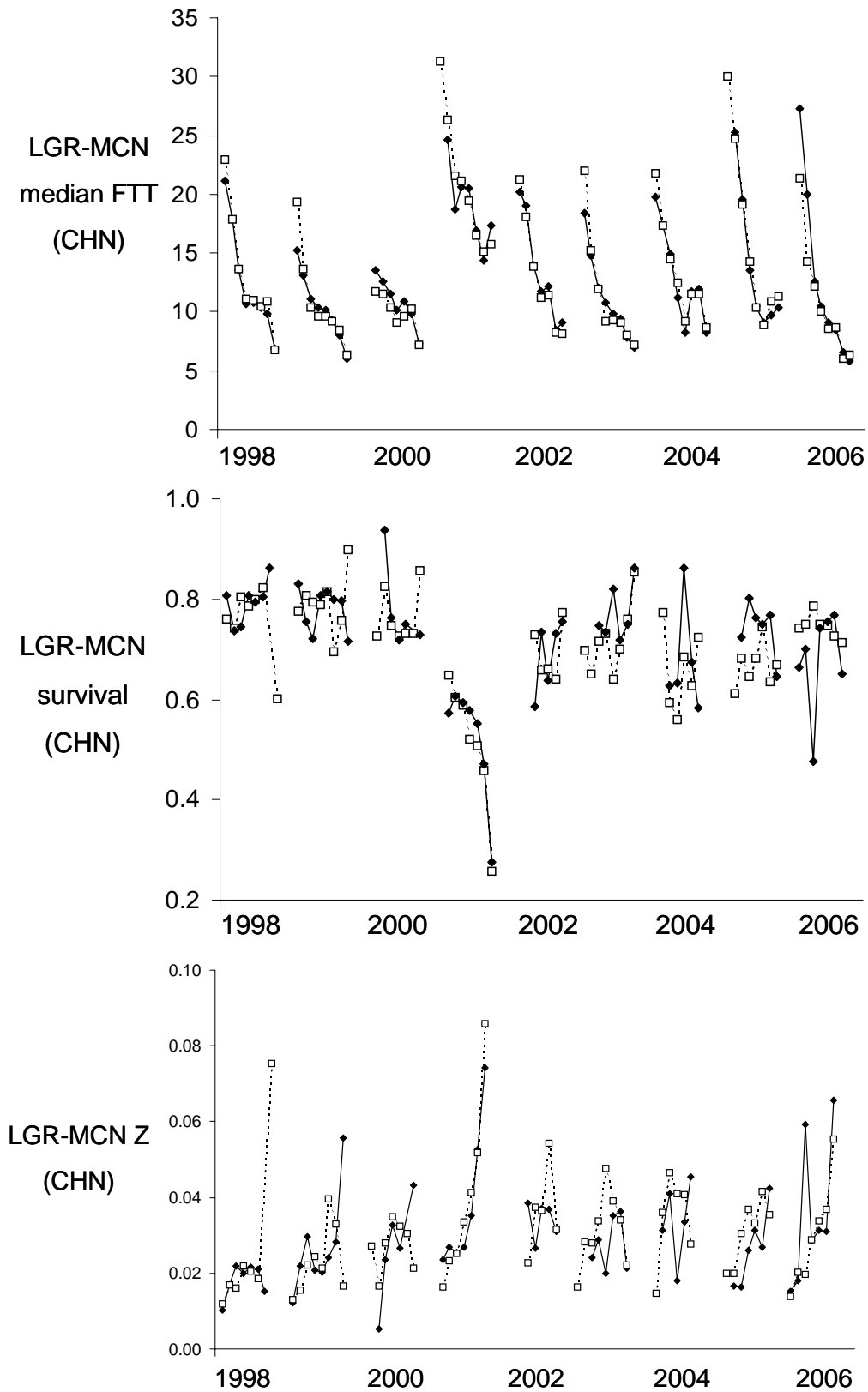


Figure 2.7. Estimates of median *FTT*, survival rates and instantaneous mortality rates for wild (open squares) and hatchery (closed diamonds) yearling Chinook in the LGR-MCN reach, 1998-2006.

MCN-BON reach

In the MCN-BON reach, cohorts of yearling Chinook and steelhead demonstrated within-year median $F\hat{T}T_i$, \hat{S}_i , and \hat{Z}_i patterns similar to those observed in the LGR-MCN reach, varying considerably both within- and across-years (Figure 2.8-2.10). For both species, median $F\hat{T}T_i$ generally decreased over the migration season, but steelhead in 1999 and 2000 maintained low median $F\hat{T}T_i$ throughout the season (Figure 2.8). Yearling Chinook in 2001 demonstrated the largest within-year variation in median $F\hat{T}T_i$, ranging from 20 days early in the season to 6 days late in the season (Figure 2.8). Due to imprecision in the estimates of \hat{S}_i , general patterns in the estimates of \hat{S}_i and \hat{Z}_i in the MCN-BON reach were difficult to discern (Figures 2.9-2.10). For steelhead, \hat{S}_i generally decreased over the season and \hat{Z}_i generally increased over the season. However, for yearling Chinook no general patterns were evident in either \hat{S}_i or \hat{Z}_i .

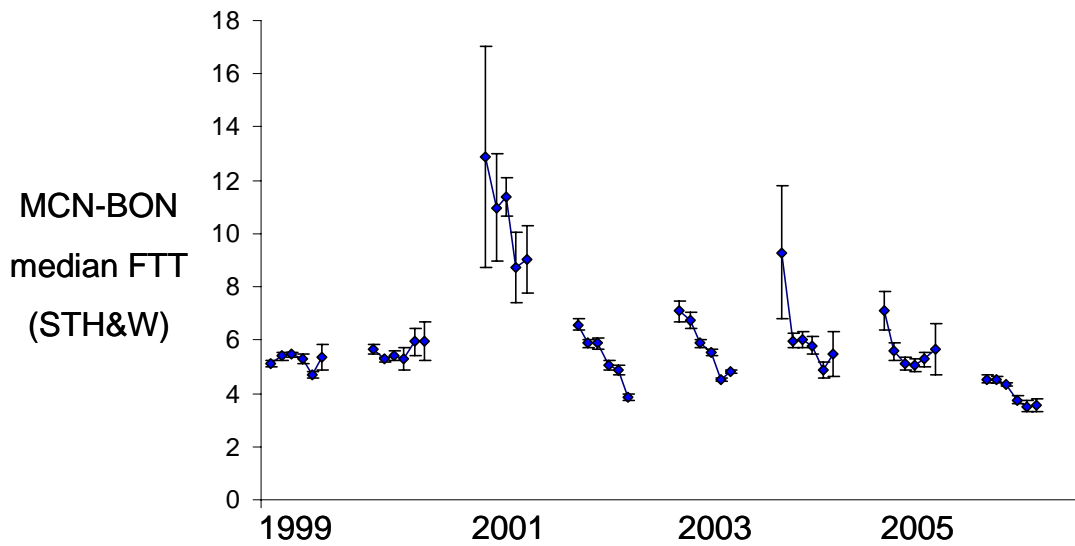
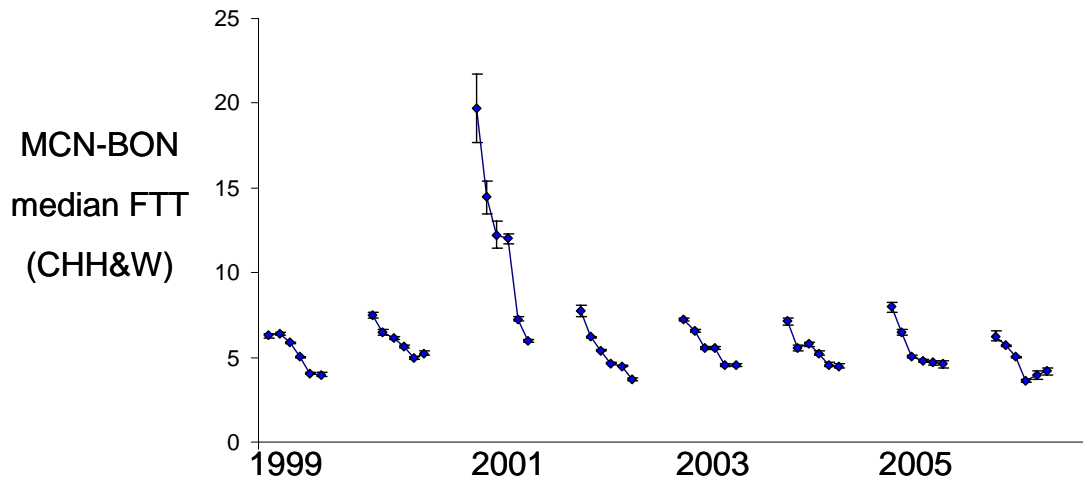


Figure 2.8. Estimates of MCN-BON median *FTT* (d) with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006.

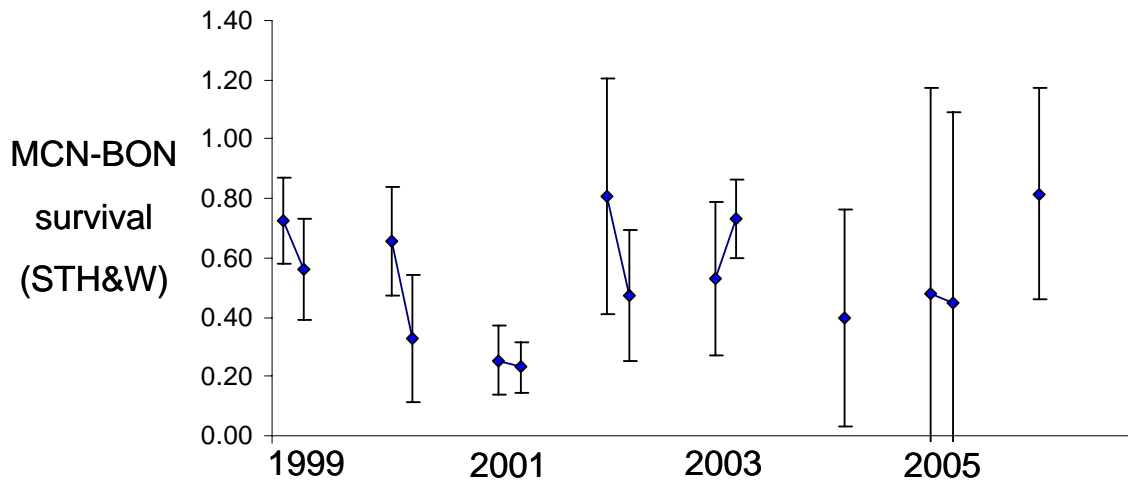
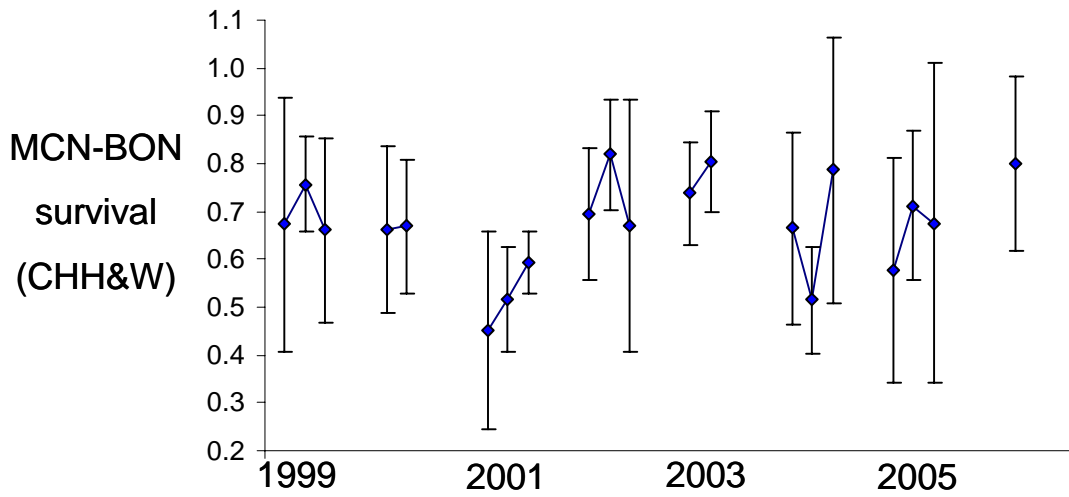


Figure 2.9. Estimates of MCN-BON survival with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

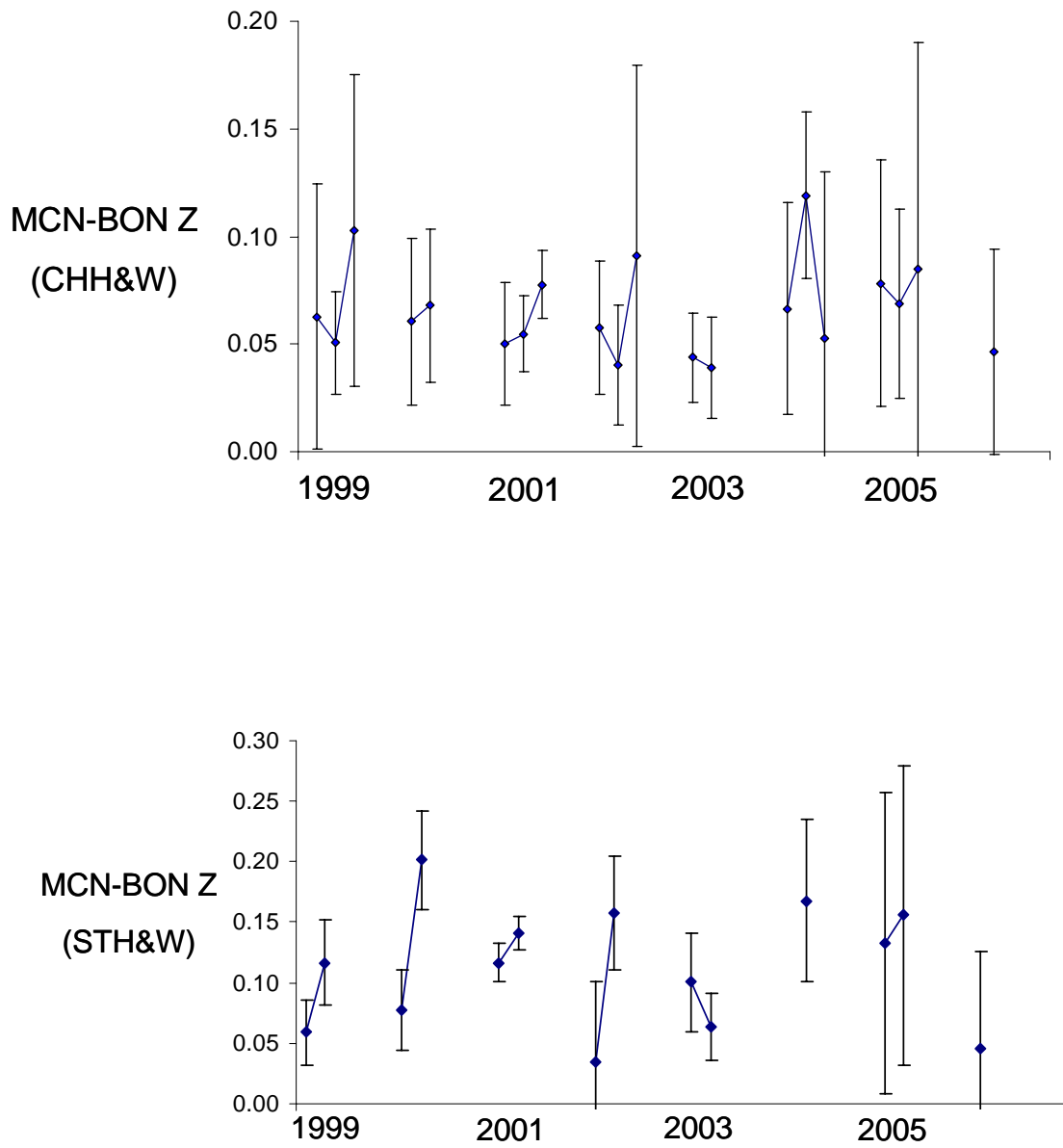


Figure 2.10. Estimates of MCN-BON Z with 95% confidence intervals for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across cohorts, 1999-2006.

Estimates of \bar{Z} , median Z, and daily percent mortality

Table 2.1 provides the mean and median of the \hat{Z}_i across cohorts and years, for wild yearling Chinook, hatchery yearling Chinook, and combined hatchery and wild steelhead in the LGR-MCN reach, and combined hatchery and wild yearling Chinook and steelhead in the MCN-BON reach. From these instantaneous mortality rate estimates, daily percent mortality estimates can be calculated as

$$\text{Daily percent mortality} = (1 - e^{-\bar{Z}}) \cdot 100\%. \quad [2.9]$$

Daily percent mortality estimates represent the percentage of the population that is expected to perish over one day. Table 2.2 provides estimates of the daily percent mortality based on the mean and median of the \hat{Z}_i reported in Table 2.1.

Two patterns emerge from these summaries of instantaneous mortality rates. First, for both species, instantaneous mortality rates and daily percent mortality rates in the MCN-BON reach are roughly double those in the LGR-MCN reach (Tables 2.1, 2.2). This means that on average, one day spent in the lower reach will result in twice the level of mortality that would occur with one day spent in the upper reach. Second, within both reaches, instantaneous mortality rates and daily percent mortality rates of steelhead are roughly double those of yearling Chinook (Tables 2.1, 2.2). This means that for each day spent in the upper segment, an average of 6.7% of the steelhead versus 3.0% of the wild yearling Chinook will perish. For each day spent in the lower segment, an average of 10.6% of the steelhead versus 6.4% of the yearling Chinook will perish.

Table 2.1. Mean and median of the \hat{Z}_i across cohorts and years for wild yearling Chinook, hatchery yearling Chinook and combined hatchery and wild steelhead in the LGR-MCN reach, and combined hatchery and wild yearling Chinook and steelhead in the MCN-BON reach.

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

Table 2.2. Daily percent mortality rates based on the mean and median of the \hat{Z}_i reported in Table 2.1.

	LGR-MCN			MCN-BON	
	CHW	CHH	STH&W	CHH&W	STH&W
Daily percent mortality (mean Z)	3.0%	2.9%	6.7%	6.4%	10.6%
Daily percent mortality (median Z)	2.8%	2.6%	5.8%	6.0%	11.0%

Modeling median FTT
LGR-MCN reach

Models that included WTT, average percent spill, and Julian day as the independent variables explained 79-90% of the variation in the median \hat{FTT}_i (Figure 2.11, Tables 2.3, 2.12, 2.15-17). For wild Chinook, hatchery Chinook, and hatchery and wild steelhead, median \hat{FTT}_i was predicted to decrease with Julian day and the average percent spilled, and increase with WTT (Table 2.12). The proportion of variation in median \hat{FTT}_i explained was highest for hatchery and wild steelhead ($R^2 = 0.90$), followed by wild Chinook ($R^2 = 0.89$) and hatchery Chinook ($R^2 = 0.79$) (Table 2.1). Of the three ways of characterizing flow (i.e., WTT, flow^{-1} , and flow), WTT best explained variation in median \hat{FTT}_i , followed closely by flow^{-1} and then by flow (Tables 2.15-17).

MCN-BON reach

Similar to the results for the LGR-MCN reach, models that included WTT, average percent spill, and Julian day explained 91-95% of the variation in median \hat{FTT}_i (Figure 2.12, Tables 2.3, 2.12, 2.18-19). For yearling Chinook, median \hat{FTT}_i was predicted to decrease with Julian day and the average percent spilled, and increase with WTT (Table 2.12). For steelhead, median \hat{FTT}_i was predicted to decrease with Julian day and increase with WTT, with an interaction between Julian day and WTT (Table 2.12). Using the same model, but also including average percent spilled as an independent variable explained nearly the same amount of variation, but had an AICc score one point higher (Table 2.19). The proportion of variation in median \hat{FTT}_i explained was higher for Chinook ($R^2 = 0.95$) than for steelhead ($R^2 = 0.91$). Also similar to the LGR-MCN results, WTT explained more of the variation in median \hat{FTT}_i than did flow^{-1} or flow (Tables 2.18-19).

Table 2.3. Proportion of variation explained (R^2 values) for the models characterizing yearling Chinook and steelhead survival, instantaneous mortality (Z), and median \hat{FTT} in the LGR-MCN and MCN-BON reaches. The survival results reported here utilized the variable Z approach.

Reach	Species & rearing type	Survival	Z	Median \hat{FTT}
LGR-MCN	CHW	0.49	0.48	0.89
LGR-MCN	CHH	0.49	0.41	0.79
LGR-MCN	STH&W	0.79	0.54	0.90
MCN-BON	CHH&W	0.48	0.15	0.95
MCN-BON	STH&W	0.75	0.51	0.91

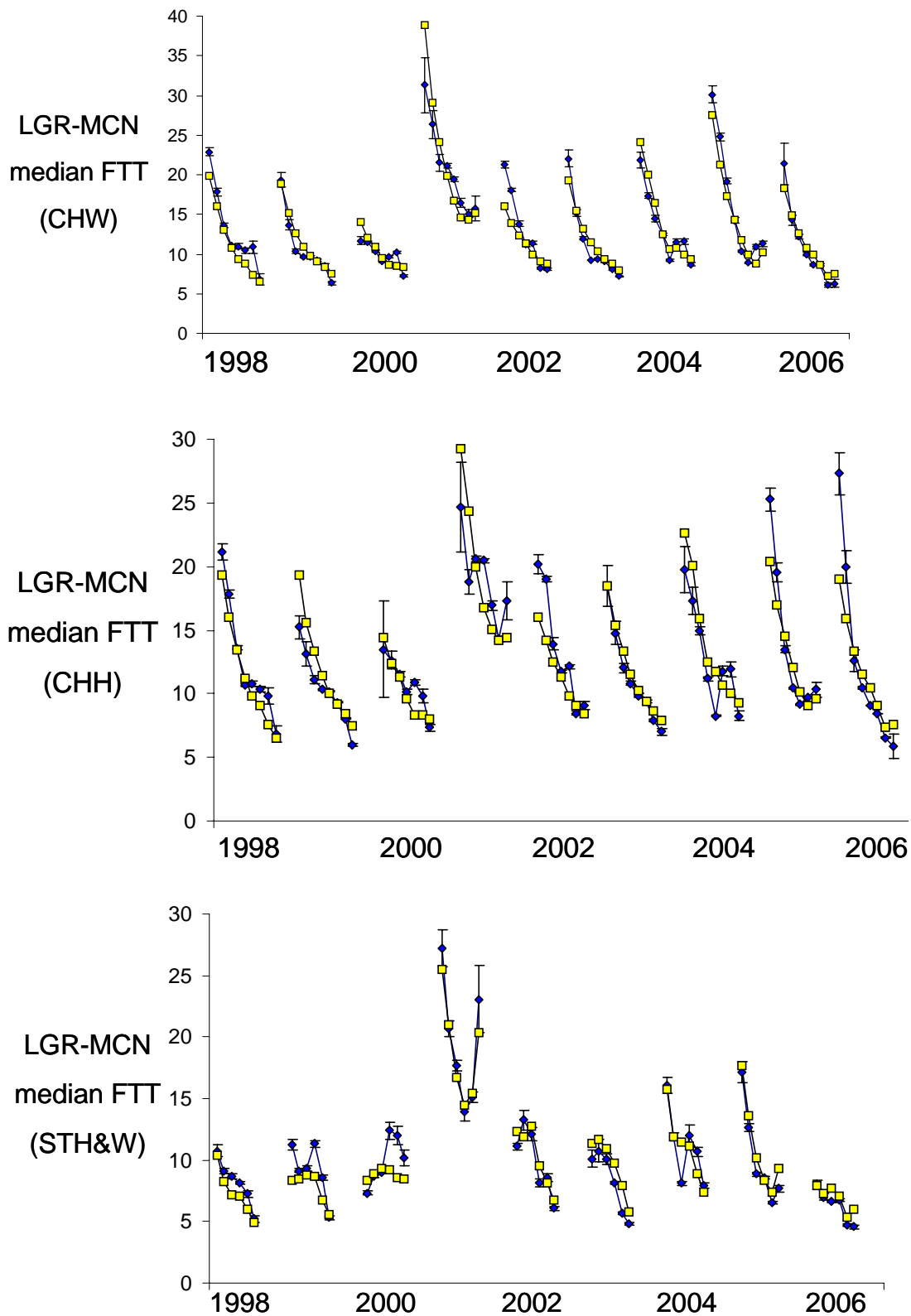


Figure 2.11. Observed LGR-MCN median *FTT* (d) (filled diamonds, with 95% confidence intervals) and model predictions for median *FTT* (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006.

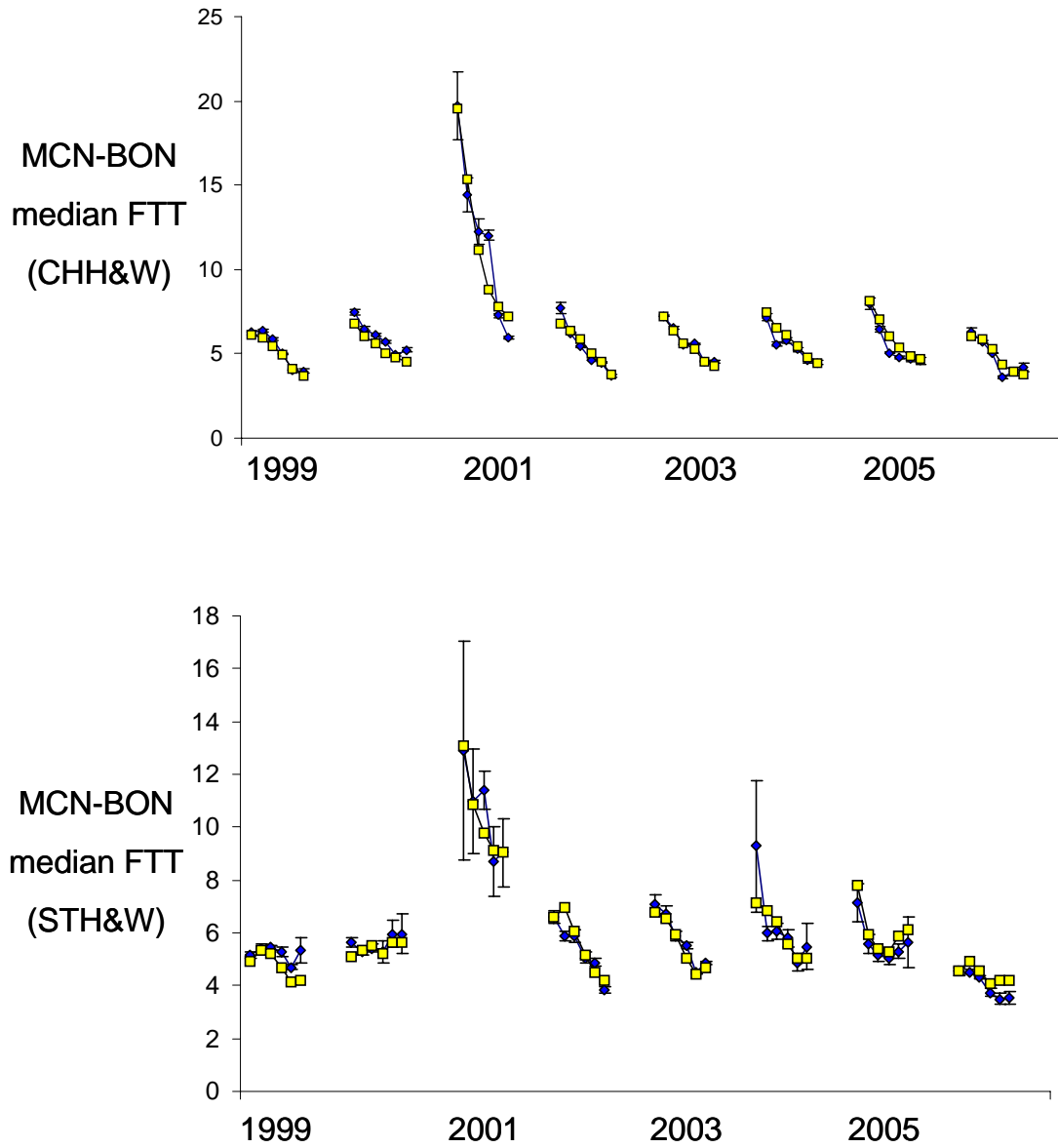


Figure 2.12. Observed MCN-BON median *FTT* (d) (closed diamonds) with 95% confidence intervals and predicted median *FTT* (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel), across weekly cohorts, 1999-2006.

Modeling instantaneous mortality rates

LGR-MCN reach

For wild Chinook, a model that included Julian day, WTT, and an interaction between Julian day and WTT explained 48% of the variation in the \hat{Z}_i (Figure 2.13, Tables 2.3, 2.13, 2.20-22). For hatchery Chinook eleven candidate models had AICc scores within 2.3 points of each other, which implies that the degree of fit was equivocal between these models (Table 2.21). However, the model that included Julian day, WTT and an interaction between Julian day and WTT explained the highest amount of variation in \hat{Z}_i (41%, Table 2.21). Because this model explained the highest amount of variation in \hat{Z}_i , and the AICc scores were equivocal for the eleven models, we selected this model as the best-fit model for hatchery Chinook in the LGR-MCN reach. For hatchery and wild steelhead, a model that included Julian day, flow⁻¹, and average percent spill explained 54% of the variation in the \hat{Z}_i (Figure 2.13, Tables 2.3, 2.13, 2.22).

MCN-BON reach

For hatchery and wild Chinook, a model that included Julian day explained 15% of the variation in the \hat{Z}_i (Figure 2.14, Tables 2.3, 2.13, 2.23). However, a model that only contained temperature produced nearly identical results. For hatchery and wild steelhead, a model that included temperature explained 51% of the variation in the \hat{Z}_i (Figure 2.14, Tables 2.3, 2.13, 2.24).

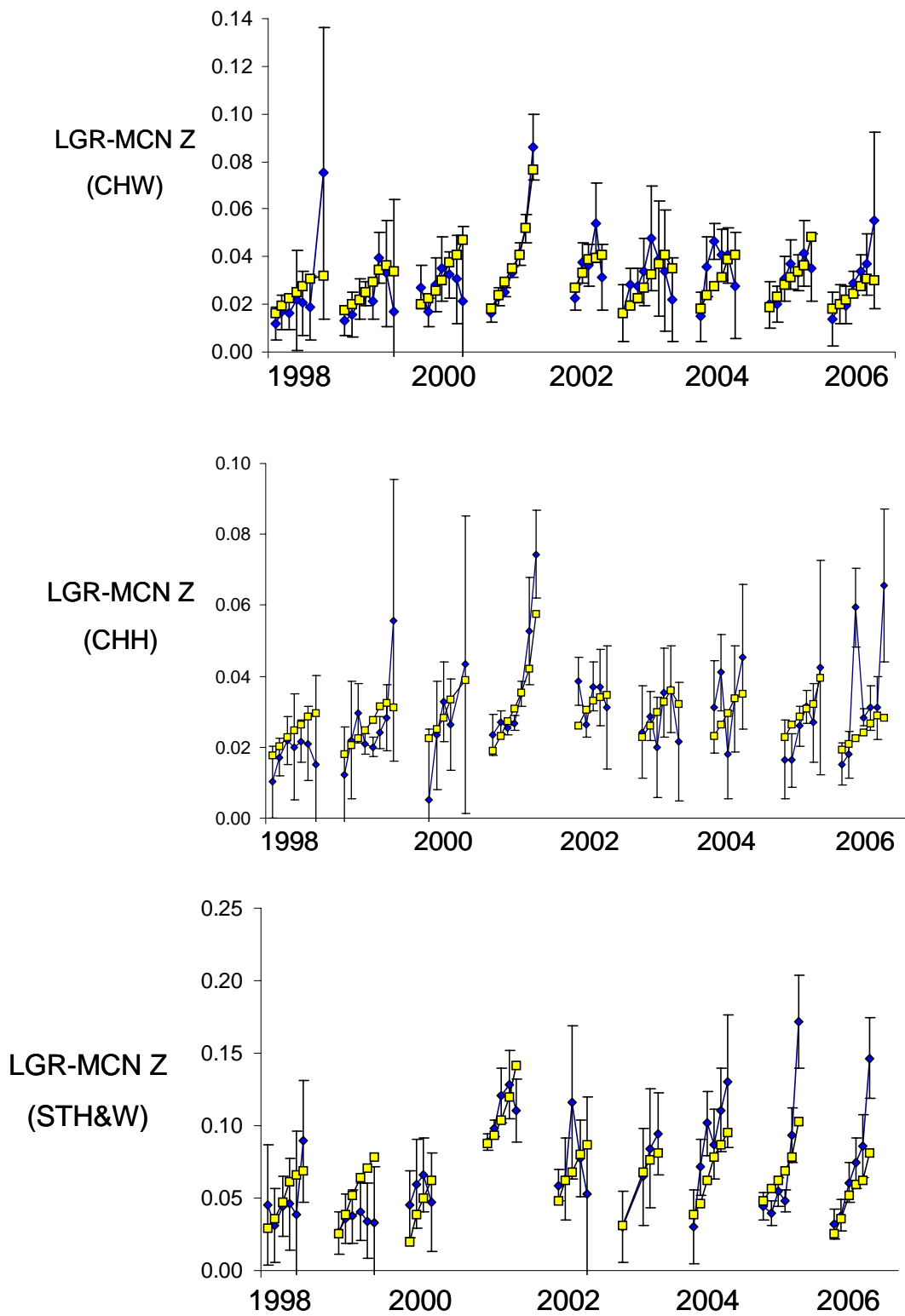


Figure 2.13. LGR-MCN \hat{Z}_i (d^{-1}) (filled diamonds, with 95% confidence intervals) and model predictions for Z_i (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006.

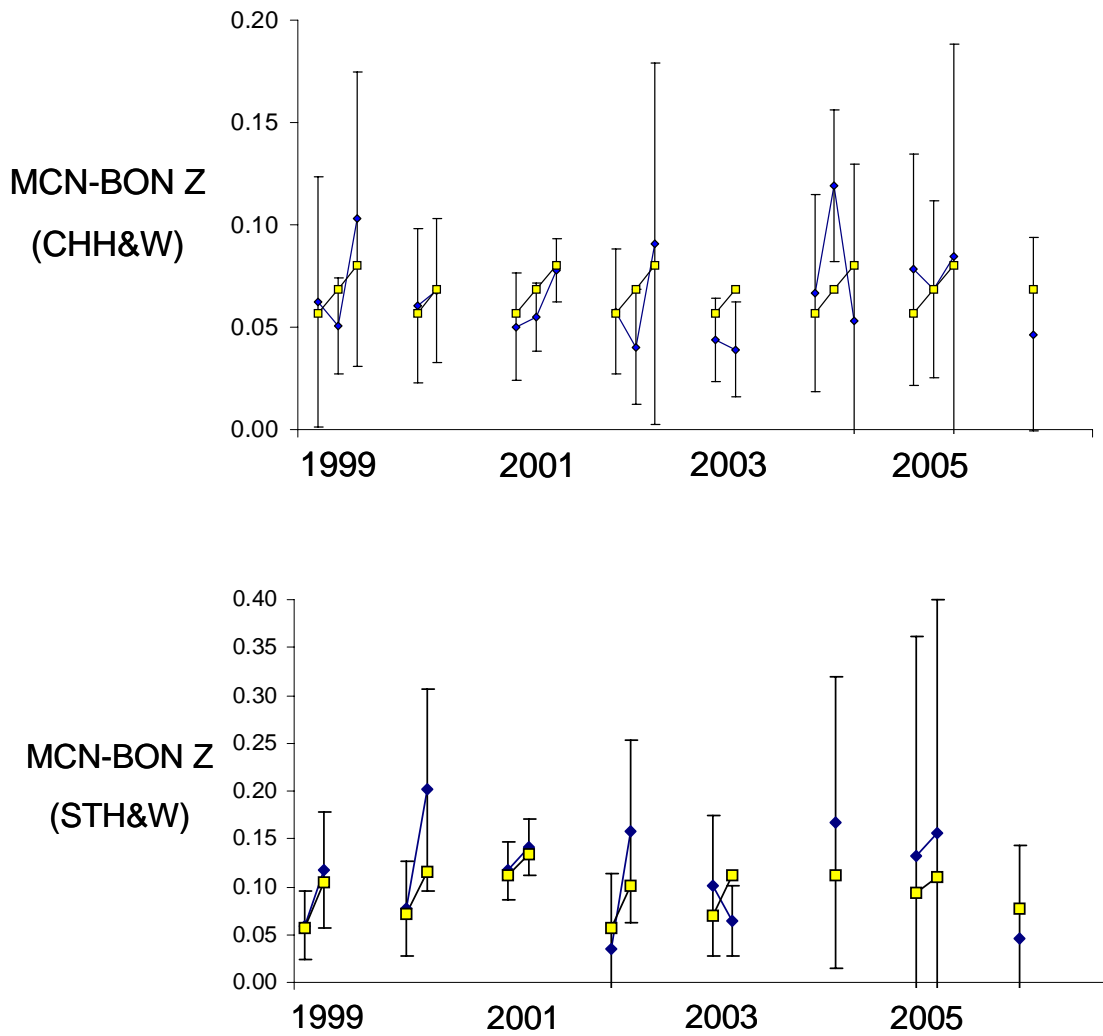


Figure 2.14. MCN-BON \hat{Z}_i (d^{-1}) (closed diamonds, with 95% confidence intervals) and predicted Z_i (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel) cohorts, 1999-2006.

Modeling survival rates

LGR-MCN

Similar environmental variables were selected in the best-fitting models using the standard survival approach to those selected for characterizing variation in \hat{Z}_i and \hat{FTT}_i . For wild Chinook, the model with the lowest AICc contained Julian day, water travel time, average percent spill, and an interaction between Julian day and water travel time (Tables 2.14, 2.25). For hatchery Chinook, the model with the lowest AICc also contained Julian date, water travel time, average percent spill, and an interaction between Julian date and water travel time (Tables 2.14, 2.26). For hatchery and wild steelhead, the model with the lowest AICc contained Julian day, flow⁻¹, average percent spill and average percent spill² (Tables 2.14, 2.27). The standard survival approach explained 49%, 49%, and 79% of the variation in the survival rates of wild Chinook, hatchery Chinook, and combined hatchery and wild steelhead (Table 2.3).

For predicting survival rates with the constant Z approach, we used the \bar{Z} estimates from Table 2.1 and our best-fit models for predicting median FTT_i (Table 2.12) within the exponential mortality model (Eqn. 2.2). The constant Z approach explained 10%, 11%, and 47% of the variation in the survival rates of wild Chinook, hatchery Chinook, and combined hatchery and wild steelhead (Table 2.4).

For predicting survival rates with the variable Z approach, we used our best-fit models for predicting both Z_i (Eqn. 2.8, Table 2.13) and FTT_i (Eqn. 2.7, Table 2.12) within the exponential mortality model (Eqn. 2.2). The variable Z approach explained 63%, 54%, and 80% of the variation in the survival rates of wild Chinook, hatchery Chinook, and combined hatchery and wild steelhead (Table 2.4).

Comparing the three survival modeling approaches in the LGR-MCN reach, the variable Z approach had the lowest AIC value for two of the three groups evaluated, and the lowest RMSE and highest R^2 for all three groups (Table 2.4). However, the variable Z approach also required the highest number of parameters to be estimated. The constant Z approach demonstrated the worst performance across the three performance measures and the three groups. Figure 2.15 displays the observed versus predicted Chinook and steelhead survival rates using the variable Z approach.

MCN-BON

Using the standard approach for modeling hatchery and wild Chinook survival, the model with the lowest AICc only contained average percent spill, but explained 48% of the variation in the survival rates (Tables 2.4, 2.14, 2.28). For hatchery and wild steelhead, the model with the lowest AICc contained flow and temperature, and explained 75% of the variation in the survival rates (Table 2.4, 2.14, 2.29).

For predicting survival rates with the constant Z approach in the MCN-BON reach, we used the \bar{Z} estimates from Table 2.1 and our best-fit models for predicting median FTT_i (Eqn. 2.7, Table 2.12) within the exponential mortality model (Eqn. 2.2). The constant Z approach explained 48% and 34% of the variation in Chinook and steelhead survival rates (Table 2.4)

For predicting survival rates with the variable Z approach in the MCN-BON reach, we used our best-fit models for predicting both Z_i (Eqn. 2.8, Table 2.13) and FTT_i (Eqn. 2.7, Table 2.12) within the exponential mortality model (Eqn. 2.2). The variable Z approach explained 51% and 71% of the variation in the survival rates of Chinook and steelhead (Table 2.4).

Comparing the three survival modeling approaches in the MCN-BON reach, the variable Z approach had the lowest RMSE and highest R^2 for Chinook, but also had the highest AIC score

(Table 2.4). The standard approach had the lowest AIC score for Chinook and steelhead. For steelhead, the variable Z approach had the second-best AIC score, RMSE, and R^2 value. The constant Z approach demonstrated relatively good performance for Chinook, but poor performance for steelhead. Figure 2.16 displays the observed versus predicted Chinook and steelhead survival rates in the MCN-BON reach using the variable Z approach.

Density-dependent effects

Through the analyses described above, we attempted to estimate the environmental factors that best characterized variation in the instantaneous mortality rates. Using the best-fitting models for instantaneous mortality rates, we then added the passage-index-derived biological variables to the regressions characterizing Z_i (Eqn. 2.8, Tables 2.20-24). We found little evidence for density-dependent effects on instantaneous mortality rates for Chinook in either reach. However, we did find limited evidence for density-dependent effects on the instantaneous mortality rates of steelhead. In the LGR-MCN reach, adding the standardized abundance index for steelhead reduced the AICc by 1.2 points and increased the adjusted R^2 by 3%. In the MCN-BON reach, adding the abundance index for steelhead increased the AICc by 1.9 points, but increased the adjusted R^2 by 7%. The coefficient signs for the index variables in both relationships were negative, implying that as within-year passage index values for steelhead increase, steelhead instantaneous mortality rates decline. We interpret these results as providing some preliminary evidence that juvenile steelhead abundance may influence instantaneous mortality rates of juvenile steelhead, but based on these results the magnitude of these effects appears to be low.

Table 2.4. Performance of the three survival modeling approaches for wild Chinook (CHW), hatchery Chinook (CHH), hatchery and wild steelhead (STH&W) and hatchery and wild Chinook (CHH&W) for the LGR-MCN and MCN-BON reaches. AIC is Akaike's Information Criterion, RMSE is the root mean squared error of the survival predictions, K is the number of parameters requiring estimation, and R² is the coefficient of determination.

Group	Reach	Survival approach	AIC	RMSE	K	R ²
CHW	LGR-MCN	standard	-300	0.081	6	0.49
	LGR-MCN	constant Z	-255	0.114	7	0.10
	LGR-MCN	variable Z	-322	0.063	11	0.63
CHH	LGR-MCN	standard	-264	0.085	6	0.49
	LGR-MCN	constant Z	-229	0.123	7	0.11
	LGR-MCN	variable Z	-265	0.077	11	0.54
STH&W	LGR-MCN	standard	-221	0.088	6	0.79
	LGR-MCN	constant Z	-176	0.141	6	0.47
	LGR-MCN	variable Z	-216	0.085	10	0.80
CHH&W	MCN-BON	standard	-98	0.073	3	0.48
	MCN-BON	constant Z	-88	0.078	7	0.48
	MCN-BON	variable Z	-87	0.072	9	0.51
STH&W	MCN-BON	standard	-57	0.099	4	0.75
	MCN-BON	constant Z	-40	0.154	6	0.34
	MCN-BON	variable Z	-45	0.113	8	0.71

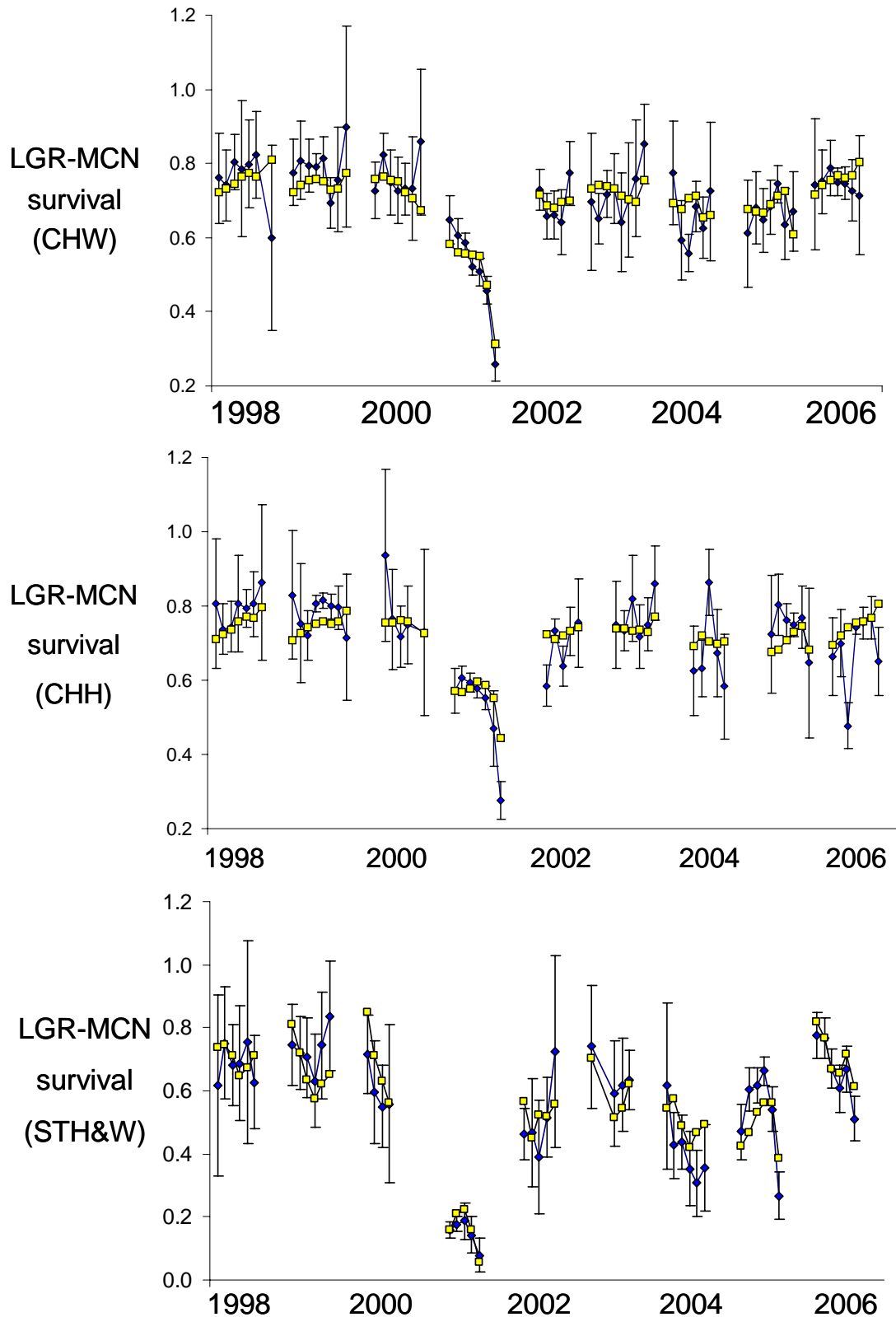


Figure 2.15. Observed LGR-MCN survival (filled diamonds, with 95% confidence intervals) and model predictions for survival (open squares) for wild yearling Chinook (upper panel), hatchery yearling Chinook (middle panel) and combined hatchery and wild steelhead (lower panel) for weekly cohorts, 1998-2006. Survival predictions were made using the variable Z approach.

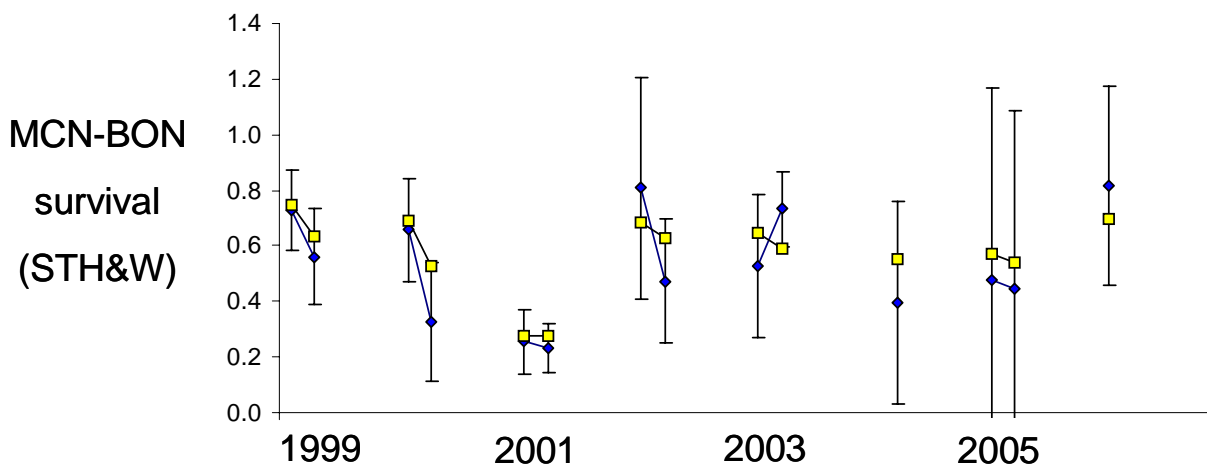
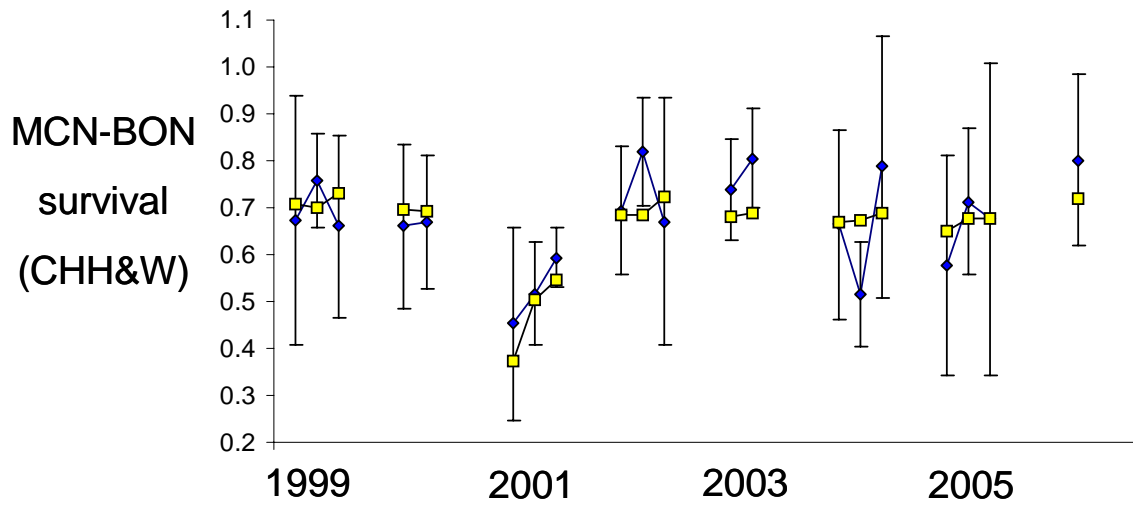


Figure 2.16. Observed MCN-BON survival (closed diamonds, with 95% confidence intervals) and model predictions of survival (open squares) for combined hatchery and wild yearling Chinook (upper panel) and steelhead (lower panel) across cohorts, 1999-2006. Survival predictions were made using the variable Z approach.

Discussion

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

In an attempt to capitalize upon this variation, we then developed models for characterizing the effects of various environmental and management factors on median fish travel times, survival rates, and instantaneous mortality rates. Through our approach of separating out the effects of environmental and management factors on fish travel time versus instantaneous mortality rates, we believe that some interesting patterns are emerging which may help to improve understanding about fish responses during outmigration through the hydrosystem. Plots showing these relationships, along with plots and summaries of the observed data, can be used to evaluate whether the model predictions are reasonable and consistent with the empirical observations.

For example, Figure 2.17 displays predicted median fish travel times over the LGR-MCN reach for wild yearling Chinook and hatchery and wild steelhead, across a range of flow and spill levels. Different curves correspond to early, mid, and late time periods of the outmigration and to average percent spill levels of 0% and 40%. Several features of the predicted curves are apparent: 1) increasing levels of flow result in shorter median fish travel times, 2) for any given flow level, increasing levels of spill result in shorter median fish travel times, and these differences are more pronounced at lower flow levels than higher flow levels, 3) fish migrating early have longer fish travel times for a given flow level than fish migrating late, and 4) early-migrating Chinook have much longer fish travel times across the range of flows than mid- or late-migrating Chinook, whereas steelhead tend to have similar median fish travel times, regardless of the migration period. When these patterns for the predicted relationships are compared to the empirical observations, each of these four features based on model predictions appear reasonable and consistent with the empirical data (Figure 2.17, Tables 2.5-2.7). To some degree, this is not surprising, as the models were derived from these same empirical data, and were an attempt to account for the sources of variation. The models were successful at accounting for the sources of variation, explaining 89-90% (Table 2.3) of the variation in the empirical median fish travel time data shown in Figure 2.17. However, we believe that the greater value of these models is for improving the understanding of fish responses to environmental factors and hydrosystem management actions. Especially for fish travel time, we feel that we were successful in this regard.

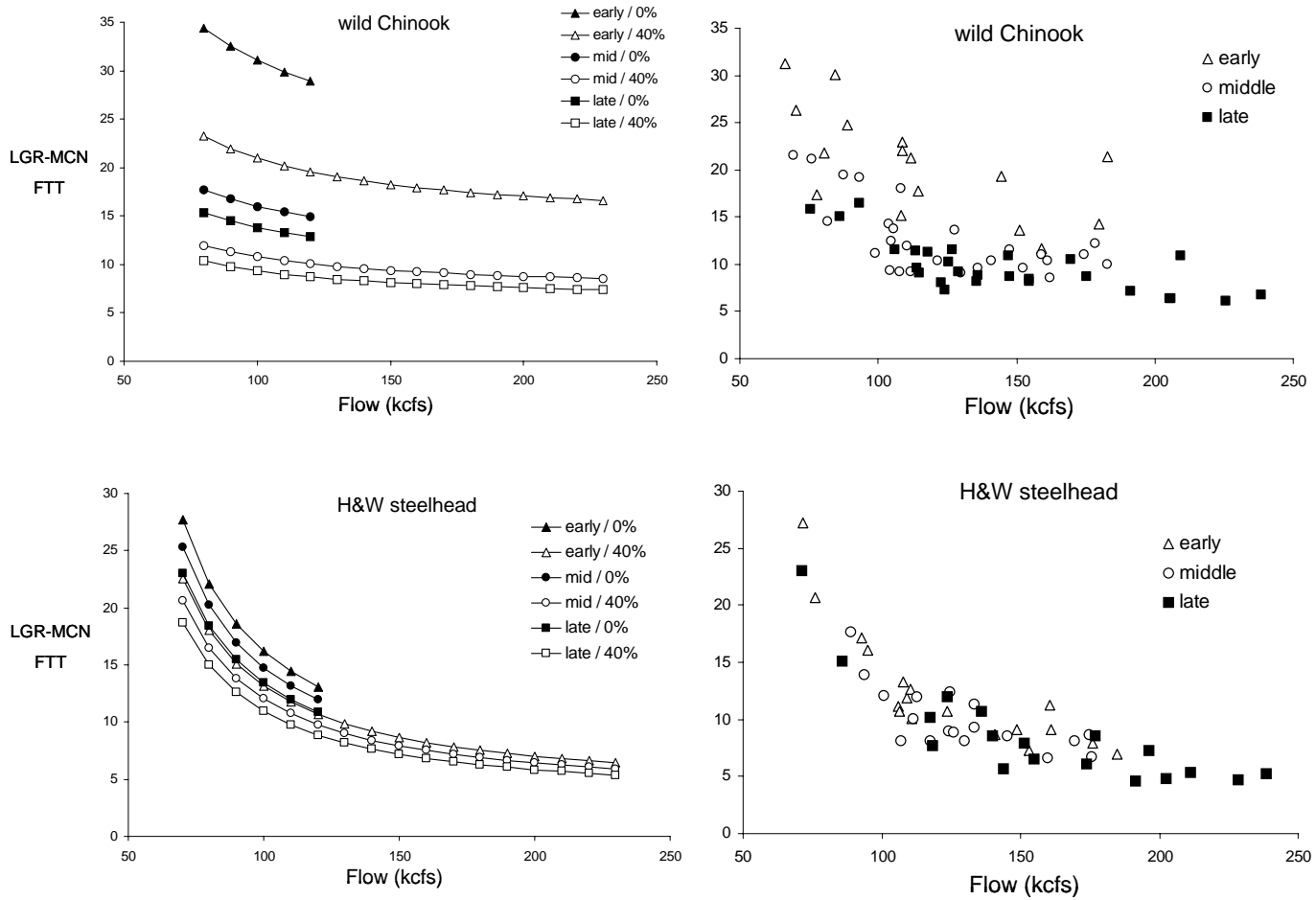


Figure 2.17. Model predictions of LGR-MCN median fish travel time (*FTT*) versus flow (kcfs) for 0% and 40% average spill levels (left panels) and observed median fish travel time versus flow (right panels), during early, mid, and late periods of the outmigration. Model predictions for scenarios with 0% average spill were limited to flows at or below 120 kcfs, the approximate hydraulic capacity of the Snake River projects.

Table 2.5. Across-cohort averages of LGR-MCN median fish travel times (d) for wild yearling Chinook during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.

Flow range (kcfs)	early	middle	late
60-100	25	18	16
100-150	20	12	10
150-200	15	10	8

Table 2.6. Across-cohort averages of LGR-MCN median fish travel times (d) for hatchery and wild steelhead during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.

Flow range (kcfs)	early	middle	late
60-100	20	16	19
100-150	11	10	9
150-200	9	8	6

Table 2.7. Across-cohort averages of LGR-MCN median fish travel times (d) for wild yearling Chinook, hatchery yearling Chinook, and hatchery and wild steelhead for average percent spill ranges of < 2%, 20-29%, 30-39%, and 40-51%, 1998-2006. There were no observations of percent spill in the 2-20% range.

Percent spill range	wild Chinook	hatchery Chinook	H&W steelhead
< 2%	21	19	20
20-29%	15	14	11
30-39%	12	13	9
40-51%	11	11	9

Similar improvements in understanding can be achieved through examining our model predictions for instantaneous mortality rates and survival rates. Figure 2.18 displays predicted instantaneous mortality rates over the LGR-MCN reach for wild yearling Chinook and hatchery and wild steelhead, across the migration season for a range of water travel times, flows, and spill levels. For yearling Chinook, the variables used to characterize variation in instantaneous mortality rates were Julian day and water travel time (Table 2.13). The plot of predicted instantaneous mortality rates for wild yearling Chinook suggests that early in the season, instantaneous mortality rates are low regardless of the water travel time. However, later in the migration season, instantaneous mortality rates are predicted to accelerate rapidly as water travel times increase (Figure 2.18). When water travel times are low, instantaneous mortality rates are predicted to remain low throughout the season.

For hatchery and wild steelhead, the variables used to characterize variation in instantaneous mortality rates were Julian day, average percent spill and the inverse of flow (Figure 2.18, Table 2.13). Across flow and spill levels, instantaneous mortality rates for hatchery and wild steelhead are predicted to increase over the migration season. This pattern is different from that of yearling Chinook, where instantaneous mortality rates are predicted to remain low across the season if water travel times are low (i.e., high flow). For steelhead, as flow and spill levels increase, instantaneous mortality rates are predicted to decrease. The plot of predicted instantaneous mortality rates for steelhead suggests that low flow levels will result in high instantaneous mortality rates, but these rates can be greatly reduced through increasing levels of spill. As an example, at a flow of 75 kcfs the predicted instantaneous mortality rates are 20-37% less under a 40% spill condition compared to a 0% spill condition (Figure 2.18). The relationships also suggest that similarly low instantaneous mortality rates can be achieved when flow levels are at 150 kcfs with 45% average spill compared to 200 kcfs with 40% average spill (Figure 2.18).

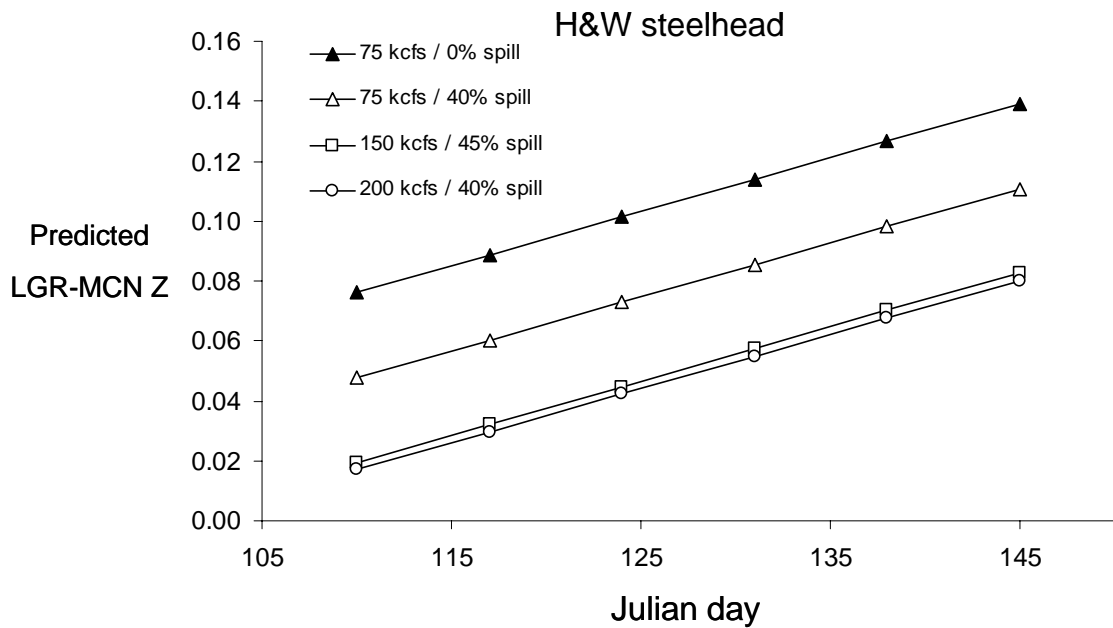
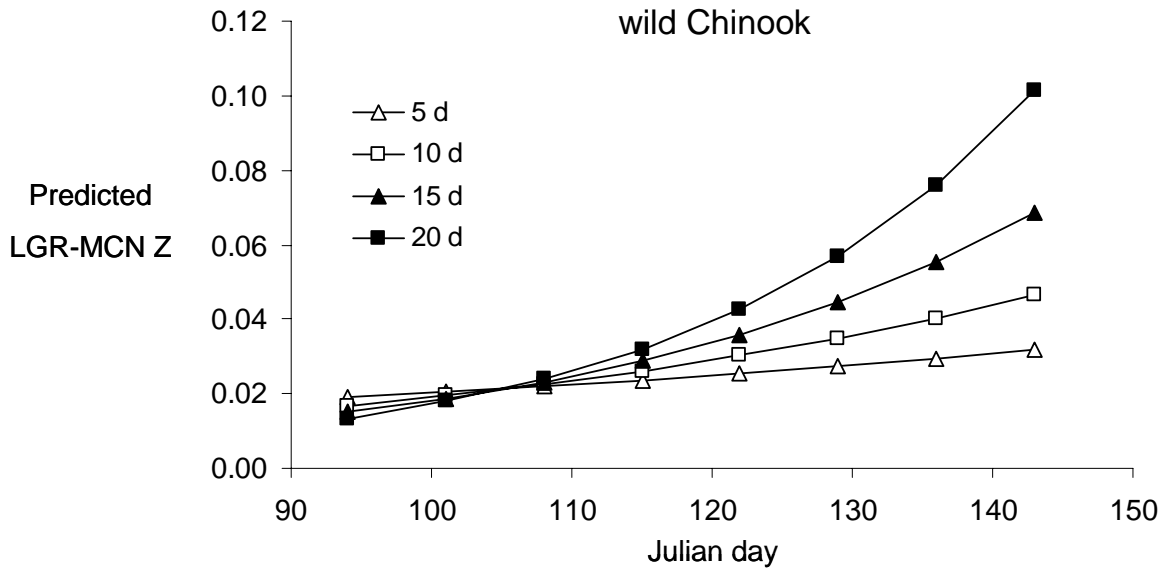


Figure 2.18. Model predictions of LGR-MCN Z for wild yearling Chinook as a function of Julian day and LGR-MCN water travel times of 5-, 10-, 15-, and 20-d (top panel) and LGR-MCN Z for hatchery and wild steelhead as a function of Julian day, flow (75, 150, and 200 kcfs), and average percent spill (0%, 40%, and 45%).

Incorporating the relationships used to characterize fish travel times and instantaneous mortality rates, we gain additional insights on how predicted survival rates may respond to various environmental conditions or hydrosystem management actions over the season (Figure 2.19). Some interesting patterns are suggested. For yearling Chinook, early in the outmigration season survival rates are predicted to increase slowly with increases in flow. During the mid-portion of the outmigration, survival is predicted to increase at a faster rate with increases in flow. During the late-portion of the outmigration season, survival increases rapidly with increases in flow. Across flow levels, the presence of spill is predicted to increase survival over the absence of spill. At low flow levels, the highest survival is predicted to occur during the early portion of the outmigration. Survival is also predicted to vary more at low flow levels, depending on outmigration period and spill levels. Within outmigration periods, survival rates are predicted to increase with flow and with increasing average percent spill levels. At low flow levels (80-120 kcfs), survival rates are predicted to be 16-46% higher with 40% average spill than with 0% average spill.

These predicted patterns are consistent with the empirical data on wild yearling Chinook survival (Figure 2.20, Tables 2.8, 2.10). During the early portion of the outmigration period, wild yearling Chinook survival increases by only a small amount with increasing levels of flow (Figure 2.20, Table 2.8). During the middle portion of the outmigration, survival increases by a greater rate with increases in flow (Figure 2.20, Table 2.8). During the late portion of the migration, survival increases rapidly with flow (Figure 2.20, Table 2.8). Plotting across all outmigration periods, the greatest variability in survival rates is observed at low flows (Figure 2.21, Table 2.8). These seasonal differences in the response between flow and survival may be one reason why flow-survival relationships for yearling Chinook have been difficult to identify. Average survival rates for hatchery and wild Chinook decline with reductions in the average percent spill (Table 2.10).

For hatchery and wild steelhead, patterns in predicted survival demonstrate some similarities and some differences compared to those predicted for yearling Chinook (Figure 2.19). Within each migration period, steelhead survival is predicted to increase rapidly with flow and the average percent spill. The rate of increase in survival versus flow is predicted to be similar across migration periods, but the asymptotic level is predicted to decline over the season. Steelhead survival rates are predicted to be higher early in the migration season than late in the migration season, for any given flow level. This is somewhat different than the pattern predicted for yearling Chinook, where early-season survival rates were predicted to be higher than late season survival rates at low flow levels (80-120 kcfs), but at higher flow levels (> 120 kcfs), survival rates were predicted to be similar across all migration periods. The highest steelhead survival rates are predicted when flow and spill levels are high, early in the migration season. The variation in survival rates is predicted to be similar across flow levels, depending on the migration period and average percent spill levels. At low flow levels (80-120 kcfs), survival rates are predicted to be 76-143% higher with 40% average spill than with 0% average spill (Figure 2.19).

The predicted survival patterns are also consistent with the empirical data on hatchery and wild steelhead survival (Figure 2.20, Tables 2.9-2.10). Within each migration period, hatchery and wild survival increases rapidly with flow (Figure 2.20, Table 2.9). The asymptotic level of survival at high flows decreases over the migration season (Figure 2.20, Table 2.9). For any given flow level, survival is highest for the early migration period and declines with migration period (Figure 2.20, Table 2.9). Plotting across all outmigration periods, similar levels

of variability in survival rates is observed across flow levels (Figure 2.22, Table 2.9). Average survival rates for hatchery and wild steelhead decline with reductions in the average percent spill, with severe reductions in survival observed at spill levels of < 2% (Table 2.10).

The approach of estimating and evaluating patterns in instantaneous mortality has applicability to a number of other management and research questions beyond those investigated here. The same approach can be used to estimate the instantaneous mortality rates within smaller reaches, which could be useful for identifying locations that have undesirably high mortality rates, diagnosing the factors or alternative hypotheses of the factors that may be associated with those mortality rates, and determining management actions that could be used to resolve those factors. For example, we found a high mortality rate for both Chinook and steelhead in the MCN-BON reach. This reach could be divided into its component MCN-JDA and JDA-BON reaches and instantaneous mortality rates calculated to help diagnose whether one of the reaches or both has high mortality rates. If one has an unacceptably high mortality rate, the factors that may be associated with that mortality could be examined (e.g., differences in predator abundance, seasonal differences in predator consumption rates, or differences in water travel times), and management actions could be developed and evaluated to reduce mortality rates.

We also see this approach as a powerful tool for continued development, evaluation, and refinement of alternative hypotheses on the effects of various environmental and management factors on smolt survival and migration rates. Particularly in the MCN-BON reach, we found that estimates of survival have substantial uncertainty. As a result, estimates of instantaneous mortality rates in this reach also have substantial uncertainty. Although we were able to develop a model that explained a substantial proportion (51-71%) of the variation in MCN-BON survival rates, questions remain as to which factors are primarily important for determining survival in the lower river. We see the only way to resolve the remaining questions is to invest in more PIT-tagging efforts for reducing this uncertainty in the lower reach.

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

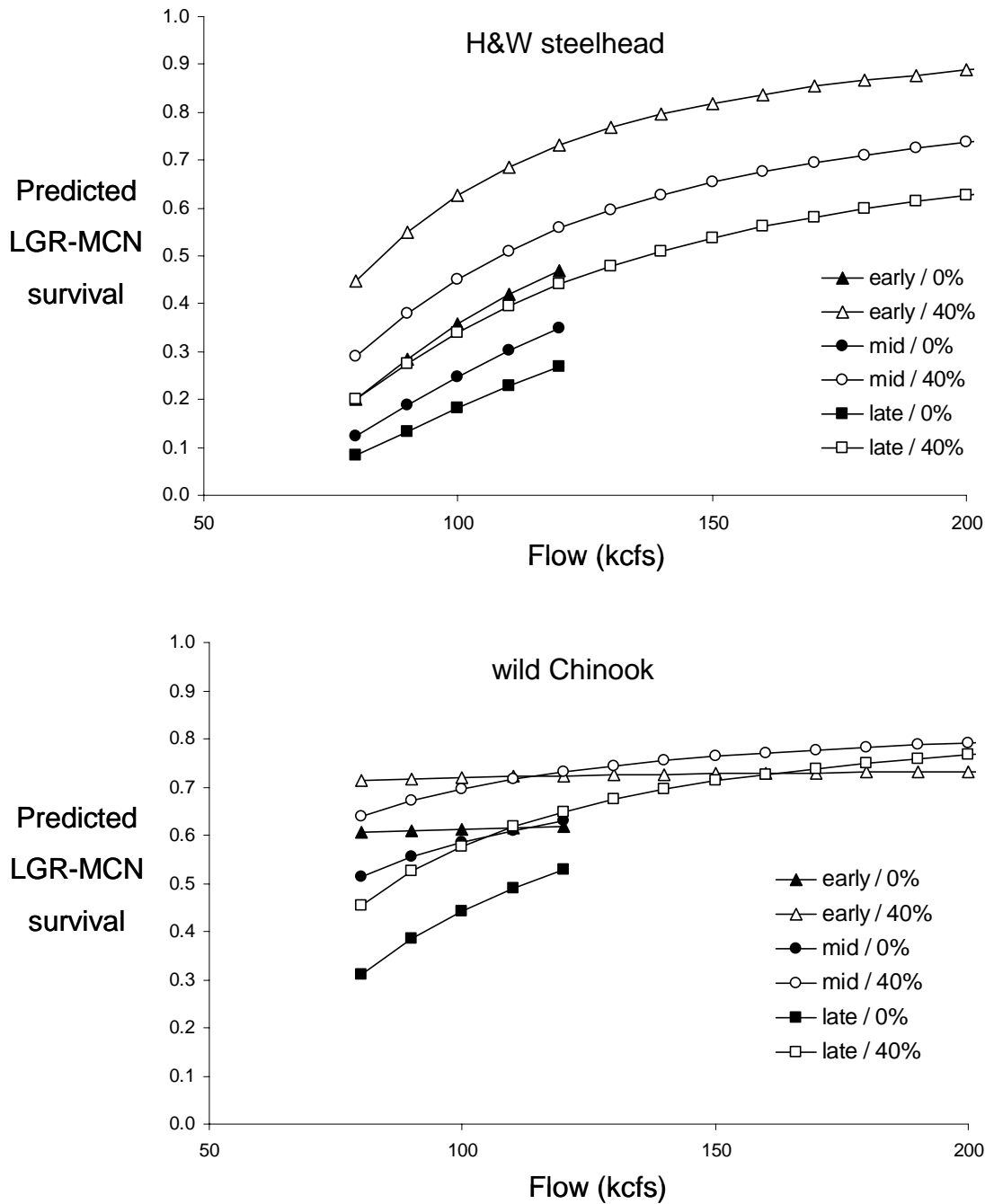


Figure 2.19. Model prediction of LGR-MCN survival for wild yearling Chinook (upper panel) and hatchery and wild steelhead (lower panel) versus flow (kcfs) at two average percent spill levels (0%, 40%), during early, mid, and late outmigration periods (early, mid, late). Model predictions for scenarios with 0% average spill were limited to flows at or below 120 kcfs, the approximate hydraulic capacity of the Snake River projects. Survival predictions utilized the variable Z approach.

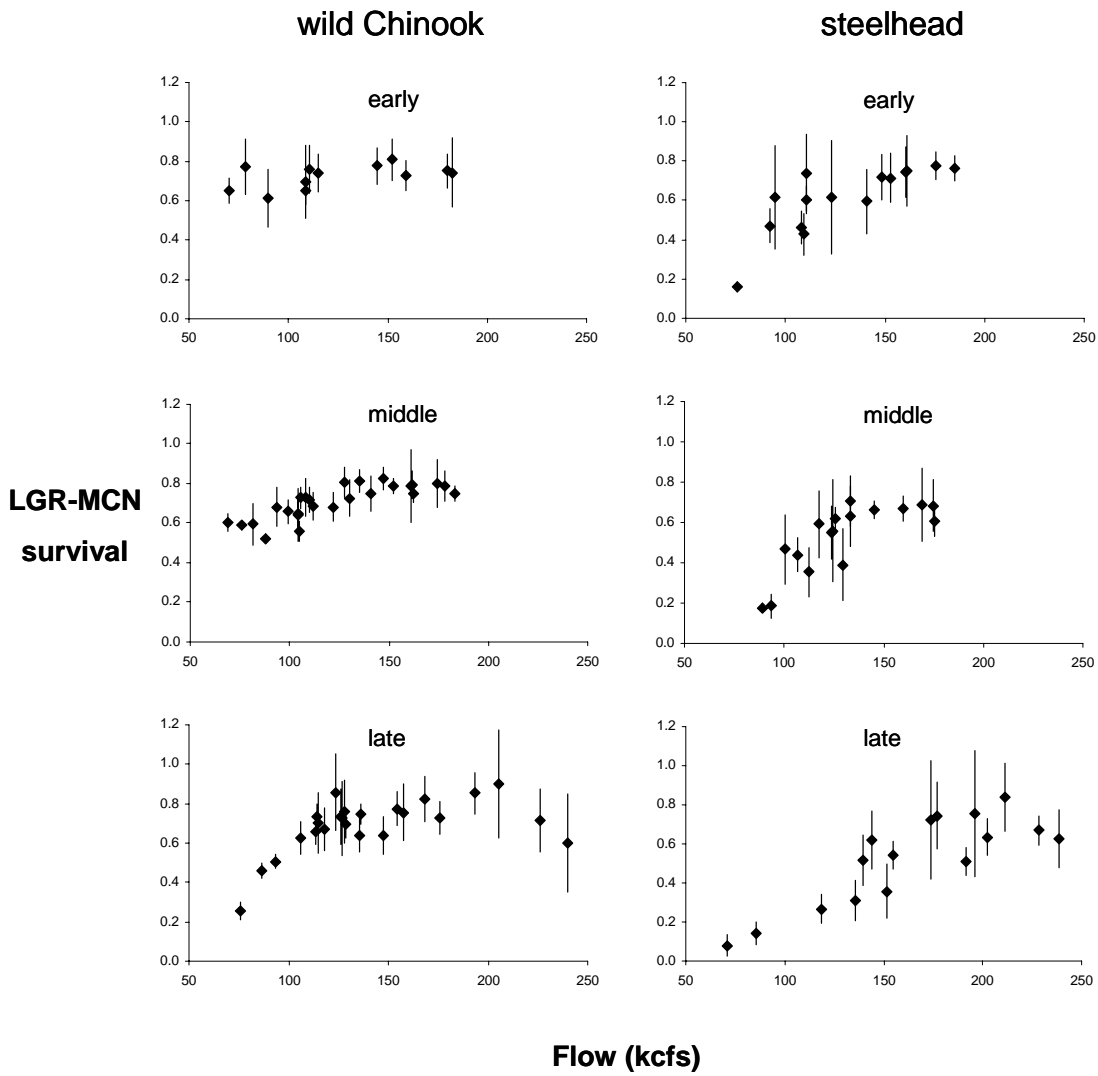


Figure 2.20. Estimates of LGR-MCN survival versus flow for wild yearling Chinook (left) and hatchery and wild steelhead (right) during the early (upper panels), middle (center panels) and late (lower panels) portions of the migration period, with their 95% confidence intervals..

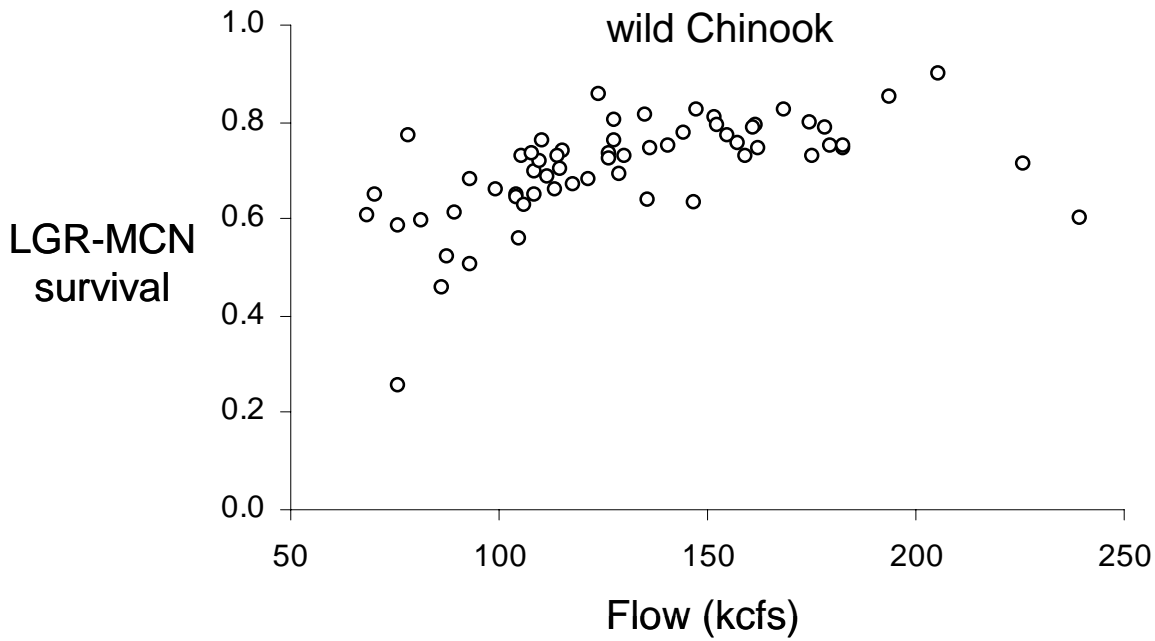


Figure 2.21. Estimates of LGR-MCN survival versus flow for wild yearling Chinook across all portions of the migration period, 1998-2006.

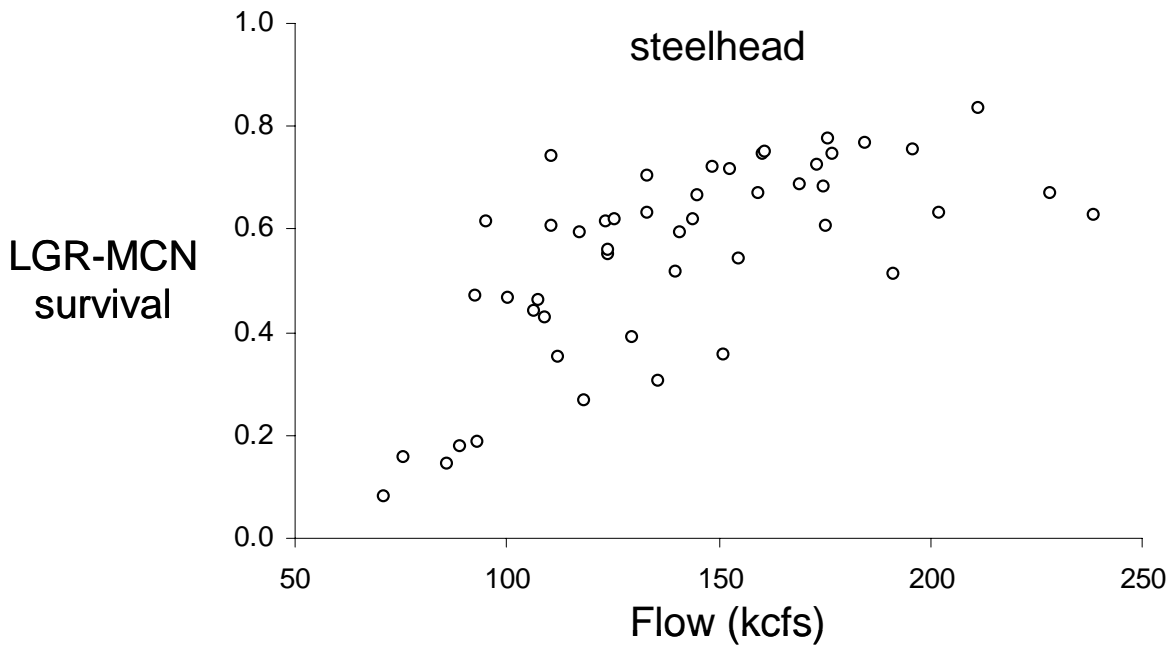


Figure 2.22. Estimates of LGR-MCN survival versus flow for hatchery and wild steelhead across all portions of the migration period, 1998-2006.

Table 2.8. Across-cohort averages of LGR-MCN survival rates for wild yearling Chinook during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.

Flow range (kcfs)	early	middle	late
60-100	0.68	0.61	0.41
100-150	0.73	0.72	0.71
150-200	0.76	0.78	0.81

Table 2.9. Across-cohort averages of LGR-MCN survival rates for hatchery and wild steelhead during the early, middle, and late periods of their outmigration, when average flows were 60-100, 100-150, and 150-200 kcfs.

Flow range (kcfs)	early	middle	late
60-100	0.41	0.18	0.11
100-150	0.59	0.54	0.43
150-200	0.75	0.66	0.61

Table 2.10. Across-cohort averages of LGR-MCN survival rates for wild yearling Chinook, hatchery yearling Chinook, and hatchery and wild steelhead for average percent spill ranges of < 2%, 20-29%, 30-39%, and 40-51%, 1998-2006. There were no observations of percent spill in the 2-20% range.

Percent spill range	wild Chinook	hatchery Chinook	H&W steelhead
< 2%	0.51	0.52	0.15
20-29%	0.68	0.71	0.43
30-39%	0.74	0.74	0.62
40-51%	0.73	0.76	0.68

Alternative mortality hypotheses

Following the presentation of the draft version of this chapter, the CSS Oversight Committee received several comments reflecting alternative hypotheses for the mortality and survival rates that we observed and modeled. We appreciate the reviewers' comments on this analysis, and believe that their hypotheses deserve consideration in light of the data available. Therefore we would like to examine some of the hypotheses that have been presented.

Dr. Usha Varanasi (NWFSC) presented the hypothesis that “management actions to decrease *FTT* would increase instantaneous mortality and that survival would remain the same.” This hypothesis may have originated based on the plots of daily mortality rate estimates versus water travel time presented in Williams et al. (2005), where daily mortality rate estimates appeared to increase as water travel times decrease.

To examine this hypothesis, we plotted the LGR-MCN instantaneous mortality rate estimates against observed median fish travel times for the early, mid, and late migration periods (Figure 2.23). We grouped the data by the early, mid, and late migration periods to account for potential seasonal differences in instantaneous mortality rates. An increase in instantaneous mortality rates as median fish travel times decrease would lend support to the NWFSC hypothesis. However, the data do not indicate that instantaneous mortality rates increase as median fish travel times decline (Figure 2.23). Based on the simple plots presented in Williams et al. (2005), which did not account for potential seasonal differences in instantaneous mortality, we understand how one might surmise that instantaneous mortality increases with decreasing fish travel times. However, we believe this is an incorrect interpretation of the data brought about by not accounting for the seasonal increases in instantaneous mortality that we frequently observed.

On a related topic, NWFSC also commented that “it is no surprise then that *Z* and *WTT* are correlated.” While we did find that water travel time (*WTT*) influenced instantaneous mortality rates in conjunction with seasonal effects (Julian day), water travel time alone was not well correlated with instantaneous mortality rates for Chinook or steelhead (Table 2.11). Only 1-3% of the variation in instantaneous mortality rates was accounted for by *WTT* alone. We found that *WTT* was an important variable for describing variation in instantaneous mortality, but the effects of *WTT* depended on Julian day through an interaction. We found that most of the variation in instantaneous mortality rates is associated with variation in survival (49% for Chinook and 58% for steelhead), followed by Julian day (35-36% for Chinook and steelhead) (Table 2.11).

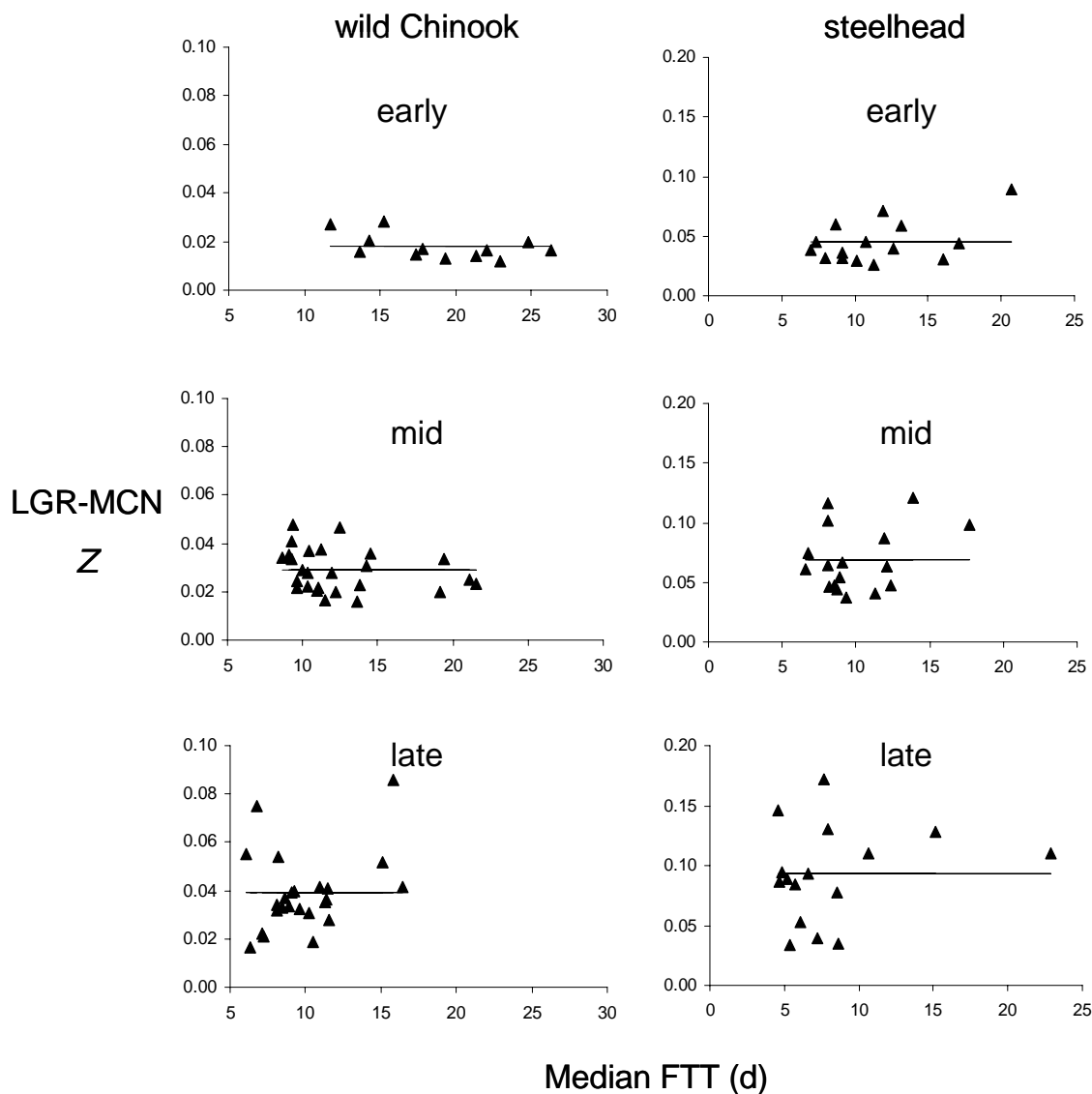


Figure 2.23. Estimates of LGR-MCN instantaneous mortality rates (Z_i) versus median fish travel time (FTT , d) for wild yearling Chinook and hatchery and wild steelhead during the early, mid, and late migration periods. Horizontal lines denote the period-specific averages of the Z_i .

Table 2.11. Squared correlation coefficients (r^2 values) for associations between instantaneous mortality rates estimates (\hat{Z}_i) and estimates of LGR-MCN survival, median FTT^{-1} , and WTT across cohorts of wild Chinook and hatchery and wild steelhead, 1998-2006.

	wild Chinook	H&W steelhead
Survival	0.49	0.58
Julian day	0.36	0.35
FTT^{-1}	0.13	0.02
WTT	0.01	0.03

Table 2.12. Parameter estimates and equations characterizing median fish travel time (*FTT*) in the LRG-MCN and MCN-BON reaches for juvenile Chinook and steelhead.

Species & rearing type	Reach		median FTT equations				
			Intercept	Julian	Julian^2	WTT	Avg.spill
CHW	LGR-MCN	log (med.FTT) =	9.1751	-0.0975	0.0003	0.0310	-0.0098
CHH	LGR-MCN	log (med.FTT) =	8.1988	-0.0775	0.0003	0.0214	-0.0109
STH&W	LGR-MCN	log (med.FTT) =	Intercept 2.1439	Julian -0.0053	WTT 0.0939	Avg.spill -0.0051	
CHH&W	MCN-BON	log (med.FTT) =	Intercept 4.5336	Julian -0.0129	WTT 0.0615	Avg.spill -0.0734	Avg.spill^2 0.0009
STH&W	MCN-BON	log (med.FTT) =	Intercept -0.2620	Julian 0.0081	WTT 0.3931	WTT:Julian -0.0019	

Table 2.13. Parameter estimates for equations characterizing instantaneous mortality rates (Z) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.

Species & rearing type	Reach	Z equations				
CHW	LGR-MCN	log (Z) =	Intercept -3.8939	Julian 0.0004	WTT -0.2144	Julian:WTT 0.0020
CHH	LGR-MCN	log (Z) =	Intercept -4.0542	Julian 0.0021	WTT -0.1448	Julian:WTT 0.0014
STH&W	LGR-MCN	Z =	Intercept -0.1718	Julian 0.0018	Inverse.flow 3.6840	Avg.spill -0.0007
CHH&W	MCN-BON	Z =	Intercept -0.0455	Julian 0.0008		
STH&W	MCN-BON	Z =	Intercept -0.1169	Temp 0.0155		

Table 2.14. Parameter estimates for equations characterizing survival rates (S) in the LGR-MCN and MCN-BON reaches for juvenile Chinook and steelhead.

Species & rearing type	Reach	Survival equations					
CHW	LGR-MCN	log (Survival) =	Intercept -1.8259	Julian 0.014322	WTT 0.1743195	Julian:WTT -0.00173799	Avg.spill 0.00332379
CHH	LGR-MCN	log (Survival) =	Intercept -1.6688	Julian 0.010745	WTT 0.1190232	Julian:WTT -0.00109779	Avg.spill 0.00634774
STH&W	LGR-MCN	log (Survival) =	Intercept 0.476549	Julian -0.009694	Inverse.flow -90.12845	Avg.spill 0.05183819	Avg.spill^2 -0.0007341
CHH&W	MCN-BON	log (Survival) =	Intercept -1.01936	Avg.spill 0.01758			
STH&W	MCN-BON	log (Survival) =	Intercept 0.10501	Flow 0.003908	Temp -0.1329137		

Description of Tables 2.15-2.29

The following tables provide the results of the model fitting process. The table titles indicate the species (CH = yearling Chinook, ST = steelhead), the rearing type (W = wild, H = hatchery, H&W = combined hatchery and wild), the dependent variable being modeled (*FTT* = median fish travel time, *Z* = instantaneous mortality rate, *S* = survival), reach (LGR-MCN or MCN-BON), whether the dependent variable was log_e-transformed or not, and the weighting scheme (unweighted, inverse-variance, inverse-CV, inverse-CV²). The independent variables included: *ju* = Julian day, *jusq* = Julian day², *sp* = average percent spill, *spsq* = average percent spill², *wt* = water travel time, *wtsq* = water travel time², *inv.fl* = flow⁻¹, *fl* = flow, *tu* = turbidity, *te* = temperature, *ju:wt* = interaction between Julian date and water travel time, *c.ind* = passage-index-derived abundance index for yearling Chinook, and *st.ind* = passage-index-derived abundance index for steelhead.

Table 2.15. CHW *FTT*, LGR-MCN, log_e(*FTT*), unweighted

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju,jusq,sp,wt	-71.8	-59.6	0.89	0.88	0.0	0.62
ju,jusq,sp,inv.fl	-70.8	-58.6	0.88	0.88	1.0	0.38
ju,sp,wt	-54.6	-44.3	0.85	0.85	17.2	0.00
ju,sp,inv.fl	-54.2	-43.9	0.85	0.84	17.6	0.00
ju,sp	-41.9	-33.5	0.82	0.82	29.9	0.00
ju,inv.fl	-35.5	-27.2	0.80	0.80	36.2	0.00
ju,wt	-31.0	-22.7	0.79	0.79	40.7	0.00
ju,fl	-19.5	-11.1	0.76	0.76	52.3	0.00
ju,tu	-6.3	2.1	0.71	0.71	65.5	0.00
ju,te	-4.0	4.3	0.69	0.68	67.7	0.00
ju	12.9	19.3	0.58	0.58	84.7	0.00
wt	24.1	30.5	0.54	0.54	95.9	0.00
inv.fl	24.8	31.2	0.52	0.52	96.6	0.00
fl	34.6	41.0	0.43	0.43	106.4	0.00
sp	53.8	60.1	0.26	0.26	125.5	0.00
te	62.1	68.5	0.14	0.14	133.9	0.00
tu	68.0	74.4	0.08	0.08	139.8	0.00

Table 2.16. CHH FTT , LGR-MCN, $\log_e(FTT)$, unweighted

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju,jusq,sp,wt	-53.2	-41.2	0.79	0.78	0.0	0.50
ju,jusq,sp,inv.fl	-52.9	-40.9	0.78	0.77	0.3	0.43
ju,sp,inv.fl	-47.5	-37.3	0.76	0.75	5.7	0.03
ju,sp,wt	-47.2	-37.1	0.76	0.75	5.9	0.03
ju,sp,tu	-43.9	-33.8	0.77	0.76	9.3	0.00
ju,sp,te	-43.3	-33.1	0.78	0.78	9.9	0.00
ju,sp	-43.0	-34.8	0.76	0.76	10.1	0.00
ju,inv.fl	-28.3	-20.1	0.67	0.66	24.8	0.00
ju,wt	-24.3	-16.1	0.65	0.64	28.8	0.00
ju,fl	-19.0	-10.8	0.63	0.63	34.2	0.00
ju,te	-9.2	-0.9	0.64	0.63	44.0	0.00
ju	3.6	9.9	0.54	0.54	56.8	0.00
inv.fl	25.7	32.0	0.37	0.37	78.9	0.00
wt	26.2	32.5	0.37	0.37	79.4	0.00
fl	30.3	36.5	0.31	0.31	83.4	0.00
sp	46.8	53.1	0.19	0.19	100.0	0.00
te	48.5	54.8	0.14	0.14	101.7	0.00
tu	58.1	64.4	0.03	0.03	111.3	0.00

Table 2.17. STH&W *FTT*, LGR-MCN, $\log_e(FTT)$, unweighted

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
wt,ju,sp	-39.4	-30.7	0.90	0.90	0.0	0.66
wt,ju	-36.6	-29.5	0.87	0.87	2.8	0.16
wt,sp	-34.8	-27.6	0.89	0.89	4.7	0.06
wt	-34.8	-29.3	0.88	0.88	4.7	0.06
inv.fl	-33.1	-27.6	0.87	0.87	6.3	0.03
wt,te	-32.4	-25.3	0.88	0.87	7.0	0.02
fl	-15.5	-10.0	0.73	0.73	23.9	0.00
ju,sp	11.3	18.5	0.67	0.67	50.8	0.00
sp	27.9	33.4	0.55	0.55	67.4	0.00
tu	38.6	44.1	0.27	0.27	78.0	0.00
ju	45.2	50.7	0.13	0.13	84.6	0.00
te	56.6	62.1	0.01	0.01	96.1	0.00

Table 2.18. CHH&W *FTT*, MCN-BON, $\log_e(FTT)$, unweighted

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
wt,sp,ju,spsq	-79.3	-70.2	0.95	0.94	0.0	0.97
wt,sp,ju,wtsq	-72.4	-63.2	0.94	0.93	7.0	0.03
wt,sp,ju	-67.1	-59.1	0.92	0.92	12.3	0.00
wt,sp,ju,jusq	-66.8	-57.6	0.92	0.92	12.5	0.00
wt,ju	-49.7	-43.1	0.84	0.84	29.7	0.00
wt,te	-35.0	-28.4	0.77	0.77	44.4	0.00
wt,sp	-15.8	-9.3	0.76	0.76	63.5	0.00
wt	-9.1	-4.1	0.64	0.64	70.2	0.00
inv.fl	-7.1	-2.0	0.61	0.61	72.2	0.00
sp	-4.3	0.8	0.76	0.76	75.1	0.00
fl	2.4	7.5	0.49	0.49	81.8	0.00
ju	17.0	22.0	0.24	0.24	96.3	0.00
te	36.7	41.8	0.00	0.00	116.1	0.00

Table 2.19. STH&W FTT , MCN-BON, $\log_e(FTT)$, unweighted

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
wt,ju,wt:ju	-77.4	-69.6	0.91	0.91	0.0	0.61
wt,ju,sp,wt:ju	-76.4	-67.4	0.91	0.90	1.0	0.37
wt,ju	-69.9	-63.4	0.87	0.86	7.5	0.01
wt,ju,sp	-68.4	-60.6	0.87	0.86	9.0	0.01
wt,te	-64.6	-58.2	0.83	0.82	12.7	0.00
wt	-56.7	-51.7	0.78	0.78	20.7	0.00
wt,sp	-55.3	-48.9	0.79	0.78	22.0	0.00
inv.fl	-53.2	-48.2	0.77	0.77	24.2	0.00
fl	-44.8	-39.8	0.72	0.72	32.6	0.00
sp	-16.9	-11.9	0.61	0.61	60.5	0.00
ju	15.5	20.5	0.05	0.05	92.9	0.00
te	18.6	23.6	0.03	0.03	96.0	0.00

Table 2.20. CHW Z, LGR-MCN, $\log_e(Z)$, inverse-CV weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju,wt,ju:wt	15.8	25.3	0.48	0.46	0.0	0.64
ju,wt,ju:wt,c.ind	17.3	28.5	0.48	0.45	1.5	0.30
ju,wt	22.9	30.7	0.40	0.39	7.1	0.02
ju,fl	23.2	31.0	0.38	0.37	7.4	0.02
ju,inv.fl	23.9	31.7	0.40	0.39	8.1	0.01
ju	26.0	32.0	0.34	0.34	10.3	0.00
ju,te	26.8	34.6	0.35	0.34	11.0	0.00
ju,sp	27.5	35.3	0.35	0.34	11.7	0.00
te	46.7	52.6	0.26	0.26	30.9	0.00
te,ju:wt	48.6	56.4	0.28	0.27	32.8	0.00
tu	66.8	72.8	0.10	0.10	51.1	0.00
ju:wt	67.0	73.0	0.13	0.13	51.2	0.00
sp,ju:wt	67.1	74.9	0.14	0.13	51.3	0.00
tu,ju:wt	68.0	75.8	0.13	0.12	52.2	0.00
sp	75.9	81.9	0.02	0.02	60.1	0.00
fl	76.8	82.8	0.00	0.00	61.0	0.00
inv.fl	77.3	83.3	0.01	0.01	61.5	0.00
wt	77.4	83.4	0.01	0.01	61.6	0.00

Table 2.21. CHH Z, LGR-BON, $\log_e(Z)$, inverse-CV weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju,wt,ju:wt,c.ind	38.5	48.9	0.42	0.38	0.0	0.26
ju,sp	40.1	47.4	0.36	0.35	1.6	0.12
ju	40.4	46.0	0.31	0.31	1.9	0.10
ju,wt,ju:wt	40.7	49.6	0.41	0.38	2.2	0.09
ju,inv.fl	40.8	48.1	0.36	0.34	2.3	0.08
ju,wt	40.9	48.2	0.35	0.34	2.4	0.08
ju,te	41.0	48.3	0.36	0.35	2.5	0.07
ju,sp,fl	42.2	51.2	0.36	0.34	3.8	0.04
ju,fl	42.2	49.6	0.33	0.31	3.8	0.04
ju,sp,te	42.3	51.3	0.37	0.35	3.8	0.04
ju,sp,tu	42.3	51.3	0.36	0.33	3.8	0.04
ju,sp,wt	42.4	51.3	0.37	0.34	3.9	0.04
te	45.6	51.2	0.32	0.32	7.1	0.01
te,ju:wt	47.7	55.0	0.33	0.32	9.2	0.00
tu	55.5	61.2	0.05	0.05	17.0	0.00
ju:wt	56.0	61.6	0.08	0.08	17.5	0.00
tu,ju:wt	57.6	65.0	0.07	0.05	19.2	0.00
sp,ju:wt	58.3	65.6	0.08	0.06	19.8	0.00
sp	58.3	63.9	0.05	0.05	19.8	0.00
inv.fl	59.5	65.1	0.00	0.00	21.0	0.00
wt	59.6	65.2	0.00	0.00	21.1	0.00
fl	59.9	65.5	0.00	0.00	21.4	0.00

Table 2.22. STH&W Z, LGR-BON, Z, inverse-variance weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju,sp,inv.fl,st.ind	-221.8	-212.6	0.58	0.55	0.0	0.42
ju,sp,inv.fl	-220.6	-212.7	0.54	0.52	1.2	0.24
ju,sp	-218.5	-211.9	0.52	0.51	3.3	0.08
ju,sp,wt	-218.3	-210.4	0.54	0.51	3.4	0.08
ju,sp,fl	-218.0	-210.1	0.55	0.53	3.8	0.06
ju,sp,tu	-217.4	-209.5	0.52	0.50	4.4	0.05
ju,inv.fl	-217.1	-210.5	0.51	0.50	4.7	0.04
ju,sp,te	-216.3	-208.3	0.52	0.50	5.5	0.03
ju,wt	-208.1	-201.5	0.49	0.48	13.7	0.00
te,sp	-207.1	-200.6	0.40	0.39	14.7	0.00
ju,fl	-205.3	-198.7	0.50	0.49	16.5	0.00
te	-195.1	-190.1	0.36	0.36	26.6	0.00
ju,te	-192.9	-186.4	0.37	0.36	28.9	0.00
sp	-192.8	-187.8	0.20	0.20	29.0	0.00
sp,inv.fl	-190.4	-183.9	0.20	0.18	31.3	0.00
ju,tu	-190.1	-183.5	0.39	0.37	31.7	0.00
inv.fl	-183.6	-178.6	0.06	0.06	38.1	0.00
fl	-178.2	-173.1	0.03	0.03	43.6	0.00
wt	-177.9	-172.8	0.03	0.03	43.9	0.00
ju	-177.6	-172.6	0.35	0.35	44.1	0.00
tu	-174.5	-169.5	0.06	0.06	47.2	0.00

Table 2.23. CHH&W Z, MCN-BON, Z, inverse-CV weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
ju	-89.1	-87.6	0.15	0.15	0.0	0.22
te	-89.0	-87.5	0.15	0.15	0.1	0.21
ju,inv.fl	-86.8	-85.5	0.16	0.10	2.3	0.07
ju,te	-86.3	-85.0	0.17	0.12	2.7	0.06
ju,sp	-86.3	-85.0	0.15	0.10	2.8	0.06
ju,c.ind	-86.3	-84.9	0.18	0.13	2.8	0.05
ju,wt	-86.2	-84.9	0.15	0.10	2.9	0.05
ju,te,wt	-86.2	-85.5	0.24	0.14	2.9	0.05
ju,fl	-86.1	-84.8	0.15	0.10	3.0	0.05
inv.fl	-86.1	-84.6	0.03	0.03	3.0	0.05
sp	-85.9	-84.4	0.01	0.01	3.2	0.04
fl	-85.8	-84.3	0.02	0.02	3.3	0.04
wt	-85.8	-84.3	0.01	0.01	3.3	0.04

Table 2.24. STH&W Z, MCN-BON, Z, inverse-variance weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
te	-44.4	-44.9	0.51	0.51	0.00	0.34
te,st.ind	-42.5	-44.4	0.62	0.58	1.93	0.13
te,inv.fl	-41.7	-43.6	0.42	0.36	2.72	0.09
te,wt	-41.7	-43.6	0.42	0.36	2.77	0.09
te,ju	-41.5	-43.4	0.42	0.36	2.96	0.08
inv.fl	-41.0	-41.5	0.05	0.05	3.44	0.06
wt	-41.0	-41.5	0.04	0.04	3.46	0.06
wt,ju	-40.8	-42.7	0.35	0.29	3.60	0.06
te,sp	-40.4	-42.3	0.49	0.44	4.02	0.05
fl	-39.9	-40.4	0.05	0.05	4.54	0.04
sp	-38.0	-38.5	0.01	0.01	6.45	0.01
ju	-36.4	-36.8	0.42	0.42	8.09	0.01

Table 2.25. CHW S, LGR-MCN, log_e(S), inverse-variance weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
sp,wt,ju,wt:ju	-111.3	-100.0	0.49	0.46	0.0	0.54
sp,inv.fl,ju,inv.fl:ju	-110.0	-98.8	0.50	0.47	1.2	0.29
sp,wt,ju,wt:ju,spsq	-108.9	-96.1	0.50	0.47	2.3	0.17
sp,fl,ju	-81.6	-72.1	0.44	0.42	29.6	0.00
sp,wt,ju	-80.8	-71.2	0.48	0.46	30.5	0.00
sp,wt,ju,jusq	-78.9	-67.6	0.48	0.45	32.4	0.00
sp,inv.fl,ju	-78.6	-69.0	0.47	0.45	32.7	0.00
sp,fl	-74.8	-67.0	0.41	0.40	36.4	0.00
sp,te	-72.4	-64.6	0.33	0.32	38.8	0.00
sp,wt	-72.2	-64.4	0.47	0.47	39.1	0.00
sp,inv.fl	-70.5	-62.6	0.47	0.46	40.8	0.00
sp,te,ju	-70.0	-60.5	0.33	0.30	41.2	0.00
sp	-64.8	-58.9	0.36	0.36	46.4	0.00
inv.fl	-57.6	-51.6	0.40	0.40	53.7	0.00
wt	-56.1	-50.1	0.38	0.38	55.2	0.00
fl	-53.1	-47.1	0.26	0.26	58.1	0.00
tu	-44.3	-38.4	0.27	0.27	66.9	0.00
te	-37.7	-31.7	0.10	0.10	73.6	0.00
ju	-12.3	-6.3	0.02	0.02	99.0	0.00

Table 2.26. CHH S , LGR-MCN, $\log_e(S)$, inverse-variance weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
sp,wt,ju,wt:ju	-71.8	-61.4	0.49	0.46	0.0	0.45
sp	-68.5	-62.9	0.43	0.43	3.4	0.08
sp,wt	-68.2	-60.9	0.44	0.43	3.6	0.07
sp,inv.fl	-68.1	-60.8	0.44	0.43	3.7	0.07
sp,inv.fl,te	-68.1	-59.2	0.45	0.43	3.8	0.07
sp,wt,te	-68.1	-59.1	0.45	0.43	3.8	0.07
sp,te	-67.6	-60.3	0.44	0.42	4.3	0.05
sp,fl	-67.2	-59.8	0.43	0.42	4.7	0.04
sp,fl,te	-66.6	-57.7	0.44	0.42	5.2	0.03
sp,ju	-66.3	-58.9	0.43	0.42	5.6	0.03
sp,wt,ju	-66.0	-57.0	0.45	0.43	5.9	0.02
inv.fl	-46.1	-40.5	0.26	0.26	25.7	0.00
wt	-42.8	-37.2	0.22	0.22	29.1	0.00
fl	-33.0	-27.4	0.14	0.14	38.8	0.00
tu	-32.0	-26.4	0.11	0.11	39.8	0.00
te	-29.1	-23.5	0.09	0.09	42.7	0.00
ju	-14.4	-8.8	0.01	0.01	57.4	0.00

Table 2.27. STH&W S , LGR-MCN, $\log_e(S)$, inverse-variance weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
sp,ju,inv.fl,spsq	-26.1	-17.0	0.79	0.77	0.0	0.89
sp,ju,wtt,spsq	-22.0	-12.8	0.77	0.76	4.2	0.11
sp,ju,inv.fl	1.9	9.8	0.78	0.77	28.0	0.00
sp,ju,inv.fl,te	3.7	12.9	0.79	0.78	29.9	0.00
sp,ju,wt	9.5	17.4	0.75	0.74	35.6	0.00
sp,inv.fl	21.9	28.5	0.63	0.62	48.1	0.00
sp,te	22.1	28.6	0.59	0.58	48.2	0.00
sp,ju	24.0	30.5	0.56	0.55	50.1	0.00
sp,te,ju	24.1	32.0	0.59	0.57	50.3	0.00
sp,wt	26.6	33.1	0.62	0.61	52.7	0.00
sp,tu	29.1	35.6	0.58	0.57	55.2	0.00
inv.fl	30.1	35.1	0.52	0.52	56.2	0.00
sp	31.1	36.1	0.54	0.54	57.2	0.00
wt	40.6	45.7	0.47	0.47	66.7	0.00
fl	52.1	57.2	0.38	0.38	78.2	0.00
tu	61.5	66.6	0.31	0.31	87.6	0.00
te	68.4	73.4	0.25	0.25	94.5	0.00
ju	75.4	80.4	0.05	0.05	101.5	0.00

Table 2.28. CHH&W S, MCN-BON, $\log_e(S)$, inverse-CV weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
sp	-16.2	-14.7	0.48	0.48	0.0	0.31
wt	-15.2	-13.8	0.42	0.42	1.0	0.19
sp,wt	-13.9	-12.5	0.50	0.47	2.4	0.09
sp,fl	-13.7	-12.4	0.48	0.45	2.5	0.09
sp,ju	-13.4	-12.1	0.49	0.45	2.8	0.08
sp,te	-13.1	-11.8	0.48	0.45	3.1	0.06
sp,inv.fl	-13.1	-11.7	0.48	0.45	3.2	0.06
fl	-12.6	-11.1	0.28	0.28	3.7	0.05
inv.fl	-11.6	-10.1	0.35	0.35	4.6	0.03
sp,ju,wt	-10.8	-10.1	0.50	0.43	5.4	0.02
sp,wt,te	-10.2	-9.6	0.51	0.44	6.0	0.02
te	-7.6	-6.1	0.09	0.09	8.6	0.00
ju	-3.6	-2.1	0.04	0.04	12.6	0.00

Table 2.29. STH&W S, MCN-BON, $\log_e(S)$, inverse-CV weighting

Variables	AIC _c	BIC	R ²	R ² _{adj.}	delta AIC _c	w _i
fl,te	1.0	-0.9	0.75	0.72	0.0	0.35
inv.fl,te	1.4	-0.5	0.76	0.73	0.4	0.28
wt,te	1.8	0.0	0.76	0.73	0.8	0.23
wt,ju	3.9	2.0	0.69	0.65	2.9	0.08
inv.fl	6.5	6.0	0.43	0.43	5.5	0.02
wt	6.7	6.3	0.43	0.43	5.7	0.02
ju,te	7.7	5.8	0.57	0.53	6.7	0.01
fl	9.6	9.1	0.33	0.33	8.6	0.00
inv.fl,sp	9.6	7.8	0.40	0.34	8.6	0.00
wt,sp	9.9	8.0	0.41	0.35	8.9	0.00
te	14.6	14.1	0.56	0.56	13.6	0.00
sp	16.2	15.7	0.28	0.28	15.2	0.00
ju	27.0	26.5	0.24	0.24	26.0	0.00

Chapter 3

Annual SAR by Study Category, *TIR*, S_R , and *D* for Hatchery and Wild Spring/Summer Chinook Salmon and Steelhead: Patterns and Significance

Introduction

The CSS was originally designed with the goal of obtaining annual estimates of smolt-to-adult survival rates (SARs) for Snake River hatchery and wild spring/summer Chinook (hereafter, Chinook) and steelhead. Estimation of the overall, aggregate SAR of fish that are transported and those that migrate entirely in-river is key to evaluation of avoidance of jeopardy as well as progress towards recovery goals. Annual estimates are needed to fit retrospective models and test hypotheses. Other metrics of hydrosystem performance that also have seasonal components are also estimated annually. For instance, downstream in-river survival probability is undoubtedly influenced by environmental conditions that vary within a migration season, yet annual estimates of annual survival rate are made (e.g. Williams et al. 2001). Annual estimates also allow investigation of the magnitude of inter-annual variation in these parameters, which has consequences for population viability, and allow comparison to target values to meet management objectives.

Another goal of the CSS has been to develop long-term indices of SAR ratios between transported and in-river fish. A common comparison, termed “Transport:In-river” ratio, or *TIR*, is the SAR of transported fish divided by the SAR of in-river fish, with SAR being estimated for smolts passing Lower Granite Dam (LGR) and returning as adults back to LGR (LGR-LGR SARs). Estimates of *TIR* address the question of whether transportation provides an overall benefit to smolt-to-adult survival, compared to leaving smolts to migrate in-river, under the hydrosystem as currently configured. The overall value of transportation in avoiding jeopardy and promoting recovery depends on the extent to which it will account for all direct mortality (*i.e.*, to smolts within the hydrosystem) and indirect, or “delayed”, mortality (*i.e.*, to smolts after passing BON) caused as a result of passage through the hydrosystem. However, because *TIR* compares SARs starting from collector projects, it does not provide a direct estimate of any delayed mortality specific to transported fish.

Related to *TIR* is “*D*”, the ratio between transported fish and in-river fish of SAR from downstream of Bonneville Dam (BON) back to LGR (BON-LGR SARs). Estimates of *D* isolate mortality occurring outside the hydrosystem from that occurring within the hydrosystem, which is useful for hypothesis generation and testing. A *D* equal to one indicates that there is no difference in survival rate after hydrosystem passage; a *D* less than one indicates that transported smolts die at a higher rate after passing BON than smolts that have migrated through the hydrosystem; a *D* greater than one indicates that transported fish have higher survival after passing BON. The parameter *D* has been used extensively in modeling the effects of the hydrosystem on Snake River Chinook salmon (Kareiva et al. 2000; Peters and Marmorek 2001; Wilson 2003; Zabel et al. in press).

The SARs and these ratios can be estimated for the entire migration year or for periods within a migration year using PIT-tag data. In this chapter, we present those estimates made for the entire migration year (in Chapter 4 we include analyses that examine within-season variations for both transported and non-transported fish). We concentrate on evaluations of SAR by the three CSS study categories, T_0 , C_0 , and C_1 , which represent, respectively, those fish

transported at Snake River collector dams (*i.e.*, Lower Granite [LGR], Little Goose [LGS], or Lower Monumental [LMN]), fish passing those three dams undetected, and those fish bypassed back to the river at the collector dams for the purpose of estimating in-river survival (in Chapter 5, the SARs developed for each of these study categories will be weighted by the proportion of the run-at-large (untagged and tagged fish) represented by these categories to provide overall annual SARs that will be evaluated in relation to river and ocean environmental conditions). Because no transported smolts and only a small number of in-river smolts are enumerated at BON, the BON-LGR SAR is estimated from the LGR-LGR SAR, adjusted by annual in-river survival rate estimates (through the hydrosystem) and assumed average direct transport survival rate from empirical studies.

Methods

Wild and hatchery smolts are marked with glass-encapsulated, passively induced transponders that are 11-12 mm in length and have a unique code to identify individual fish. These PIT-tags are normally implanted into the fish's body cavity using a hand-held syringe, and they are generally retained and function throughout the life of the fish. Wild and hatchery Chinook and steelhead used in the CSS analyses were obtained from all available marking efforts in the Snake River basin above LGR (Appendix A). Wild Chinook from each tributary (plus fish tagged at the Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years 1994 to 2004 (number and origin of PIT-tagged wild Chinook analyzed is in Table D-1). Wild steelhead smolts from each tributary (plus fish tagged at the Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years 1997 to 2003 (number and origin of PIT-tagged wild steelhead analyzed is in Table D-3). Hatchery steelhead from each tributary, plus PIT-tag releases in the mainstem Snake River at the Lewiston trap and below Hells Canon Dam, were represented in the PIT-tag aggregates for migration years 1997 to 2003 (number and origin of PIT-tagged hatchery steelhead analyzed is in Table D-4). The origins of the wild Chinook, wild steelhead, and hatchery steelhead in the PIT-tag aggregates appear to be well spread across the drainages above LGR.

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

Throughout this report, we will classify the Imnaha River Chinook as a summer stock (contrary to ODFW's classification) due to its high return rate of jacks and later timing of returning adults, which is consistent with the summer stock from McCall Hatchery stock. The average percentage of the total that return as jacks was higher for the summer Chinook stocks

than for the spring Chinook stocks, and was the highest for Chinook from Imnaha River acclimation pond (Table D-41).

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

The Snake River basin fish used in SAR estimation were PIT-tagged and released in tributaries and mainstem locations upstream from LGR reservoir. Other investigators (Sanford and Smith 2002; Paulsen and Fisher 2005; Budy and Schaller 2007) have used smolts released both above LGR and at LGR for their estimates of SARs. Because all Snake River spring/summer Chinook must pass through LGR reservoir, we believe that smolts released upstream from LGR most closely reflect the impacts of the Lower Snake and Columbia River hydrosystem on the untagged run-at-large in-river migrating fish and thus we use only these release groups to compose the C_0 group (fish that remained in-river throughout their migration) in this analysis; fish collected and marked at LGR do not have a similar experience (explained in more detail below).

Estimation Overview

Generally we estimated the survival of various life stages through known release and detected return numbers of PIT-tagged fish. The PIT-tags in juvenile fish are read as the fish pass through the coils of detectors installed in the collection/bypass channels at six Snake and Columbia River dams, including LGR, LGS, LMN, McNary (MCN), John Day (JDA), and BON (Figure 1.2 and 1.3). Upon arrival at LGR, LGS and LMN, smolts can go through three different routes of passage: they can go over the spillway, or they can go into the powerhouse where they either go through the turbines or are diverted with screens and pipes into the collection and bypass facility. Those fish that pass over the spillway or through the turbines are not detected, but bypass facility detectors record the fish identification number and the time and date detected. Fish without PIT-tags that enter the collection facility are generally put in trucks or barges and transported to below BON; however collected PIT-tagged smolts are often returned to the river. In addition, PIT-tag detections are obtained from a special trawling operation (TWX) by NMFS in the lower Columbia River in the vicinity of Jones Beach. Returning adults with PIT-tags are detected in the fish ladders at LGR with nearly 100% probability. (PIT-tag detection capability for returning adults has been added at BON, MCN, and IHR in more recent years, allowing additional adult return sites for analyses in Chapters 5 and 6.)

By comparing the number of fish detected at downstream dams and an upstream dam with fish detected at downstream dams but not at the upstream dam, an estimate of the probability of being detected at the upstream dam is possible, and ultimately an estimate of survival. In the simplest case, multiplying the survival rate between release and LGR provides the number of smolts arriving at LGR. Because several more detection sites are located downstream, including below BON, survival and removal can be estimated throughout the hydrosystem using mark-recapture techniques. The number of adults returning to LGR from an

estimated number of smolts at either LGR or BON provides an estimate of SAR. Finally, these SARs can be compared between routes of passage, for example smolts that were barged around the hydrosystem versus those that migrated through the hydrosystem.

Assessment of the variance of estimates of survival rates and ratios is necessary to describe the precision of these estimates for statistical inference and to help facilitate efficient monitoring of actions to mitigate effects of the hydrosystem. For a number of the quantities described above, theoretical estimates of variance are tractable. However, variance components of other quantities are often unknown or are extremely complicated and thus impracticable to estimate using theoretical variances. Therefore, we developed a bootstrapping approach where all quantities are estimated, and then a new sample of fish is drawn with replacement from the original sample, and the quantities are then estimated again. This resampling with replacement is conducted over thousands of iterations to produce a distribution of values that describes the mean and variance associated with the estimate.

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

Estimation of in-river survival rates

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

The total number of reaches for which survival was estimable was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was limited PIT-tag detection capability at JDA and TWX. Therefore, reliable survival estimates in those years were possible only to the tailrace of LMN or MCN. In years subsequent to 1998, reliable survival estimates to the tailrace of JDA have been possible in most cases. When direct estimates of S_R were not possible or were unreliable an extrapolation was necessary. Survival estimates over the longest reach possible were converted to survival per mile using the number of miles in that reach. The estimates of survival per mile were then expanded to the number of miles between LGR and BON. However, because per mile survival rates thus

generated were generally lower for the Snake River than for the lower Columbia River, direct estimates of in-river survival over the longest reach possible were preferable.

Estimation of smolts in study categories

For convenience, we made comparisons between SARs of groups of smolts with different hydrosystem experiences from a common starting and end point. Thus, LGR-LGR SARs were estimated for all groups, including smolts not detected at LGR. The population of PIT-tagged study fish arriving at LGR was partitioned into three categories of smolts related to the route of subsequent passage through the hydrosystem. Fish were “destined” to 1) pass in-river through the Snake River collector dams in a non-bypass channel route (spillways or turbines), 2) pass in-river through the dam’s bypass channel, or 3) pass in a truck or barge to below BON. These three routes of hydrosystem passage defined the study categories C₀, C₁ and T₀, respectively.

The PIT-tagged study groups should mimic the experience of the non-tagged fish that they represent. For example, only first-time detected tagged smolts at a dam may be considered for inclusion in the transportation (T₀) group since non-tagged smolts were nearly always transported when they entered a bypass/collector facility (where PIT-tag detectors are in operation) at a Snake River dam. Smolts transported at LGR, in “LGR equivalents”, represented a larger group than the sum of smolts actually transported at all projects, because some smolts died while migrating in-river from LGR to either LGS or LMN. The number of smolts actually transported at the lower transport projects were inflated to account for mortality during in-river migration to those transportation sites, before being added to the number transported from LGR, to derive LGR equivalent transport smolt number (T₀; equation 3.1). The actual transport numbers at LGR, LGS, and LMN are in Tables D-45 to D-47. The PIT-tagged fish destined for transportation at LGR, LGS, and LMN together formed Category T₀. Using the definitions presented in the following text box, the formula for estimating the number of fish in Category T₀ was

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

Symbol Definitions:

- R = number of PIT-tagged fish released
- n₂ (or X₁₂) = number of smolts transported at LGR
- n₃ (or X₁₀₂) = number first-detected and transported at LGS
- n₄ (or X₁₀₀₂) = number first-detected and transported at LMN

- S₁ = estimated survival from hatchery release site to LGR tailrace
- S₂ = estimated survival from LGR tailrace to LGS tailrace
- S₃ = estimated survival from LGS tailrace to LMN tailrace

- m₁₂ = number of fish first detected at LGR
- m₁₃ = number of fish first detected at LGS
- m₁₄ = number of fish first detected at LMN
- m₁₅ = number of fish first detected at MCN
- m₁₆ = number of fish first detected at JDA
- m₁₇ = number of fish first detected at BON
- m₁₈ = number of fish first detected at TWX

d_2 = number of fish removed at LGR regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
 d_3 = number of fish removed at LGS regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
 d_4 = number of fish removed at LMN regardless of prior capture history (includes transported fish, site-specific mortalities, unknown disposition fish, and fish accidentally removed at LMN for use in NMFS survival study at IHR)
 d_0 = site-specific removals at dams below LMN of fish not detected previously at a Snake River Dam (includes incidental fish transported at MCN, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at JDA and used in NMFS survival study at The Dalles Dam [TDA])
 d_1 = site-specific removals at dams below LMN of fish previously detected at a Snake River Dam (includes incidental fish transported at MCN, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at JDA and used in NMFS survival study at TDA)

Note: both d_0 and d_1 are inflated by a constant factor of 2 to offset the approximate 50% survival rate to the lower Columbia River of fish starting at LGR.

AT_{LGR} = tally of smolts transported at LGR, capture history “12”

AT_{LGS} = tally of smolts transported at LGS, capture history “102”

AT_{LMN} = tally of smolts transported at LMN, capture history “1002”

The PIT-tagged smolts that passed all Snake River dams undetected (C_0) were the group most representative of the non-tagged smolts that migrated in-river during the years covered in the report, never entering collection facilities at collector dams. Detected PIT-tagged fish were not representative because they do enter these facilities, and because non-tagged fish that entered a detection/collection facility were normally removed for transportation. The starting number of C_0 fish was also computed in LGR equivalents, and therefore required estimates of survival. To estimate the number of smolts that were not detected at any of the collector projects, the number of smolts first detected (transported and non-transported) at LGR, LGS, and LMN (in LGR equivalents) was subtracted from the total number of smolts estimated to arrive at LGR. The number of Chinook smolts arriving at LGR dam was estimated by dividing the number of smolts detected at LGR by the CJS estimate of seasonal LGR collection efficiency specific for the Chinook group of interest. Smolts detected at MCN, JDA, and BON were not excluded from the C_0 group since fish entering the bypass facilities at these projects, both tagged and untagged, were generally returned to the river. Using symbols defined in the text box, the formula for estimating the expected number of fish in Category C_0 was

$$C_0 = RS_1 - (m_{12} + m_{13}/S_2 + m_{14}/S_2S_3) - 2d_0 \quad [3.2]$$

The last group of interest was comprised of fish that were detected at one or more Snake River dams and remained in-river below LMN. These PIT-tagged fish formed Category C_1 . The C_1 category exists because a portion of the PIT-tagged smolts entering the detection/collection facility are returned to the river so reach survival estimates are possible. Although these fish do not mimic the general untagged population, they are of interest with regards to possible effects of passing through Snake River dam bypass/collection systems on subsequent survival, and in

investigating cross-season trends in SARs. Using symbols defined in the text box, the formula for estimating the expected number of fish in Category C_1 was

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

Estimation of SARs and Ratios of SARs for Study Categories

LGR has been the primary upriver evaluation site for many objectives of the CSS. Adults detected at LGR were assigned to a particular study category based on the study category they belonged to as a smolt (fish with no previous detections at any dam were automatically assigned to Category C_0). In the SAR estimation, the adult steelhead count is the sum of the 1-, 2-, and 3-ocean returns (only fish returning in the same year as their smolt outmigration, called minis, are excluded). The number of returning adults at LGR by age is in Table D-43 for wild steelhead and Table D-44 for hatchery steelhead. The adult Chinook count is the sum of the 2-, 3-, and 4-ocean returns. Chinook minis and jacks (1-ocean) are excluded from SARs due to the limited contribution to spawning of these age classes. The number of returning adults (and jacks) at LGR by age is in Table D-39 for wild Chinook and Table D-41 for hatchery Chinook.

The formulas for computing SARs by study category (adult tally in numerator and estimated smolt number in denominator) were:

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

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

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

In Appendices B and D and past CSS Annual Reports, $SAR(T_0)$ is denoted as $SAR_2(T_0)$ in order to distinguish it from an alternative method of estimating this SAR using a weighted-average of dam-specific SARs, denote $SAR_1(T_0)$. Equation 3.4 has replaced the use of the weighted approach for reasons detailed in appendices A and B.

The difference between $SAR(T_0)$ and $SAR(C_0)$ was characterized as the ratio of these SARs and denoted as the *TIR* (transport: in-river ratio):

$$TIR = SAR(T_0) / SAR(C_0) \quad [3.7]$$

The statistical test of whether $SAR(T_0)$ is significantly ($\alpha = 0.05$) greater than $SAR(C_0)$ is conducted by evaluating whether *TIR* is significantly greater than 1. We use the criteria that the lower limit of the non-parametric 90% confidence interval of *TIR* must exceed 1 (*i.e.*, below this lower limit threshold occurs at 5% of the *TIR* estimates in ascending rank order from the distribution of bootstrap iterations). This provides a statistical one-tailed ($\alpha = 0.05$) test of H_0 *TIR* ≤ 1 versus H_A *TIR* > 1 .

Estimation of D

Methods to estimate LGR-LGR SARs for transported and in-river fish have been described above. This measurement of survival from smolts-to-adults includes survival rates through the hydrosystem as well as survival after smolts pass BON and return to LGR. Like the *TIR*, the parameter *D* is the ratio of SAR of transported smolts (T_0) relative to smolts migrating

in-river (C_0), except that SAR is estimated from below BON instead of from LGR. If the value of D is around 1, there is little or no differential mortality occurring between transported and in-river migrating smolts once they are both below BON.

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

Because the total number of smolts passing BON was not observed, the survival rates S_T and S_R for passage through the hydrosystem were removed from their respective LGR-LGR SAR values to estimate BON-LGR SARs for each study group. The resulting estimate of D was

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

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

In the denominator of D (in-river portion), the quotient was simply $\text{SAR}(C_0) / S_R$, where S_R was estimated through the CJS estimate (expanded to the entire hydro system if necessary). Errors in estimates of S_R influenced the accuracy of D estimates; recall that when it was not possible to estimate CJS in-river survival directly to BON tailrace, an extrapolation based on a “per mile” survival rate obtained from an upstream reach (where survival could be directly estimated) was instead applied to the remaining downstream reach.

In the numerator of D (transportation portion), the quotient was $\text{SAR}(T_0) / S_T$, where S_T reflected an adjustment of the project-specific proportions of the transported PIT-tagged fish to mimic the proportions of untagged fish transported at the different projects. Calculation of S_T included an estimate of survival to each transportation site, effectively putting S_T into LGR equivalents similar to $\text{SAR}(T_0)$, with a fixed 98% survival rate for the fish once they were placed into the transportation vehicle (truck or barge). The resulting formula for estimating S_T used estimates of the total number of PIT-tagged fish that would have been transported at each dam (estimates t_j for the j^{th} dam) if all PIT-tagged fish had been routed to transport at the same rate as the untagged fish. The S_T estimate was

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

where the t_j s are estimates of the fraction of PIT-tagged fish that would have been transported at each dam (t_j for the j^{th} dam) if all PIT-tagged fish had been routed to transport at the same rate as the untagged fish. The estimates of S_T have ranged between 0.88 and 0.98 for Chinook and steelhead across the years evaluated in the report.

A statistical test of whether D is significantly ($\alpha = 0.05$) greater than 1 will be conducted in the same manner as was done with *TIR*. We use the criteria that the lower limit of the non-parametric 90% confidence interval of D must exceed 1 (*i.e.*, below this lower limit threshold occurs at 5% of the D estimates in ascending rank order from the distribution of bootstrap iterations). This provides a statistical one-tailed ($\alpha = 0.05$) test of $H_0 D \leq 1$ versus $H_A D > 1$.

Results

The following survival rates, patterns and trends were observed for the spring/summer Chinook and summer steelhead PIT-tagged smolts analyzed in the CSS. The primary focus of comparisons was between the transported and in-river smolts. Key parameters for these comparisons were $SAR(T_0)$, $SAR(C_0)$, $SAR(C_1)$, S_R , TIR , and D . A combination of factors in 2001, such as exceptional environmental conditions, low in-river survival, hydrosystem operations which maximized transportation of smolts, and holdover of steelhead smolts, resulted in very few C_0 migrants. Due to these conditions, 2001 data is presented separately for comparison to other years in the multi-year geometric averages computed for S_R , TIR , and D .

The total PIT-tags released and analyzed for wild Chinook, hatchery Chinook, wild steelhead, and hatchery steelhead are presented in Appendix D Tables D-1, D-2, D-3, and D-4, respectively. The number of PIT-tagged smolts transported at LGR, LGS, and LMN (*i.e.*, capture histories X_{12} , X_{102} , and X_{1002}), and corresponding adult returns, are presented in Tables D-45 to D-47. A complete listing of parameter estimation results based on both the computational and expectation formulas are presented in Appendix E for all fish analyzed.

Wild Chinook

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

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

Estimated LGR-LGR SARs for PIT-tagged wild Chinook were generally low, exceeding 2% in only 3 of 11 years for the $SAR(C_0)$ and in only one for the $SAR(T_0)$ (Table 3.1 and Figure 3.1). Wild Chinook survival levels are far below those recommended as minimal to maintain a stable population (2%) or to achieve recovery (4% -- Marmorek et al. 1998). The estimated SARs were exceptionally low (<0.6%) for both the $SAR(C_0)$ and $SAR(T_0)$ in 5 of 11 years and for the $SAR(C_0)$ in 2001. Over the 11-year migration period 1994 through 2004, there was not a consistent pattern of relative performance for $SAR(T_0)$ and $SAR(C_0)$. $SAR(C_0)$ was greater than $SAR(T_0)$ in six years and the 90% confidence intervals were overlapping in all years except

2001. Relative to the 11-year average SAR(C₀) of wild Chinook that passed the three collector dams undetected, a 3% lower transportation average SAR(T₀) and 27% lower bypass average SAR(C₁) was estimated (Table 3.1).

Table 3.1. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
1994	0.45 (0.20 – 0.72)	0.28 (0.11 – 0.51)	0.07 (0.02 – 0.14)
1995	0.35 (0.17 – 0.57)	0.37 (0.18 – 0.57)	0.25 (0.18 – 0.32)
1996	0.50 (0.00 – 1.07)	0.26 (0.10 – 0.48)	0.13 (0.06 – 0.23)
1997	1.74 (0.44 – 3.27)	2.35 (1.45 – 3.36)	0.93 (0.60 – 1.32)
1998	1.18 (0.71 – 1.70)	1.36 (1.05 – 1.70)	1.07 (0.91 – 1.22)
1999	2.43 (1.85 – 3.07)	2.13 (1.78 – 2.50)	1.89 (1.76 – 2.04)
2000	1.43 (0.74 – 2.14)	2.39 (2.08 – 2.72)	2.33 (2.12 – 2.52)
2001	1.28 (0.54 – 2.14)	Assume = SAR(C ₁)	0.14 (0.10 – 0.18)
2002	0.80 (0.57 – 1.04)	1.22 (0.99 – 1.45)	0.99 (0.84 – 1.14)
2003	0.34 (0.24 – 0.45)	0.33 (0.23 – 0.43)	0.17 (0.12 – 0.24)
2004 ^A	0.30 (0.22 – 0.39)	0.31 (0.13 – 0.52)	0.18 (0.13 – 0.24)
Average	0.98	1.01	0.74
Std Error	0.209	0.275	0.236
90% CI	(0.60 – 1.36)	(0.51 – 1.51)	(0.31 – 1.17)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

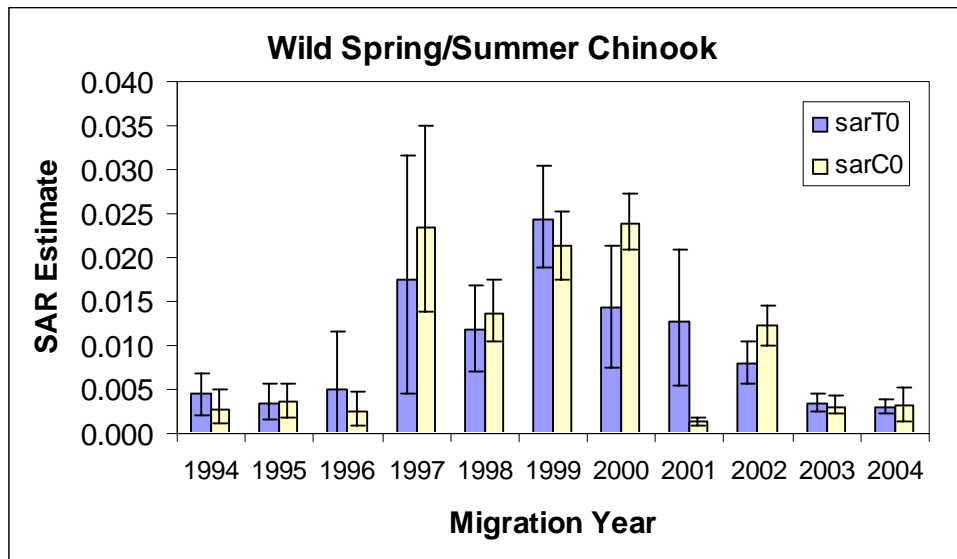


Figure 3.1. Estimated LGR-LGR SAR for PIT-tagged wild Chinook aggregate in transport [SAR(T₀)] and in-river [SAR(C₀)] study categories for migration years 1994 to 2004 (incomplete adult returns for 2004).

The estimated in-river survival (S_R) for migration from LGR tailrace to BON tailrace had considerable annual variability (Table D-21), and a geometric mean of 0.46. The annual trend in S_R for wild Chinook is presented in Figure 3.7 and discussed later when comparisons are made to CSS PIT-tagged hatchery Chinook.

The *TIR* is a measure of the relative annual performance for the transported T_0 and in-river C_0 smolts. Due to the T_0 smolts having an average survival through the juvenile traversal of the hydrosystem about twice that of the C_0 smolts (0.98% versus 0.46%), the *TIR* for wild Chinook should have an “expected value” of approximately 2.0, under the hypothesis that there is no delayed mortality specific to transportation.. The estimated *TIR*'s for wild Chinook (Table D-21) had a range of 0.60 to 1.92 and geometric mean of 0.99 for the 10-yr series without 2001, and exceeds 2 only in 2001. The 90% confidence intervals of *TIR* tend to be large due to small numbers of adult returns. The annual trend in *TIR* for wild Chinook is presented in Figure 3.8 and discussed later when comparisons are made to CSS PIT-tagged hatchery Chinook.

A *TIR*>1, which indicates a positive effect for transportation, was estimated in five of the 11 years for wild Chinook (Table 3.2). However, the lower limit of the 90% confidence interval for *TIR* exceeded 1 only in 2001. Except for 2001 when there was a substantial *TIR*~ 9 estimated (with statistical significance achieved), the remaining years of PIT-tag data for wild Chinook show a pattern whereby the benefits of transportation are uncertain.

In the absence of differential delayed mortality of transported fish post-BON compared to in-river migrants, the geometric mean of *D* should approximate 1. However, for wild Chinook, the 10-yr geometric mean (excluding 2001) of *D* was 0.49, while the 2001 *D* estimate was slightly greater than 2. It should be noted that the 90% confidence intervals around the estimated *D* show low precision in most years, indicating the difficulty of getting precise *D* estimates with the observed SARs and sample sizes of PIT-tagged wild Chinook available. Table 3.3 shows a statistically significant *D*>1 was not achieved in 2001 for wild Chinook, despite a statistically significant *TIR* in that year. The annual trend in *D* for wild Chinook is presented in Figure 3.9 and discussed later when comparisons are made to CSS PIT-tagged hatchery Chinook.

Table 3.2. Estimated *TIR* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating *TIR* >1 are highlighted in bold (red).

Migr. Year	Wild Chinook		Hatchery Spring Chinook					
			Rapid River H		Dworshak H		Catherine Ck AP	
	<i>TIR</i>	LL	<i>TIR</i>	LL	<i>TIR</i>	LL	<i>TIR</i>	LL
1994	1.62	0.62						
1995	0.95	0.39						
1996	1.92	0.00						
1997	0.74	0.17	1.73	1.08	1.75	0.92		
1998	0.87	0.50	1.66	1.32	0.72	0.59		
1999	1.14	0.82	1.28	1.11	0.99	0.81		
2000	0.60	0.32	1.32	1.13	0.99	0.82		
2001	8.96	3.61	21.7	13.3	8.76	5.04	5.33	0.00
2002	0.65	0.45	1.5	1.20	1.24	0.93	1.81	1.02
2003	1.05	0.69	1.07	0.70	1.20	0.82	1.44	0.60
2004	0.97	0.53	1.79	0.94	0.95	0.60	1.75	0.00

Table 3.3. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).

Migr. Year	Wild Chinook		Hatchery Spring Chinook					
			Rapid River H		Dworshak H		Catherine Ck AP	
	D	LL	D	LL	D	LL	D	LL
1994	0.36	0.13						
1995	0.42	0.17						
1996	0.92	0.00						
1997	0.40	0.08	0.61	0.37	0.88	0.40		
1998	0.55	0.31	1.01	0.80	0.37	0.30		
1999	0.72	0.52	0.79	0.65	0.60	0.47		
2000	0.32	0.17	0.82	0.66	0.53	0.42		
2001	2.16	0.87	7.33	4.40	2.21	1.23	1.38	0.03
2002	0.44	0.29	1.14	0.87	0.84	0.61	1.23	0.59
2003	0.68	0.43	0.75	0.48	0.87	0.58	0.93	0.38
2004	0.40	0.21	0.65	0.32	0.49	0.29	0.59	0.00

Hatchery Chinook

Estimated numbers of hatchery Chinook smolts in each study category are presented in Tables D-6 to D-10 for fish from Rapid River, Dworshak, Catherine Creek, McCall, and Imnaha hatcheries, respectively, along with the estimated population of tagged fish arriving at Lower Granite Dam. The table provides a bootstrapped 90% confidence interval around each estimate, along with the number of returning adults in each study category.

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

The estimated LGR-LGR SAR for hatchery Chinook were low for the SAR(C_0) and generally less than or equal to wild Chinook (Tables D-13 to D-18 and Figure 3.2 [top plot]). Whereas, SAR(T_0) was not as low in general for hatchery Chinook and, except for Dworshak Hatchery, tended to be greater than the wild Chinook (Figure 3.2 [lower plot]).

There is considerable within-year variability in SAR performance between hatchery Chinook populations (Figure 3.2). However, the between-year variability is generally similar between hatcheries, as well as between hatchery groups in the aggregate and wild Chinook. The aggregate hatchery groups appear to have the potential for surrogate representation of the wild Chinook regarding annual survival rate trends, but not in the magnitude of survival rates.

The SARs for the PIT-tagged hatchery Chinook are generally in the same range as the PIT-tagged wild Chinook for the C_0 smolts. McCall hatchery summer Chinook are the only hatchery population with an average SAR(C_0) equal to wild Chinook, all others exhibit lower

SAR(C_0) values (Figure 3.2 top). SARs for the hatchery T_0 smolts had mixed performance relative to wild T_0 smolts (Figure 3.2 bottom). Two hatcheries (Dworshak and Catherine Creek) exhibited lower T_0 than wild smolts. The other three hatcheries (Rapid River, McCall, and Imnaha) exhibited greater T_0 than wild smolts. The C_1 category for the hatchery smolts had average SARs that were lower than the C_0 SARs for all hatcheries except Catherine Creek (Tables 3.4 to 3.8).

Relative to the 8-year average SAR(C_0) of hatchery Chinook that passed the three collector dams undetected, the following percent difference in transportation average SAR(T_0) and bypass average SAR(C_1) was estimated for hatcheries with eight years of SAR data (Tables 3.4, 3.5, 3.7, and 3.8):

<u>Hatchery</u>	<u>Transport T_0</u>	<u>Bypass C_1</u>
Rapid River	+ 57%	-24%
Dworshak	+10%	-20%
McCall	+76%	-15%
Imnaha	+57%	-23%

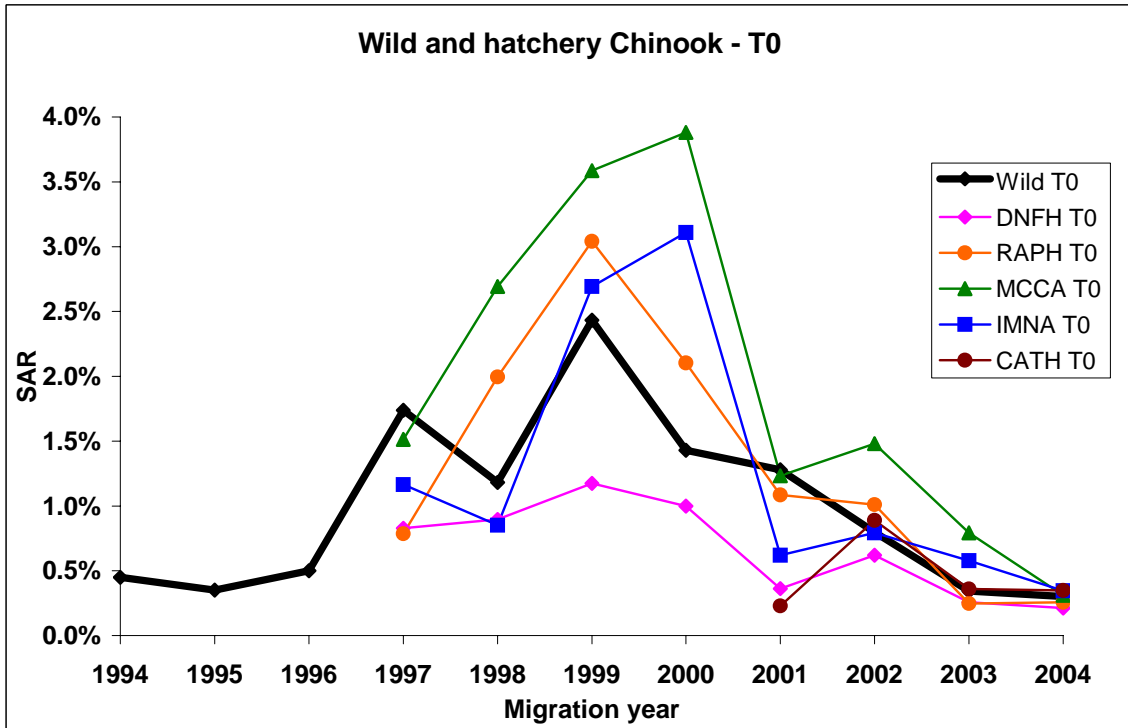
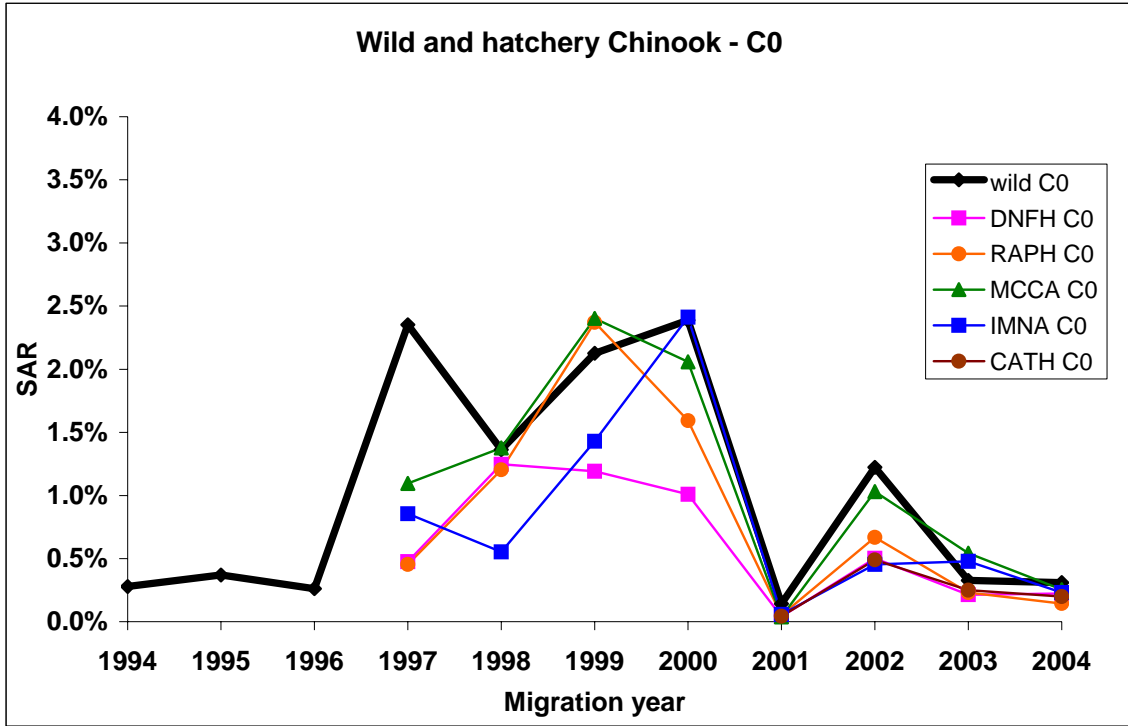


Figure 3.2 Trend in SAR(C₀) (top plot) and SAR(T₀) (bottom plot) for PIT-tagged Snake River wild and hatchery spring/summer Chinook in migration years 1994 to 2004 (see Tables D-13 to D-18 for 90% confidence intervals).

Table 3.4. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
1997	0.79 (0.57 – 1.01)	0.45 (0.31 – 0.63)	0.53 (0.39 – 0.68)
1998	2.00 (1.80 – 2.21)	1.20 (0.95 – 1.48)	0.67 (0.56 – 0.79)
1999	3.04 (2.78 – 3.31)	2.37 (2.07 – 2.68)	1.63 (1.46 – 1.79)
2000	2.10 (1.91 – 2.28)	1.59 (1.40 – 1.81)	1.33 (1.07 – 1.58)
2001	1.08 (0.96 – 1.21)	{Assume =SAR(C ₁)}	0.05 (0.02 – 0.08)
2002	1.01 (0.86 – 1.16)	0.67 (0.55 – 0.79)	0.63 (0.53 – 0.74)
2003	0.25 (0.17 – 0.32)	0.23 (0.17 – 0.29)	0.16 (0.08 – 0.24)
2004 ^A	0.26 (0.20 – 0.31)	0.14 (0.05 – 0.26)	0.09 (0.05 – 0.13)
Average	1.32	0.84	0.64
Std_error	0.375	0.289	0.205
90% CI	(0.61 – 2.03)	(0.29 – 1.39)	(0.25 – 1.03)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

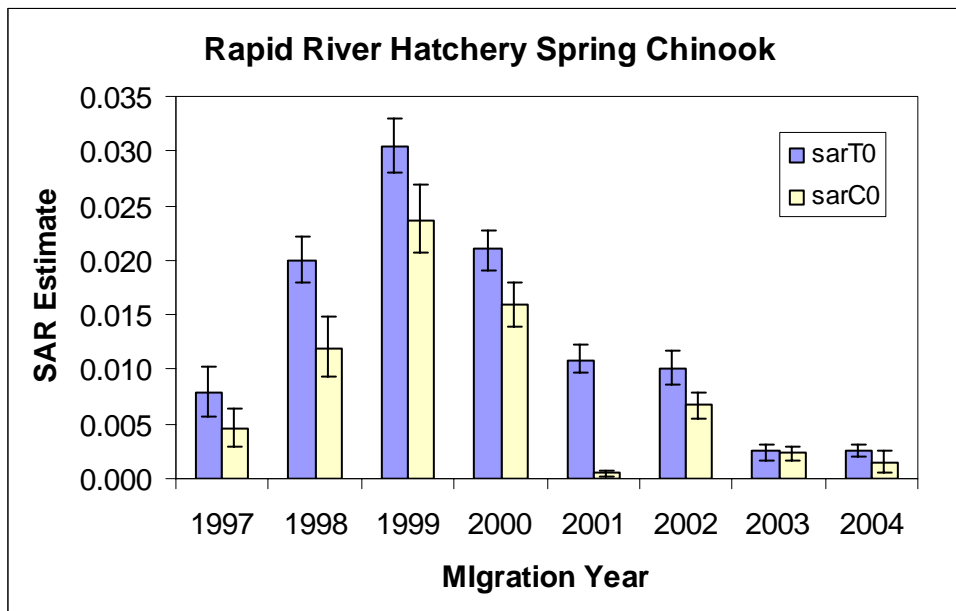


Figure 3.3. Trend in estimated transport and in-river SARs for Rapid River Hatchery spring Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).

Table 3.5. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
1997	0.83 (0.52 – 1.19)	0.47 (0.26 – 0.72)	0.36 (0.21 – 0.54)
1998	0.90 (0.77 – 1.02)	1.25 (1.08 – 1.42)	0.90 (0.77 – 1.04)
1999	1.18 (1.01 – 1.35)	1.19 (1.01 – 1.37)	0.95 (0.82 – 1.07)
2000	1.00 (0.88 – 1.12)	1.01 (0.87 – 1.16)	0.81 (0.62 – 1.02)
2001	0.36 (0.29 – 0.43)	{ Assume =SAR(C ₁)} 0.50 (0.42 – 0.58)	0.04 (0.02 – 0.07)
2002	0.62 (0.49 – 0.75)	0.50 (0.42 – 0.58)	0.50 (0.40 – 0.58)
2003	0.26 (0.19 – 0.33)	0.21 (0.16 – 0.27)	0.18 (0.10 – 0.27)
2004 ^A	0.21 (0.16 – 0.27)	0.22 (0.13 – 0.32)	0.16 (0.11 – 0.21)
Average	0.67	0.61	0.49
Std_error	0.129	0.168	0.127
90% CI	(0.43 – 0.91)	(0.29 – 0.93)	(0.25 – 0.73)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

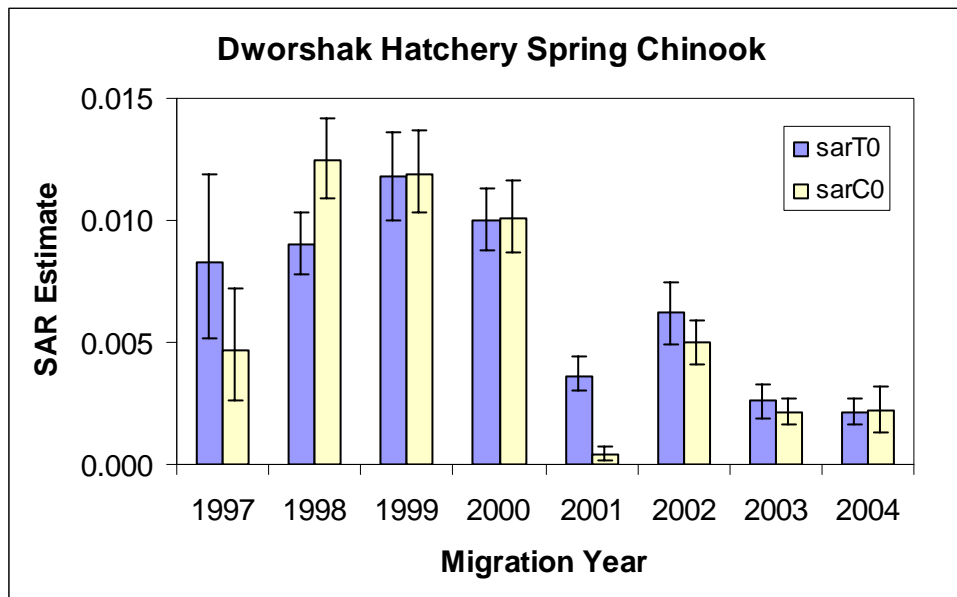


Figure 3.4. Estimated transport and in-river SARs for PIT-tagged Dworshak Hatchery spring Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).

Table 3.6. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 2001 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
2001	0.23 (0.12 – 0.35)	{Assume =SAR(C ₁)}	0.04 (0.00 – 0.09)
2002	0.89 (0.59 – 1.20)	0.49 (0.28 – 0.74)	0.32 (0.18 – 0.50)
2003	0.36 (0.17 – 0.59)	0.25 (0.12 – 0.41)	0.36 (0.14 – 0.64)
2004 ^A	0.35 (0.17 – 0.55)	0.20 (0.00 – 0.61)	0.32 (0.11 – 0.56)
Average	0.46	0.25	0.26
Std_error	0.147	0.093	0.074
90% CI	(0.11 – 0.81)	(0.03 – 0.47)	(0.09 – 0.43)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

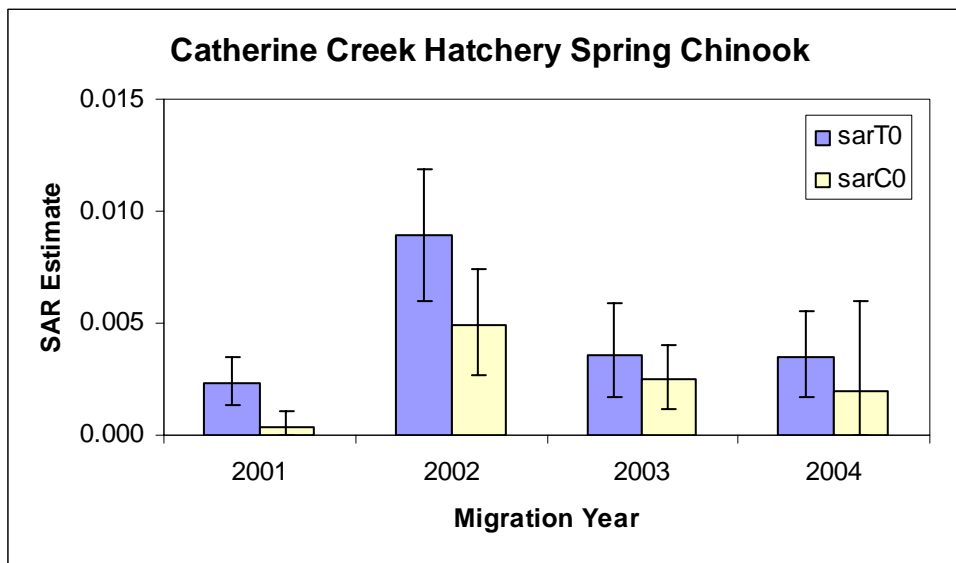


Figure 3.5. Estimated transport and in-river SARs for PIT-tagged Catherine Creek Acclimation Pond spring Chinook for migration years 2001 to 2004 (incomplete adult returns for 2004).

Table 3.7. Estimated SAR_{LGR-10-LGR} (%) for PIT-tagged summer Chinook from McCall Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
1997	1.51 (1.26 – 1.77)	1.09 (0.88 – 1.34)	1.10 (0.92 – 1.29)
1998	2.69 (2.44 – 2.96)	1.38 (1.05 – 1.69)	0.73 (0.62 – 0.87)
1999	3.59 (3.29 – 3.87)	2.40 (2.12 – 2.69)	2.03 (1.82 – 2.26)
2000	3.88 (3.60 – 4.18)	2.06 (1.84 – 2.29)	2.03 (1.68 – 2.38)
2001	1.24 (1.10 – 1.38)	{ Assume =SAR(C ₁)} 0.04 (0.01 – 0.07)	0.04 (0.01 – 0.07)
2002	1.48 (1.27 – 1.70)	1.03 (0.87 – 1.20)	1.02 (0.89 – 1.18)
2003	0.79 (0.68 – 0.91)	0.54 (0.46 – 0.63)	0.35 (0.25 – 0.45)
2004 ^A	0.31 (0.24 – 0.38)	0.25 (0.09 – 0.43)	0.12 (0.07 – 0.16)
Average	1.94	1.10	0.93
Std_error	0.461	0.294	0.277
90% CI	(1.07 – 2.81)	(0.54 – 1.66)	(0.41 – 1.45)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

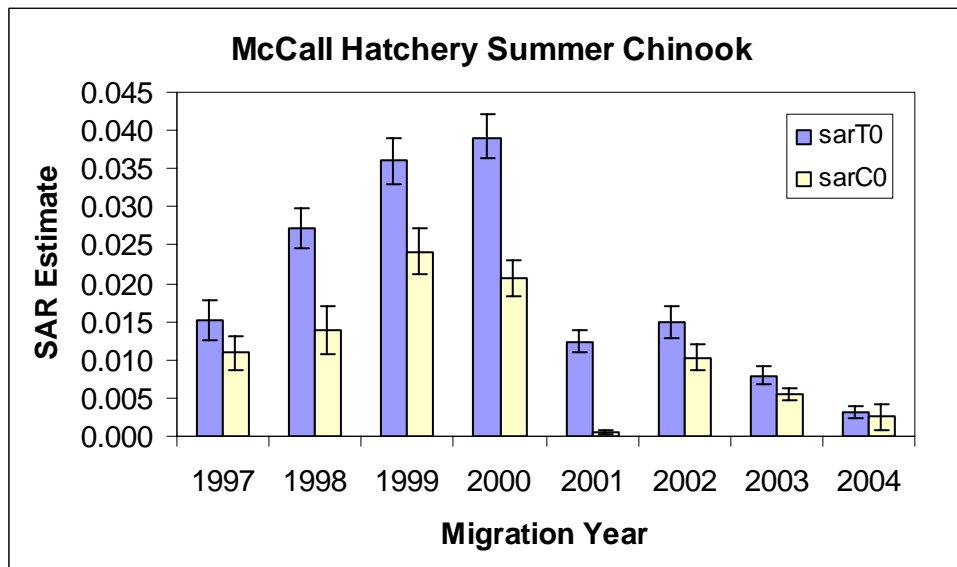


Figure 3.6. Estimated transport and in-river SARs for PIT-tagged McCall Hatchery summer Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).

Table 3.8. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged summer Chinook from Imnaha River AP for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR(T ₀) %	SAR(C ₀) %	SAR(C ₁) %
1997	1.16 (0.77 – 1.60)	0.86 (0.53 – 1.22)	0.69 (0.48 – 0.93)
1998	0.85 (0.65 – 1.09)	0.55 (0.28 – 0.83)	0.30 (0.20 – 0.42)
1999	2.69 (2.28 – 3.08)	1.43 (1.08 – 1.82)	1.22 (0.98 – 1.49)
2000	3.11 (2.77 – 3.44)	2.41 (2.01 – 2.83)	1.64 (1.22 – 2.08)
2001	0.62 (0.49 – 0.78)	{Assume =SAR(C ₁)}	0.06 (0.01 – 0.11)
2002	0.79 (0.56 – 1.04)	0.45 (0.29 – 0.63)	0.55 (0.38 – 0.72)
2003	0.58 (0.41 – 0.74)	0.48 (0.34 – 0.62)	0.38 (0.20 – 0.55)
2004 ^A	0.35 (0.23 – 0.47)	0.23 (0.07 – 0.46)	0.11 (0.04 – 0.20)
Average	1.27	0.81	0.62
Std_error	0.368	0.272	0.196
90% CI	(0.57 – 1.97)	(0.29 – 1.33)	(0.25 – 0.99)

^A Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

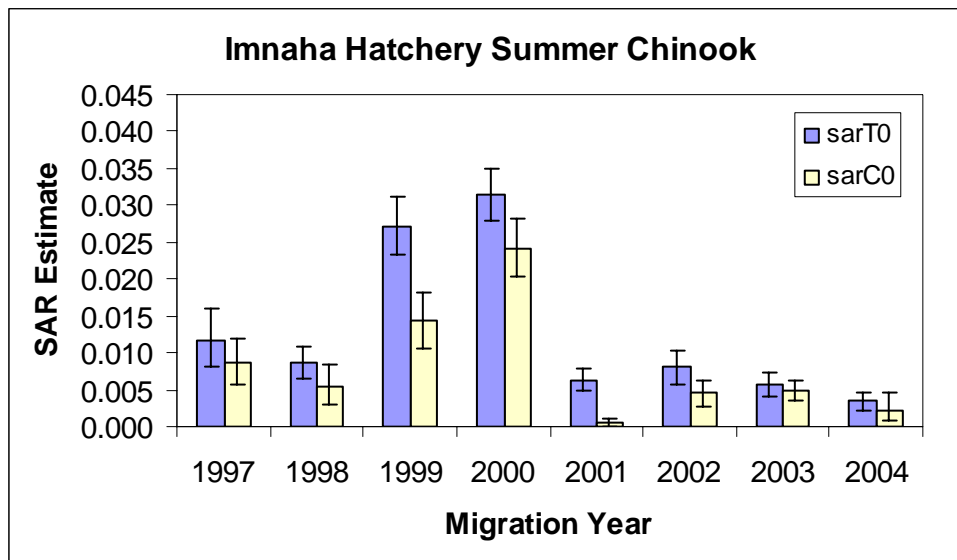


Figure 3.7. Estimated transport and in-river SARs for PIT-tagged Imnaha River Acclimation Pond summer Chinook for migration years 1997 to 2004 (incomplete adult returns for 2004).

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

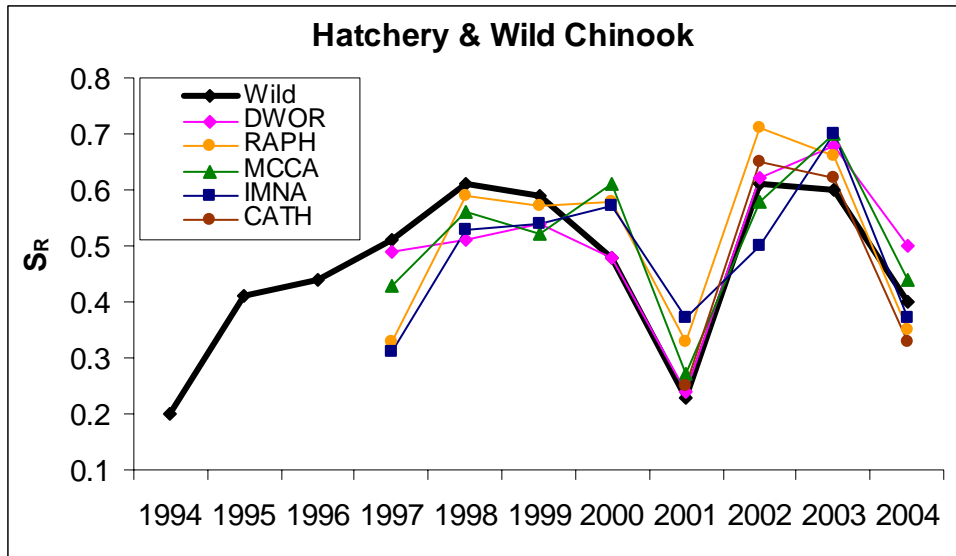


Figure 3.8. Trend in in-river survival (S_R) for PIT-tagged Snake River wild and hatchery spring/summer Chinook in migration years 1994 to 2004 (see Tables D-21 to D-26 for 90% confidence intervals).

TIR had substantial variability between hatcheries and between years. Excluding migration year 2001, which had *TIR*s exceeding 5 in all hatchery groups, geometric mean *TIR*s covering the seven years from 1997-2000 and 2002-2004 have been around 1.5 for Rapid River, Imnaha, and McCall Hatchery Chinook (Tables D-22, D-26, and D-25, respectively). For Dworshak Hatchery Chinook, the 7-yr geometric mean *TIR* was less than 1.1 (Table D-23). Although Catherine Creek AP hatchery Chinook have a shorter time series of data (Table D-24), this stock's *TIR*s tend to follow the former three hatcheries closer than Dworshak Hatchery. Trends in *TIR* (log transformed) are presented in Figure 3.9.

The geometric means of annual *TIR*s for all hatchery Chinook were > 1 for the seven years 1997 to 2004, excluding 2001. In 2001, all hatchery Chinook *TIR*s were very large as illustrated in Figure 3.9. For the 7 years without 2001, Dworshak Hatchery had the lowest geometric mean *TIR* (1.08), and was the only hatchery with annual *TIR* < 1 (Tables D-22 to D-26; Tables 3.9 and 3.10; Figure 3.9 with $\ln(TIR) < 0$). Twenty-seven of thirty-one *TIR* estimates for hatchery Chinook groups were > 1 . In addition, the lower limit of the 90% confidence interval for *TIR* exceeded 1 in 19 of these 31 *TIR* estimates, demonstrating a statistical significance (Tables 3.9 and 3.10). The hatchery breakdown of the statistically significant *TIR* > 1 was Rapid River Hatchery in 6 of 8 years, Dworshak Hatchery in 1 of 8 years, Catherine Ck Hatchery in 1 of 4 years, McCall Hatchery in 7 of 8 years, and Imnaha Hatchery in 4 of 8 years. For hatchery spring/summer Chinook smolts, transportation was generally beneficial and smolt transport was highly beneficial in 2001 with *TIR* > 5 at each hatchery (Tables 3.9 and 3.10). However, the generally lower annual *TIR*s for Dworshak Hatchery suggest a more limited benefit of transportation for that stock.

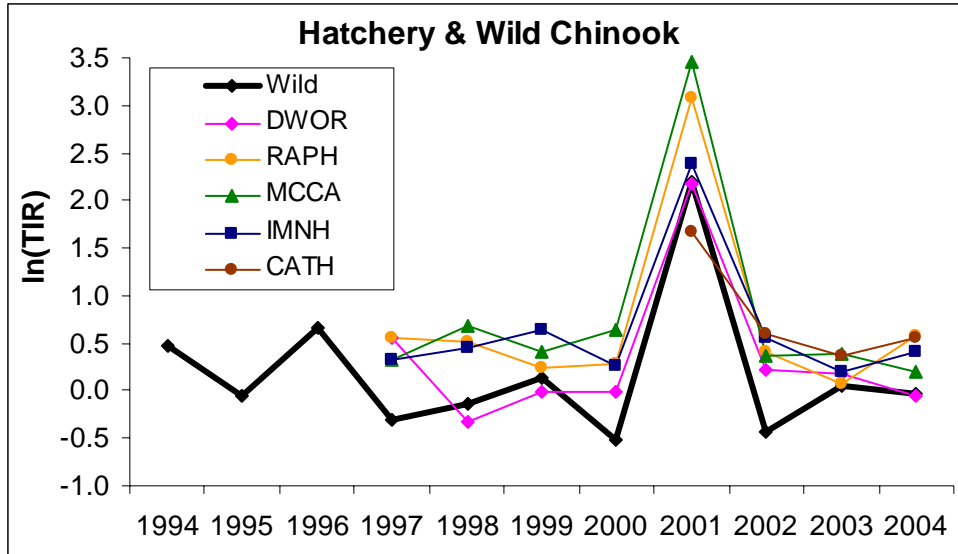


Figure 3.9. Trend in *TIR* (log-transformed) for PIT-tagged Snake river hatchery and wild Chinook for migration years 1994 to 2004 (see Tables D-21 to D-26 for 90% confidence intervals).

Table 3.9. Estimated *TIR* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook.

Migr. Year	Wild Chinook		Hatchery Spring Chinook					
	<i>TIR</i>	LL	Rapid River H		Dworshak H		Catherine Ck AP	
			<i>TIR</i>	LL	<i>TIR</i>	LL	<i>TIR</i>	LL
1994	1.62	0.62						
1995	0.95	0.39						
1996	1.92	0.00						
1997	0.74	0.17	1.73	1.08	1.75	0.92		
1998	0.87	0.50	1.66	1.32	0.72	0.59		
1999	1.14	0.82	1.28	1.11	0.99	0.81		
2000	0.60	0.32	1.32	1.13	0.99	0.82		
2001	8.96	3.61	21.7	13.3	8.76	5.04	5.33	0.00
2002	0.65	0.45	1.5	1.20	1.24	0.93	1.81	1.02
2003	1.05	0.69	1.07	0.70	1.20	0.82	1.44	0.60
2004	0.97	0.53	1.79	0.94	0.95	0.60	1.75	0.00

Table 3.10. Estimated *TIR* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to hatchery summer Chinook. Point estimates and lower limits indicating *TIR* >1 are highlighted in bold (red).

Migr. Year	Wild Chinook		Hatchery Summer Chinook			
	<i>TIR</i>	LL	McCall H		Imnaha AP	
			<i>TIR</i>	LL	<i>TIR</i>	LL
1994	1.62	0.62				
1995	0.95	0.39				
1996	1.92	0.00				
1997	0.74	0.17	1.38	1.06	1.36	0.83
1998	0.87	0.50	1.96	1.54	1.55	0.93
1999	1.14	0.82	1.49	1.29	1.89	1.40
2000	0.60	0.32	1.89	1.67	1.29	1.06
2001	8.96	3.61	31.9	7.90	10.8	4.94
2002	0.65	0.45	1.44	1.18	1.75	1.07
2003	1.05	0.69	1.46	1.17	1.21	0.79
2004	0.97	0.53	1.23	0.66	1.50	0.48

In the absence of differential delayed mortality, geometric mean *D* should be close to 1. However, except for 2001 when estimated *D* was greater than 1 at each hatchery, the remaining years have seen a 7-yr geometric mean *D* of 0.62 at Dworshak Table D-23), 0.78 at Imnaha (Table D-26), 0.81 at Rapid River (Table D-22), and 0.88 at McCall (Table D-25) hatcheries. A statistically significant *D* > 1 was demonstrated in 2001 for Chinook from Rapid River, Dworshak, McCall, and Imnaha hatcheries (Tables 3.11 and 3.12). Trends in *D* (log transformed) are presented in Figure 3.10.

Table 3.11. Estimated *D* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery spring Chinook. Point estimates and lower limits indicating *D* >1 are highlighted in bold (red).

Migr. Year	Wild Chinook		Hatchery Spring Chinook					
	<i>D</i>	LL	Rapid River H		Dworshak H		Catherine Ck AP	
			<i>D</i>	LL	<i>D</i>	LL	<i>D</i>	LL
1994	0.36	0.13						
1995	0.42	0.17						
1996	0.92	0.00						
1997	0.40	0.08	0.61	0.37	0.88	0.40		
1998	0.55	0.31	1.01	0.80	0.37	0.30		
1999	0.72	0.52	0.79	0.65	0.60	0.47		
2000	0.32	0.17	0.82	0.66	0.53	0.42		
2001	2.16	0.87	7.33	4.40	2.21	1.23	1.38	0.03
2002	0.44	0.29	1.14	0.87	0.84	0.61	1.23	0.59
2003	0.68	0.43	0.75	0.48	0.87	0.58	0.93	0.38
2004	0.40	0.21	0.65	0.32	0.49	0.29	0.59	0.00

Table 3.12. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to hatchery summer Chinook. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).

Migr. Year	Wild Chinook		Hatchery Summer Chinook			
	D	LL	McCall H		Imnaha AP	
			D	LL	D	LL
1994	0.36	0.13				
1995	0.42	0.17				
1996	0.92	0.00				
1997	0.40	0.08	0.64	0.43	0.45	0.24
1998	0.55	0.31	1.16	0.89	0.87	0.51
1999	0.72	0.52	0.87	0.72	1.11	0.75
2000	0.32	0.17	1.24	0.98	0.82	0.56
2001	2.16	0.87	8.95	4.87	4.15	1.83
2002	0.44	0.29	0.87	0.68	0.95	0.54
2003	0.68	0.43	1.08	0.85	0.91	0.58
2004	0.40	0.21	0.55	0.30	0.58	0.15

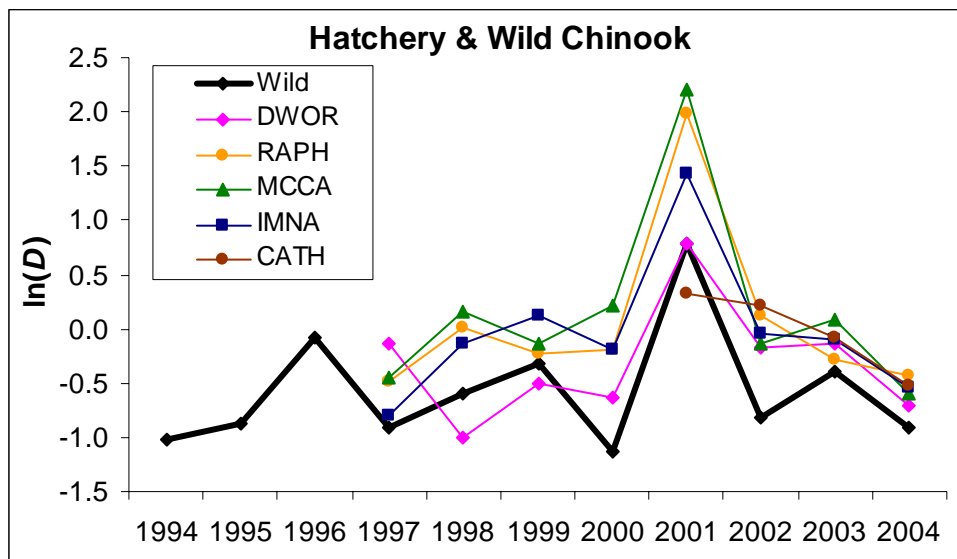


Figure 3.10. Trend in D (log-transformed) for PIT-tagged Snake River hatchery and wild Chinook in migration years 1994-2004 (see Tables D-21 to D-26 for 90% confidence intervals).

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

had higher D values than wild fish, but wild and hatchery D s also tracked well across years (Figure 3.10).

Wild steelhead

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

Obtaining a valid estimate of the number of PIT-tagged wild steelhead in Category C_0 in 2001 is problematic due to the apparently large amount of residualism that year. Most in-river migrants with an adult return were actually detected as smolts in the lower river in 2002 (e.g., six of the eight adult returns of Category C_1 wild steelhead from migration year 2001 were detected in the lower river in 2002). For the three PIT-tagged wild steelhead adult returns with no detection in 2001, it was more likely that these fish either completed their smolt migration in 2002 or passed undetected into the raceways during a computer outage in mid-May at LGR than that they traversed the entire hydrosystem undetected in 2001, when <1% of the wild steelhead run-at-large was estimated to be “destined” to ever pass all three Snake River collector dams through turbines (no spill route available). Because of the uncertainty in passage route and timing of the undetected PIT-tagged wild steelhead smolts in 2001, the in-river SAR of C_1 fish rather than C_0 fish was used in comparisons with the transported fish (T_0) SAR that year. The SARs for group C_0 PIT-tagged wild steelhead were generally low for the (average 0.9%) and never exceed 2% (Table 3.13). The SARs for the T_0 groups were greater (average 2%) and exceeded 2% in four of the seven years analyzed (1999 -2003). Relative to the 7-year average SAR(C_0) of wild steelhead that passed the three collector dams undetected, a 138% higher transportation average SAR(T_0) and 27% lower bypass average SAR(C_1) was estimated. The sample sizes for wild steelhead have been small, which results in few adult returns and rather large 90% confidence intervals for the SAR estimates (Table 3.13 and Figure 3.11).

Table 3.13. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	SAR(T ₀)	SAR(C ₀)	SAR(C ₁)
1997	1.45 (0.36 – 2.80)	0.66 (0.0 – 1.34)	0.23 (0.10 – 0.39)
1998	0.21 (0.0 – 0.63)	1.07 (0.51 – 1.73)	0.21 (0.12 – 0.33)
1999	3.07 (1.74 – 4.66)	1.35 (0.80 – 1.96)	0.76 (0.60 – 0.94)
2000	2.79 (1.55 – 4.11)	1.92 (1.40 – 2.49)	1.81 (1.59 – 2.03)
2001	2.49 (0.93 – 4.37)	{ Assume =SAR(C ₁) }	0.07 (0.03 – 0.10)
2002	2.84 (1.52 – 4.43)	0.67 (0.46 – 0.90)	0.94 (0.77 – 1.11)
2003 ^A	1.99 (1.49 – 2.49)	0.48 (0.30 – 0.68)	0.52 (0.38 – 0.66)
Average	2.12	0.89	0.65
Std_error	0.382	0.231	0.227
90% CI	(1.38 – 2.86)	(0.44 – 1.34)	(0.21 – 1.09)

^A Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

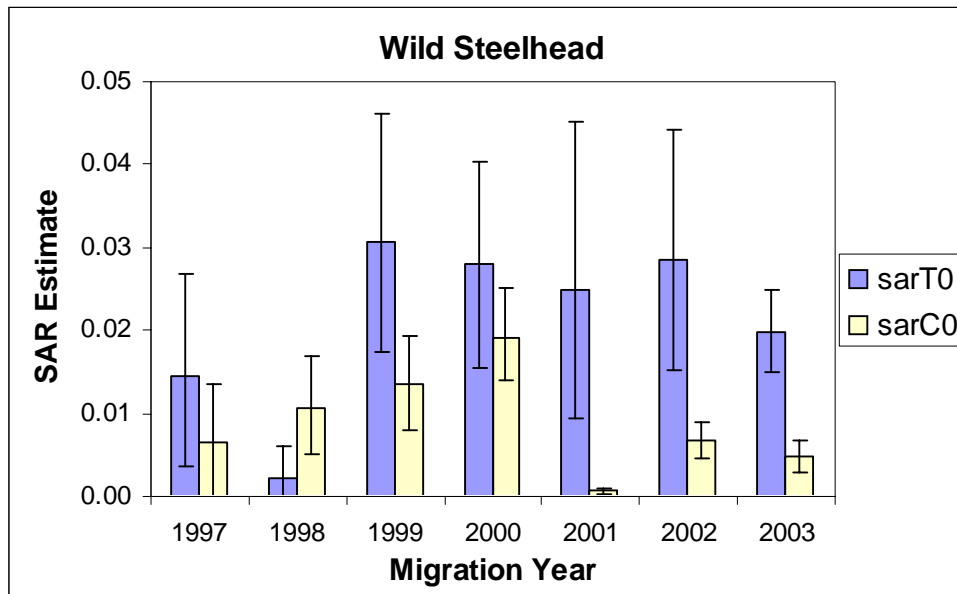


Figure 3.11. Estimated transport and in-river SARs (with 90% confidence intervals) for PIT-tagged wild steelhead aggregate for migration years 1997 to 2003 (incomplete 2003 returns).

For PIT-tagged wild steelhead, the geometric mean of S_R for 1997 to 2003, excluding 2001, was 0.44 (Table D-27). In 2001, the estimated S_R is very low (0.038) as it includes both dead and holdover steelhead as mortalities. Over these same six years, the wild Chinook S_R estimates had a geometric mean of 0.56, which was 27% higher. The individual reach survival estimates for each migration year used to obtain S_R are presented in Table D-37. Figure 3.12 shows the trend in annual S_R estimates for wild steelhead compared to wild Chinook for 1997-2003.

The TIR estimates for wild steelhead, though based on small sample sizes, were generally >1 , with a geometric mean of 1.72 for 1997 to 2003, excluding 2001. The 2001 TIR estimate was very high (~ 37), due to exceptionally low in-river wild steelhead survival in that drought

year. The 1998 migration year was the only year with estimated $TIR < 1$, and across the seven years analyzed, the lower limit of the 90% confidence interval for TIR was > 1 in four years (1999 and 2001-2003), which demonstrates a statistical significance for those years (Table 3.14). For PIT-tagged wild steelhead smolts, transportation was generally beneficial and smolt transportation was highly beneficial in 2001 (Table 3.14). From 1999 to 2003, PIT-tagged wild steelhead exhibited a similar trend in TIR across years to that of PIT-tagged wild Chinook, but with a higher magnitude in TIR for each of these years (Figure 3.13).

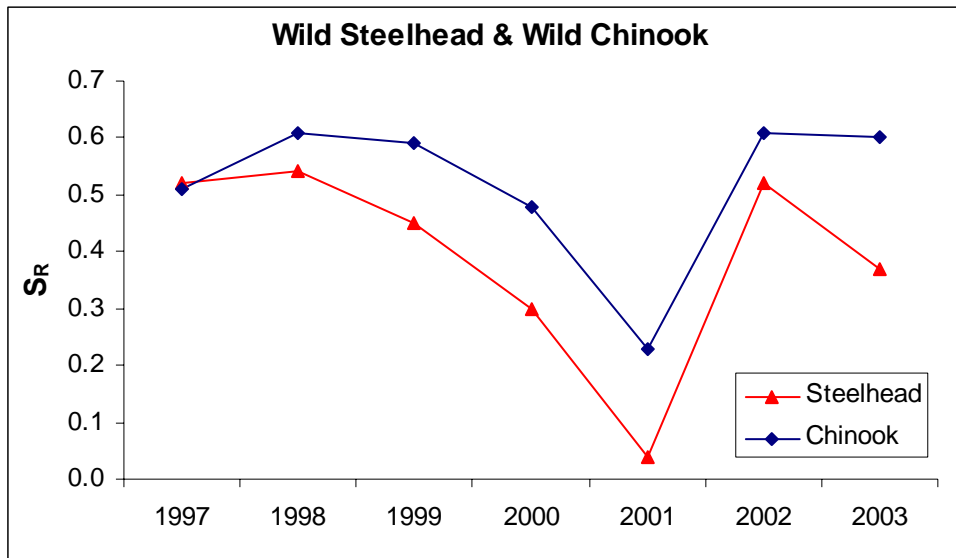


Figure 3.12. Trend in in-river survival (S_R) for PIT-tagged Snake River wild steelhead and wild Chinook for migration years 1997 to 2003 (see Tables D-21 and D-27 for 90% confidence intervals).

Table 3.14. Estimated TIR and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. Point estimates and lower limits indicating $TIR > 1$ are highlighted in bold (red).

Migr. Year	Wild Chinook		Wild Steelhead		Hatchery Steelhead	
	TIR	LL	TIR	LL	TIR	LL
1994	1.62	0.62				
1995	0.95	0.39				
1996	1.92	0.00				
1997	0.74	0.17	2.20	0.00	2.21	0.99
1998	0.87	0.50	0.20	0.00	0.58	0.23
1999	1.14	0.82	2.28	1.15	0.87	0.48
2000	0.60	0.32	1.45	0.77	2.20	1.22
2001	8.96	3.61	37.0	10.6	59.7	0.00
2002	0.65	0.45	4.25	2.12	1.51	0.38
2003	1.05	0.69	4.13	2.62	2.65	1.99

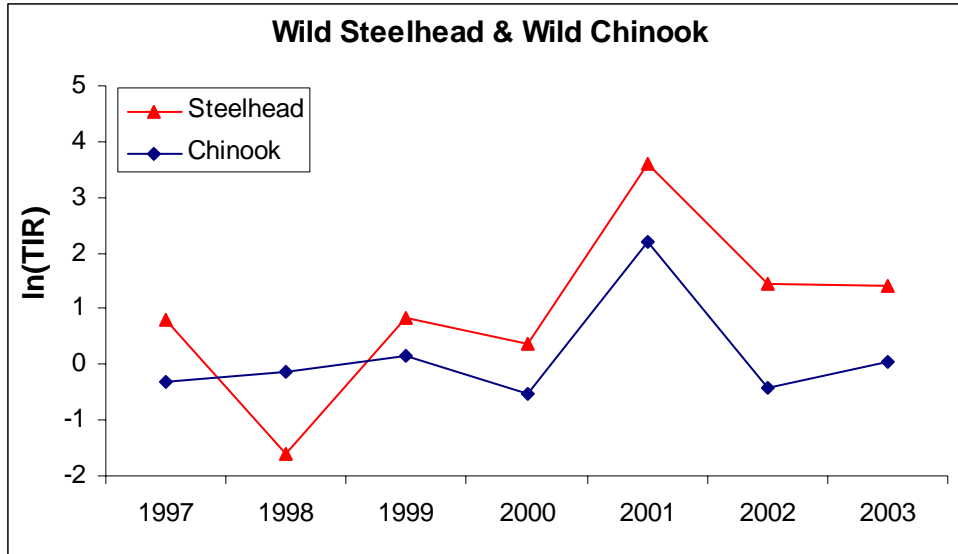


Figure 3.13. Trend in TIR (log transformed) for PIT-tagged wild steelhead and wild Chinook from migration years 1997 to 2003 (see Tables D-21 and D-27 for 90% confidence intervals).

The estimate of D was >1 in five of seven years for wild steelhead (Table 3.15). In two of those years (2002 and 2003), the lower limit of the 90% confidence interval for D was >1 , which demonstrates a statistical significance for those years (Table 3.15). The D estimates for 1997-2000 and 2002-2003 had a geometric mean of 0.80 for wild steelhead and 0.50 for wild Chinook (Tables D-21 and D-27). This finding along with the trend across years shown in Figure 3.14, suggests a very different response to transportation for listed wild Chinook and wild steelhead.

Table 3.15. Estimated D and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. Point estimates and lower limits indicating $D > 1$ are highlighted in bold (red).

Migr. Year	Wild Chinook		Wild Steelhead		Hatchery Steelhead	
	D	LL	D	LL	D	LL
1994	0.36	0.13				
1995	0.42	0.17				
1996	0.92	0.00				
1997	0.40	0.08	1.18	0.00	0.92	0.36
1998	0.55	0.31	0.11	0.00	0.39	0.16
1999	0.72	0.52	1.07	0.53	0.41	0.22
2000	0.32	0.17	0.50	0.27	0.55	0.30
2001	2.16	0.87	1.46	0.40	2.40	0.00
2002	0.44	0.29	2.24	1.09	0.60	0.14
2003	0.68	0.43	1.64	1.01	1.43	1.02

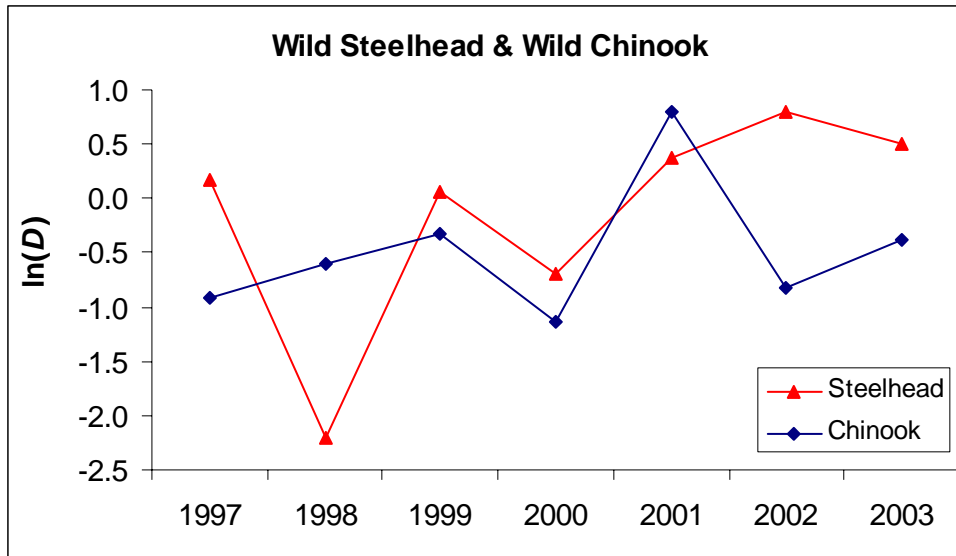


Figure 3.14. Trend in D (log-transformed) for PIT-tagged Snake River wild steelhead and wild Chinook in migration years 1997-2003 (see Tables D-21 and D-27 for 90% confidence intervals).

Hatchery Steelhead

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

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

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

Estimated SARs for hatchery steelhead in-river migrants [$SAR(C_0)$] are exceptionally low (average 0.6%) and exceeded 1% only in 1999 (Table 3.16). The SARs for the transported smolts [$SAR(T_0)$] were also low (average 1%), and exceeded 2% only in 2000. Relative to the 7-year average $SAR(C_0)$ of hatchery steelhead that passed the three collector dams undetected, a 72% higher transportation average $SAR(T_0)$ and 31% lower bypass average $SAR(C_1)$ was estimated (Table 3.16). The pattern of inter-annual variability for SARs was similar for hatchery and wild steelhead (Figures 3.11 and 3.15).

Table 3.16. Estimated $SAR_{LGR-10-LGR}$ (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	$SAR(T_0)$	$SAR(C_0)$	$SAR(C_1)$
1997	0.52 (0.24 – 0.81)	0.24 (0.09 – 0.39)	0.17 (0.12 – 0.22)
1998	0.51 (0.22 – 0.84)	0.89 (0.61 – 1.19)	0.22 (0.17 – 0.28)
1999	0.90 (0.51 – 1.33)	1.04 (0.79 – 1.31)	0.59 (0.51 – 0.69)
2000	2.10 (1.22 – 3.07)	0.95 (0.71 – 1.19)	1.05 (0.92 – 1.18)
2001	0.94 (0.24 – 1.78)	{Assume = $SAR(C_1)$ }	0.016 (0.005 – 0.03)
2002	1.06 (0.32 – 2.11)	0.70 (0.54 – 0.88)	0.73 (0.61 – 0.85)
2003 ^A	1.81 (1.50 – 2.14)	0.68 (0.52 – 0.85)	0.37 (0.26 – 0.47)
Average	1.12	0.65	0.45
Std_error	0.232	0.144	0.137
90% CI	(0.67 – 1.57)	(0.37 – 0.93)	(0.18 – 0.72)

^A Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

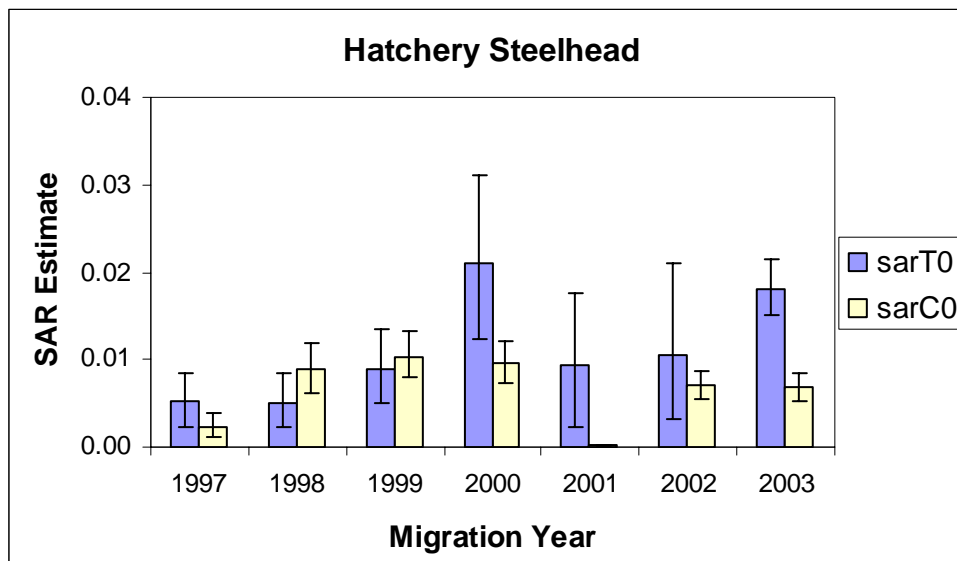


Figure 3.15. Estimated transport and in-river SARs for PIT-tagged hatchery steelhead aggregate for migration years 1997 to 2003 (incomplete adult returns for 2003).

For PIT-tagged hatchery steelhead, the geometric mean of S_R for 1997 to 2003, excluding 2001, was 0.41 (Table D-28), a level close to that estimated for wild steelhead (geometric mean 0.44; Table D-27). In 2001, the estimated S_R is very low (0.038) as it includes both dead and holdover steelhead as mortalities. Both hatchery and wild steelhead had the same estimated magnitude of S_R for 2001. The individual reach survival estimates for each migration year used

to obtain S_R are presented in Table D-38. The trend in annual S_R estimates for wild steelhead compared to hatchery steelhead for 1997-2003 is shown in Figure 3.16.

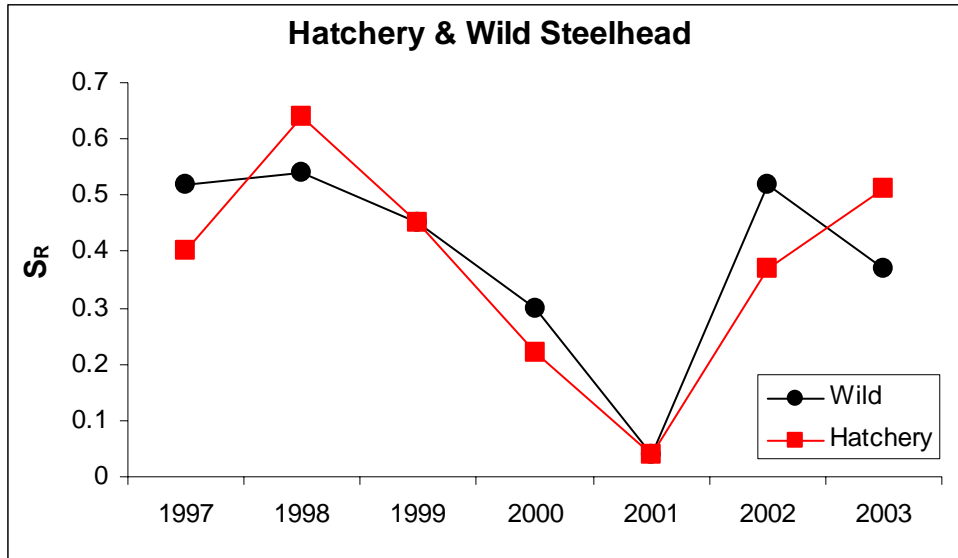


Figure 3.16. Trend in in-river survival (S_R) for PIT-tagged Snake River hatchery and wild steelhead for migration years 1997 to 2003 (see Tables D-27 and D-28 for 90% confidence intervals).

The hatchery steelhead TIR , excluding 2001, ranged from 0.58 to 2.65 with a geometric mean of 1.46 (Table 3.17 and D-28). In five of seven years (1997 and 2000 to 2003), TIR exceeded 1. A statistically significant $TIR > 1$ was demonstrated only in 2000 and 2003. However, this may be partially due to small sample sizes, particularly in 2001 when an estimated TIR of 60 had a lower limit of the 90% confidence limit at 0.

For hatchery steelhead smolts, transportation was generally beneficial, though not as beneficial as for wild steelhead (Table 3.17). In spite of the extremely wide confidence intervals of the 2001 TIR for hatchery steelhead, transportation was highly beneficial to all steelhead that year as demonstrated in the trend of TIR s across years for both hatchery and wild steelhead in Figure 3.17.

Table 3.17. Estimated *TIR* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: TIR \leq 1$ versus $H_A: TIR > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. Point estimates and lower limits indicating $TIR > 1$ are highlighted in bold (red).

Migr. Year	Wild Chinook		Wild Steelhead		Hatchery Steelhead	
	<i>TIR</i>	LL	<i>TIR</i>	LL	<i>TIR</i>	LL
1994	1.62	0.62				
1995	0.95	0.39				
1996	1.92	0.00				
1997	0.74	0.17	2.20	0.00	2.21	0.99
1998	0.87	0.50	0.20	0.00	0.58	0.23
1999	1.14	0.82	2.28	1.15	0.87	0.48
2000	0.60	0.32	1.45	0.77	2.20	1.22
2001	8.96	3.61	37.0	10.6	59.7	0.00
2002	0.65	0.45	4.25	2.12	1.51	0.38
2003	1.05	0.69	4.13	2.62	2.65	1.99

The estimate of *D* was > 1 in two of seven years for hatchery steelhead, and in one of those years (2003), the lower limit of the 90% confidence interval for *D* was > 1 , which demonstrates a statistical significance for that year (Table 3.18). The *D* estimates for 1997-2000 and 2002-2003 had a geometric mean of 0.64 for hatchery steelhead, approximately 20% lower than the geometric mean *D* of 0.80 estimated for wild steelhead (Tables D-27 and D-28). Although differences arise between the estimates for wild and hatchery steelhead, these data suggest that steelhead as a whole respond more favorably to transportation than do the listed wild Chinook.

Table 3.18. Estimated *D* and corresponding lower limit of non-parametric confidence interval, which provides a one-tail ($\alpha=0.05$) test of $H_0: D \leq 1$ versus $H_A: D > 1$, of PIT-tagged wild Chinook compared to wild and hatchery Steelhead. $D > 1$ is highlighted in red and *D* lower limit > 1 is highlighted in yellow.

Migr. Year	Wild Chinook		Wild Steelhead		Hatchery Steelhead	
	<i>D</i>	LL	<i>D</i>	LL	<i>D</i>	LL
1994	0.36	0.13				
1995	0.42	0.17				
1996	0.92	0.00				
1997	0.40	0.08	1.18	0.00	0.92	0.36
1998	0.55	0.31	0.11	0.00	0.39	0.16
1999	0.72	0.52	1.07	0.53	0.41	0.22
2000	0.32	0.17	0.50	0.27	0.55	0.30
2001	2.16	0.87	1.46	0.40	2.40	0.00
2002	0.44	0.29	2.24	1.09	0.60	0.14
2003	0.68	0.43	1.64	1.01	1.43	1.02

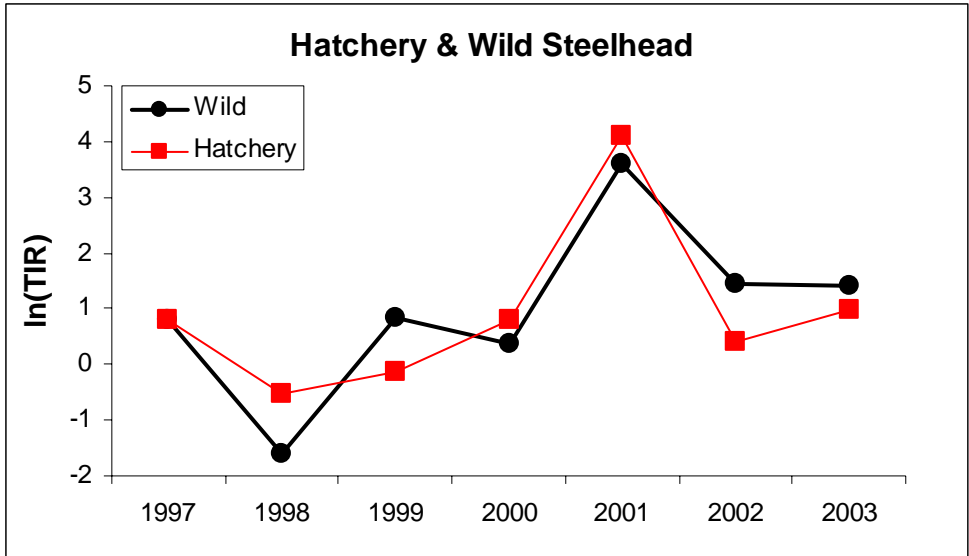


Figure 3.17. Trend in *TIR* (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997 to 2003 (see Tables D-27 and D-28 for 90% confidence intervals).

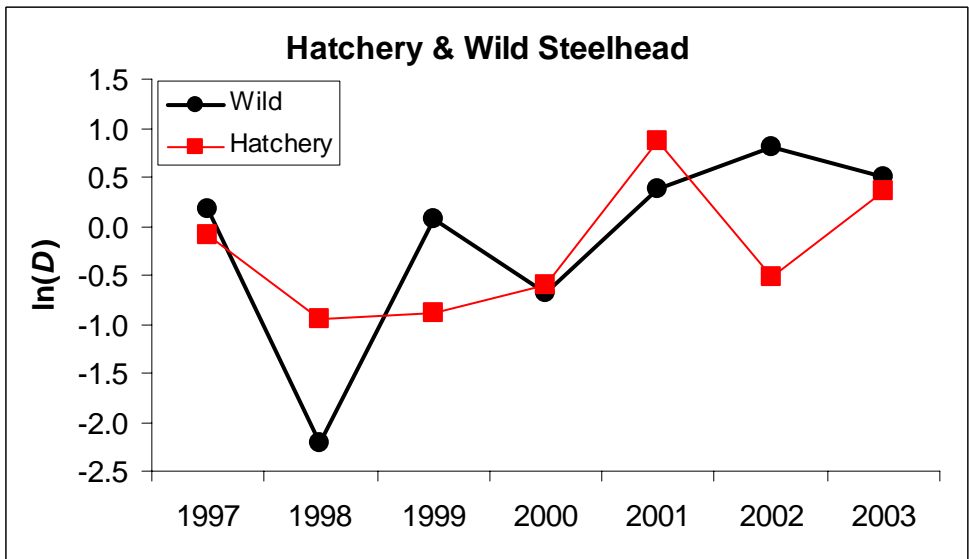


Figure 3.18. Trend in *D* (log-transformed) for PIT-tagged Snake River hatchery and wild steelhead in migration years 1997-2003 (see Tables D-27 and D-28 for 90% confidence intervals).

Discussion

The analysis of the CSS study groups for wild spring/summer Chinook, hatchery spring Chinook, hatchery summer Chinook, wild steelhead, and hatchery steelhead has demonstrated considerable variability in smolt survivals among study groups and between years.

The *TIR* parameters estimates have been used as the initial indicator of potential benefit for smolt transportation for each study grouping. The unusual environmental conditions, extreme drought, and hydrosystem operations which included no spill and maximization of smolt transportation created the situation in 2001 of exceptionally small sample sizes for all the C_0

groups. For all study categories in 2001 C_1 smolts were substituted for C_0 smolts in order to compute a *TIR* estimate. The combination of exceptionally low in-river smolt survivals in 2001 and generally average survivals for transported smolts resulted in exceptionally large *TIR* values for all study categories. These *TIR*s indicate a substantial benefit for smolt transportation in 2001.

For the rest of the CSS evaluation years, *TIR* estimates indicate the relative smolt transportation performance as follows: Wild spring/summer Chinook lacked a consistent positive pattern and lacked demonstrated statistical significance, thus indicating a lack of benefit. Hatchery spring and summer Chinook had a positive performance pattern and moderate demonstration of statistical significance indicating a benefit. Wild steelhead had a positive performance pattern and some demonstrated statistical significance. However, small sample sizes limit the confidence that transportation has been beneficial in particular years. Hatchery steelhead had a moderately consistent pattern positive performance pattern and minor demonstration of statistical significance indicating a benefit in half of the CSS study years.

For the majority of smolt groups analyzed across species and wild and hatchery production (45 of 53 groups), the $SAR(C_1)$ was less than the $SAR(C_0)$, indicating that the process of being “collected” to the point necessary for PIT-tag detection and subsequently migrating in-river compromised smolt survival.

The *D* values were also less than one for the majority of the smolt groups analyzed (41 of 53 groups), indicating that smolt collection and transportation compromises post Bonneville Dam survival. This reduction in smolt viability is potentially due to the stress, injury, and disease exposure associated with the “collection” process (Budy *et al.* 2002; Marmorek *et al.* 2004). If the detrimental effects of the “collection” process can be substantially reduced, then there is an opportunity to substantially improve SARs for bypassed and transported salmonid smolts.

Chapter 4

Estimating environmental stochasticity in SARs, *TIRs*, and *Ds*

Introduction

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

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

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

With the methods presented here, distributions are produced which reflect the maximum likelihood distribution of true *TIRs* and *Ds* over the time period. These distributions are produced for each collector project and can be used in prospective modeling under the assumption that future *TIRs* or *Ds* will on average resemble those from the estimation period. Alternatively, the methods can be used in monitoring and evaluation to estimate variation in

realized *TIRs* under the implemented management regime. The initial in-river population used is category C_0 fish (i.e. PIT-tagged fish that are not detected at any of the collector projects and aren't transported). The method can be extended to use other in-river groups, depending on the management question of interest.

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

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

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

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

Methods

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

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

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

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

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

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

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

The impact of treating SAR(C_0) as a binomial proportion for purposes of estimating sampling variance can be explored using standard errors in C_0 estimated from the bootstrap program. The actual variance of the ratio of returning adults to estimated number of smolts can be derived using the delta method, assuming both the numerator and denominator are random variables. A close approximation of the variance of the ratio of two random variables X and Y is (after Blumenfeld 2001, Eq 2.29)

$$\text{Var}\left(\frac{X}{Y}\right) \cong \left(\frac{\mu_X^2}{\mu_Y^4}\right)\sigma_Y^2 + \frac{\sigma_X^2}{\mu_Y^2} - 2\left(\frac{\mu_X}{\mu_Y^3}\right)\rho\sigma_X\sigma_Y, \quad [4.2]$$

where μ and σ^2 are mean and variance, respectively, and ρ is the correlation between X and Y . In the true binomial, variance of Y is zero, and the variance of the ratio reduces to the usual formula for variance of a binomial proportion p , i.e. $p(1-p) / N$, where N is the number of trials (number of smolts). By plugging in a value for coefficient of variation (CV) of N when N is not known with certainty, the expected true sampling variance can be estimated. As seen in Appendix E, the standard errors in C_0 are relatively low, with CVs ranging from 1- 10%, with most between 2 and 4%. We explore the effect of a CV of 4% in the numerator, along with two assumptions about the correlation between smolt numbers and adult returns (ρ), and two assumptions about mean smolt numbers, which reflect most of the range in annual C_0 estimates. Mean SAR is assumed to be 1%, which is close to estimated values of SAR(C_0) for both wild steelhead and wild Chinook. We estimate plausible values of ρ using simulations of binomial draws from a normal random variable representing C_0 , with the appropriate mean and standard deviation corresponding to a 4% CV, and using 1% as the binomial probability. The two values of ρ used in the actual sampling variance estimation, 0 and 0.5, cover the likely range of values. In addition, we use actual estimates of mean C_0 , CV of C_0 , SAR, and corresponding estimated ρ for two years: one with the lowest C_0 , highest CV of C_0 , and high SAR (steelhead in 2001); and one with the highest C_0 , lowest CV of C_0 , and low SAR (Chinook in 2003), to explore the range of impacts of non-binomial variation on estimates of sampling variance actually used in the analyses of this chapter.

Once the estimate of environmental variance is obtained by removing sampling variance from total variance, the values for the mean and remaining variance of the time series for a given SAR are then converted into the parameters of a beta distribution, using

$$a = \bar{x} \left(\frac{\bar{x}(1-\bar{x})}{s^2} - 1 \right) \quad [4.3]$$

and

$$b = (1 - \bar{x}) \left(\frac{\bar{x}(1-\bar{x})}{s^2} - 1 \right) \quad [4.4]$$

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

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

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

$$\mu = \ln(E[X]) - \frac{\sigma^2}{2} \quad [4.5]$$

$$\text{and } \sigma^2 = \ln \left(\frac{\text{Var}[X]}{E[X]^2} + 1 \right). \quad [4.6]$$

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

The ratio of correlated beta random variables, reflecting observed correlation between annual in-river and transport SARs, was simulated using the CORAND array function from the Excel add-in SimTools (<http://home.uchicago.edu/~rmyerson/addins.htm>) and the BETAINV function of Microsoft Excel™. For the correlation coefficients observed, this method provides two beta random variables with the intended distributions, with a median correlation approximately equal to the nominal correlation. The resulting distributions of simulated *TIRs*

with positive correlations between the SARs were approximately lognormal, with smaller variances than simulations using the same beta parameters and assuming complete independence ($r = 0$) of SARs.

D can be simulated by using the same distributions of SARs as used to simulate TIR , incorporating distributions of reach survival and the direct (assumed constant) survival until barge release of transported juveniles. Distributions of reach survival rates, reflecting environmental variance alone, are derived from annual CSS estimates of mean and standard deviation, by again assuming independence of sampling and process error. The square of the bootstrapped standard deviation of annual estimates of reach survival was used for sampling error. In a given year, the total number of reaches for which survival was estimable was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was limited PIT- tag detection capability at John Day (JDA) and Bonneville (BON) dams and the NMFS trawl. Therefore, reliable survival estimates in those years were possible only to the tailrace of LMN or McNary Dam (MCN). In years subsequent to 1998, reliable survival estimates to the tailrace of JDA or BON have been possible in most cases. When direct estimates of S_R were not possible or were unreliable an expansion was necessary. Survival estimates over the longest reach possible were converted to survival per mile, which was then extrapolated to the number of mile between LGR and BON. The amount of the expansion is indicated in Tables D-21 and D-27 for Chinook and steelhead, respectively.

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

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

$$E(g(X)) \approx g(\mu_X) + \frac{1}{2}g''(\mu_X)\sigma_X^2 \text{ and } Var(g(X)) \approx g'(\mu_X)^2\sigma_X^2. \quad [4.7]$$

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

$$\mu_R = \mu_d^F + \frac{F}{2}(F-1)\mu_d^{F-2}\sigma_d^2 \text{ and } \sigma_R^2 = (F\mu_d^{F-1})^2\sigma_d^2 \quad [4.8]$$

where the d subscript indicates the longest directly estimated reach, R corresponds to the whole reach (as in S_R), and F is equal to $1/(1 - \text{expansion percentage})$ where expansion percentage is from Table D-21 or D-27).

As with SARs, we used the total weighted variance method used by Akçakaya (2002) and Kendall (1998: equation 1) to estimate the multi-year mean and variance reach survival probabilities. In this case, the inverse relative variances of the annual estimates were used as the weights (Sandford and Smith 2002). The weighted sampling error variance was then subtracted

from the weighted total variance. The resulting estimates of the environmental variance, together with weighted means, were then used in equations 4.3 and 4.4 to derive the parameters of a beta distribution. The reach survival distributions estimated are S_R , S_2 , and S_3 .

Project-specific *TIRs* can be calculated from the project-specific transport SARs and using SAR(C_0) for LGR, and by dividing SAR(C_0) by the appropriate reach survival estimates to get an estimate of in-river SAR from the lower transport projects. *Ds* for LGR transport, LGS transport, and LMN transport, respectively, can be calculated from these SARs and survival probabilities. Distributions of project-specific *D* are generated by simulating the ratio of correlated beta random variables representing transport and in-river SARs, as with *TIR*, and multiplying and dividing by the appropriate beta distributions of reach survival probabilities (and fixed transport survival $S_{T\bullet} = .98$) according to the formulas

$$D_1 = \frac{SAR_{T1} \cdot S_R}{SAR_{R1} \cdot S_{T\bullet}}; \quad [4.9]$$

$$D_2 = \frac{SAR_{T2} \cdot S_R}{SAR_{R2} \cdot S_{T\bullet} \cdot S_2}; \quad [4.10]$$

$$D_3 = \frac{SAR_{T3} \cdot S_R}{SAR_{R3} \cdot S_{T\bullet} \cdot S_2 \cdot S_3} \quad [4.11]$$

where the numerical subscripts on SAR refer to LGR, LGS, and LMN, respectively, T refers to transport, and R to in-river migration. Thus, for example, SAR_{T2} is the SAR of transported fish from LGS, and SAR_{R2} is the SAR of in-river migrating (C_0) fish from LGS tailrace. *D* values are generated 25000 times, and the resulting distributions of parameter values are fit to a lognormal distribution, as done earlier for *TIR*.

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

$$\pi_1 = P_2, \quad [4.12]$$

$$\pi_2 = P_3(1 - P_2), \quad [4.13]$$

$$\pi_3 = P_4(1 - P_3)(1 - P_2), \quad [4.14]$$

$$\pi_R = 1 - \pi_1 - \pi_2 - \pi_3, \quad [4.15]$$

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

Treating the pathway probabilities (π_i) as random variables with mean and variance estimated from annual estimates, using the mean and variance of pathway-specific SARs estimated as described, along with estimated distributions of reach survival rates S_2 , S_3 , and S_R (described below), the following formulas allow estimation of mean and variance of the overall SAR :

$$E[XY] = \mu_X \mu_Y; \text{Var}(XY) = \mu_X^2 \sigma_Y^2 + \mu_Y^2 \sigma_X^2 + \sigma_X^2 \sigma_Y^2 \quad [4.16]$$

$$E[X + Y] = \mu_X + \mu_Y; \text{Var}(X + Y) = \sigma_X^2 + \sigma_Y^2 + 2\sigma_{XY} \quad [4.17]$$

where X and Y are random variables and σ_{XY} is the covariance between X and Y (Blumenfeld 2001). The use of Equation 4.16 assumes that covariance is negligible among the components of survival of a particular pathway (e.g. the reach survival rate from LGR to LGS does not correlate strongly with SAR of fish transported from LGS, which is supported by observed correlation coefficients of 0.21 for Chinook and -0.15 for steelhead). In contrast, annual SARs of fish traveling by the different pathways tend to be positively correlated (though the pathway probabilities are negatively correlated with each other). Hence, in adding the contribution of each pathway to overall SAR, measured covariance is included in estimating the overall variance (Equation 4.17). The annual contribution of each pathway is estimated by multiplying the total annual survival rate estimate of that pathway by the annual pathway probability estimate. Estimated first is covariance between pathway 1 and 2, then covariance between pathway 3 and the sum of the contributions of pathways 1 and 2, and then between pathway 4 and the sum of the contributions of pathways 1, 2, and 3. Equations 4.16 and 4.17 are then used with the mean and variance of the time series pathway probabilities and the estimated distributions of reach survival rates and SARs, with measurement variance removed, to derive the mean and variance of the overall SAR distribution. A beta distribution is then fit to the mean and variance as before.

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

Data from PIT-tagged wild Chinook and steelhead were used to investigate the consistency of seasonal variation in SARs between years. As for annual estimates, the method uses an assumption of binomial sampling error in the SAR estimates to remove measurement error variance from total variance to estimate inter-annual process error (environmental) variance. Instead of using data from each migration year in the aggregate to estimate environmental variance in SARs, here the data from each of three periods within the migration season is treated separately. The resulting distributions can be then be used to derive estimates of, for instance, the frequency with which true SAR would be within management targets for each of the time periods. In this analysis, LGR is the only transport project investigated (though

the exercise could be performed for other projects). In contrast to the analysis using annual data, the in-river fish used here are “C₁” fish, i.e., PIT-tagged fish detected at LGR dam. The C₀ fish cannot be used to estimate within-season trends in SARs; because a C₀ smolt is not detected at LGR (or any of the collector projects), a date of passage at collector project cannot be accurately assigned to it. Note that C₁ fish generally exhibit lower SARs than C₀ fish (see Appendix Tables D-13 through D-20).

Results

The results of the investigation into the appropriateness of the assumption of binomial sampling variance in SAR(C₀) are shown in Tables 4.1 and 4.2. Table 4.1 suggests that in general, the effect of observed levels of variance in the denominator of SAR(C₀) is minimal. Simulations of binomial draws from a normal random variable representing C₀ indicate that, as expected, correlation between adult returns and smolts number increases with smolt numbers. Even at 5000 smolts, however, the estimated correlation at CV of C₀ = 4% is only 0.27, suggesting that the actual sampling variance departs little from the assumed binomial variance. Additionally, a positive correlation between smolt number and adult returns results in the binomial variance overestimating the sampling variance. This suggests that assuming binomial sampling variance may result in slight underestimation of environmental variance, for the range of correlations pertaining in this analysis.

Table 4.1. Effect of CV of 4% in C_0 estimate on sampling variance of SAR(C_0), for different correlations and mean smolt number. SAR assumed = 1%. Binomial variance was assumed in Chapter 4 analyses. CV of SAR is sqrt (variance) / 1%.

Mean C_0	ρ	Actual variance	Actual CV	Binomial variance	Binomial CV
200	0	4.97×10^{-5}	70%	4.95×10^{-5}	70%
200	0.5	4.68×10^{-5}	68%	4.95×10^{-5}	70%
5000	0	2.14×10^{-6}	15%	1.98×10^{-6}	14%
5000	0.5	1.58×10^{-6}	13%	1.98×10^{-6}	14%

The results of using actual estimated SAR, C_0 , and CV(C_0) for two years representing the ends of the range with respect to C_0 and CV(C_0) (Table 4.2) suggest that departure of sampling variance in SAR(C_0) from binomial is extremely small across the range of data. As indicated above, the binomial variance is a very slight overestimate of the actual sampling variance. Because the difference is so small, the simplifying assumption of binomial sampling variance in SAR(C_0) is justified.

Table 4.2. Effect of variance of two C_0 estimates, on actual sampling variance of SAR(C_0), compared to assumed binomial sampling variance. In first row, C_0 , CV, and SAR estimates are from wild steelhead in 2001; second is from wild Chinook in 2003. Correlation (ρ) between C_0 adults and smolts is estimated through simulation as described in Methods. Binomial variance was assumed in Chapter 4 analyses. CV of SAR is sqrt (variance) / SAR est.

Mean C_0	CV of C_0	SAR est.	ρ	Actual variance	Actual CV	Binomial variance	Binomial CV
103	10%	2.91%	0.17	2.66×10^{-4}	56%	2.74×10^{-4}	57%
8879	1.5%	0.33%	0.08	3.68×10^{-7}	18%	3.70×10^{-7}	18%

Table 4.3 shows the estimated parameters of the beta distributions representing transport and in-river SAR from each transport project, and the observed correlation between them. The estimated probability density functions (PDFs) of SARs from the three transport projects, and for untransported fish, are plotted in Figures 4.1 and 4.2 for Chinook and steelhead, respectively.

Table 4.3. Parameters of SAR distributions for wild spring/summer Chinook and Steelhead, and observed correlation coefficient between point estimates of annual T and C_0 SARs. Migration years 1994-2003 for Chinook; 1997-2002 for steelhead.

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

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

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

The figures indicate that SARs of the individual components are generally less than target minimum SAR for recovery (2%). In fact, regardless of pathway, wild Chinook SARs of PIT-tagged fish rarely fall into the target region. Migrants that remain in-river appear generally to survive at the highest rate. For steelhead, SARs are higher than for Chinook, and transported groups tend to have higher survival rates than untransported fish.

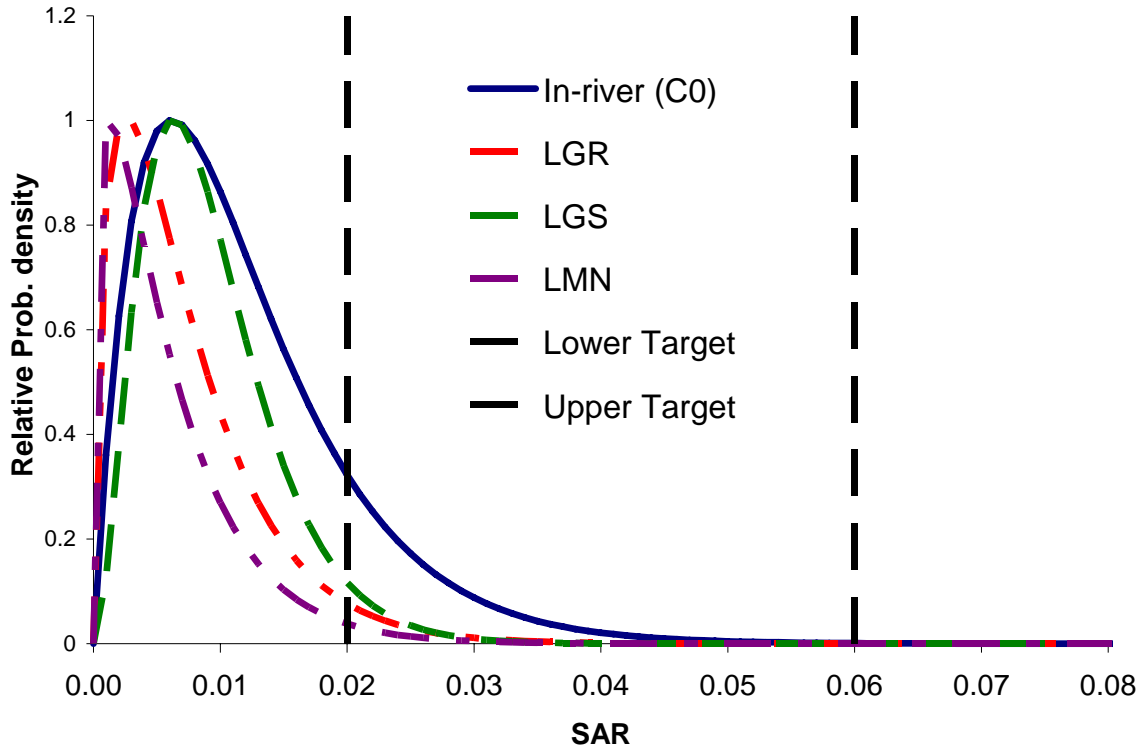


Figure 4.1. Probability density functions (PDFs) across migration years 1994 – 2003, for SARs of wild Chinook transported from LGR, LGS, and LMN dams, and for in-river (C_0) Chinook. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Also shown is NPCC 2-6% SAR target range. .

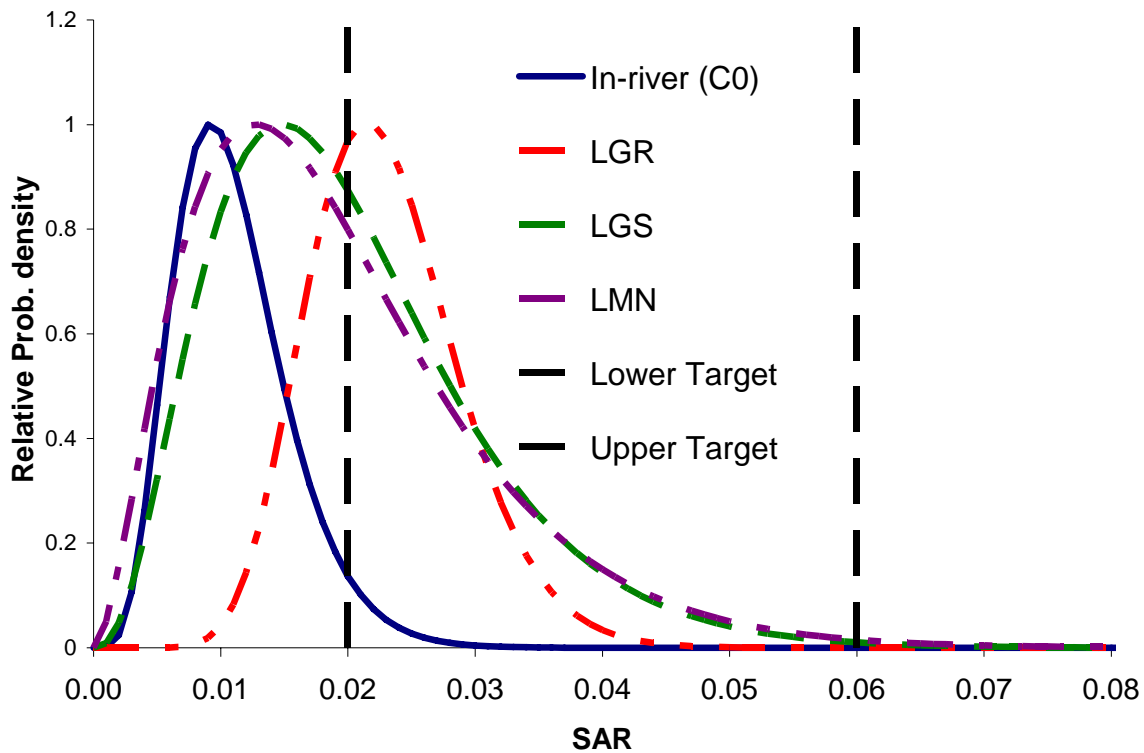


Figure 4.2. PDFs across migration years 1997-2002, for SARs of wild steelhead transported from LGR, LGS, and LMN dams, and for in-river (C_0) steelhead. Transport SARs are from point of collection (i.e. do not include mortality incurred migrating to collector project). Also shown is NPCC 2-6% SAR target range.

To test the appropriateness of the lognormal assumption used in specifying distributions of ratios of SARs, 25,000 realizations of the ratio of two beta random variables were simulated and recorded, using the parameters derived from the data for steelhead, for LMN transport and in-river SAR beta distributions. From the simulated values, the parameters of a lognormal distribution were estimated as described above. The exact distribution was computed per Pham-Gia (2000) from the same SAR beta distribution parameters and plotted along with the lognormal distribution. The lognormal distribution is easier to implement for modeling than the exact PDF, and appears to provide a good approximation to the exact distribution, for the beta parameters examined (Figure 4.3).

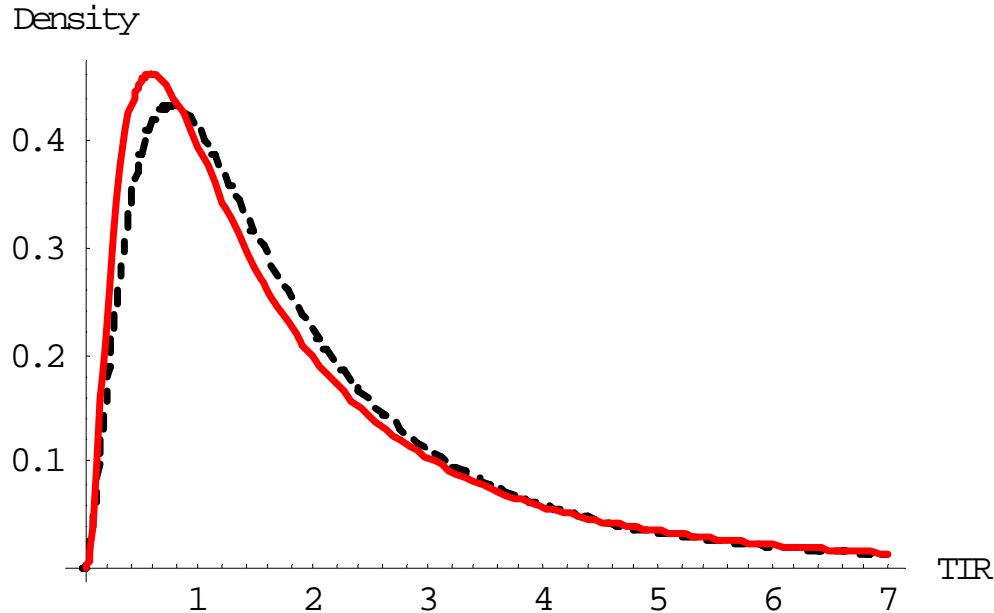


Figure 4.3. Exact probability density function of ratio of beta random variables, based on parameters of steelhead SARs from LMN (dashed line); lognormal approximation using values for μ and σ fit to 25000 values of simulated *TIR* (solid red line).

The parameters of the resulting project- and species-specific *TIR* distributions were calculated as described, using the SAR parameters shown in Table 4.3. The resulting lognormal parameters, along with median and mean of the distributions, are shown in Table 4.4. PDFs and cumulative density functions (CDFs) of the distributions are shown in Figures 4.4 – 4.6 (Chinook) and Figures 4.7 – 4.9 (steelhead).

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

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

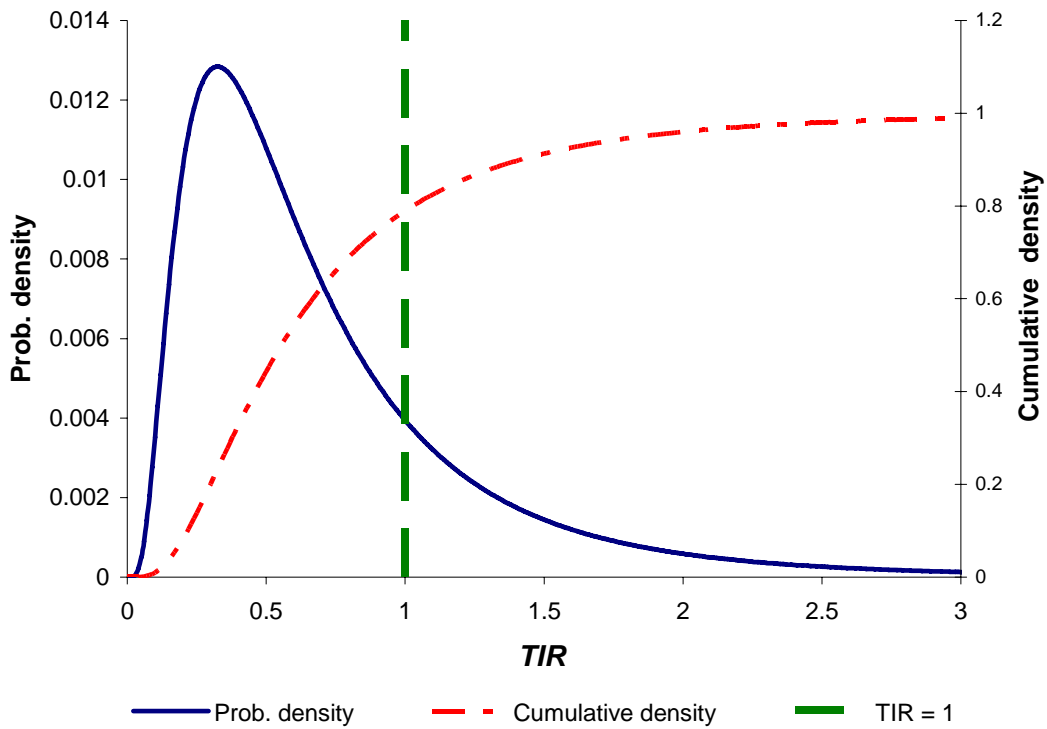


Figure 4.4. Estimated lognormal distribution of TIR for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.

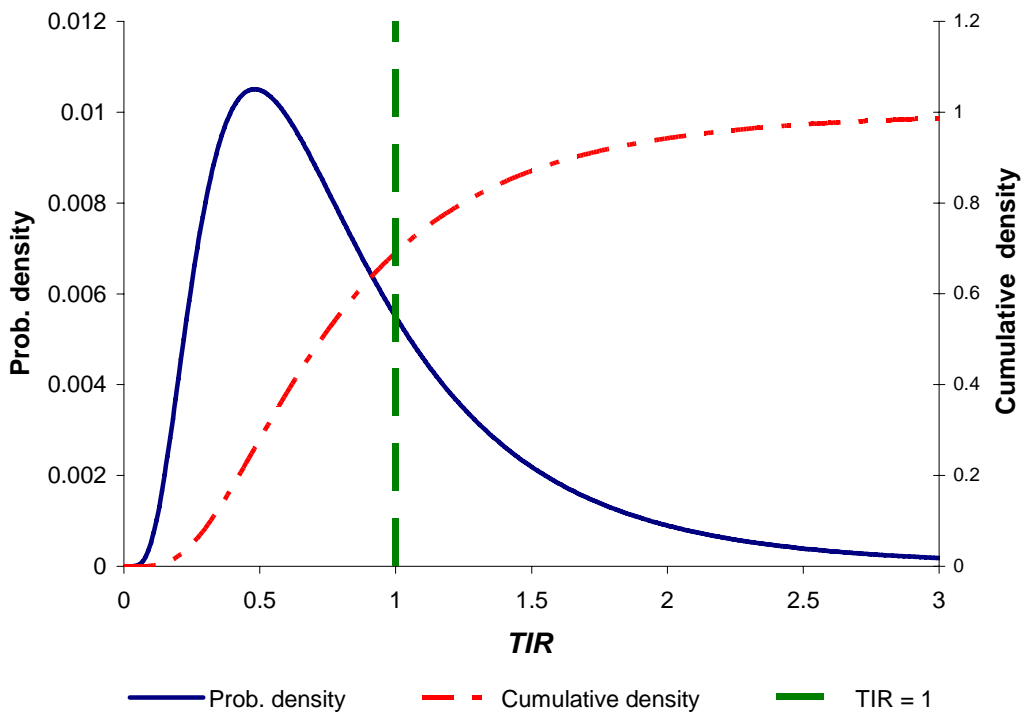


Figure 4.5. Estimated lognormal distribution of TIR for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.

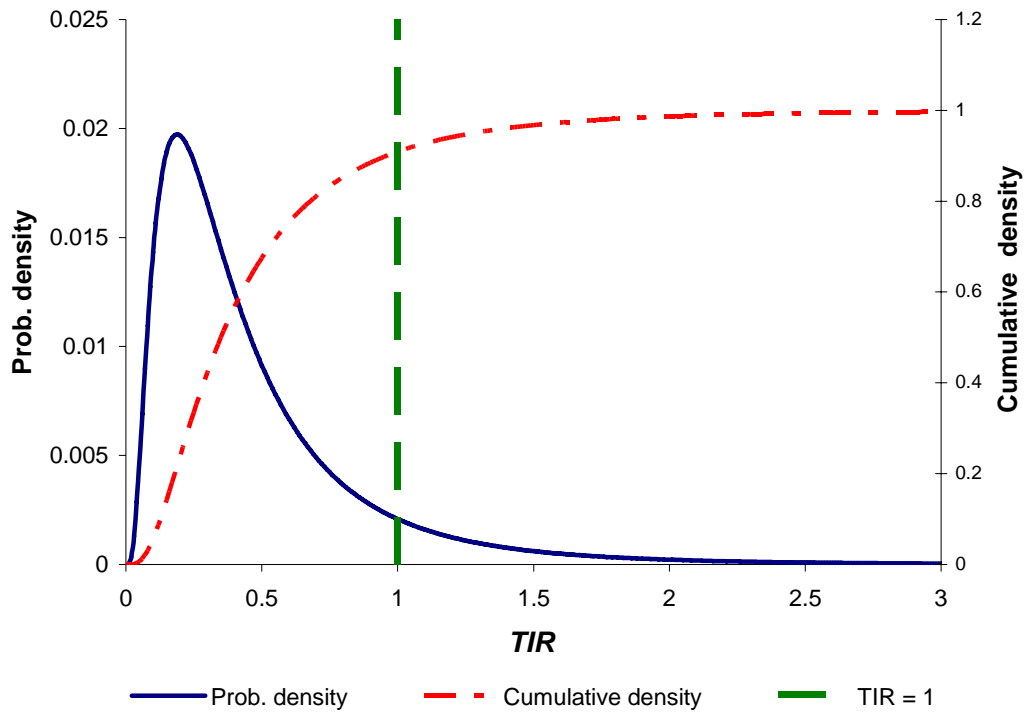


Figure 4.6. Estimated lognormal distribution of TIR for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.

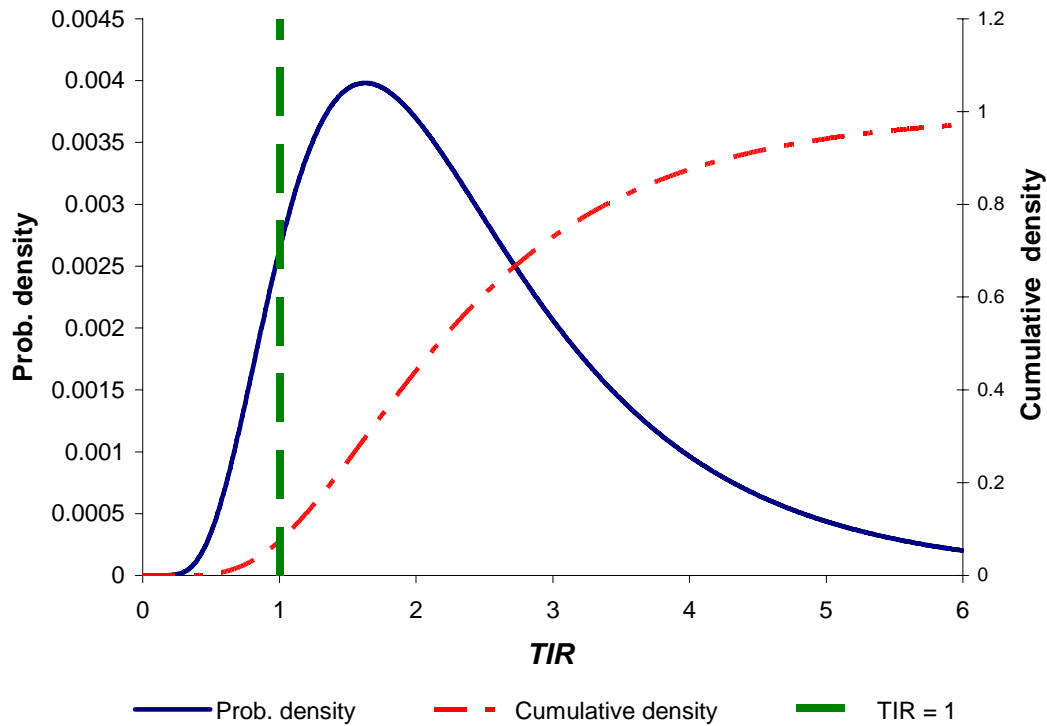


Figure 4.7. Estimated lognormal distribution of TIR for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.

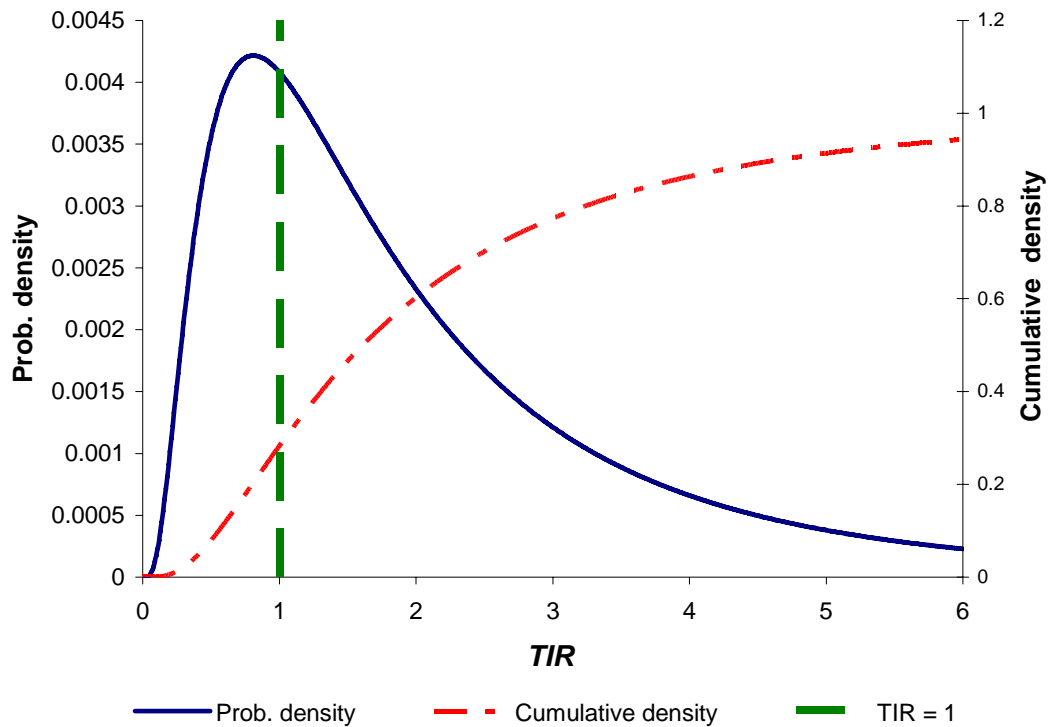


Figure 4.8. Estimated lognormal distribution of *TIR* for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.

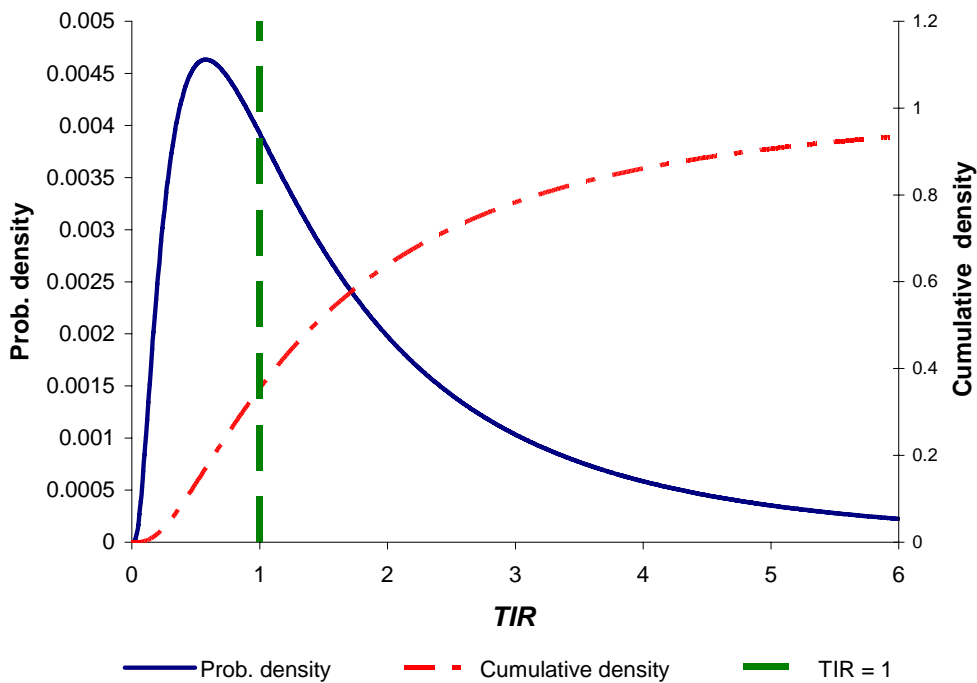


Figure 4.9. Estimated lognormal distribution of *TIR* for wild steelhead transported from LMN. Data from 1997 – 2002 migration years.

The figures show that *TIRs* for wild Chinook are generally below 1.0, indicating that transportation does not on average provide greater survival than that experienced by fish migrating in-river through the system, if not bypassed at transportation projects. Transportation of wild Chinook from LMN seems particularly ineffective, with the mean *TIR* less than 0.5. For steelhead, the results are considerably different (Figures 4.7-4.9), with both median and mean *TIRs* greater than one at all projects. *TIR* declines consistently the lower a transport project is in the system.

Details of estimated distributions of environmental variance in reach survival rates are shown in Table 4.5. These parameters are used with the SAR parameters, as described, to produce distributions of environmental stochasticity in *D* for both Chinook and steelhead. The resulting lognormal parameters, and the mean and median of the *D* distributions, are shown in Table 4.6. These distributions (PDFs and CDFs) are plotted in Figures 4.10 – 4.12 (Chinook) and Figures 4.13 – 4.15 (steelhead).

Table 4.5. Weighted mean, estimated standard deviation of environmental variance, and parameters of beta distribution, reach survival rates used to calculate *D*. Spring/summer Chinook data from 1994-2003 migration years; steelhead data from 1997-2002 migration years.

Species	Reach	Mean	Std. deviation	Alpha	Beta
Chinook	S _R	0.488	0.149	5.04	5.27
Chinook	S ₂	0.930	0.030	68.0	5.09
Chinook	S ₃	0.880	0.074	16.3	2.22
Steelhead	S _R	0.405	0.110	7.73	11.4
Steelhead	S ₂	0.890	0.074	15.2	1.87
Steelhead	S ₃	0.891	0.121	5.01	0.611

Table 4.6. Species- and project-specific parameters of lognormal *D* distributions for implementation of the hypothesis. Lognormal fit to output from 25000 iterations. SAR data from 1994-2003 migration years (Chinook); 1997-2002 migration years (steelhead).

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

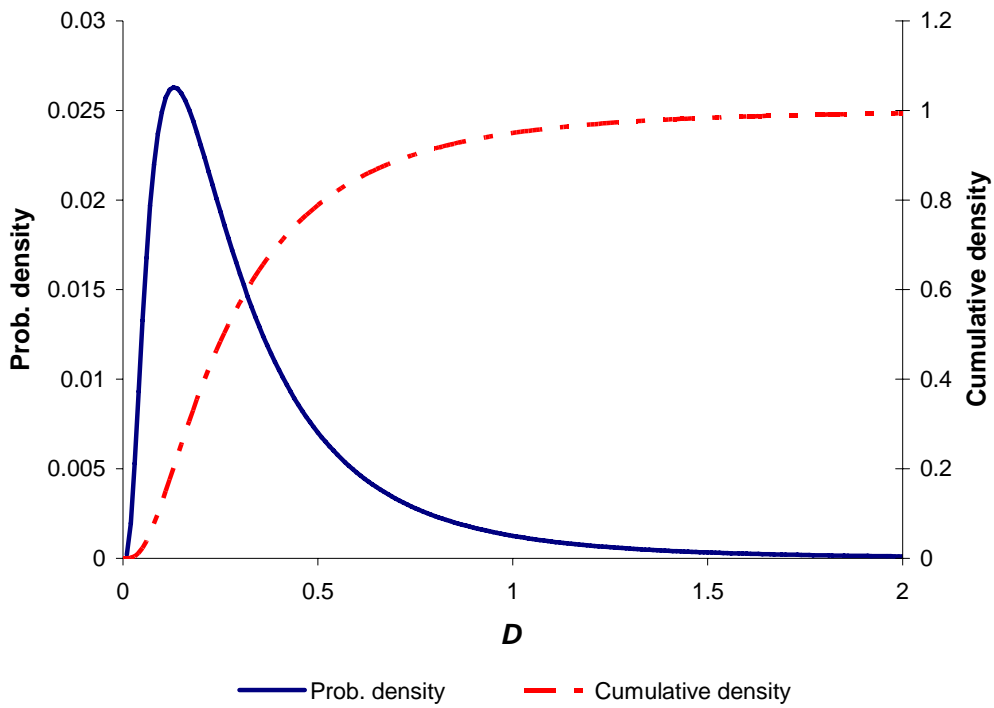


Figure 4.10. Estimated lognormal distribution of D for wild Chinook transported from LGR. Data from 1994 – 2003 migration years.

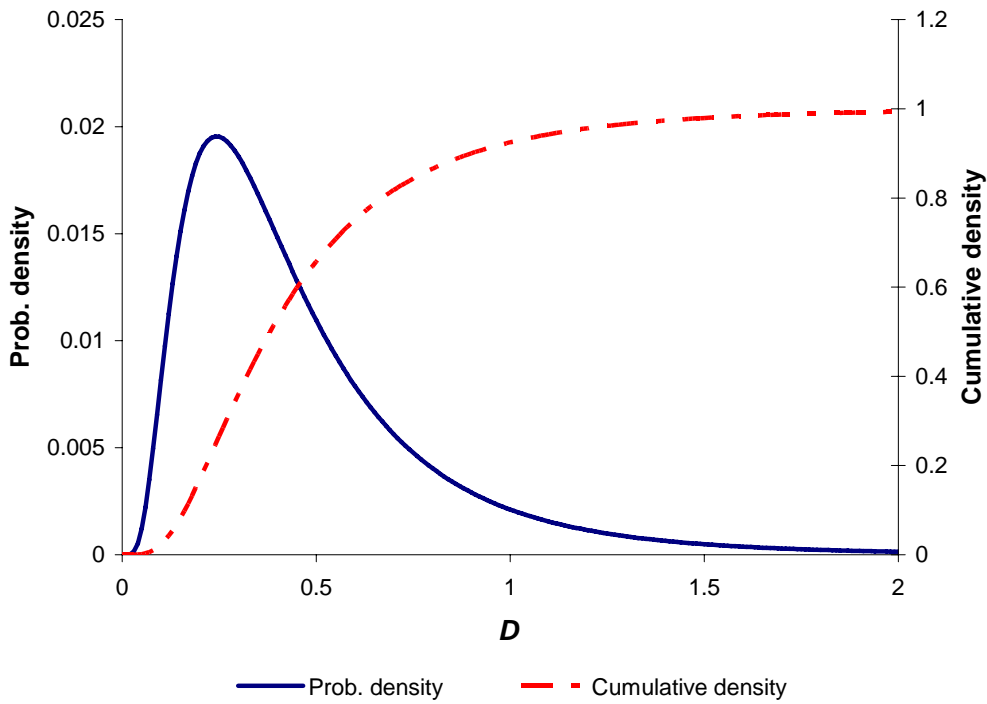


Figure 4.11. Estimated lognormal distribution of D for wild Chinook transported from LGS. Data from 1994 – 2003 migration years.

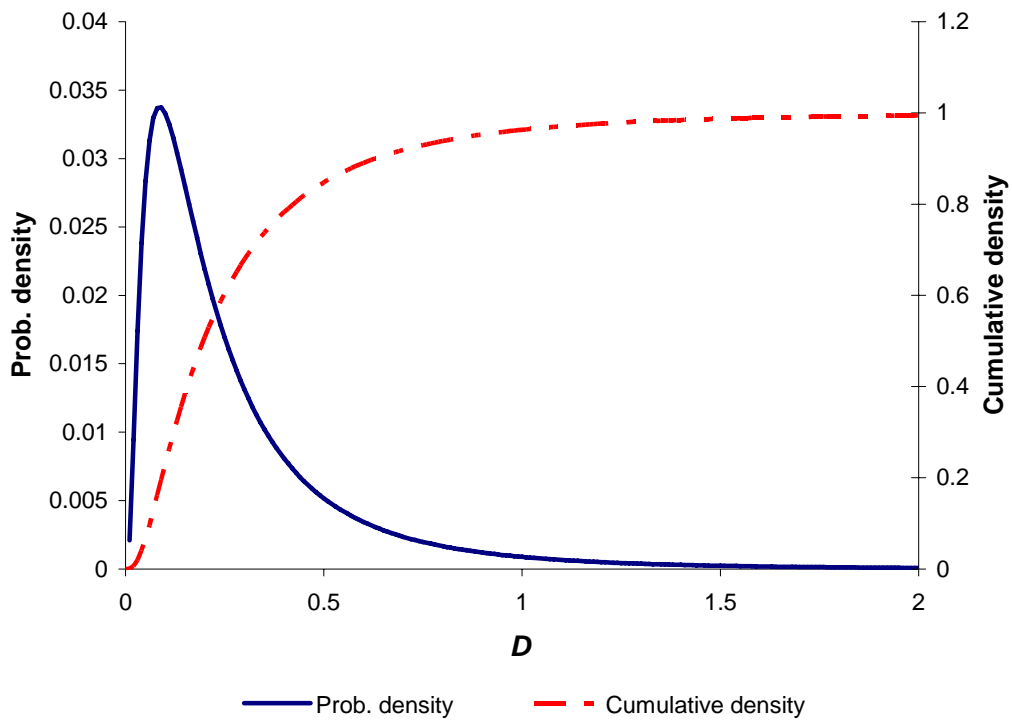


Figure 4.12. Estimated lognormal distribution of D for wild Chinook transported from LMN. Data from 1994 – 2003 migration years.

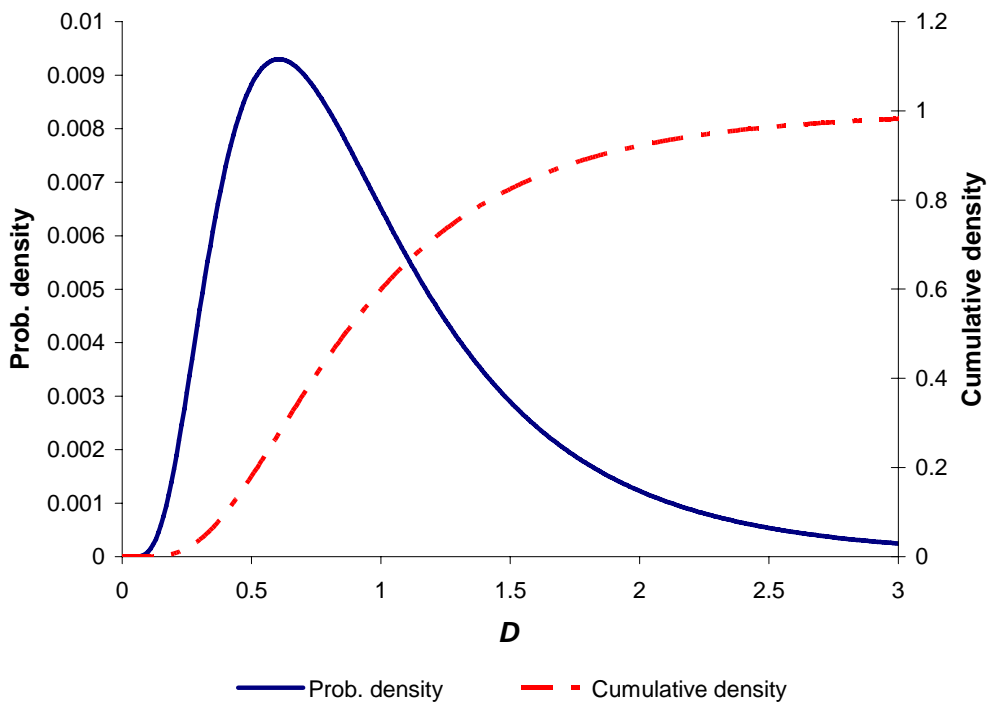


Figure 4.13. Estimated lognormal distribution of D for wild steelhead transported from LGR. Data from 1997 – 2002 migration years.

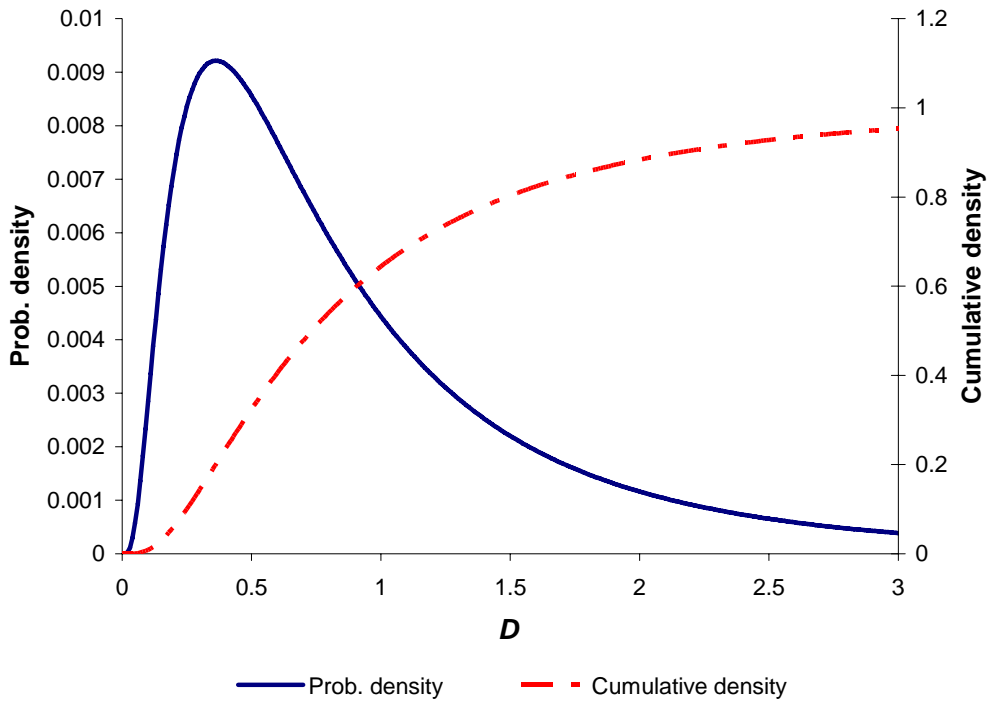


Figure 4.14. Estimated lognormal distribution of D for wild steelhead transported from LGS. Data from 1997 – 2002 migration years.

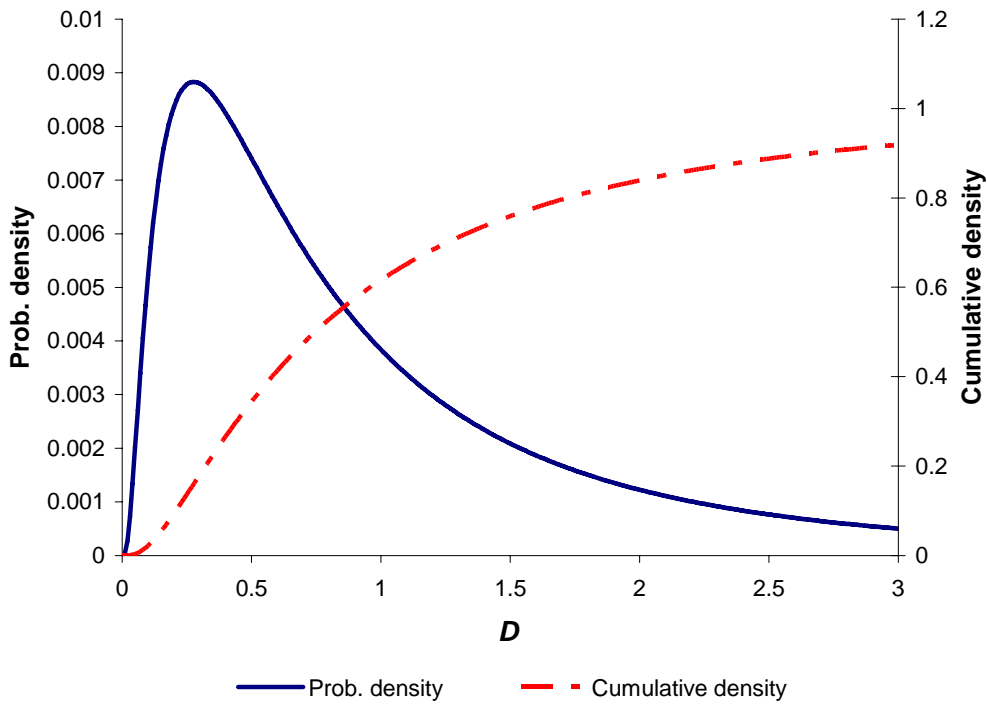


Figure 4.15. Estimated lognormal distribution of D for wild steelhead transported from LMN. Data from 1997 – 2002 migration years.

The resulting distributions indicate that D is usually substantially below one for Chinook, implying that there is substantial delayed (post-hydrosystem) mortality experienced as a consequence of being transported below the hydrosystem. Based on the median values, in more than half of the annual migrations, we can expect delayed transport mortality of 60% or more for wild Chinook. In contrast, D distributions for wild steelhead indicate expected values much closer to one. Most of the time, regardless of transport project, we can expect steelhead D to be less than one (medians in Table 4.6); however, D s equal to or greater than one can be expected to occur much more frequently than for Chinook, and the mean D values are all around one. Consequently, expected delayed mortality due to transport is considerably less for steelhead than for Chinook.

Pathway probabilities indicate that a large majority of wild Chinook smolts are transported. The transport fraction is particularly large when spill at the collector projects is low or absent, as in 2001 (Table 4.7). The fraction of the population migrating in-river is highly variable, ranging from less than 1 percent to more than a quarter.

Table 4.7. Estimated pathway probability (π_i) for different routes of passage for wild spring/summer Chinook, and for transport as a whole (π_T). Subscripts 1-3 represent the three Snake River transport projects; subscript R is the in-river route.

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

Wild steelhead pathway probabilities also indicate that a large majority of steelhead smolts are transported. The transport fraction is particularly large when spill at the collector projects is low or absent, as in 2001 (Table 4.8). The fraction of the population migrating in-river is somewhat less variable from year to year than for wild Chinook, though it has been relatively high in the most recent years.

Table 4.8. Estimated pathway probability (π_i) for different routes of passage for wild steelhead, and for transport as a whole. Subscripts 1-3 represent the three Snake River transport projects; subscript R is the in-river route.

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

The details of the estimation of covariance of the various pathways to the overall wild Chinook and steelhead SAR distributions are provided in Tables D-29 and D-30, respectively; the overall SAR PDFs are shown in Figures 4.16 and 4.17. The overall SAR distribution for Chinook indicates that overall SARs of the migration rarely fall in the desired range (Figure 4.16); in fact, average SAR over the time period is estimated to be 0.82%, less than half the lower end of the desired range. The overall SAR distribution for steelhead indicates that SARs fall within the desired range much more frequently than Chinook SARs, but that most of the time they fall below the range (Figure 4.17). The steelhead mean SAR approaches the lower end of the desired range.

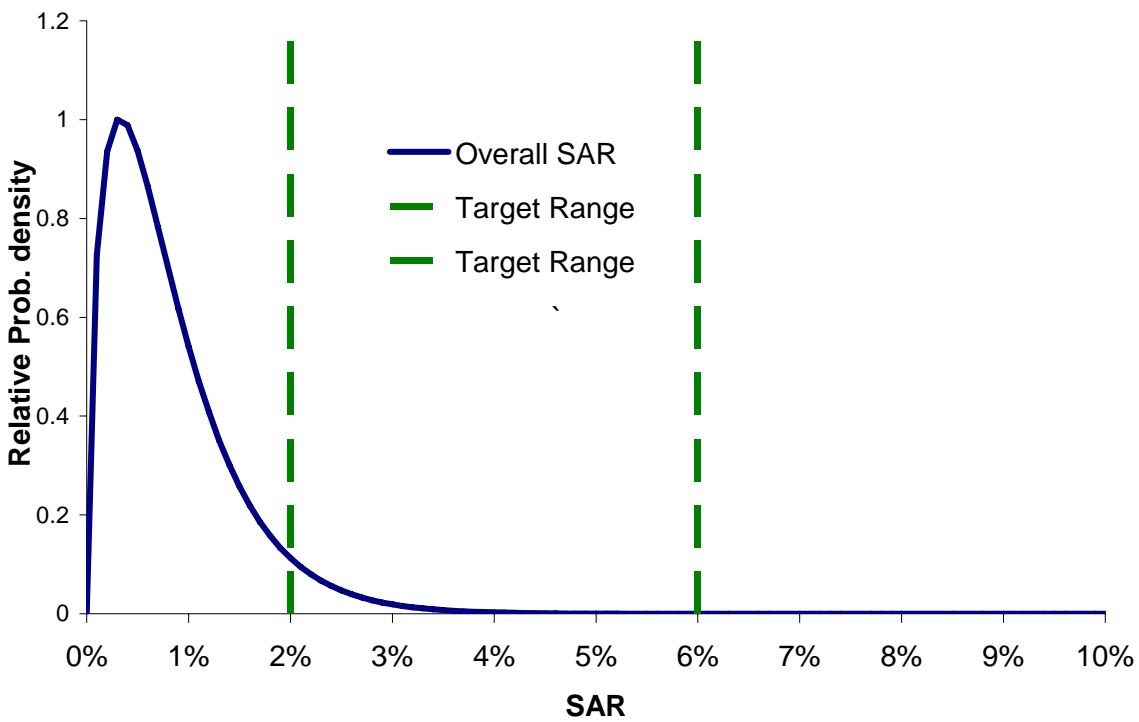


Figure 4.16. Distribution of overall wild Chinook SAR; data from migration years 1994 – 2003. Mean = 0.82%

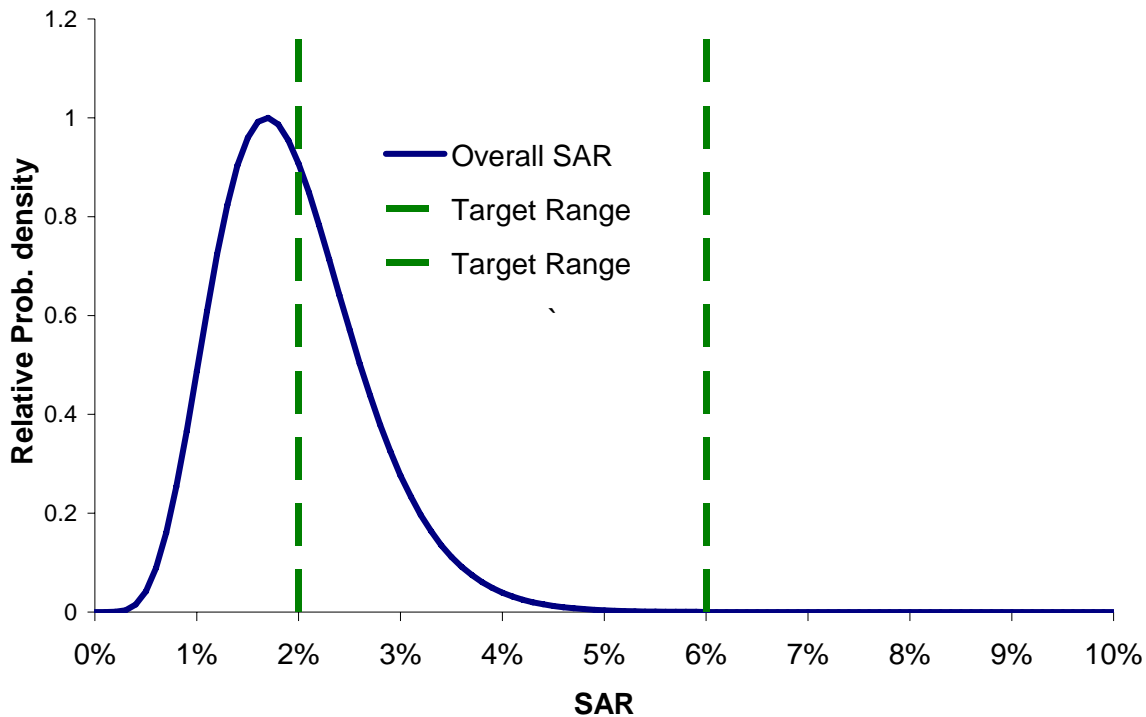


Figure 4.17. Distribution of overall wild steelhead SAR; data from migration years 1997 – 2002. Mean = 1.95%.

Within-season variation

Each migration year, the season was broken into three periods based on detection date at LGR: Before April 26, April 26 to May 10, and after May 10. For Chinook, this resulted in approximately equal total numbers of PIT-tagged fish in each group, over the six year period. Summary information from the resulting SAR distributions is presented in the Tables 4.9 and 4.10 below. It appears that SARs can vary substantially over the season. Inspecting the distributions of transport and C_1 SARs for Chinook suggests that although transport SARs are somewhat higher later in the season than earlier (Fig. 4.18 and Table 4.9), C_1 SARs decline dramatically in the middle and end of the season (Fig. 4.19 and Table 4.10). This suggests that the primary reason for the increasing trend in *TIRs* observed in previous investigations is the dramatic decline in the success of the C_1 migration as the season progresses.

SARs for wild transported steelhead show a modest increasing trend over the season (Table 4.10 and Figure 4.20), while, as for Chinook, C_1 SARs exhibit a dramatic drop-off as the season progresses (Table 4.10 and Figure 4.21).

Table 4.9. Mean SARs and variances for early, mid and late periods, for migrating wild Chinook from LGR dam. Data from migration years 1998-2003.

Period	T smolts	Mean SAR(T)	C ₁ smolts	Mean SAR(C ₁)
Before 4/26	4059	0.76%	15380	1.76%
4/26 – 5/10	2366	1.39%	19568	1.05%
After 5/10	3022	1.09%	15348	0.53%

Table 4.10. Mean SARs and variances for early, mid and late periods, for migrating wild steelhead from LGR dam. Data from migration years 1997-2002.

Period	T smolts	Mean SAR(T)	C ₁ smolts	Mean SAR(C ₁)
Before 4/26	404	2.72%	6574	1.89%
4/26 – 5/10	468	3.21%	13872	0.47%
After 5/10	314	3.50%	8913	0.46%

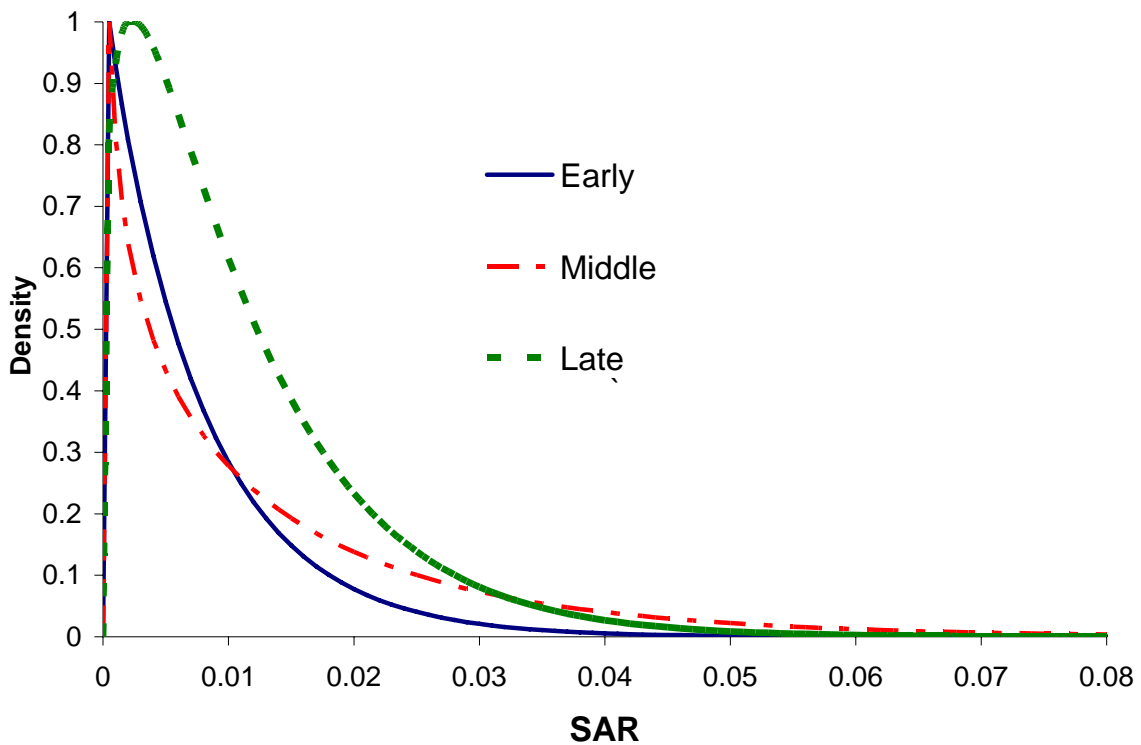


Figure 4.18. PDFs for SAR of wild Chinook transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1998-2003.

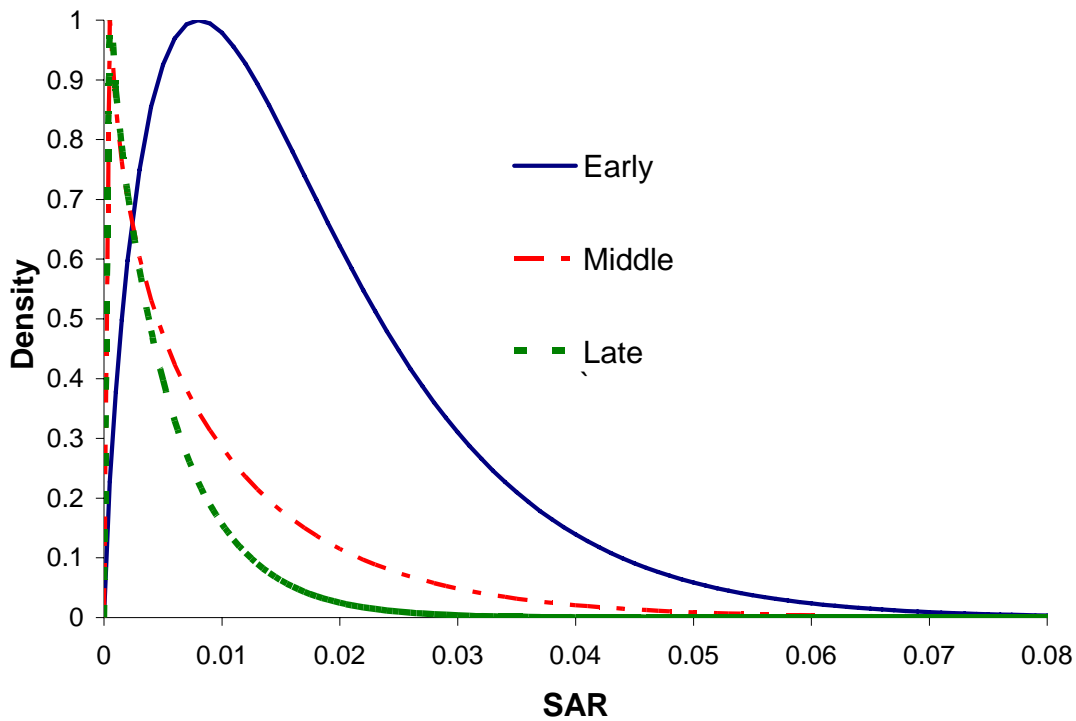


Figure 4.19. PDFs for SAR of wild Chinook migrating in-river (C_1) from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1998-2003.

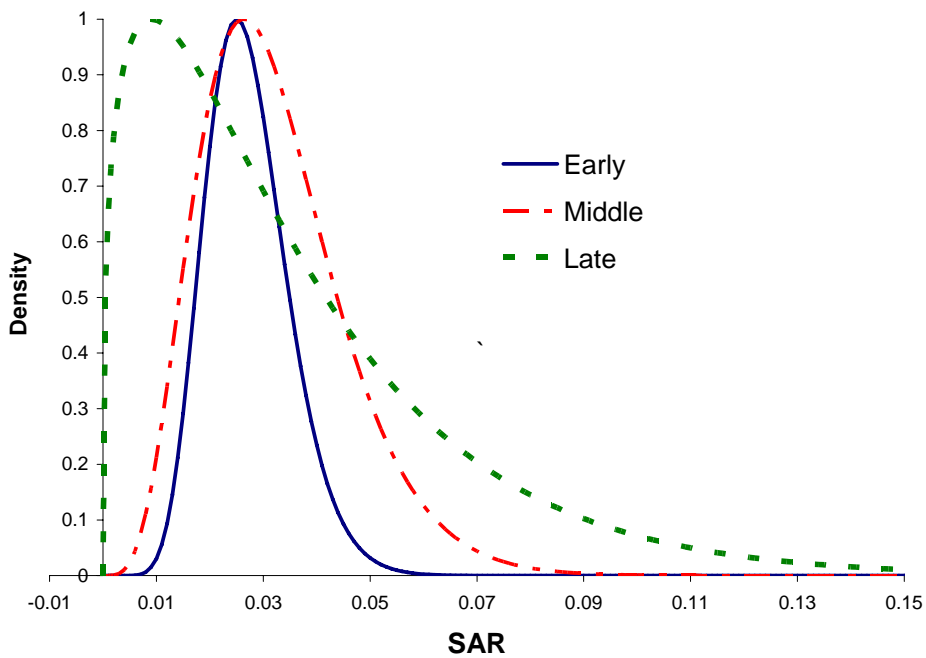


Figure 4.20. PDFs for SAR of wild steelhead transported from LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.

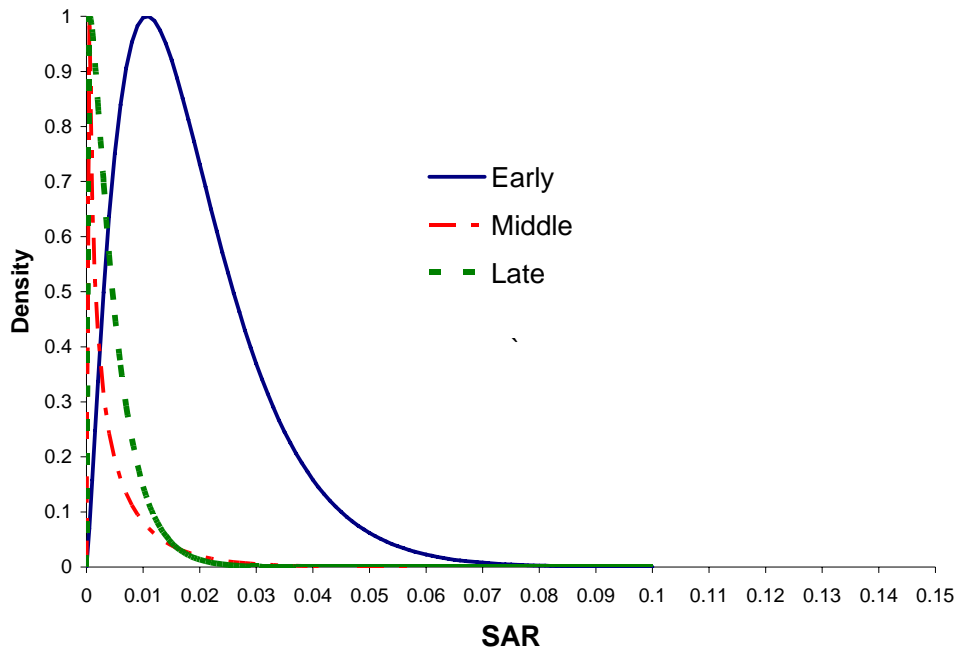


Figure 4.21. PDFs for SAR of wild steelhead migrating in-river (C_1) from detection at LGR Dam, for early, middle, and late periods based on arrival timing at LGR. Data from migration years 1997-2002.

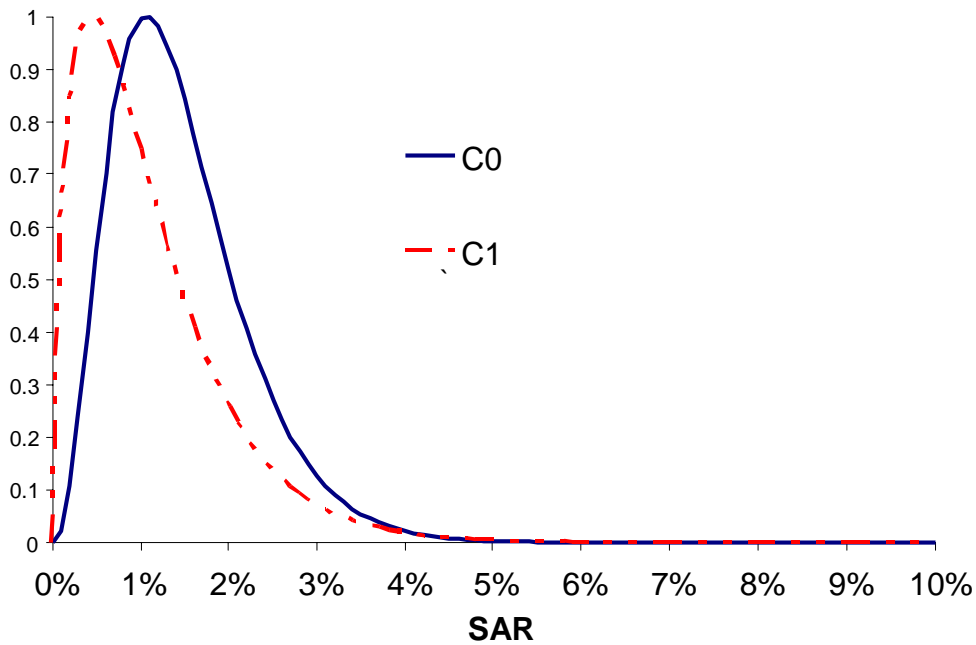


Figure 4.22. Distributions of SAR for in-river smolts (C_0) and smolts detected at Lower Granite and returned to the river (C_1), 1994-2002 migration years.

We cannot estimate within-season SARs for the C_0 fish. However, in general C_0 SARs are greater than C_1 SARs (Berggren et al. 2005). The seasonal *TIRs* therefore are likely positively biased with respect to untagged fish, because in-river fish (C_0), which migrate through spill and turbine routes at collector dams, have shown higher SARs than fish bypassed at one or more of the collector dams. The SAR distributions for C_0 smolts and for smolts detected and returned to the river at LGR dam (C_1) using the variance partitioning methods are shown in Figure 4.22. If in-river survivals are similar for C_1 and C_0 groups, as generally assumed, the differential SAR is evidence of delayed mortality for bypassed fish (see Budy et al. 2002). It is also possible that the trend in increasing *TIRs* may more or less pronounced for C_0 fish than for C_1 fish, particularly in years when the spill program is implemented.

Discussion

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

Taking into account precision of SAR estimates likely results in better estimates of the central tendencies and distributions of *TIR* than unweighted, multiple-year means. The resultant distributions suggest that on average, transportation as currently implemented is not of benefit for wild Chinook, regardless of transport project, since most of the *TIR* distribution at each transport project falls below 1. Transportation from LMN seems to be particularly ineffective at increasing wild Chinook survival. Mean *TIR* estimates are considerably lower than estimates from other multi-year studies that did not account for variation in sampling error of annual estimates or covariance between transport and in-river SARs.

For wild steelhead, in contrast, transportation (particularly from LGR) appears to provide a significant benefit compared to in-river migration under the current system. The benefit of transportation appears to decline the lower a transport project is in the system. The shorter time series of PIT-tag data available for wild steelhead, along with the lesser tagging effort for this species, results in wider probability distributions than for Chinook and hence less confidence in the true values of *TIR* and *D*. This results partly from relatively high error in annual point estimates of SARs, which limits our ability to detect covariance among years between transported and in-river wild steelhead SARs.

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

Within-season estimates of SARs and their ratios are complicated by the limited number of wild fish able to be marked, and the low number of adult returns from subsets of the migration. These subsets, or blocks, can be based on arrival timing at transport projects (LGR;

LGS, and LMN), or at Bonneville Dam. The resulting low numbers of adult returns in each block lead to wide confidence intervals of SARs, making analysis and inference challenging. Further, estimation of SARs for the in-river group is limited to fish with known detection date at the dam of interest, such as fish in the CSS group C_1 . This is because fish that pass undetected through spill or turbines, as group C_0 fish do at the Snake River collector dams, do not have an estimable date of passage at these projects. Since it is impossible to estimate seasonal trends in SARs or *TIRs* for the C_0 group from collector projects, any inferences about temporal variation for this latter group must be indirect.

The exercise of estimating SAR distributions for wild Chinook and steelhead migrants for three separate periods within the migration period indicates that SARs vary over the migration season, though there is significant overlap between periods. The relatively high in-river (C_1) SARs early in the season provide one possible reason that current strategies that maximize transportation of collected fish over the entire migration season are likely not optimizing overall wild Chinook SAR. The results also suggest that previously observed increasing trends in Chinook *TIRs* (where C_1 fish are used in the denominator) over the migration season are a result mainly of the dramatic decline in C_1 SARs over the season, rather than dramatically increasing survival of transported fish late in the migration season.

Similar patterns in in-river SARs within the season are seen for steelhead; however the relatively high transport SARs seen for steelhead suggest that full season transportation may be optimizing steelhead survival under the current configuration and operation of the hydrosystem. Smolt-to-adult survival of transported steelhead appears to be much more variable later in the season than earlier, however. Given the different responses to transportation of the two species, it would seem that optimization of survival of both wild Chinook and wild Steelhead cannot be accomplished with smolt transportation as currently implemented.

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

The simplifying assumptions used in the exercise of removing sampling error from SAR estimates were found in general to be justifiable, likely resulting in little bias in estimates of inter-annual variance. The fact that the number of C_0 smolts at LGR is estimated rather than directly observed, and consequently annual SAR(C_0) estimates are not exactly from a binomial process, did not pose a difficulty. The lognormal approximation to the ratio of beta random variables used for *TIR* and *D* distributions, while good for the range of parameters examined in this report, is less useful when mean survival rates are very close to zero or exhibit extremely high variability. Consequently, the ability to apply this approximation to SAR distributions estimated from smaller datasets, such as from temporal or geographic subsets of the annual Snake River wild migration of either species, may be limited.

Results for steelhead should be qualified in acknowledgement of the short time series and the strong influence of 2002 migration year on steelhead C_0 SARs, *TIRs*, and *Ds*, due to the high number of tagged smolts in that year, compared to other years. Almost all of the tagged smolts were untransported that year, and the estimated in-river SAR was particularly low. The low survival rates may be in part due to the absence of spill at LMN that year, owing to repairs to the stilling basin. Annual steelhead transport and in-river SARs are likely positively correlated, but the sample sizes (tagged smolt numbers) were low compared to Chinook, and consequently point

estimates were subject to large error. Unlike Chinook, the data therefore didn't reflect this correlation, and thus the resulting distributions of TIR and D are necessarily wider than for Chinook.

Chapter 5

Evaluation and Comparison of Overall SARs

Introduction

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

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

The NPCC 2-6% SAR objectives have a scientific basis in analyses by the Plan for Analyzing and Testing Hypotheses (PATH), conducted in support of the 2000 Biological Opinion. Marmorek et al. (1998) found that median SARs of 4% were necessary to meet the NMFS interim 48-year recovery standard for Snake River spring/summer Chinook; meeting the 100-year interim survival standard required a median SAR of at least 2%. PATH analyses did not identify specific SARs necessary for steelhead survival and recovery, however, historic steelhead SARs before FCRPS completion were somewhat greater than those of spring/summer Chinook (Marmorek et al. 1998). Currently, the Interior Columbia River Technical Recovery Team (IC-TRT) is developing biological recovery criteria based on the Viable Salmonid Population concepts (McElhany et al. 2000). Additional SAR objectives may be associated with the IC-TRT recovery criteria when adopted or incorporated into a Recovery Plan. Regardless of specific future SAR objectives, the same types of data and analytical methods will be required in the future to evaluate the overall effectiveness of the hydrosystem mitigation strategy. In addition, the ISAB (2006) raised the issue that more attention should be given to whether PIT-tagged fish survive as well as the untagged fish. Differences, and causes of any differences, need to be identified to relate PIT-tag SARs to the regional recovery objectives.

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

Background -- Patterns observed in recruits-per-spawner (R/S) and smolt-to-adult survival (SAR) data collected as part of the CSS, as well as studies done by other researchers (e.g., Pyper et al. 2005), indicate that strong covariation in performance exists among

anadromous salmon populations in the Pacific Northwest. Such synchronized population behavior is believed to be driven primarily by large-scale climate variables or ‘year’ effects. Thus, towards a more complete understanding of factors influencing inter-annual patterns in PIT-tag-based SARs and other performance measures used by the CSS (i.e., *TIR* ratios and *D*), we evaluated relationships between SARs and selected environmental parameters in this chapter. We compare CSS hatchery and wild Chinook SARs with estimates of SAR from NMFS run reconstruction (Williams et al. 2005) for a recent period, 1994-2004. SARs in this analysis are defined as smolts at LGR to adult recruits to LGR, expanded for mainstem Columbia River harvest. We provide an analysis of SAR variation due to in-river, estuary/early ocean, and off-shore marine environmental conditions for a recent period (1994-2004) using CSS estimates of wild Chinook SAR, and for a longer historical period (1964-1984, 1992-2004) using run reconstruction and CSS estimates of wild Chinook SARs.

We also compare SARs for Snake River spring/summer Chinook and SARs from downriver populations which are less influenced by the hydrosystem. The upriver/downriver population comparison was initiated primarily to provide information relevant to the patterns observed in spawner-recruit (SR) patterns between upriver and downriver stream-type Chinook (e.g., Schaller et al. 1999, Deriso et al. 2001, Schaller and Petrosky 2007). The PATH comparison of SR patterns indicated productivity and survival rates of Snake River populations declined more than those of downriver populations, coincident with development and operation of the FCRPS. The SR comparisons also provided evidence of delayed mortality of in-river migrants from the Snake River, after accounting for direct mortality, differential delayed mortality of transported smolts (*D*), and the common year effect (Peters and Marmorek 2001; CSS Delayed Mortality Workshop proceedings, Marmorek et al. 2004; Schaller and Petrosky 2007). Our specific interest in Chapter 5 is whether upriver/downriver differences in SARs for wild and/or hatchery stream-type Chinook were consistent with the differential mortality estimated from SR models for wild populations. We also compared biological characteristics (smolt FL, migration timing, and migration rate) of wild upriver and downriver stream-type Chinook populations, to evaluate if there are any biological differences that would explain a systematic shift in patterns of differential mortality between the two population groups that was coincident with dam construction and operation.

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

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

Methods

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

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

Overall SARs

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

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

Overall annual SARs, reflective of the run-at-large, were estimated by weighting the SARs for each respective study category (C_0 , C_1 , T_0) by the proportion of the run-at-large transported and remaining in-river (See Appendix B for details).

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

To evaluate SARs by Subbasin above LGR, we used the wild PIT-tagged juvenile Chinook from all available marking efforts in the Snake River basin above Lower Granite Dam.

Wild Chinook from each subbasin (plus fish tagged at Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years 1994 to 2004 (Table 5.1).

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

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

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

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

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

aggregate wild Chinook tagged populations. Excluding the fish released from the Snake River trap, the remaining PIT-tagged fish were fairly evenly split (within an 11- 20% range) across the other drainages.

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

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

^A One returning adult with no detections may have inadvertently been transported; therefore, in-river SARs are based solely on Category C₁ fish in 2001.

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

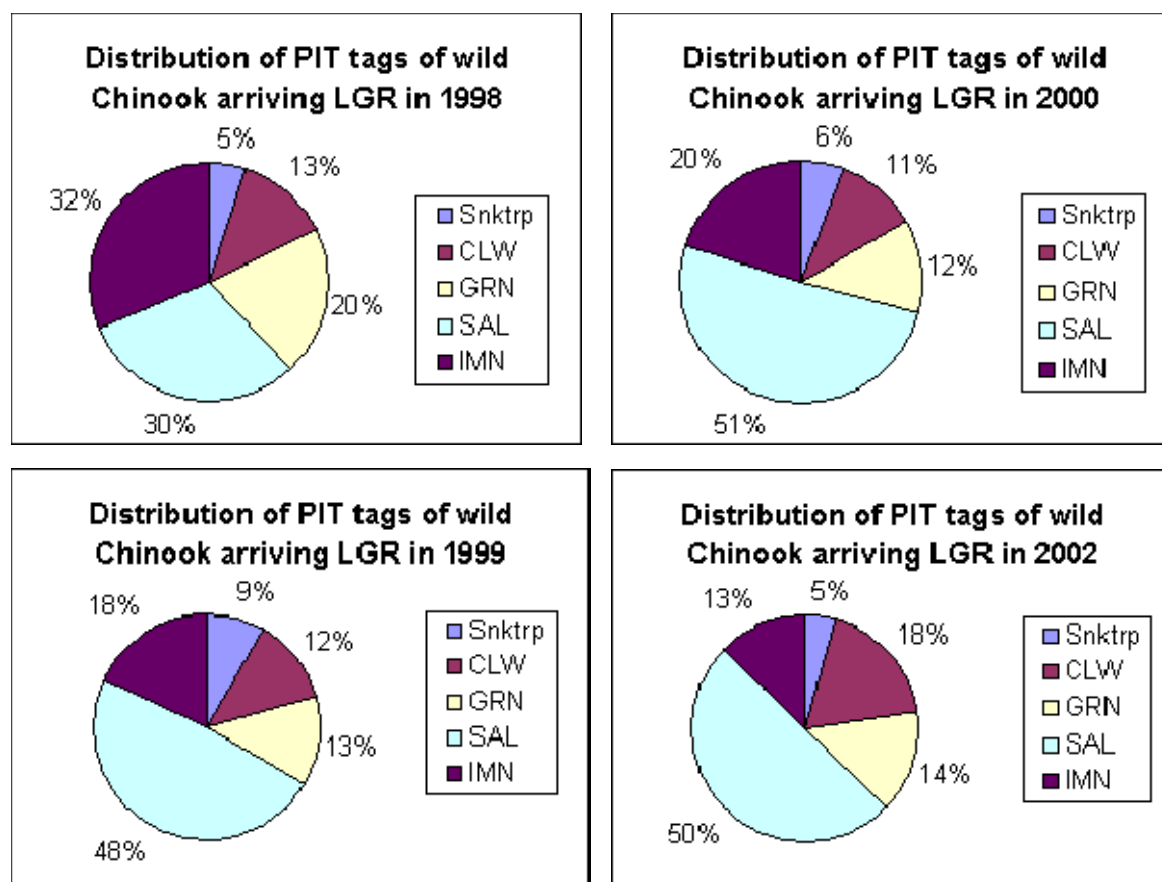


Figure 5.1. Percentage of PIT-tags in wild Chinook aggregate from Clearwater (CLW), Grande Ronde (GRN), Salmon (SAL), and Imnaha (IMN) rivers, plus Snake River trap at Lewiston, Idaho, for migration years 1998, 1999, 2000, and 2002.

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

SAR estimates - Smolt-to-adult return rate (SAR) provides a measure of overall survival from the out-migrating smolt stage to the returning adult (or recruit) stage. For wild spring/summer Chinook, we quantified relationships between environmental variables and smolt-to-adult survival using annual SAR estimates from the CSS PIT-tag estimates for 1994-2004 (11 years). We used annual weighted SAR estimates for both wild and hatchery fish (Appendix E). These values incorporate SARs of both transported (T_0) and in-river (C_0 , C_1) study groups, with the contribution of each category to the overall estimate being weighted by its relative abundance in the run at large (during outmigration). We also quantified relationships between environmental variables and a longer SAR time series which pre-dates the completion of the FCRPS. For the longer time series, we combined the CSS estimates with run reconstruction SARs for 1964-1984 and 1992-1993 (34 years). The historical run reconstruction SARs represent pre-harvest adult recruits (adults to upper dam adjusted by harvest rates experienced in the mainstem Columbia tribal and non-tribal fisheries). The run reconstruction SARs are

calculated as the number of adults (age 4-6) returning to the uppermost dam by brood year, expanded by the return year harvest rate, which are then divided by number of smolts (from that brood) arriving at the uppermost dam on the Snake River. These SARs were estimated for the aggregate Snake River wild spring and summer Chinook using the methods described in Petrosky et al. (2001) and extended by Williams et al. (2005). We also adjusted the CSS SAR_{LGR-LGR} for harvest rates experienced on wild spring/summer Chinook during the respective return years 1996-2006 (range 4.8% to 14.6%; U.S. v. Oregon Technical Advisory Committee 2006). In contrast to other studies (Scheuerell and Williams 2005; Williams et al. 2005), we excluded years when estimated smolt abundance was based on spawner-recruit model predictions (i.e., MY 1985-1991). A time series plot of SARs for wild spring summer Chinook appears in Figure 5.2.

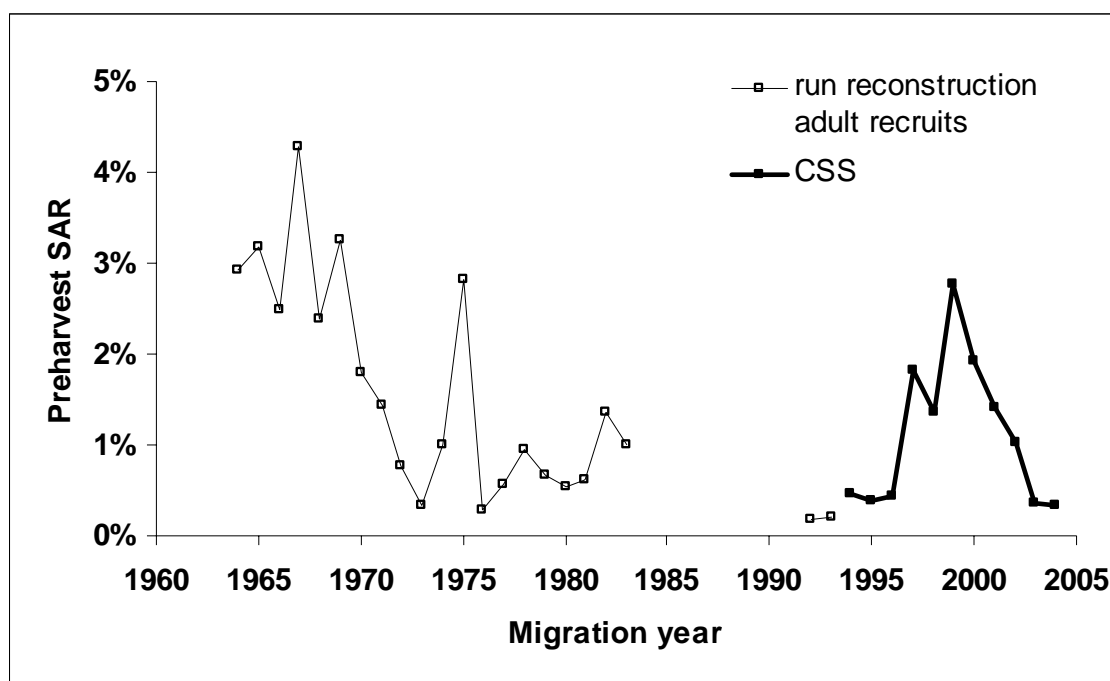


Figure 5.2. Preharvest smolt-to-adult returns for Snake River wild spring/summer Chinook, migration years 1964-2004.

SARs were estimated for hatchery Chinook salmon populations based on PIT-tag releases occurring at Dworshak National Fish Hatchery, Imnaha Hatchery, McCall Hatchery, Rapid River Hatchery and the Catherine Creek Acclimation Pond. Our hatchery Chinook salmon SAR time series extends from MY 1997 to 2004 (8 years), and represented the average SAR across hatcheries (Figure 5.3). The CSS wild PIT SAR estimates were highly correlated ($r=0.94$) with the aggregate wild run reconstruction estimates, for migration years 1994-2001. The CSS hatchery PIT SAR estimates were highly correlated ($r=0.90$) with the aggregate wild run reconstruction estimates, for migration years 1997-2001. Lastly, the CSS hatchery PIT SAR estimates were also highly correlated ($r=0.86$) with the CSS wild PIT SAR estimates. Given the high correlation among SAR estimates, we focused the remainder of the analyses on the contemporary CSS wild PIT estimates and on the longer time series that included the aggregate

wild run reconstruction estimates (migration years 1964-1984, 1992-1993) and the CSS wild PIT estimates (migration years 1994-2004) in order to get the largest contrast in survival estimates.

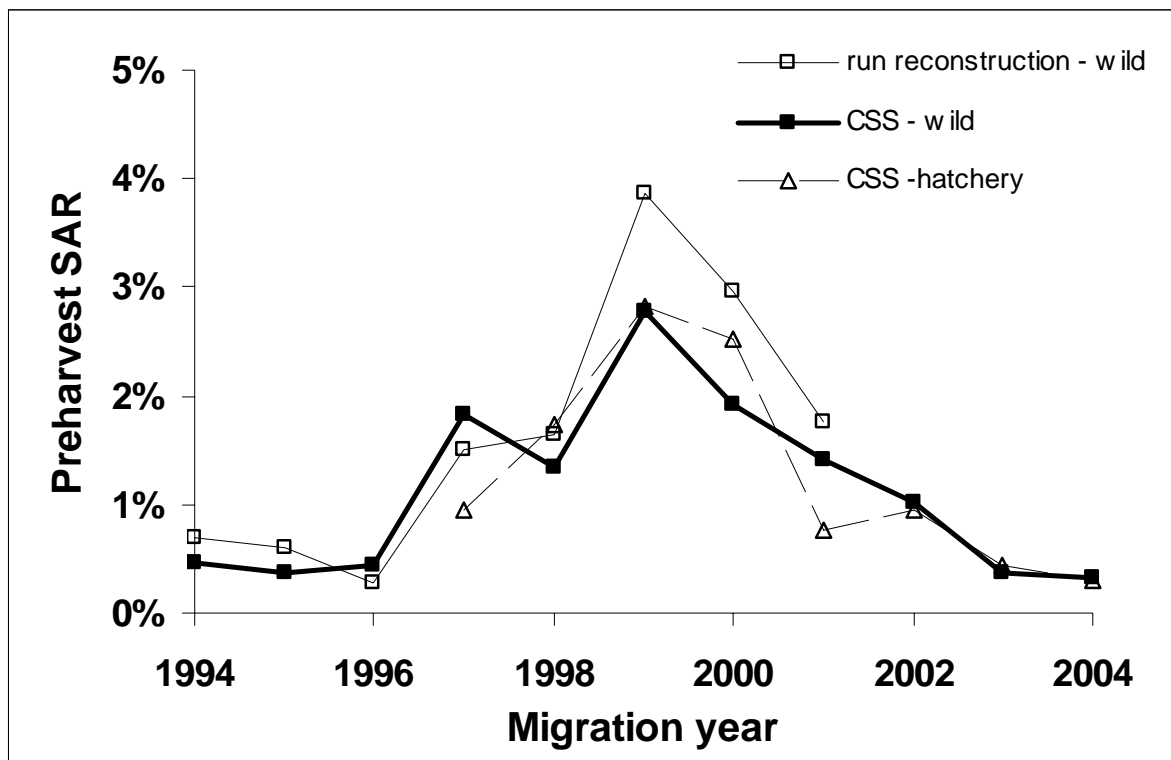


Figure 5.3. Preharvest smolt-to-adult returns for Snake River spring/summer Chinook, migration years 1994-2004 (open squares are run reconstruction wild, solid squares are CSS wild, and open triangles are CSS hatchery)

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

Water velocity in the mainstem migratory corridor is generally expressed as the average time (in days) it takes for a water particle to travel through a river reach (water travel time) during a specified period. Water travel times (SNWTT), from the confluence of the Snake and Clearwater rivers to Bonneville Dam, were calculated for the period April 15-May 31, the primary spring migration period. Water travel time is a function of reservoir volume and inflow, both of which are partially subject to management control. SNWTT ranged from 5 to 40 days during the 1964-2004 smolt migrations (Figure 5.4).

We included in our analysis two variables describing environmental conditions existing during the early-ocean phase of Chinook salmon. First, we described conditions existing immediately off shore using monthly indices of coastal upwelling intensity (i.e., the Bakun Index, CUI) estimated at 45N and 125W. Upwelling indices have also been linked to ocean survival for Columbia stream-type Chinook salmon (Scheuerell and Williams 2005) and Oregon coastal Coho salmon (Nickelson 1986). Monthly CUI indices were obtained from NOAA Pacific

Fisheries Environmental Laboratory website

<http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html> and are displayed in Figure 5.5.

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

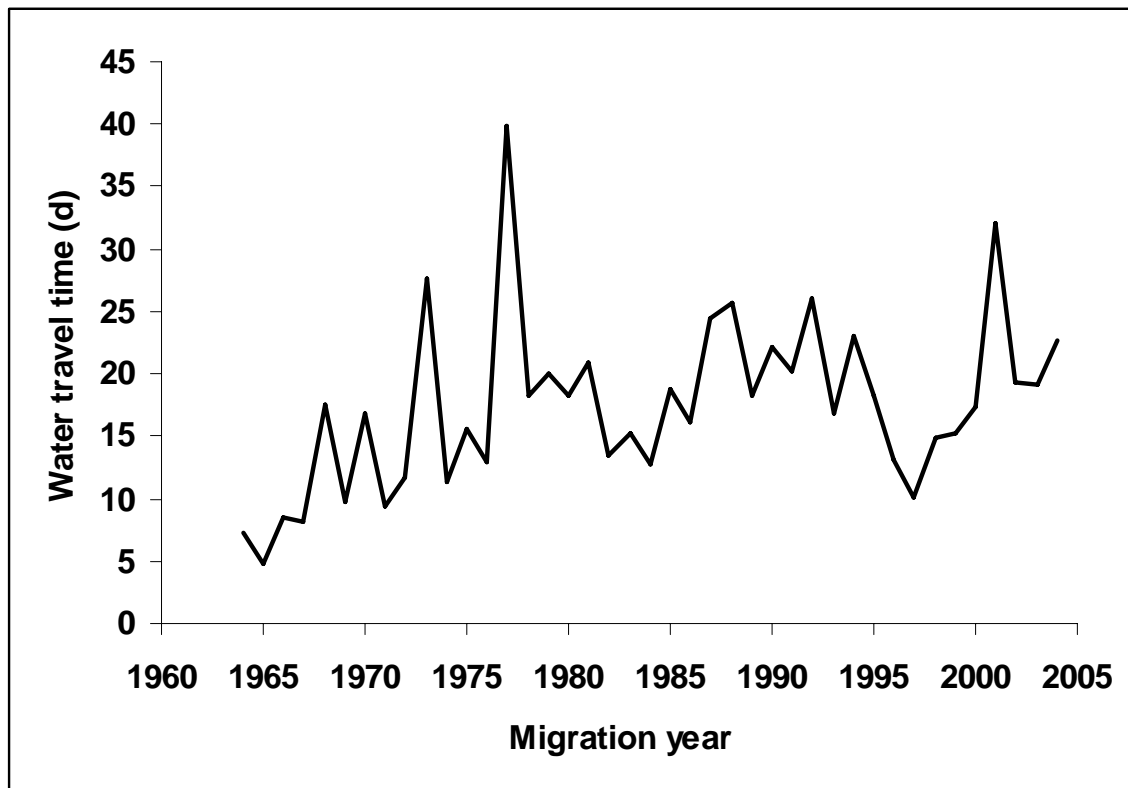


Figure 5.4. Water travel time(d) experienced by juvenile spring Snake River migrants, 1964-2004.

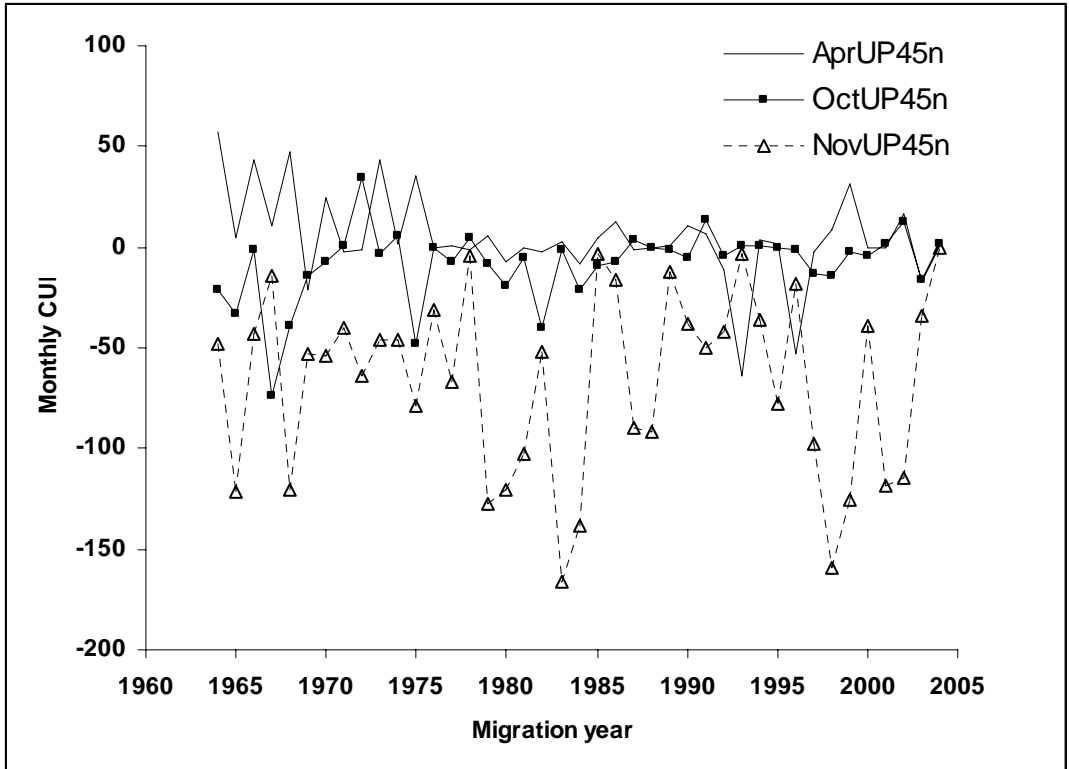


Figure 5.5. Monthly CUI indices (45N 125W) for April, October and November, 1964-2004 migration years. April, October and November indices were frequently selected in multiple regression models describing SAR.

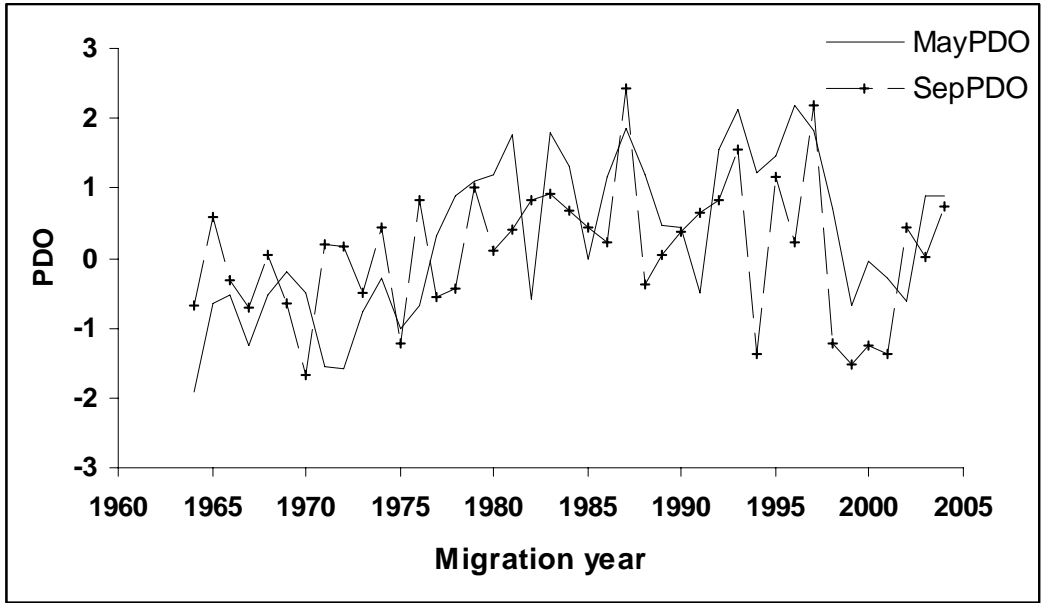


Figure 5.6. Monthly PDO indices for May and September, 1964-2004 migration years. May and September indices were frequently selected in multiple regression models describing SAR.

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

Multiple Factor Model

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

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

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

$$-\ln[SAR(t)] = \beta_0 + \beta_{WTT} \cdot WTT(t) + \beta_{SepPDO} \cdot PDO_{Sep}(t) + \beta_{AprUPWELL} \cdot UPWELL_{Apr}(t) + \varepsilon t, \quad [5.1]$$

All analyses were completed using SAS version 9.1.

Snake River and Downriver SAR Comparison

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

$$\ln(R_{t,i} / S_{t,i}) = (a_i + \delta_t - m_{t,i}) - \beta_i S_{t,i} + \varepsilon_{t,i} \quad [5.2]$$

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

The differential mortality (μ) experienced by Snake River populations relative to the downriver populations can be indirectly estimated by output from the delta model. Differential mortality is the difference between model estimated total mortality for the Snake River populations ($m_{t,i}$) and juvenile passage mortality ($M_{t,i}$) experienced by the downriver populations (equations 4-6 in Deriso et al. 2001). Schaller and Petrosky (2007) used Paulsen and Hinrichsen (2002) ordinary least square (OLS) method to fit the delta model, to all years of SR data updated through brood year 1998. They used the same Snake River populations as Deriso et al. (2001), but for the downriver populations used only the three John Day populations in these analyses because updated estimates for the other downriver populations were not available. Sensitivity analysis indicated the estimate of μ was not greatly influenced by the inclusion or exclusion of the other downriver populations through brood year 1990 (Schaller and Petrosky 2007).

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

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

where $\text{SAR}_{\text{Snake}} = (\text{smolts arriving at first dam encountered, LGR})/(\text{adult return to BOA})$; $\text{SAR}_{\text{John Day}} = (\text{smolts arriving at first dam encountered, JDA})/(\text{adult return to BOA})$; and t is brood year. Adult recruits for upriver and downriver populations are enumerated at Bonneville Dam, assuming similar lower river harvest rates, for consistency with the SR definition of recruitment employed in equation 5.2. The estimates of $\text{SAR}_{\text{Snake}}$ and $\text{SAR}_{\text{John Day}}$ were available from CSS for migration years 2000 to 2004, where the John Day PIT-tag studies began in 2000.

Finally, we compared differential mortality estimates based on the SR data for smolt years 1972-2000 (Schaller and Petrosky 2007; equation 5.2) with those from SAR ratios of upriver and downriver wild and hatchery populations (equation 5.3).

Wild upriver/downriver SAR difference: In the lower Columbia River basin, the CSS utilizes the PIT-tagged wild spring Chinook from the aggregate John Day River population (tagged under a separate contract between ODFW and BPA) for the upriver/downriver comparison. ODFW crews PIT-tagged 1,800 to 6,100 juvenile Chinook within the John Day River basin in migration years 2000-2004 (Table 5.3). Methods and locations of this PIT-tagging are found in Carmichael et al. (2002).

Table 5.3. Number of PIT-tagged wild Chinook released in John Day River basin, estimated survival and resulting smolt population arriving John Day Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.

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

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

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

Snake River wild Chinook SARs were estimated according to methods described in Chapter 3 and Appendix B, except that adults were enumerated at BOA (see equation 5.3). Estimating SAR for John Day River populations from first dam encountered as smolts to BOA as adults requires an estimate of the number of PIT-tagged John Day River wild Chinook smolts passing JDA. This smolt estimate was obtained by multiplying the tag release number by estimated survival from release to JDA tailrace (Table 5.3). In estimating this survival, we did not include the PIT-tag recoveries from the bird colonies on estuary islands, since the detections at BON and the trawl alone provided sufficient precision in the survival estimate to JDA tailrace.

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

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

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

However, along with utilizing the PIT-tags recovered from bird colony comes the unproven assumption that the birds did not capture PIT-tagged fish above Bonneville Dam. Table 5.4 presents the resulting survival estimates to BON.

Table 5.4. Number of PIT-tagged Carson Hatchery Chinook released in the Wind River, estimated survival and resulting smolt population arriving Bonneville Dam in migration years 2000 to 2004 (with 90% confidence intervals) with detected adults at BOA.

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

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

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

In determining SARs indexed on adult returns at (BOA), we need an estimate of the number of smolts passing BON and number of PIT-tagged adults passing BOA in the fish ladders. Only 2-ocean and older adult returns are used in the computations of the SARs (the full age composition of the returning jacks and adults for each migration year is shown in Appendix D). Beginning with return year 2002 there was the capability to detect nearly all PIT-tagged adult fish passing the three ladders at BOA. However, since a portion of the fish swim over the weir crests and don't pass through the orifices where the detection equipment is installed, the detection rate for PIT-tagged adult fish at BON remains less than 100%. To expand the number of adult PIT-tag detections at BON to account for "missed" fish, we computed BOA adult PIT-tag detection efficiency estimates for migration years 2000 (see Table 46 of Berggren et al. 2005) and 2001 to 2004 (Table 5.5). The combined hatchery/wild detection efficiency estimates were used for all wild and hatchery Chinook groups in the estimation of SARs.

Table 5.5. PIT-tag detections of returning adult Chinook (ages 2- and 3-ocean) at Bonneville and Lower Granite dams with percentage of fish undetected at Bonneville Dam – returns from smolts that outmigrated in 2001 to 2004.

Smolt Migr. Year	Dam for unique adult detections ¹	Age 2-and 3-Ocean Returning Adult Chinook		
		Hatchery Chinook ²	Wild Chinook ³	Combined Chinook
2001	BOA & Upriver ⁴	616	45	631
	Total Upriver ⁵	626	46	642
	BOA detection efficiency ⁶	98.4%	97.8%	98.3 %
2002	BOA & Upriver ⁴	1,026	232	1,258
	To Upriver ⁵	1,065	240	1,305
	BOA detection efficiency ⁶	96.3%	96.7%	96.4 %
2003 ⁶	BOA & Upriver ⁴	514	84	598
	Total Upriver ⁵	543	90	633
	BOA detection efficiency ⁵	94.7%	93.3%	94.5 %
2004 ⁶	BOA & Upriver ⁴	318	86	404
	Total Upriver ⁵	326	88	414
	BOA detection efficiency ⁶	97.5%	97.7%	97.6%

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

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

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

⁴ BOA & Upriver = sum of unique PIT-tagged returning adults detected at both BOA and an upriver dam.

⁵ Total Upriver = sum of unique PIT-tagged returning adults detected at upriver dams.

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

⁶ Calculated as $p = (N \text{ jointly detected at BOA \& upriver}) / (N \text{ jointly detected at BOA \& upriver} + N \text{ passing BOA undetected \& detected upriver})$.

Comparison of biological characteristics of Snake River and downriver wild smolts

Background -- The use of an upriver-downriver stock-comparison approach towards evaluating the effects of the FCRPS on threatened anadromous salmonids (e.g., Schaller et al. 1999; Deriso et al. 2001; Schaller and Petrosky 2007) has been criticized for a number of reasons (Zabel and Williams 2000; Williams et al. 2005). Critics suggest that downriver stocks, which pass through fewer dams than upriver stocks (i.e., 3 vs. 8 projects), are not appropriate controls for evaluating the effects of hydropower development because a number of confounding issues are at play. For instance, downriver smolts may migrate to sea at a different time than upriver stocks and therefore experience different (more favorable) conditions during estuary/early ocean residence (Zabel and Williams 2000; Williams et al. 2005); also, they may be less exposed to ocean fisheries than their upriver counterparts (Zabel and Williams 2000). More recently, it has been suggested that smolts produced by upriver populations may be smaller than those originating from downriver stocks (Williams et al. 2005), thereby suffering greater (size-selective) mortality at sea (Zabel and Williams 2002). Overall, critics argue that the existence of systematic differences in upriver and downriver population life history attributes precludes the ability to ascribe stock viability differences to the FCRPS.

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

For our present purpose, we explore whether or not there are any observable (present-time) differences between upriver and downriver wild populations that could explain the observed differential mortality. We focused on life history characteristics associated with the active outmigrant, or smolt, life stage. For both upriver and downriver populations, we quantified and compared outmigration attributes in order to understand the possible confounding effects of smolt life history differences on the results reported in this chapter and elsewhere (Schaller et al. 1999; Schaller and Petrosky 2007). To do this, we exploited a six-year time series of outmigrant smolt data collected at juvenile traps affiliated with the wild Chinook salmon tagging component of the CSS. We contrasted size-at-tagging (fork length, in mm), emigration timing (using the trap site as a reference point for emigration), downriver migration rates (in km / day, to Bonneville Dam, BON), and estuary arrival timing (taken as arrival at BON) between wild/natural Chinook salmon smolts captured, tagged, and released at upriver (above Lower Granite Dam, LGR) trap sites and the John Day River mainstem trap site for migration years (MY) 2000 through 2005.

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

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

sizes involved were quite large and statistical significance was therefore virtually guaranteed for all tests, we judged biological significance when between-group size differences were greater than 5 mm in magnitude.

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

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

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

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

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

Comparison of biological characteristics of Snake River and downriver hatchery smolts

Differential mortality between upriver and downriver stream-type Chinook populations has been estimated for wild populations from both spawner-recruit (Schaller et al. 1999; Deriso et al. 2001; Schaller and Petrosky 2007) and PIT-tag SAR (CSS study) data sources. The CSS also investigated whether a similar level of differential mortality was present between PIT-tag SARs for five upriver and one downriver hatchery Chinook populations. Because biological characteristics of a population could differentially influence survival to adult return (see above), we also summarized hatchery presmolt FL at the time of tagging, and hatchery smolt arrival timing distributions entering the hydrosystem (LGR or BON) and arriving at the estuary (BON). The CSS to date has sampled FL at the time of tagging at each hatchery facility, which occurs from one to five months prior to the hatchery smolt release. We also estimated passage distribution statistics for each hatchery Chinook population at LGR and BON for migration years (MY) 2000-2005.

SARs by Bonneville Arrival Timing

The numbers of Snake River wild spring/summer Chinook PIT-tagged smolts and returning adults from the CSS study groups T0, C0, and C1 were summarized for smolt arrival timing based on their detection at Bonneville Dam, at John Day Dam or trawl samples below Bonneville Dam, 2000-2003 migration years. Bonneville arrival dates for smolts detected only at John Day Dam or in the trawl were corrected for median travel times to or from the Bonneville detector. Numbers of PIT-tagged wild John Day River spring Chinook smolts and adults for the same arrival periods and years were included in the summary. SARs in this case represent smolts from Bonneville dam to adult returns to Bonneville dam. Numbers of smolts and adult returns by group were summarized by biweekly period (before April 16; April 16-30; May 1-15; May 16-31; June 1-15; June 16-30; July 1 and later). Adult returns for 2003 were summarized for 2-ocean returns only in this analysis. We compared SARs and calculated binomial confidence intervals of Snake River CSS groups and John Day River smolts each year for the primary migration period of John Day smolts (April 16-May 31).

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

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

Results

Overall SARs

The estimated SARs for Snake River wild spring/summer Chinook were less than the NPCC minimum 2% SAR objective in 10 of 11 years, and the bootstrapped 90% confidence interval included 2% in only 4 of 11 years (Figure 5.7). The geometric mean SAR for 1994-2003 was 0.86%. Annual average SARs ranged from 0.34% to 2.39%. Coefficients of variation on annual estimates ranged from 12% in 2002 to 58% in 1996. The mean SAR (based on natural log transformation) was 0.82%, and using a t-distribution, less than 1% of the distribution exceeded a 2% SAR. Using the process error approach (Chapter 4 results), the mean SAR is 0.82% and approximately 5.6% of the distribution is above 2%.

SARs covaried during 1998-2004 for wild spring/summer Chinook from the Clearwater, Grande Ronde, Salmon and Imnaha subbasins (Figure 5.8). With our criteria of at least 15 adults per category, estimates at the subbasin level were achieved in 1998, 1999, 2000 and 2002. Bootstrapped 90% CI generally overlapped within year for SARs from the different subbasins; however, it appears that Imnaha Chinook tended to have higher than average SARs and Clearwater Chinook may have had lower than average SARs.

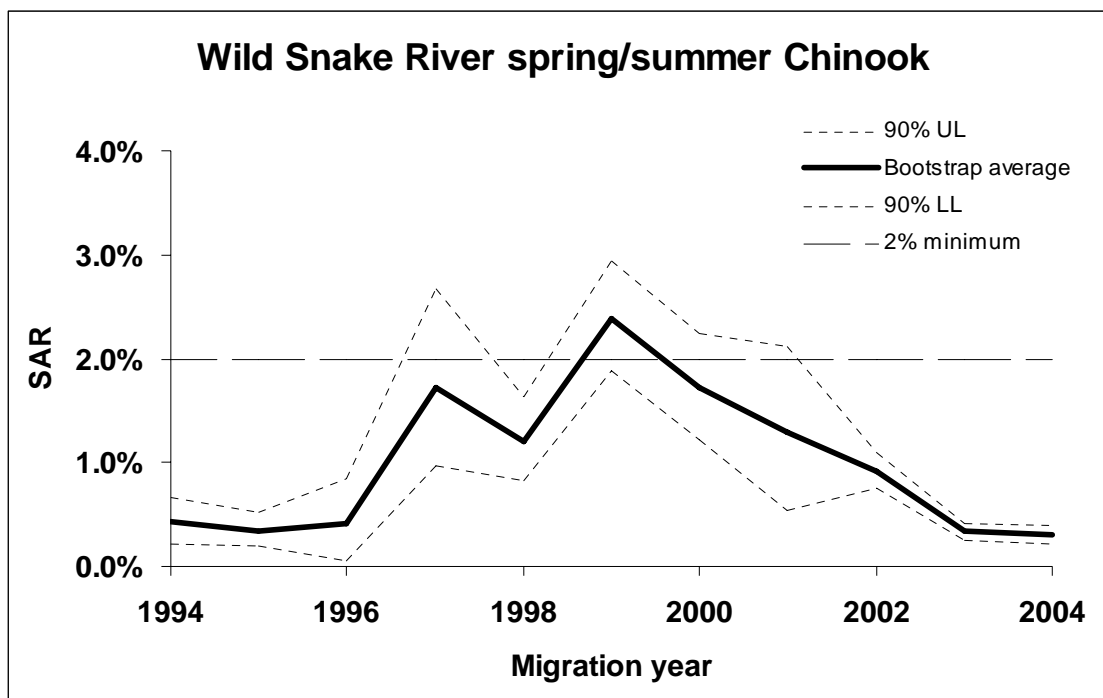


Figure 5.7 Bootstrapped SAR and upper and lower CI for wild aggregate Snake River spring/summer Chinook, migration years 1994-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

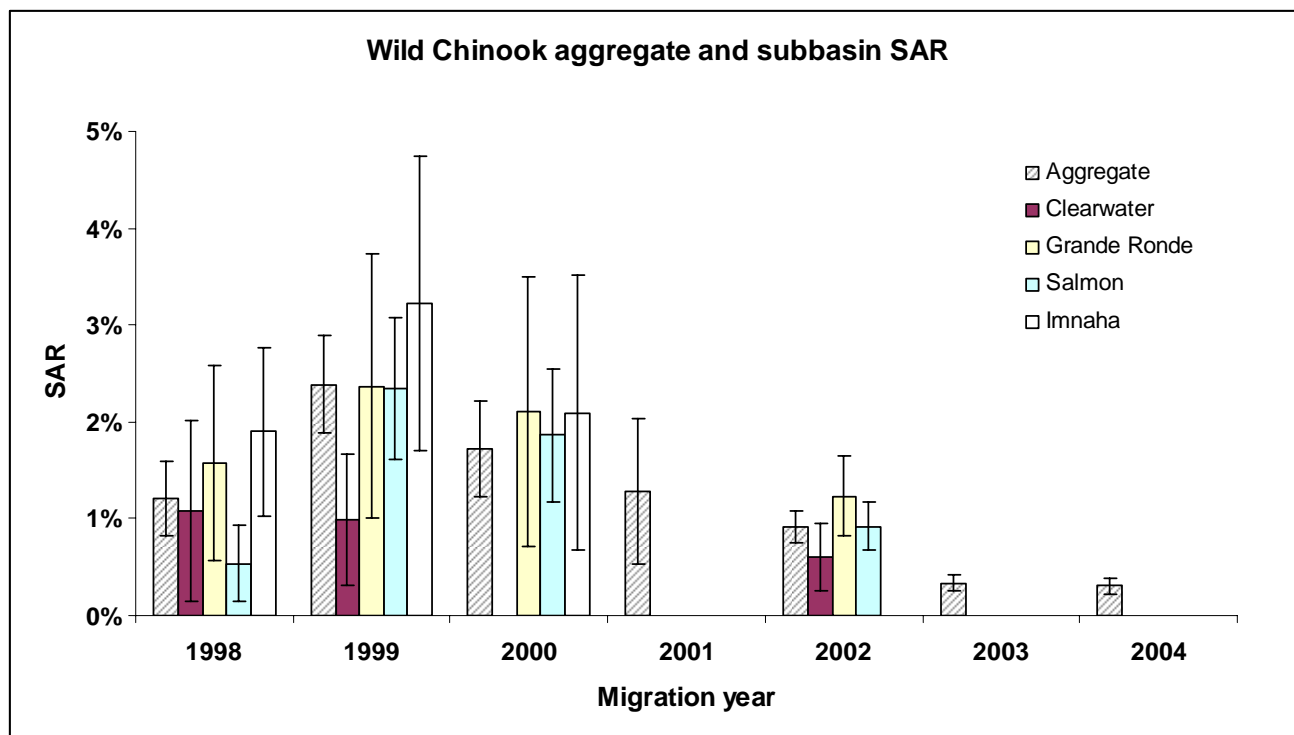


Figure 5.8. SARs and 90% CI for wild aggregate Snake River spring/summer Chinook, and four subbasins above LGR (Clearwater, Grande Ronde, Salmon and Imnaha), 1998-2004.

SARs for the Snake River hatchery spring/summer Chinook tracked closely with wild aggregate SARs during 1997-2004 (Figure 5.9). Correlations among all hatchery and wild groups (excluding Catherine Creek, which had only four years of data) ranged from 0.77 to 0.97. Dworshak Hatchery spring Chinook SARs tended to be less than wild aggregate SARs.

The geometric mean SAR for Dworshak Hatchery spring Chinook during 1997-2003 was 0.62%, and annual estimated SARs ranged from 0.21% to 1.18% (Figure 5.10; Appendix E). Coefficients of variation on annual estimates ranged from 6% to 18%.

The geometric mean SAR for Rapid River Hatchery spring Chinook during 1997-2003 was 1.07%, and annual estimated SARs ranged from 0.24% to 2.91% (Figure 5.10; Appendix E). Coefficients of variation on annual estimates ranged from 4% to 14%.

The geometric mean SAR for McCall Hatchery summer Chinook during 1997-2003 was 1.67%, and annual estimated SARs ranged from 0.68% to 3.26% (Figure 5.10; Appendix E). Coefficients of variation on annual estimates ranged from 4% to 12%.

The geometric mean SAR for Imnaha Hatchery summer Chinook during 1997-2003 was 1.03%, and annual estimated SARs ranged from 0.53% to 2.89% (Figure 5.10; Appendix E). Coefficients of variation on annual estimates ranged from 5% to 20%.

The geometric mean SAR for Catherine Creek Hatchery spring Chinook during 2001-2003 was 0.38%, and annual estimated SARs ranged from 0.22% to 0.77% (Figure 5.10; Appendix E). Coefficients of variation on annual estimates ranged from 18% to 30%.

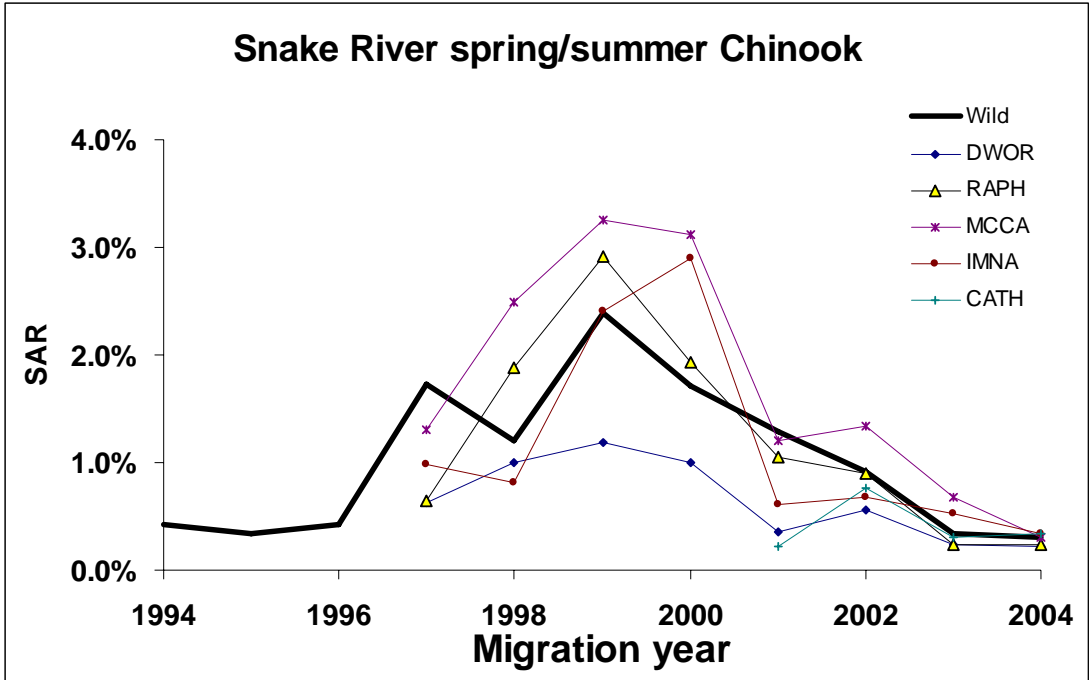


Figure 5.9. Bootstrapped SAR for aggregate wild and five hatchery populations of Snake River spring/summer Chinook, 1994-2004. Migration year 2004 is complete through 2-ocean returns only.

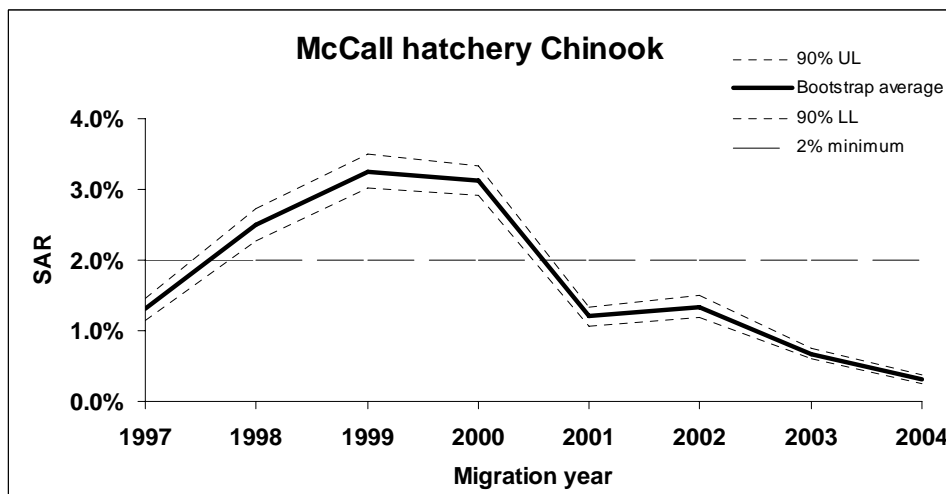
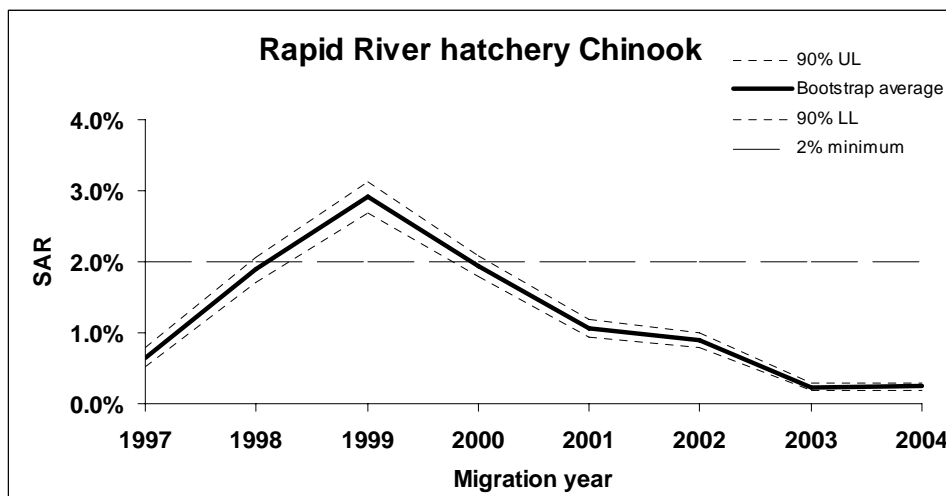
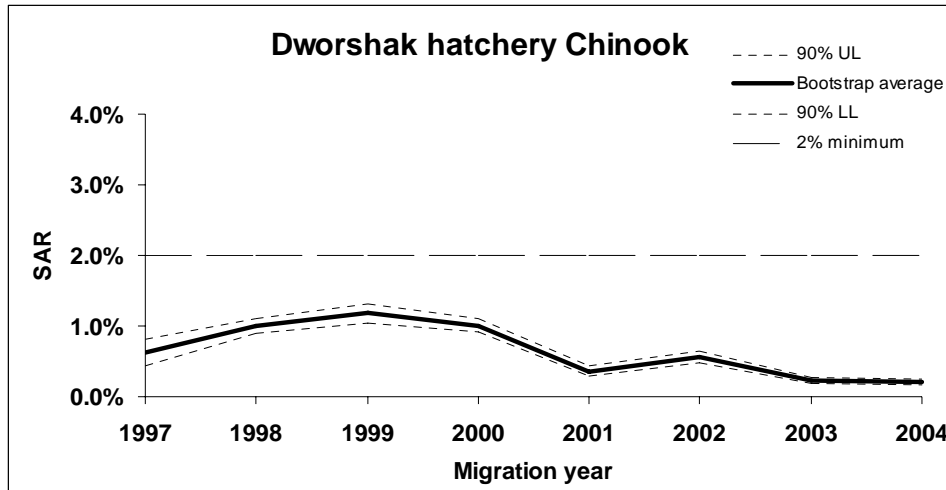


Figure 5.10 Bootstrapped SAR and upper and lower CI for selected hatchery Snake River spring/summer Chinook, migration years 1997-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

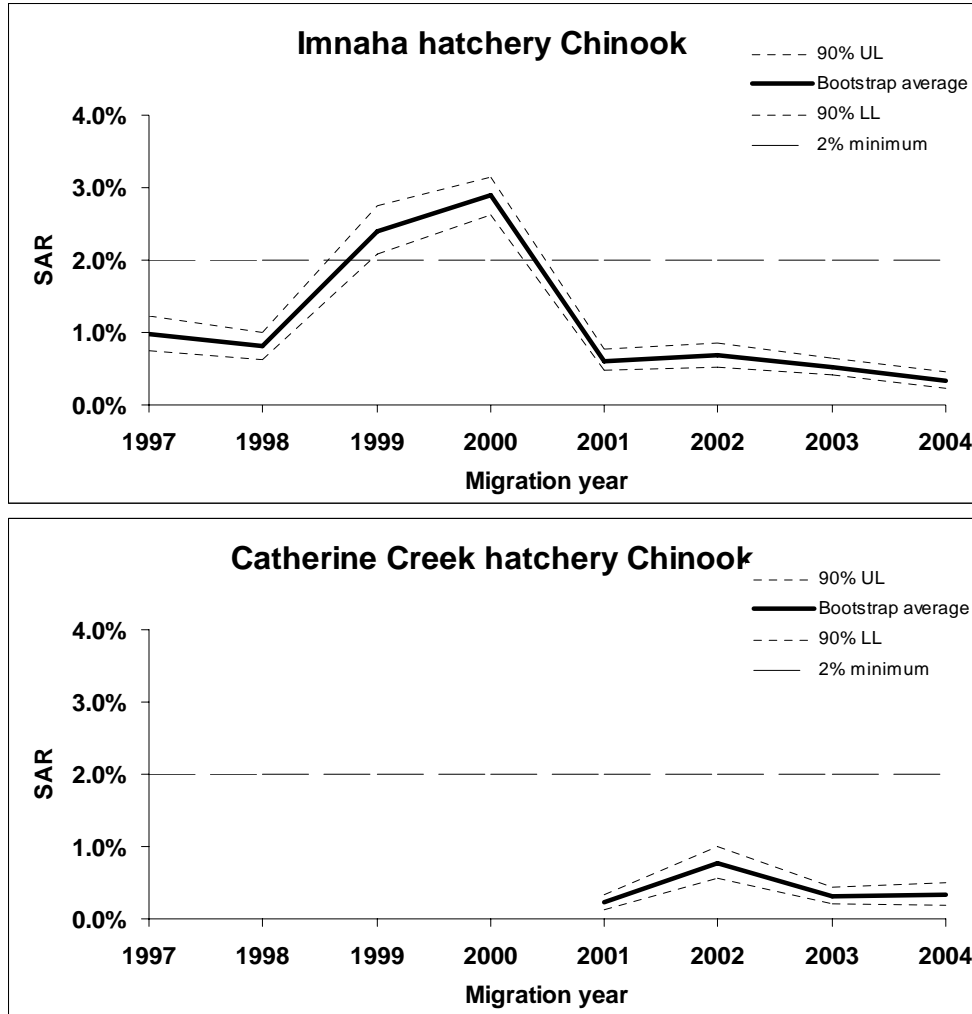


Figure 5.10 (continued). Bootstrapped SAR and upper and lower CI for selected hatchery Snake River spring/summer Chinook, migration years 1997-2004. Migration year 2004 is complete through 2-ocean returns only. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

SARs for Snake River wild steelhead were closer to the NPCC minimum 2% SAR objective than were those of wild spring summer Chinook, but the geometric mean was only 1.56%. Annual estimated SARs ranged from 0.31% to 2.91% (Figure 5.11). The estimated SARs for Snake River wild steelhead exceeded the NPCC minimum 2% SAR objective in four of seven years, but were consistently less than the NPCC 4% recommended average. The bootstrapped 90% lower CI was consistently less than 2%; the upper confidence interval exceeded 2% in five of seven years (Figure 5.11). Coefficients of variation on annual estimates ranged from 14% in 2003 to 62% in 1998.

The mean SAR (based on natural log transformation) was 1.56%, and using a t-distribution, approximately 44% of the distribution exceeded a 2% SAR. Using the process error approach (Chapter 4 results), the mean SAR was 1.95% and approximately 42% of the distribution was above 2%.

Hatchery steelhead SARs generally tracked wild steelhead SARs during 1997-2003 (Figure 5.11). The correlation between wild and hatchery SARs was 0.57 for the seven years of estimates. The geometric mean SAR for aggregate hatchery steelhead during 1997-2003 was 0.91%, and annual estimated SARs ranged from 0.40% to 1.88%. Coefficients of variation on annual estimates ranged from 10% to 47%.

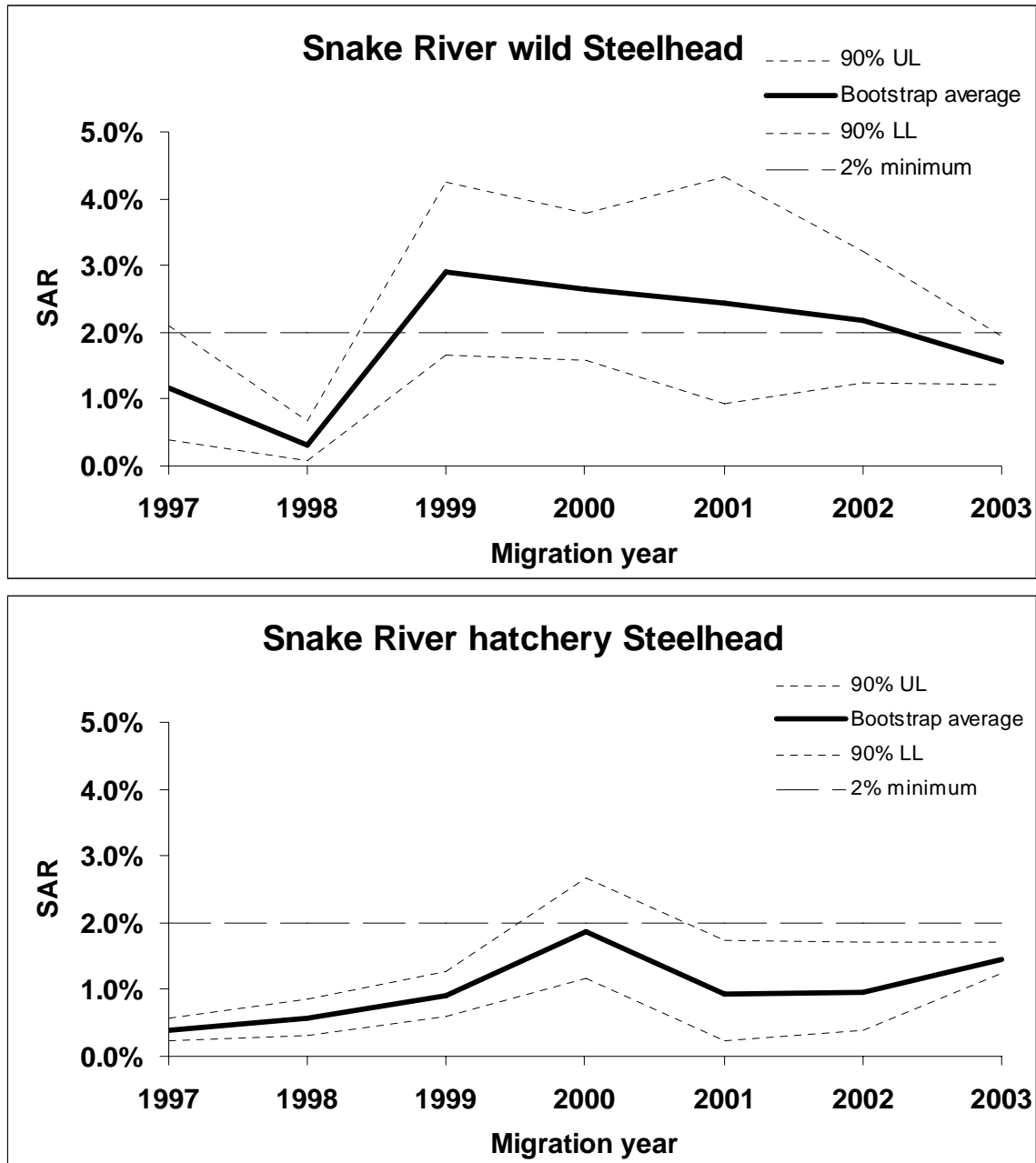


Figure 5.11. Bootstrapped SAR and upper and lower CI for aggregate wild and aggregate hatchery Snake River steelhead, migration years 1997-2003. The NPCC (2003) minimum 2% SAR for listed wild populations is shown for reference.

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

Both PIT-tag-based current time series SARs and in-river and marine environmental conditions varied considerably across migration years 1994-2004 (Figures 5.2-5.6). These SARs spanned a range of over an order of magnitude across observations (min to max: 0.3 to 2.8 %). The long time series of SARs (including run reconstruction and PIT-tag estimates) spanned a wider range across observations (min to max: 0.2 to 4.6 %, Figure 5.3).

First we evaluated the correlation amongst monthly PDO indices and monthly CUI 45N indices to select months that were not highly correlated (Table 5.6). We then used the bi-variate results to guide the suite of PDO and CUI monthly indices to enter into the multiple regression model selection process (Tables 5.7 and 5.8).

Table 5.6. Correlation matrices for monthly environmental variables for the years 1964-2004. A is monthly Pacific Decadal Oscillation indices. B is monthly Bacun Upwelling indices at 45 degrees North.

A - Correlation Matrix

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

B - Correlation Matrix

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

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

Long Time Series				
Variables	R²	AIC	BIC	
MayPDO	0.32	-20.36	-18.40	
AugPDO	0.23	-15.94	-14.49	
JulPDO	0.16	-13.13	-12.00	
SepPDO	0.15	-12.77	-11.69	
OctPDO	0.15	-12.68	-11.60	
AprPDO	0.14	-12.34	-11.30	
JunPDO	0.11	-10.94	-10.06	
NovPDO	0.09	-10.51	-9.68	
MarPDO	0.09	-10.35	-9.53	
JanPDO	0.08	-10.03	-9.24	
DecPDO	0.05	-8.76	-8.11	
FebPDO	0.04	-8.64	-8.01	

Current Time Series				
Variables	R²	AIC	BIC	
MayPDO	0.24	-6.43	-10.43	
FebPDO	0.22	-6.18	-10.18	
AprPDO	0.19	-5.75	-9.75	
JanPDO	0.15	-5.20	-9.20	
JulPDO	0.06	-4.14	-8.14	
MarPDO	0.06	-4.08	-8.08	
OctPDO	0.06	-4.06	-8.06	
SepPDO	0.01	-3.54	-7.54	
JunPDO	-0.01	-3.25	-7.25	
AugPDO	-0.08	-2.54	-6.54	
NovPDO	-0.10	-2.39	-6.39	
DecPDO	-0.11	-2.26	-6.26	

Table 5.8. Bi-variate selection results for LN(SAR)-environmental variable (Upwelling) regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).

Long Time Series				
Variables	R²	AIC	BIC	
AprUP45n	0.24	-16.34	-14.65	
OctUP45n	0.23	-15.85	-14.21	
MayUP45n	0.05	-9.08	-8.21	
NovUP45n	0.04	-8.72	-7.90	
JunUP45n	0.03	-8.16	-7.39	
SepUP45n	0.03	-8.05	-7.30	
JanUP45n	0.02	-7.85	-7.12	
JulUP45n	-0.01	-6.72	-6.11	
DecUP45n	-0.02	-6.46	-5.88	
MarUP45n	-0.03	-6.17	-5.62	
FebUP45n	-0.03	-6.13	-5.58	
AugUP45n	-0.03	-6.11	-5.57	

Current Time Series				
Variables	R²	AIC	BIC	
NovUP45n	0.41	-9.12	-13.12	
AprUP45n	0.18	-5.65	-9.65	
JanUP45n	0.14	-5.06	-9.06	
FebUP45n	0.13	-4.94	-8.94	
MayUP45n	0.03	-3.76	-7.76	
SepUP45n	0.03	-3.70	-7.70	
DecUP45n	-0.03	-3.10	-7.10	
JunUP45n	-0.05	-2.85	-6.85	
JulUP45n	-0.08	-2.57	-6.57	
OctUP45n	-0.10	-2.37	-6.37	
MarUP45n	-0.11	-2.28	-6.28	
AugUP45n	-0.11	-2.27	-6.27	

The long time series yielded fairly good fits to 2 and 3 parameter models. Parameter values for SNWTT were fairly consistent across models, indicating a decrease in survival with increasing WTT (Table 5.9). Parameter values for September PDO were similarly consistent across the models indicating increasing survival with cooler phase ocean conditions. We also observed a consistent inverse relationship in the late fall with the upwelling index; strong downwelling in the fall was associated with improved survival.

Current time series results for multiple regression analysis yielded poorer fits than the long time series (Table 5.9). Parameter values for SNWTT were fairly consistent across models – also indicating a decrease in survival with increasing WTT. Parameter values for SNWTT for the current time series were similar to those for the long time series however, SNWTT was less significant (or nonsignificant) for the shorter (11 year) time series. The model selection identified May PDO as influential, but the parameter values also indicated increasing survival

with cooler phase ocean conditions. Lastly, when upwelling entered into the model for the current time series, the value was similar to the long time series.

Table 5.9. Model selection results for LN(SAR)-environmental variable regressions using long time series (1964-1984,1992-2004) of data and current time series (1994-2004).

Model Fit	Adjusted R ²	AIC	BIC	Variables	Parameter Estimate	Pr > t
Long Time Series						
Best	0.70	-45.19	-39.79	Intercept	-4.190	<.0001
				SNWTT	-0.054	0.0003
				MayPDO	-0.196	0.0331
				SepPDO	-0.331	0.0039
				OctUP45n	-0.011	0.0127
				NovUP45n	-0.006	0.0043
Best 3 Parm	0.64	-37.01	-35.77	Intercept	-3.779	<.0001
				SNWTT	-0.075	<.0001
				SepPDO	-0.496	<.0001
				NovUP45n	-0.006	0.0104
Best 2 Parm	0.52	-31.44	-31.24	Intercept	-3.397	<.0001
				SNWTT	-0.074	<.0001
				SepPDO	-0.489	0.0001
Current Time Series						
Best	0.51	-10.09	-0.54	Intercept	-3.9457	0.0033
				SNWTT	-0.0529	0.1644
				MayPDO	-0.4305	0.1048
				NovUP45n	-0.0062	0.1652
Best 2 Parm	0.43	-8.84	-3.11	Intercept	-3.0399	0.0036
				SNWTT	-0.0696	0.0822
				MayPDO	-0.6241	0.0181

Snake River and Downriver SAR Comparison

Wild upriver/downriver SAR difference: The SARs from first-dam encountered as smolts to Bonneville Dam as adults were substantially higher for the John Day River wild Chinook (downriver group) than aggregate Snake River stocks (upriver group) across migration years 2000 to 2004 (Table 5.10; Figure 5.12). SARs for Snake River wild spring/summer Chinook ranged from 0.4% to 2.7%, whereas John Day SARs ranged from 2.5% to 11.1% (Table 5.8). Snake River SARs were only 23% of those for the John Day River for the 5 migration years (geometric mean of U/D ratios). The PIT-tag aggregate of wild Chinook from the John Day River and the PIT-tag aggregate of wild Chinook from the Snake River basin above LGR both had a decreasing trend in SARs from migration year 2000 to 2004. The ratio of the upriver SAR to downriver SAR was significantly higher for migration years 2001 and 2002 compared to 2003

and 2004 based on non-overlapping 90% confidence intervals. The U/D ratio for migration year 2000 was intermediate to the other years.

Table 5.10. Estimates of SAR from first dam encountered¹ as smolts to Bonneville Dam (BOA) as adults² for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.

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

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

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

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

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

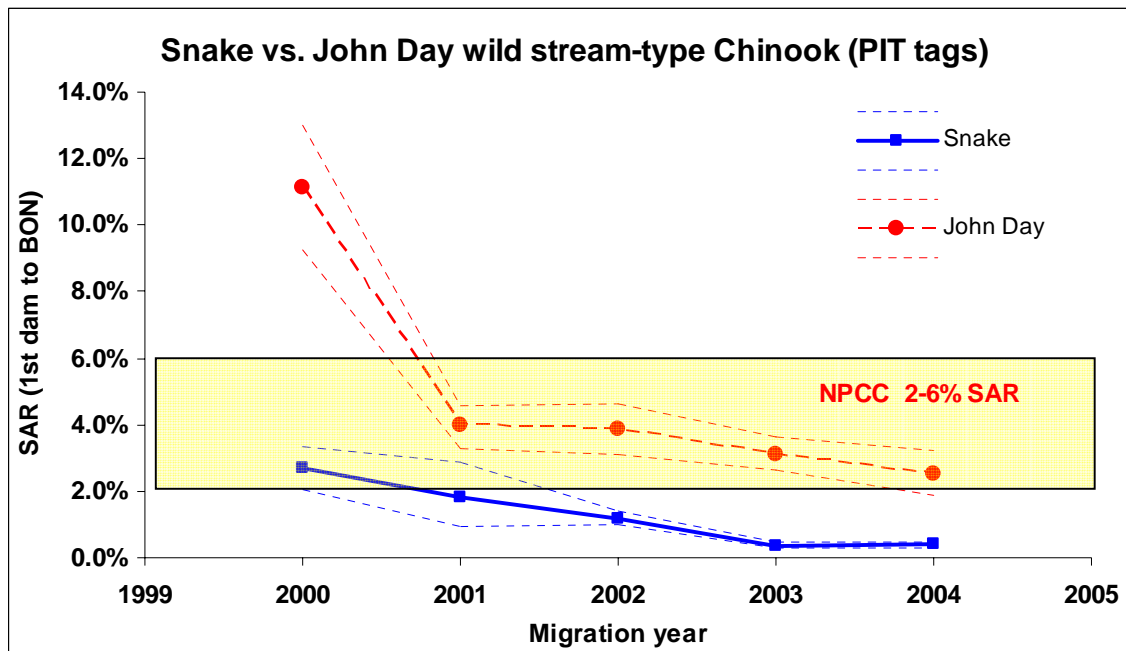


Figure 5.12. SARs (90% CI) for Snake River and John Day River wild stream-type Chinook from smolts at first dam encountered to adult returns to Bonneville Dam. The NPCC interim SAR goal for listed Snake and upper Columbia River salmon and steelhead is shown for reference.

Estimates of differential mortality (equation 5.3) for the five years of SAR data (smolt migration years 2000 to 2004) from PIT-tagged wild populations (Snake and John Day rivers) are presented in Table 5.11 with associated 95% confidence intervals for comparison with the historic differential mortality estimates from Deriso et al. (2001) and Schaller and Petrosky (2007). Wider confidence intervals (95% instead of 90%) are used to match those of the historic data set. In the one year of overlap between the two data series, the PIT-tag wild Chinook SAR-based differential mortality estimate (μ SAR) for 2000 agreed well with the differential mortality estimated from the spawner-recruit analysis (Figure 5.13). A benefit of the SAR-based differential mortality estimate appears to be a much narrower confidence interval than obtained from the spawner-recruit analysis – see the trend in confidence interval spread from 2000 to 2004. The ISAB (2006) recommended incorporating additional downriver wild populations in future estimates of differential mortality.

Table 5.11 Conversion of estimated upriver/downriver ratios to differential mortality rates for comparison to differential mortality rates computed by spawner-recruit analyses, 95% confidence intervals shown with each method.

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

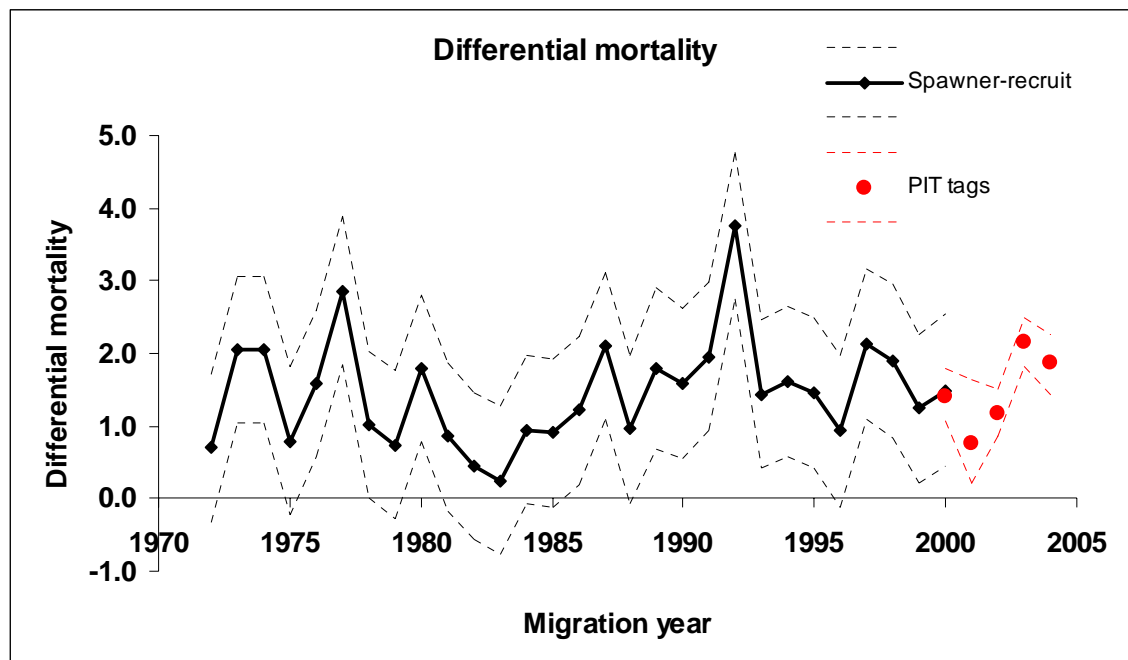


Figure 5.13 Differential mortality from SR data through migration year 2000 (Schaller and Petrosky 2007) compared to estimates based on SARs of wild Snake River and John Day River stream-type Chinook, smolt migration years 2000-2004.

Hatchery upriver/downriver SAR difference: Differential mortality estimates between SARs from upriver and downriver hatcheries were less than differential mortality estimates for wild spring/summer Chinook based on SARs and S-R data (Figure 5.14). Differential mortality estimates also varied according to which Snake River hatchery was included in the comparison (Table 5.12; Figure 5.14). The SARs from first-dam encountered as smolts to Bonneville Dam as adults was generally higher across migration years 2000 to 2004 for Carson NFH Chinook (downriver group) than for the upriver spring Chinook hatchery releases, but not always higher for the upriver summer Chinook (Table 5.9). The SAR computations used BOA adult numbers expanded by the reciprocal of the PIT-tag detection efficiency estimated for that site. The PIT-tag hatchery Chinook from the upriver Snake River hatcheries and the downriver hatchery both had a decreasing trend in SARs from migration year 2000 to 2004. The ratio of the upriver SAR to downriver SAR was highest among all five upriver hatcheries in migration year 2003, and lowest in 2001 for Dworshak, Catherine Creek, and Imnaha hatcheries and lowest in 2004 for Rapid River and McCall hatcheries (Table 5.12). The upriver/downriver ratios in 2003 were significant higher than prior years based on non-overlapping 90% confidence intervals for the two summer stocks (McCall and Imnaha hatcheries). Confidence intervals were not available for migration year 2004 data, because the estimation of the population of PIT-tagged smolts at BON for that year could only be indirectly estimated using the average survival rate from release to BON tailrace of the prior four years.

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

Table 5.12. Estimates of SAR from first dam encountered¹ as smolts to Bonneville Dam (BOA) as adults² for the upriver PIT-tagged wild Chinook aggregate and the downriver PIT-tagged John Day River wild Chinook that outmigrated in 2000 to 2004.

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

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

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

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

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

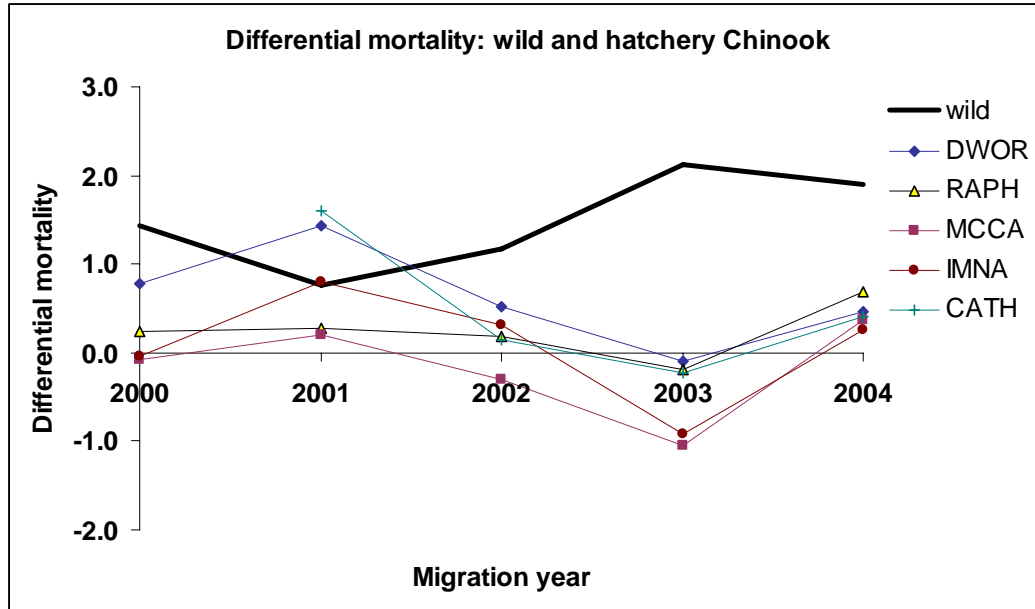


Figure 5.14. Differential mortality of Snake River wild and hatchery populations of spring/summer Chinook 2000-2004 migration years.

Comparison of biological characteristics of Snake River and downriver wild smolts

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

Smolt size analysis -- Our analysis demonstrates that smolt size varies considerably across migration years, both within and across sites (Table 5.13; Figure 5.15). Within these data, however, there was no clear indication of a systematic size difference between the John Day fish relative to those captured at upriver trap sites. During some years, JDAR1 smolts were larger than those captured at upriver sites whereas in other years they were considerably smaller. The only clear and consistent trend indicated that those fish captured at the GRNTRP site were generally the largest whereas those captured at the CLWTRP site were the smallest of all sites in question. More importantly, with the exception of GRNTRP and CLWTRP sites, JDAR1 fish were generally within 5 mm of upriver sites.

Table 5.13. Summary statistics for wild Chinook salmon smolts captured, tagged, and released at CSS trap sites between March 15th and May 20th during migration years 2000-2005.

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

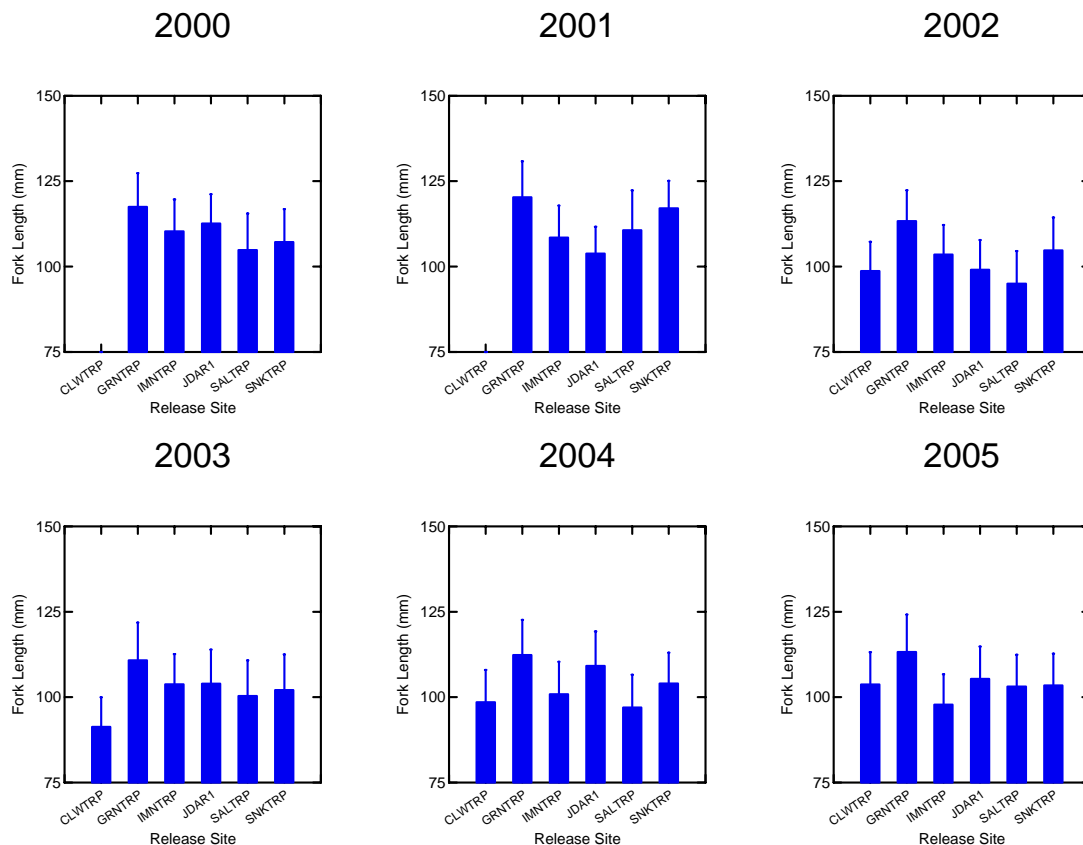


Figure 5.15. Wild Chinook salmon smolt size (mean fork length \pm 1 SD) for fish tagged and released during migration years 2000-2005 (between 15 March and 20 May). From left to right, trap sites are: CLWTRP = Clearwater R., GRNTRP = Grande Ronde R., IMNTRP = Imnaha R., JDAR1 = John Day R., SALTRP = Salmon R., SNKTRP = Snake R. *Note:* there were no wild Chinook smolt size data available for CLWTRP prior to 2002.

Table 5.14. Results from an ANCOVA-based comparison of smolt size across upriver and downriver release sites, using redd density as a covariate.

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

Analysis of Covariance (ANCOVA) results indicate that fork length varies across sites, but as a site-specific function of redd density (Table 5.14). With the exception of GRNTRP, smolt size—redd density regressions all had negative, non-zero ($P < 0.001$ for all parameter significance tests) slopes (Figure 5.16). Given that the density effect was site specific, we contrasted least-squares adjusted mean fork length between release sites at both the average density and at 4 redds per km – a level of abundance common to all sites (i.e., to avoid

extrapolating for low-escapement sites). At an average level of density (8.9 redds per km), density-adjusted mean fork lengths differed significantly between all release sites ($P < 0.001$ for all pairwise contrasts); values were 74, 121, 106, 106, 100, and 100 mm for CLWTRP, GRNTRP, IMNTRP, JDAR1, SALTRP, and SNKTRP fish. At 4 redds per km, density-adjusted sizes for the same release groups (respectively) were 90, 117, 108, 107, 100, and 104 mm. There is evidence for statistically significant differences between fish sizes across release sites within the Snake basin. However, the John Day fish sizes were in the mid range of those from the Snake.

In addition to explicitly incorporating density effects, we also contrasted fork lengths between release sites using ANOVA with MY as a factor. This approach accounted for a greater proportion of overall fork length variation than the density-specific model (i.e., Table 5.15 vs. Table 5.14). Similar to the ANCOVA results, ANOVA results indicate that significant differences exist among release sites, but that the general pattern varies depending on the migration year in question (Tables 5.14 and 5.15; Figure 5.15). Post-hoc pair-wise comparisons indicate the rank of JDAR1 fish size relative to upriver sites varied across years ($P < 0.001$ for all contrasts): 1) in 2000, JDAR1 fish were between 2 and 8 mm larger than those collected at upriver sites; 2) in 2001, they were between 5 and 17 mm smaller than those captured at all other sites; 3) JDAR1 smolts were smaller than all but SALTRP and CLWTRP fish in 2002; 4) excluding CLWTRP and GRNTRP in 2004 and GRNTRP and IMNTRP in 2005, JDAR1 fish were within 5 mm of those collected at upriver sites in both of these years.

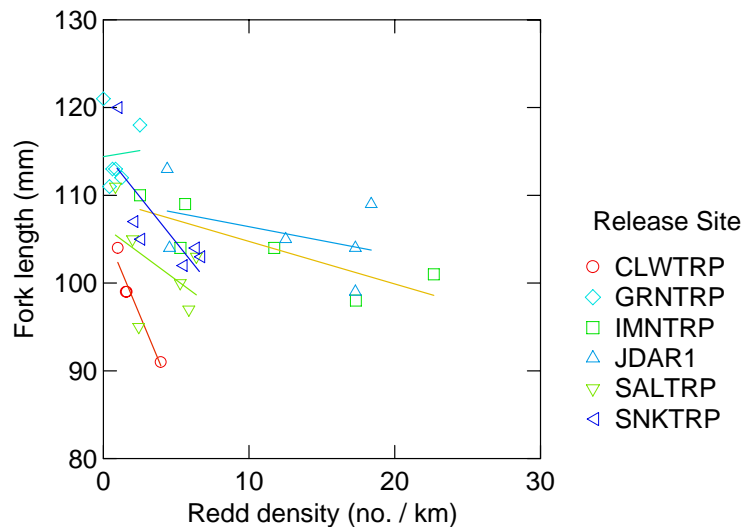


Figure 5.16. Scatter plot of mean fork length (mm) against redd density (redds / km) for wild Chinook salmon smolts collected, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 5.18 caption for release site abbreviation definitions.

Table 5.15. Results from an ANOVA evaluating smolt size variation across release sites and migration years.

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

Outmigration timing -- Outmigration timing varied considerably across sites and migration years, particularly so for upriver-origin smolts. In most years, the 50% passage date occurred in mid April, but was as early as March 27th (SALTRP, MY 2004) and as late as May 17th (SNKTRP, MY 2005). Variability in JDAR1 outmigration timing was considerably less than that observed for upriver release groups. Table 5.16 details median passage dates for each site and migration year. Despite the wide range of variability in outmigration timing, there was no evidence for any systematic difference between upriver and downriver populations – that is, in some years downriver populations emigrated earlier than upriver populations whereas in other years they emigrated later. Despite the variability within sites across years, it appears that upriver and downriver populations initiate emigration from subbasin streams within a similar time window, on average (Figure 5.17); both the upriver aggregate (i.e., all traps together) and the JDAR1 6-year average date of 50% passage was April 13th (across 2000-2005). Thus, in terms of trap catch data, we found no evidence for a disparity in outmigration timing for upriver and downriver groups.

Table 5.16. Dates of 50% passage (i.e., median emigration date) for Chinook salmon captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.

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

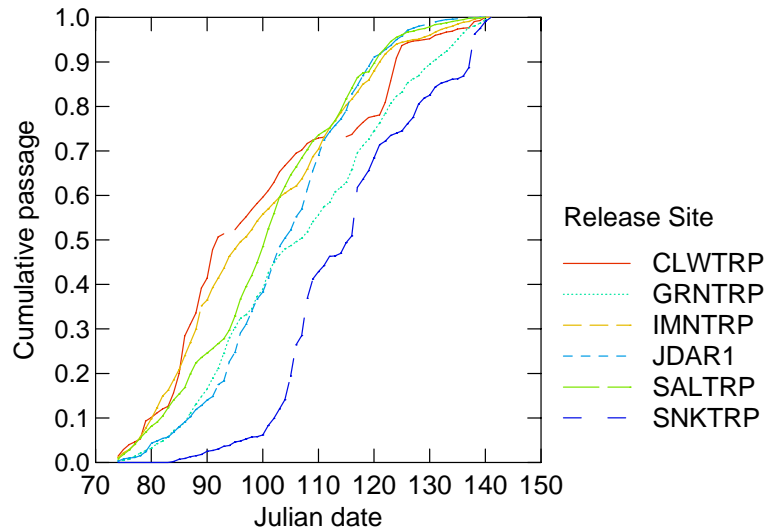


Figure 5.17 6-year mean trap passage (i.e., emigration) distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. Note: Julian date 75 is March 16th, 100 is April 10th, 125 is May 5th, and 150 is May 30th. See Figure 5.18 caption for release site abbreviation definitions.

Downriver migration rates -- Based on those fish tagged, released, and later detected at BON, we also estimated total downriver migration rates (km / d) and compared them between upriver and downriver populations. This comparison demonstrates that smolts from upriver populations and downriver-origin smolts migrated at a similar rate. As illustrated in Figure 5.18, JDAR1 fish migrated to the estuary at a rate of approximately 15-24 km / d whereas upriver fish migrated at a rate of 11-23 km / d. In the 2006 annual report, we concluded John Day smolts were migrating at a slower rate than Snake River smolts, however this conclusion was a result of using an incorrect distance between Bonneville Dam and the JDAR1 collection site (170 km). When we used the correct distance (405 km), this apparent difference between groups diminished greatly.

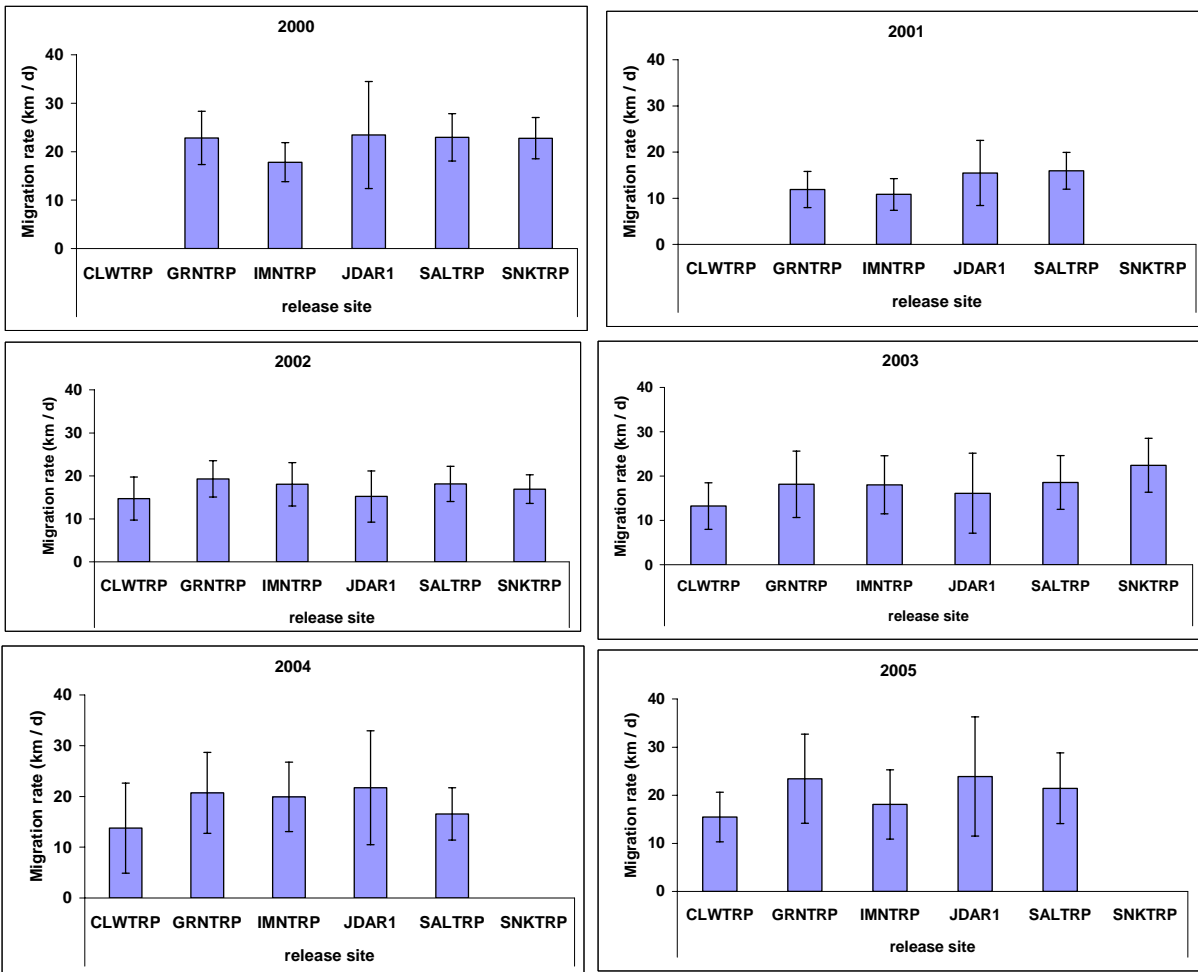


Figure 5.18. Wild Chinook salmon smolt downriver migration rates (km / d, +/- 1 SD) for those fish captured, tagged, and released at CSS trap sites during migration years 2000-2005 (between 15 March and 20 May). See Figure 5.18 caption for release site abbreviation definitions. Note, CLWTRP operations did not begin until 2002; also, too few tags were available for SNKTRP estimation in 2001, 2004-2005.

We also found evidence of similar and WTT-influenced first-to-third dam migration lengths (in days) for both upriver and downriver populations (Figure 5.19). In particular, analysis of covariance (with site and WTT effects) suggests a strong positive influence of WTT ($F_{1,27} = 71.3, P < 0.001$) but no effect of release site on migration duration, once upriver-downriver WTT differences are considered ($F_{5,27} = 0.9, P = 0.485$). The mean (WTT-adjusted) first-to-third dam migration duration ($\pm 2SE$) for JDAR1 was 12 ± 2 days; for upriver populations, durations averaged 10 ± 2 days.

Estuary arrival timing – Despite the contemporaneous natal stream departure schedule and the similar downriver migration rates, upriver-origin smolts generally reached the estuary later than downriver fish (Table 5.17; Figure 5.20). That is, while upriver release groups reached BON within roughly a day of each other on average (based on 6-year average of 50% passage date), they arrived 9-10 days after the downriver release group. On average, downriver fish

arrived at the estuary on May 9th whereas upriver fish arrived on May 18th. Further, this pattern of delayed arrival was generally consistent across years.

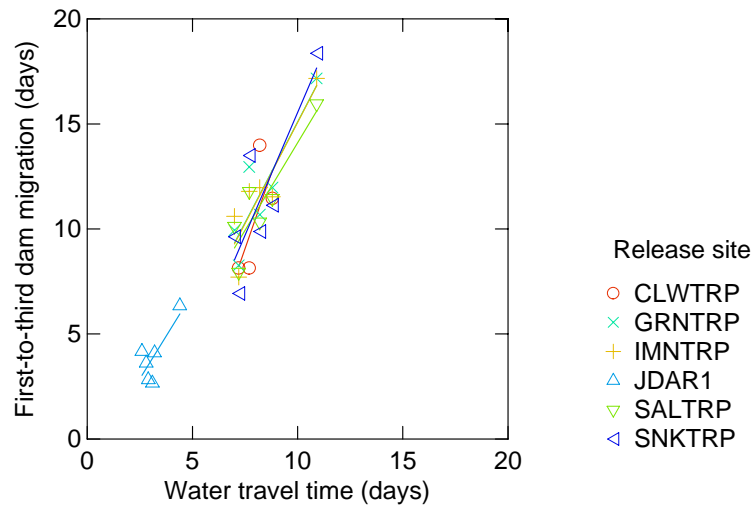


Figure 5.19. Scatter plot of first-to-third dam migration duration as a function of water travel time. Each dot reflects the mean value for a year-site combination. See Figure 5.18 caption for release site abbreviation definitions.

Table 5.17. Median estuary arrival (i.e., BON detection) dates for Chinook salmon smolts captured, tagged, and released at CSS-affiliated trap sites during MYs 2000-2006.

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

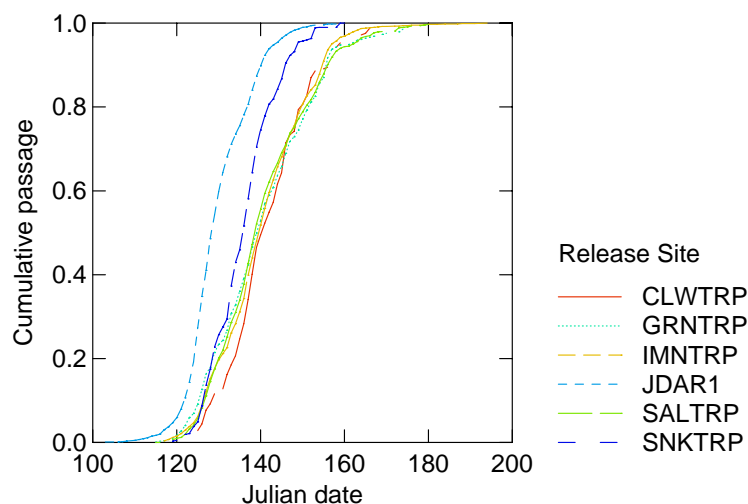


Figure 5.20. 6-year mean estuary arrival (measured at BON) timing distributions for JDAR1, SNKTRP, SALTRP, CLWTRP, IMNTRP, and GRNTRP release sites. Note: Julian date 100 is April 10th, 125 is May 5th, 150 is May 30th, and 175 is June 24th. See Figure 5.18 caption for release site abbreviation definitions.

Comparison of biological characteristics of Snake River and downriver hatchery smolts

Median fork length at time of PIT-tagging for each hatchery and year (1997-2004) are summarized in Appendix F. RAPH hatchery Chinook were PIT-tagged from 1 to 1.5 months before release and ranged from 100 to 122 mm median FL. DWOR hatchery Chinook were PIT-tagged 1 month before release each year and ranged from 112 to 121 mm median FL. MCCA hatchery Chinook were tagged 1.5 months before release and ranged from 117 to 129 mm median FL. IMNA hatchery Chinook were tagged 1.5 to 5 months before release and ranged from 98 to 123 mm median FL. CATH hatchery Chinook were tagged 5 months before release and ranged from 109 to 123 mm. The downriver (CARS) hatchery Chinook were tagged 3 months before release at a median FL of 108 to 120 mm. In general, the median size of presmolt overlapped among hatcheries at the time of PIT-tagging, but FL at time of migration was not measured.

Smolt arrival timing at LGR for each Snake River hatchery and year (2000-2005) is summarized in Appendix F. Smolt arrival timing at LGR was generally similar among CSS hatchery populations; however, MCCA hatchery Chinook exhibited slightly later arrival timing than other Snake River hatcheries. The six year (MY 2000-2005) median arrival date for MCCA was May 8, compared to May 3 for RAPH and DWOR, May 4 for IMNA, and May 6 for CATH (Figure F-10a).

Smolt arrival timing at BON for the downriver hatchery and each Snake River hatchery and year (2000-2005) is summarized in Appendix F. Smolt arrival timing at BON was generally similar among Snake River hatchery populations, and considerably later than the downriver (CARS) hatchery population. The six year median arrival date ranged from May 20 (RAPH) to May 25 (MCCA) (Figure F-10b). In comparison, the CARS hatchery median BON arrival date was April 29, three weeks earlier than Snake River arrival timing at BON and also a few days earlier than Snake River hatchery arrival timing at LGR. Differences in BON arrival timing

between CARS and Snake River hatcheries were most pronounced for the CSS in-river groups C₀ and C₁) (Figures F-9a-h), which were most influenced by passage delays associated with WTT and FCRPS operations.

SARs by Bonneville Arrival Timing

The arrival timing of John Day wild smolts was primarily late April through May all years (similar to Snake River wild smolt timing at Lower Granite Dam) (Table 5.18). A combination of delayed migration of in-river smolts and transportation has altered the arrival timing of Snake River migrants to the lower Columbia River estuary. Less than 1% of John Day smolts arrived outside the April 16-May 31 window whereas 27.5% of Snake River smolts arrived outside this window (Table 5.18). All groups of Snake River wild Chinook experienced significantly lower SARs (Bonneville to Bonneville) than John Day wild Chinook within the same arrival time period and for the season (Figure 5.21), based on non-overlapping 90% CI.

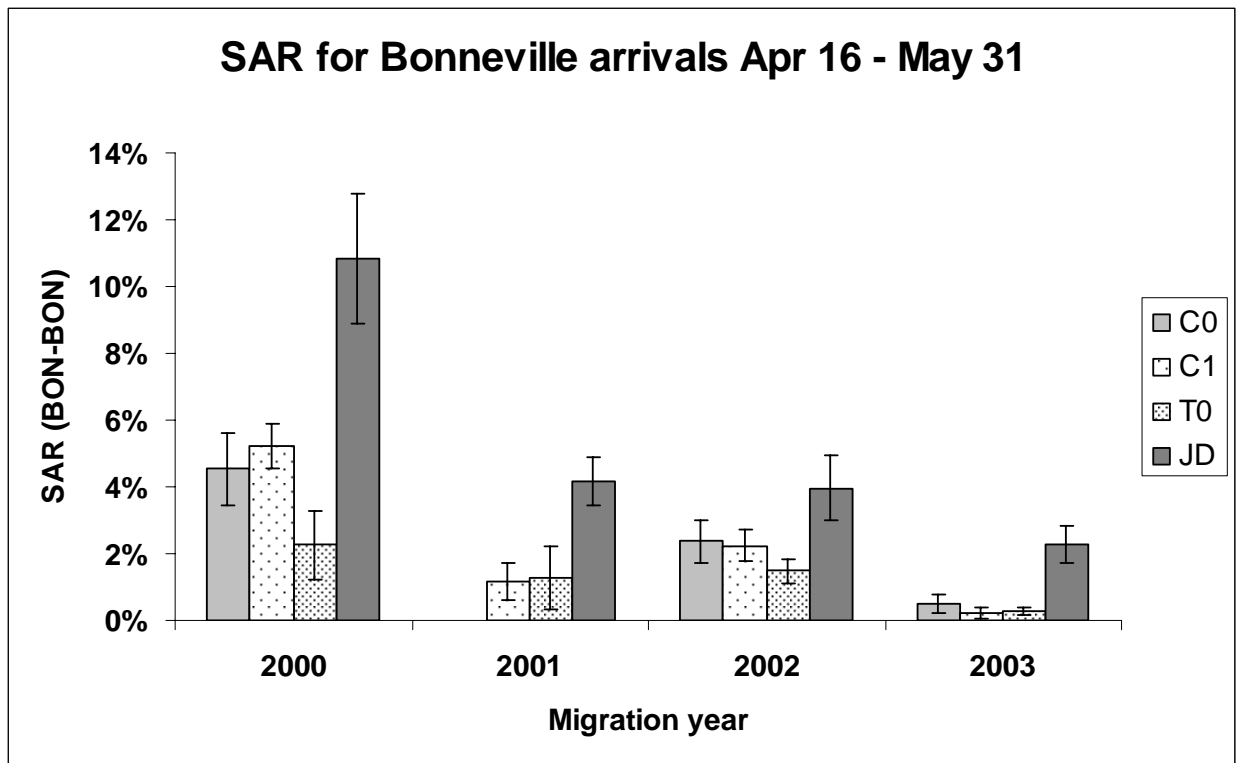


Figure 5.21. SAR and 90% binomial confidence intervals for Snake River wild spring/summer Chinook by group (C0, C1, T0) and for John Day River wild spring Chinook (JD) for smolts passing Bonneville Dam during the period April 16 – May 31, migration years 2000-2003.

Table 5.18 Number of smolts and adult returns for Snake River wild spring/summer Chinook by group (C0, C1, T0) and for John Day River wild spring Chinook for smolts passing Bonneville Dam during biweekly periods, smolt migration years 2000-2003.

Smolt migration year	Group	Bonneville Dam Arrival Time							Total year
		to Apr 15	Apr 16-30	May 1-15	May 16-31	Jun 1-15	Jun 16-31	Jul 1 to end	
2000	C0 adults		3	24	18	6			51
2000	C0smolts		66	516	411	161	34	2	1190
2000	C1 adults		13	112	38	8	1		172
2000	C1 smolts	1	277	2124	716	248	19	5	3390
2000	T0 adults	5	4	8	1	3	1		22
2000	T0 smolts	52	271	225	77	71	37	25	758
2000	JDA adults		14	57	3				74
2000	JDA smolts	9	162	467	54				692
2001	C0 adults								0
2001	C0smolts			2	10	24	6	4	46
2001	C1 adults				11	5			16
2001	C1 smolts			11	938	1662	466	163	3240
2001	T0 adults	6	3	2					11
2001	T0 smolts	63	203	119	68	48	25	11	537
2001	JDA adults		4	66	12	1			83
2001	JDA smolts	2	23	1485	464	32	12		2018
2002	C0 adults			12	22	5	1		40
2002	C0smolts		1	560	877	260	72	6	1776
2002	C1 adults			16	41	15	2		74
2002	C1 smolts			650	1889	715	239	42	3535
2002	T0 adults		4	18	21	2	2	1	48
2002	T0 smolts	68	878	1248	790	361	278	40	3663
2002	JDA adults		3	30	10				43
2002	JDA smolts	1	131	710	242	4	2		1090
2003	C0 adults			7	3				10
2003	C0smolts		27	932	1007	425	42	1	2434
2003	C1 adults			3	2	2			7
2003	C1 smolts		23	1078	1098	1359	127	11	3696
2003	T0 adults	1	9	2	8	3			23
2003	T0 smolts	661	3108	1583	1777	904	153	59	8245
2003	JDA adults		3	23	19				45
2003	JDA smolts	1	92	932	934	1			1960

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

The run reconstruction SARs of natural-origin spring summer Chinook point estimates (Williams et al. 2005) tend to be larger than SAR point estimates of the CSS PIT-tag group (Figure 5.22). The geometric mean ratio of run reconstruction SAR to PIT-tag SAR was 1.19 (range 0.62 to 1.58). Run reconstruction SAR point estimates exceeded PIT-tag point estimate in all but two years during 1996-2001, but fell within the CSS 90% confidence intervals in five of eight years (Figure 5.22). Origin of salmon passing the viewing window at LGR has been classified by the U.S. v. Oregon Technical Advisory Committee since the late 1990s based on the presence/absence of an adipose fin. However, the 'natural' category included unclipped hatchery fish, partially clipped fish with regenerated fins, and supplementation fish, which deliberately were not marked with an adipose clip (Copeland et al. 2005). Several assumptions are currently necessary to estimate the proportion of hatchery-origin unclipped adults that can influence the run reconstruction estimates of recruits. Until more reliable estimates of the hatchery proportion of adipose-intact adults at LGR are available, it is difficult to determine whether the CSS PIT-tag SARs are negatively biased, the run reconstruction SARs are positively biased, or both (Berggren et al. 2006; Marmorek et al. 2004). The primary concern of negative bias from PIT-tag SARs would be in evaluating whether SARs are meeting NPCC biological objectives (2% minimum, 4% average).

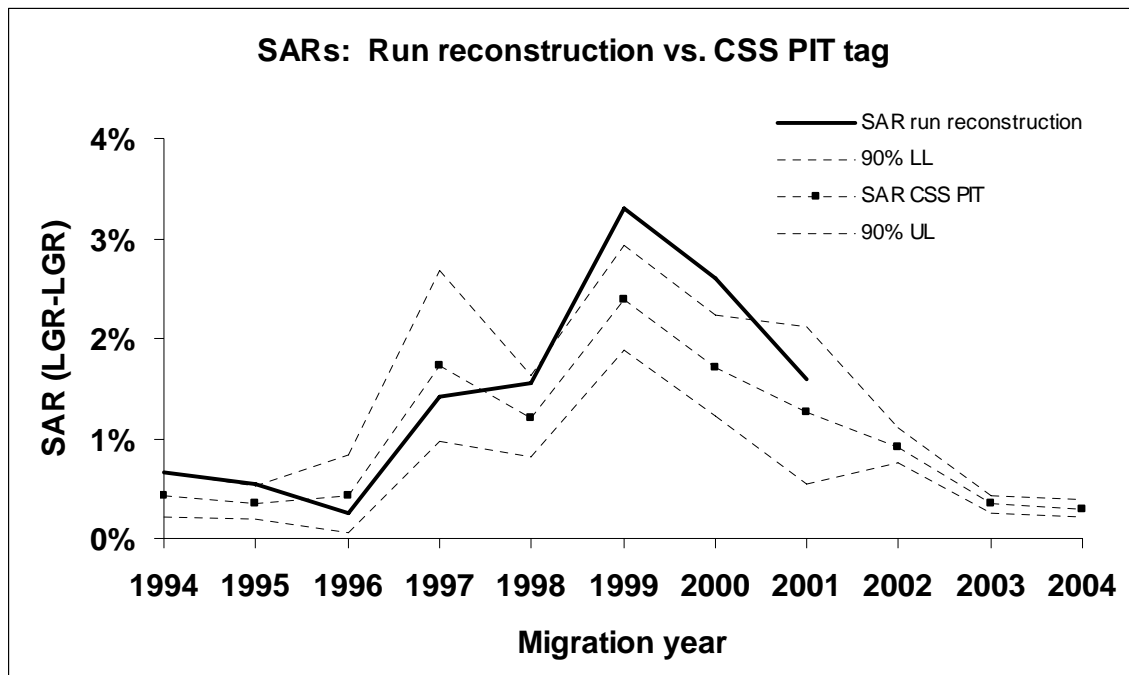


Figure 5.22. SARs from Lower Granite Dam smolts and adults based on run reconstruction (Williams et al. 2005) and SARs and 90% confidence limits from CSS PIT-tags.

Discussion

SARs of Snake River wild spring/summer Chinook were less than NPCC interim objectives (2% minimum, 4% average) in most years, achieving the minimum in only 1 of 11 years during 1994-2004. Snake River wild steelhead SARs averaged less than NPCC the minimum of 2%, but met the minimum in 4 of 7 years during 1997-2003. Wild spring/summer Chinook SARs summarized in this report did not include jacks as recruits, and were thus a conservative estimate relative to the NPCC (2003) objectives, which implicitly included jacks (Marmorek et al. 1998). On average, jacks comprised only 4.2% of total wild Chinook returns, and the observed SARs fell far short of NPCC objectives. Future CSS reports will include jacks when comparing spring/summer Chinook SARs to the NPCC objectives to maintain consistency with the original PATH analysis.

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

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

The ISAB (2006) concluded that more attention should be given by the CSS and the Region as a whole to the apparent documentation that PIT-tagged fish do not survive as well as untagged fish. This question is currently difficult to address because of issues with estimating the number of natural-origin spring/summer Chinook adults at LGR for run reconstructions. Copeland et al. (2005) estimated the age composition for the aggregate Snake River natural adult run passing LGR using video sampling estimates of length frequency of adipose-intact adults, and analysis of fin-ray sections from salmon carcasses on spawning grounds to determine length-at-age for each return year. Origin of salmon passing the viewing window at LGR has been classified by the U.S. v. Oregon Technical Advisory Committee since the late 1990s based on the presence/absence of an adipose fin. However, the ‘natural’ category included unclipped hatchery fish, partially clipped fish with regenerated fins, and supplementation fish, which deliberately were not marked with an adipose clip (Copeland et al. 2005). Misclassification of hatchery

adults could introduce a positive bias in run reconstruction SAR estimates for natural fish because the hatchery returns numbers were much larger than the natural escapement. A fairly small misclassification rate in a large hatchery run could seriously inflate the estimates of natural adult run-size. Copeland et al. (2005) recommended that precision and bias of the run reconstruction SAR estimates be examined. A primary data need is to determine the proportion of adipose intact adults of hatchery origin, through Genetic Stock Identification (GSI) techniques and/or scale pattern analysis. A Lower Snake River Compensation Plan project to assess the feasibility of estimating numbers of adults by origin through GSI techniques began collecting scales at LGR in 2006 (J. White, IDFG. pers. comm.). The CSS project plans to continue to examine the question as results of this study become available.

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

SARs of downriver wild spring Chinook from the John Day River averaged about four times higher than those from the Snake River during migration years 2000-2004. The difference in SARs between upriver and downriver wild Chinook is consistent with previous findings of differential mortality between upriver and downriver population groups based on spawner and recruit data before and after FCRPS completion (Schaller et al. 1999, 2000, Deriso et al. 2001; Schaller and Petrosky 2007). The recent John Day SARs ranged from 2.5% to 11.1%, whereas Snake River SARs ranged from 0.4% to 2.7%. In this contrast, SARs represent smolts at the first dam encountered to adult return to Bonneville Dam for consistency with spawner-recruit based estimates of differential mortality. One benefit of the SAR-based differential mortality estimate is a much narrower confidence interval than obtained from the spawner-recruit analysis. Also, SAR-based estimates of differential mortality do not rely on recruit/spawner residuals, therefore, this method does not rely on any assumptions about the form of a spawner/recruit function. CSS currently has the ability to compare downriver SARs from the John Day River (3 populations) with those from the Snake River (over 30 populations), and has proposed (but not received funding for) PIT-tagging wild spring Chinook smolts in the Warm Springs River (Deschutes Subbasin). Additional candidate populations relevant to these SAR comparisons from downriver areas of the Interior Columbia include Klickitat and Yakima rivers. Future monitoring should also consider incorporating PIT-tag SARs from the upper Columbia region to expand these regional comparisons.

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

who reported greater variation in passage timing (at BON) for unmarked, upriver-origin yearling Chinook salmon.

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

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

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

In Chapter 5, we also summarized the presmolt FL at tagging and smolt arrival timing distributions for Snake River and downriver (Carson) hatchery Chinook populations. A current limitation to comparing biological attributes of hatchery populations is the lack of FL measures at the time of smolt release. Smolts are released from 1 to 5 months after tagging depending on the facility. Although we have considerable data on length of fish at tagging, the hatchery-specific size distributions of actively migrating hatchery smolts within the hydrosystem is not currently measured. Additional sampling effort at the time of release would be required if evaluation of influence of smolt size on hatchery SARs becomes a future priority for CSS. This potential information need should be considered in development of specific marking proposals for additional downriver hatchery groups, and coordinated with ongoing hatchery program evaluations.

Multiple linear regression analysis indicated that SARs of Snake River wild spring/summer Chinook were best described by water travel time experienced during the smolt migration and certain ocean/climatic variables. These general results were consistent for both the recent SAR time series based on CSS PIT-tag estimates (1994-2004), and for a longer time

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

Altered arrival timing due to the FCRPS presence and operation has been hypothesized as one factor that may reduce survival of juvenile spring/summer Chinook salmon in the ocean (Budy et al. 2002, Williams et al. 2005; Muir et al. 2006). The CSS results clearly demonstrate delayed estuary entry of in-river smolts due to the presence and operation of the FCRPS. Nonetheless, estuary entry of Snake River spring/summer Chinook overlaps with that of downriver spring Chinook from the John Day River, which are less affected by the hydrosystem. Enough PIT-tag data exist to compare SARs from smolts detected at Bonneville or the lower river to compare SARs between Snake and John Day River populations during the primary migration period (April 16 - May 31). All study groups of Snake River wild smolts experienced significantly lower SARs than the downriver smolts.

In summary, it appears that both Snake River spring/summer Chinook and steelhead wild populations are not consistently meeting the NPCC 2-6% interim SAR objective. There appears to be a substantial difference in survival between wild Snake River stream-type Chinook with those of down river populations, with similar biological characteristics, that migrate through fewer dams. SARs for these populations were strongly related to water travel time; an index that influences the smolt migration rate, and is indirectly related to spill and other hydrosystem factors. Lastly, the disparity between SARs for Snake River wild Chinook, when they arrive to the lower Columbia River in the same time window (April 16 - May 31) as the John Day River smolts, provides additional support for mechanisms of delayed hydrosystem mortality in addition to the alteration of estuary entry timing. Although Snake River hatchery Chinook exhibited a generally more positive response to transportation and relatively lower levels of differential mortality than wild populations, annual SARs of wild and hatchery Snake River Chinook were highly correlated. In view of this high correlation, continuing the CSS time series of hatchery SARs will be important to augment wild Chinook SAR information following future years of low escapements, in addition to providing valuable management information for the specific hatcheries.

Chapter 6

Partitioning survival rates – hatchery release to return

Introduction

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

An objective of CSS has been to develop a long-term index of survival rates from release of yearling Chinook salmon (hereafter, Chinook) smolts at hatcheries to return of adults to hatcheries. This objective includes partitioning survival rates of (i) hatchery smolts to Lower Granite Dam (LGR), (ii) seaward migrant smolts at LGR returning as adults to LGR, and (iii) adults at LGR to their natal hatcheries.

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

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

Methods

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

Smolt survival from hatchery release to LGR

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

Adult survival from LGR to hatchery

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

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

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

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

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

Approach -- We tested for an effect of juvenile transportation on upstream adult migration timing, duration, and success for Chinook salmon through three separate analyses: 1) we tested whether BON-LGR migration success was independent of juvenile outmigration history using χ^2 -tests (Note: given the ~100% detection probability at LGR, we take detection at LGR [i.e., BON-LGR migration success] to be synonymous with upstream-migration survival [i.e., inclusive of both mortality and straying]); 2) we modeled individual survival, a binary response, using logistic regression; within this analysis, we tested for transportation and environmental variables effects using an Akaike's Information Criterion (AIC)-based model-selection exercise and based on significance tests for fitted model parameters and associated odds ratios; and 3) we contrasted adult return timing (i.e., arrival at BON) and BON-LGR upstream travel time (i.e., passage duration, in days) across outmigration histories using analysis of variance.

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

Table 6.1. Counts of hatchery Chinook salmon adults that failed ('F') or were successful ('S') in surviving their BON-LGR migration in return years 2002-2006, grouped by migration year and outmigration experience (see Methods for group definitions). There was evidence for a significant association between transport history and migration success where sufficient observations-per-cell were available (see Table 6.3 for details).

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

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

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

Environmental variables -- Within the context of our logistic regression-based assessment of transportation effects, we also wished to account for variation in BON-LGR survival that could be attributed to in-river migration conditions. Specifically, given the results from the University of Idaho's radio telemetry work (Keefer et al. 2004; Naughton et al. 2006), we quantified the influence of discharge, spill (%), and water temperature on adult passage success. We summarized these variables using records from the Fish Passage Center and USACE's websites. Discharge and temperature data were summarized for LGR (i.e., used as a proxy for Snake River hydrological and thermal conditions) and BON (i.e., as a proxy for Columbia River conditions) and averaged across 2-week time blocks in each RY. Similarly, spill was summarized as average Lower Columbia (BON, TDA, JDA, and MCN, averaged) and Lower Snake (IHR, LMN, LGS, and LGR, averaged) values for the same time blocks. Environmental variables were matched with individual fish records based on their BON arrival date. However, given that the majority of adults (hatchery: 570/714, or 80%; wild: 64/78, or 82%) that failed to arrive at LGR dropped out before MCN, and that variables are correlated across sites, we used only Lower Columbia environmental variables in our final analysis.

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

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

For the final component of our analysis, we contrasted BON arrival timing (i.e., date of adult return, measured as the Julian calendar date) and BON-LGR upstream travel times (in days, \log_{10} -transformed for normality) among in-river, LGR, and LGSdown groups. We performed separate ANOVAs on both hatchery and wild Chinook data sets, including RY (as a blocking factor) as well as interaction terms between the three transport histories and associated RY. We evaluated model-effect significance based on *F*-tests (Type-III sums-of-squares) and subsequently contrasted responses between categories using Tukey's HSD test.

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

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

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

Results

Smolt survival from hatchery release to LGR

Survival from hatchery release to LGR averaged about 65% from CSS hatcheries during 1997-2004 (Figure 6.1; Appendix D). Survival from DWOR Hatchery was generally higher than other CSS hatcheries; survival from CATH was notably lower than the others.

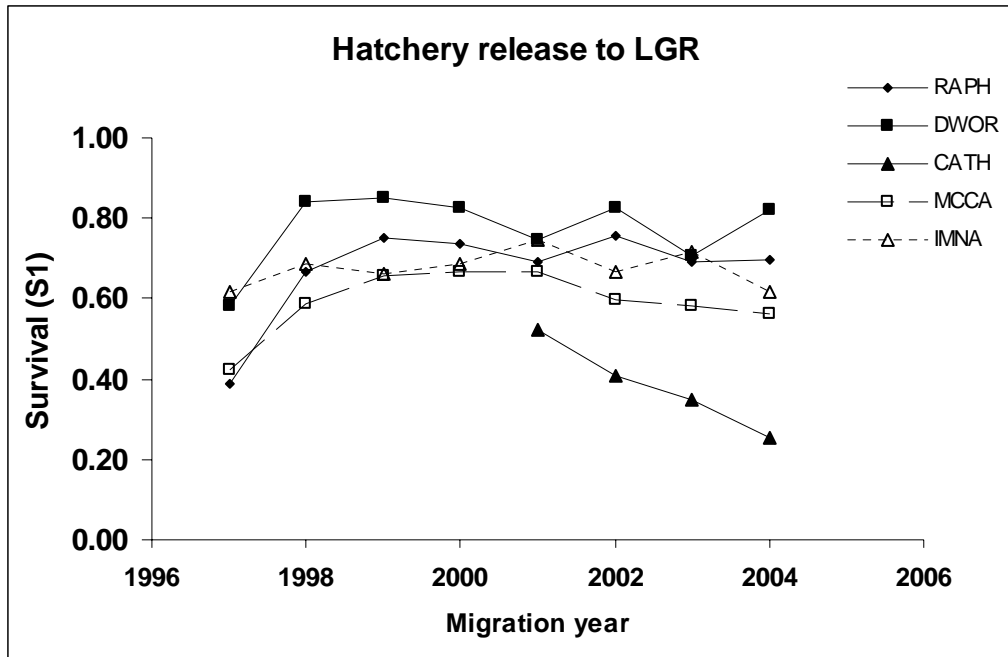


Figure 6.1. Survival from hatchery release to Lower Granite Dam for Rapid River Hatchery, Dworshak Hatchery, Catherine Creek AP, McCall hatchery, and Imnaha AP, migration years 1997 – 2004.

Adult Survival from LGR to Hatcheries

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

We attempted in the CSS 2005 Annual Report to estimate survival of PIT-tagged adults from LGR to the hatchery racks by expanding proportions detected at the racks by the harvest rates estimated by individual agencies each return year (Berggren et al. 2005). The IMNA PIT-tag data were excluded from this analysis because adults typically pass the weir site before installation. The average detection proportion accounted for by this approach, across hatcheries and migration years, was 59% (Figure 6.3). Berggren et al. (2005) concluded that multiple factors could explain this apparent low detection proportion: (1) unaccounted adults spawning below the weirs and trapping sites; (2) adults overshooting the trapping sites during periods when weirs are not installed; (3) straying into other streams; (4) missed detections of PIT-tagged adults or shed tags at the hatchery; (5) under-reporting of harvest; (6) delayed mortality from hooking and handling these fish during fisheries; and (7) high natural mortality of adults after passing

upstream through the hydrosystem. Future monitoring, in coordination with CSS, may be able to estimate the magnitude of factors 1, 2 and 3 for hatchery weirs in locations with intensive spawning ground and carcass surveys, such as the upper Grande Ronde River and Catherine Creek, Imnaha River, and South Fork Salmon Rivers (MCCA). An evaluation specifically directed at tag loss or detection efficiency (factor 4) would also be useful.

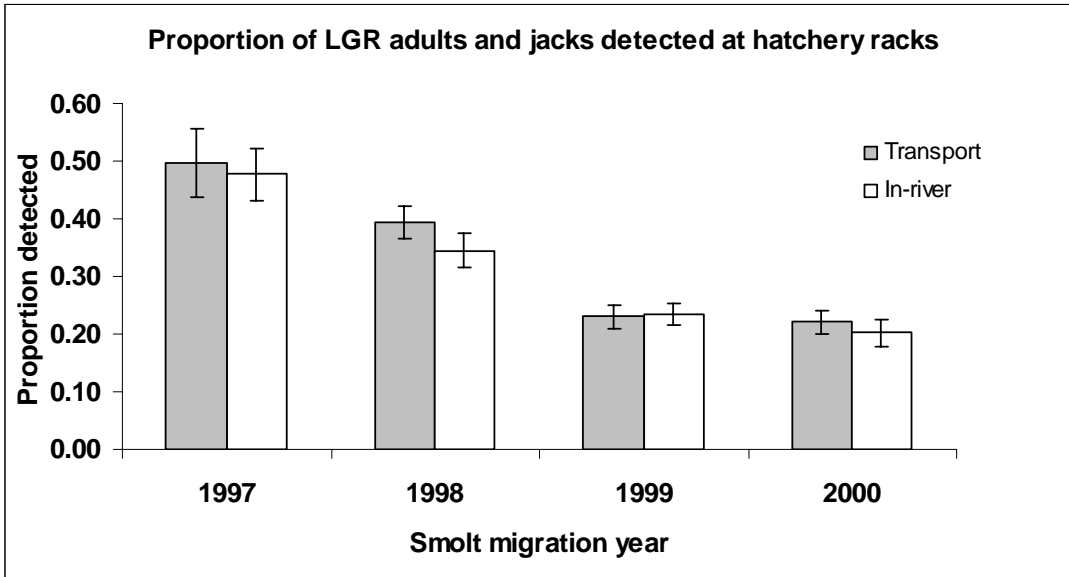


Figure 6.2. Proportion (and 90% CI) of PIT-tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks (pooled across hatcheries), by juvenile passage route (in-river or transport) and smolt migration year (1997-2000).

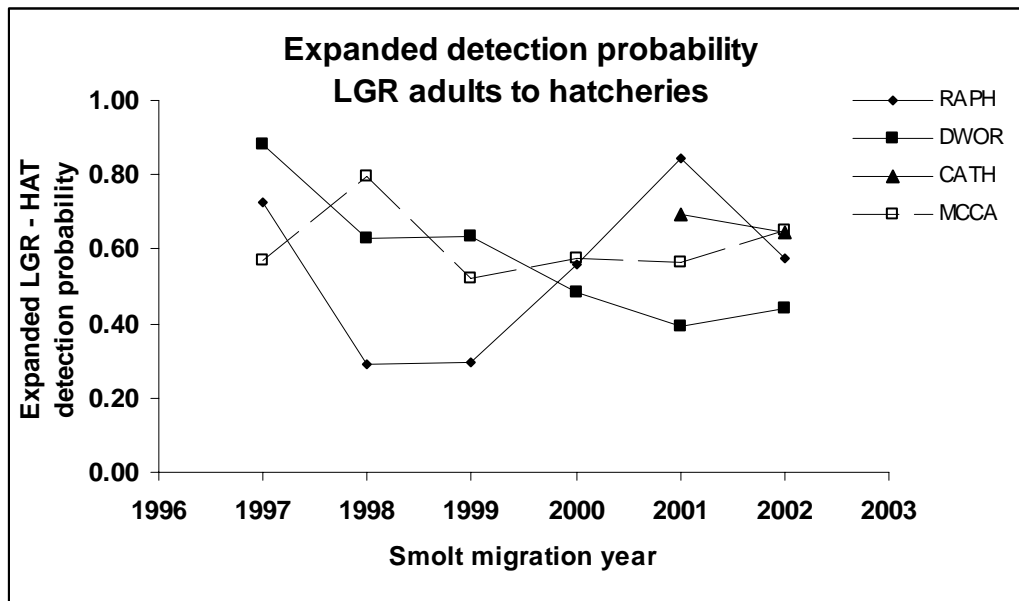


Figure 6.3. Proportion of PIT-tagged adults and jacks detected at LGR that were subsequently detected at the hatchery racks, expanded for estimated harvest rate, smolt migration year (1997-2002).

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

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

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

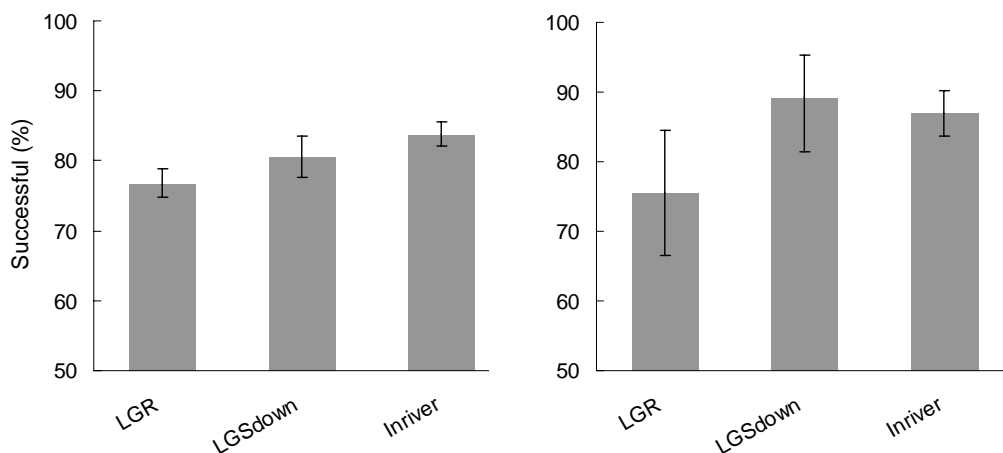


Figure 6.4. Bar chart of the percent of hatchery (left) and wild (right) Chinook salmon that were successful in migrating from BON to LGR for in-river, LGR, and LGS-down outmigration histories across return years 2002-2006 (i.e., combined counts). Error bars correspond 95% confidence intervals.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

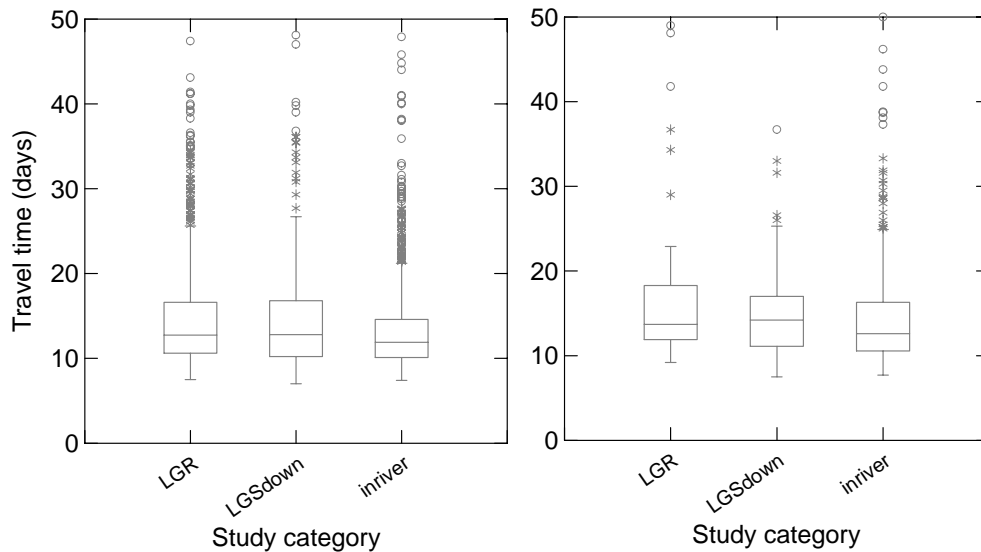


Figure 6.5. Box-and-whisker plot of BON-LGR travel times for hatchery (left) and wild (right) Chinook salmon, by outmigration experience (pooled across RYs 2002-2006). Lower and upper box bounds correspond to 25th and 75th percentiles, respectively; the mid line represents the median; the upper and lower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

Discussion

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

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

Previous research suggests that transportation can affect adult survival rates in the direction we observed in several ways. First, it has been suggested that smolt transportation can disrupt the imprinting process, which typically occurs during smoltification (e.g., Quinn 2005), and thus lead to increased straying of spawners upon return (e.g., Pascual et al. 1995; Bugert et

al. 1997; Chapman et al. 1997). In the case where successful migration is defined by an individual's arrival at LGR, inter-dam straying is equivalent to mortality. Additionally, elevated fallback rates and extensive downstream forays by adult salmon have been attributed to juvenile transportation (Keefer et al. 2006). Given that mortality can increase with the number of fallback events and re-ascension attempts that are made by individuals (Keefer et al. 2005), transport-related fallback may also explain a portion of the observed disparity between study categories. Though less clear, other possible mechanisms may account for the mortality differential we observed. For instance, if increased fallback and impaired homing increase an individual's residence time between BON and MCN dams, transported fish may be more vulnerable to the zone-6 tribal fishery. This possibility, however, has not been evaluated to any great extent.

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

- 1) A portion of deviation in both *TIR* and *D* from their null expectations may be attributed to survival differences occurring in the mainstem Columbia and Snake Rivers after adults return to the freshwater environment to spawn.
- 2) The effect of outmigration experience on upstream adult survival appears to be tempered by a distance-from-release effect. Although we provide only a preliminary analysis of this issue in the present report, we observed two results supporting this conclusion: a) in contrast to LGR-transported fish, the differential between transported and in-river outmigrants was considerably less for those fish collected and transported from LGS or sites even further downstream (i.e., LMN, MCN); and b) the survival discrepancy between LGR and in-river outmigrants tended to be less for hatcheries existing higher in the watershed. This finding is consistent with the results of Solazzi et al. (1991), who documented an increase in the straying rates of adult coho salmon that were transported and released as smolts at differing distances from their hatchery rearing site. Further, the lack of a transportation effect on homing for adults transported from IHR as smolts (Ebel et al. 1973) prior to the completion of LGR suggests that sufficient distance for imprinting may exist between LGR and IHR.
- 3) Finally, using project-specific PIT-tag detections has become the standard for estimating inter-dam conversion rates for use in in-season fisheries management. While a PIT-tag approach has permitted managers to avoid some of the pitfalls associated with traditional count-based approaches towards conversion rate estimation (Dauble and Mueller 2000), our data suggest that such estimates may be biased (relative to the run at large) if transportation history is not considered in the estimation process. This is because a smaller proportion of PIT-tagged fish were actually transported than that for the run-at-large.

We document a clear in-river, upstream-migrant mortality effect resulting from different juvenile outmigration experiences for Snake River wild and hatchery Chinook. Similar upstream-migrant mortality effects of juvenile transportation have been documented for Snake River wild and hatchery steelhead (M. DeHart memo to S. Marshall, January 18, 2007, <http://www.fpc.org/>). We intend to further explore these results, their implications, as well as perform additional supporting analyses for future reports. The consequences of increased straying or mortality due to transportation may also extend beyond the Snake River hatchery and

wild populations in these analyses. For instance, the high proportion of out-of-ESU steelhead spawners (including Snake River) has been identified as a constraint to viability of Mid-Columbia steelhead (OR recovery planning documents). The CSS data and evaluations can be used to evaluate the extent to which transportation management contributes to straying for out-of-basin ESU fish.

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

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

Chapter 7

Simulation studies to explore impact of CJS model assumption violations on parameter estimation

Introduction

The Cormack-Jolly-Seber (CJS) estimation methodology is used extensively within the Columbia Basin and within the CSS for estimating reach survival between dams and collection efficiency at dams. A primary assumption of the CJS estimation methodology is that all members of a tagged group of interest have a common underlying probability of survival and of collection at dams (Assumption #2, Appendix C). When this assumption is met (along with other assumptions mentioned in Appendix C), the CJS estimates of reach survival between dams and of collection efficiency at dams will be unbiased with minimum variance.

Violations of the assumption of equal detection and survival probabilities could occur due to seasonal variation in migration conditions. These in turn could affect the estimates of the number of smolts within each of the CSS's three study categories (C_0 , C_1 , and T_0) and thus affect estimation of SAR, *TIR*, and *D*. In the 2006 CSS Annual Report (Chapter 10), the simulation program used to investigate this question employed a fixed set of default values for parameter inputs (survival and detection probabilities). These default values were set at nominal values that reflected the survival and collection probabilities that have been historically observed. The 2006 work evaluated the performance of bootstrap estimates of reach survival rates and the number of smolts in the CSS study categories. In this ten-year report, we investigate the effects of a wider range of variation in survival probabilities (i.e., not fixed at historically observed values), including scenarios with unrealistically severe temporal trends, on these parameters as well as on SAR, *TIR*, and *D*.

Using simulation studies to perform sensitivity analysis, we investigated whether the violation of Assumption #2 may impact our ability to obtain relatively unbiased estimates of reach survival rates and other study parameters. Assumption #2 is that all fish in a release group have equal detection and survival probabilities within the same river reach or at the same dam. To evaluate this assumption, we first developed a series of simulated data sets with known values for detection probabilities and survival rates, which form the basis for the key study groups and metrics used in the CSS (C_0 , C_1 , T_0 , SAR, *TIR*, and *D*). We then used the CJS methodology to estimate the detection probabilities and survival rates by applying the computational formulas (Appendix B) to the simulated data sets. Finally, we compared the estimated values from these simulations to the known values.

We developed and analyzed twelve alternative scenarios, reflecting a range of alternative assumptions of how survival and detection probabilities may change over time. For each of twelve scenarios investigated, we simulated 1000 independent datasets representing alternative realizations of datasets that could have occurred, given the scenario specifications. Then for each dataset, we used the CJS methodology to estimate detection and survival probabilities, and the CSS metrics. We evaluated bias by comparing the CJS estimates and the CSS metrics to their known values.

Methods

Simulator program overview

In 2006, we developed a simulator program (described in Chapter 10 of the 2006 CSS Annual Report) to generate data sets of fish capture histories given known values for various CSS parameters. The simulator program generated a set of simulated capture histories based on a simulated population of fish migrating through the hydrosystem. The migration characteristics of the fish populations were set for each simulation run, characterizing the survival rate and arrival distribution to LGR and successive dams downstream. Also simulated were probabilities for collection efficiency and removal of collected fish for transportation, as well as SARs. In the simulations completed for this report, survival rates of smolts to LGR and from MCN to TWX were set at the default inputs previously used (2006 CSS Annual Report), as were the collection probabilities at JDA, BON, and TWX and all travel time distributions.

Each run of the simulator program created a population of tagged fish that moved through the hydrosystem experiencing user-defined variations in probabilities of survival and collection over the migration season. The simulator program accounted for travel time and temporal spread of the passage distributions of migrating fish as they move through the hydrosystem in order to reflect how real fish pass the monitored dams. Capture history codes were created for the various combinations of fish that were undetected, detected and bypassed, or detected and transported at each of these dams. The resulting simulated population of fish with associated capture history codes were then run through the bootstrap program to obtain the CJS reach survival estimates. Estimates of reach survival rates between LGR and LMN were used in expanding study category smolt numbers to LGR-equivalents, consistent with the CSS methodologies (Appendix B). Historical estimates of in-river survival rates between LGR and BON were used in calculating the S_R term in the computation of D .

There are seven input screens to the simulator program to establish the migration characteristics to be modeled for a particular population. The initial screens, contain a default (base case) set of input parameter values. The input screens (which represent passage at each dam PIT detection capability) and default values are illustrated in Figures 7.1 to 7.7.

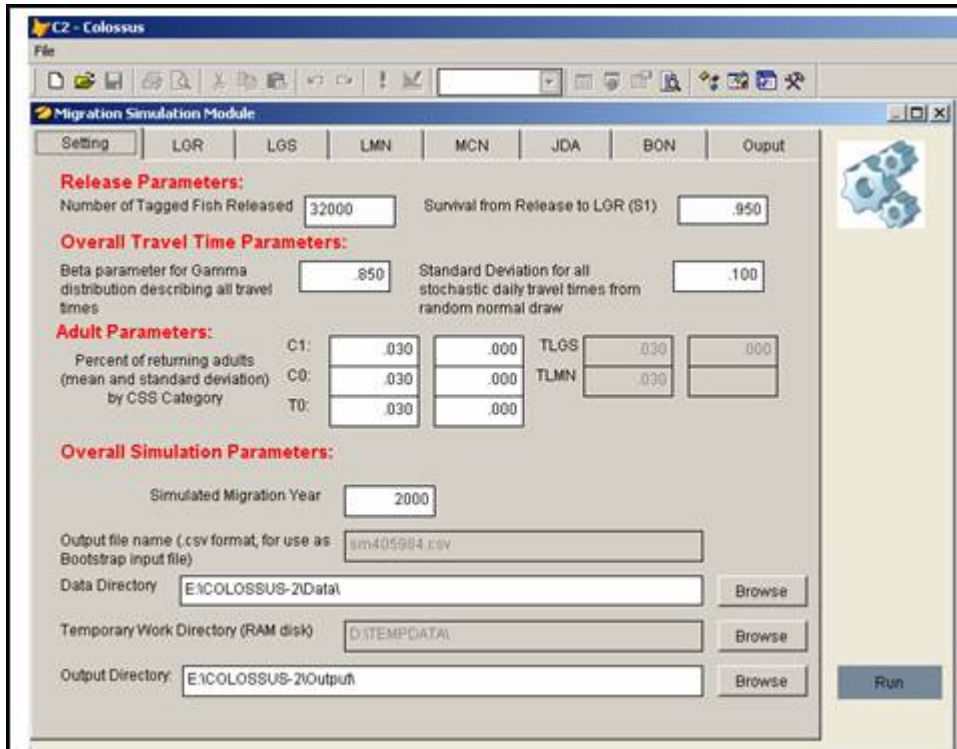


Figure 7.1. First simulator input screen – initial settings including release number and survival to LGR, travel time related parameters, and assumed SAR levels.

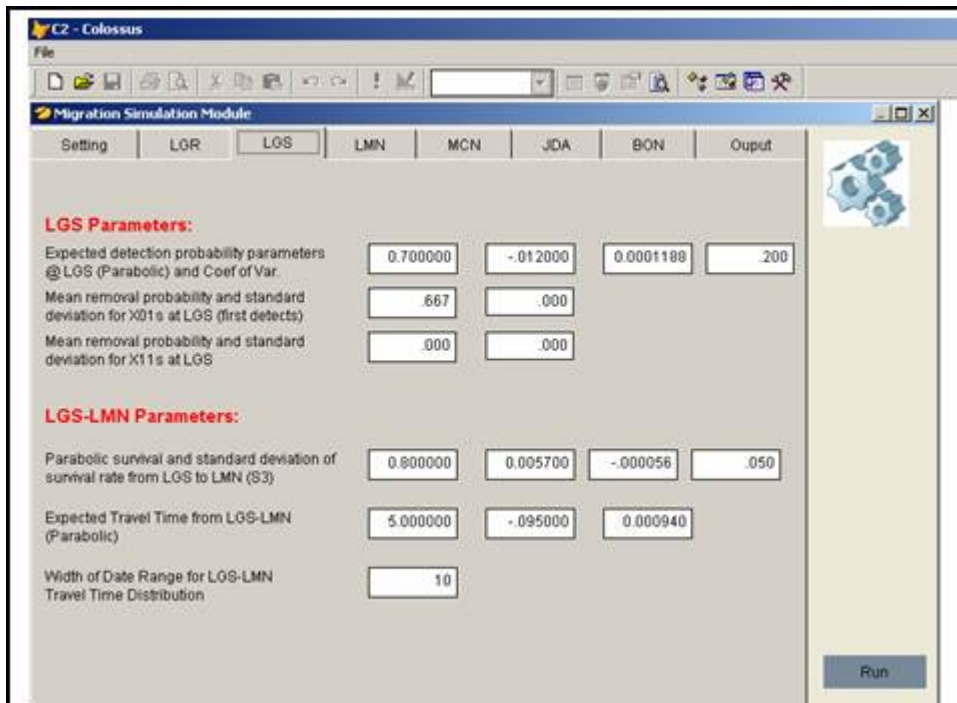


Figure 7.2. Second simulator input screen – arrival population characteristics, collection efficiency and removal rates at LGR, and smolt travel time and survival to LGS.

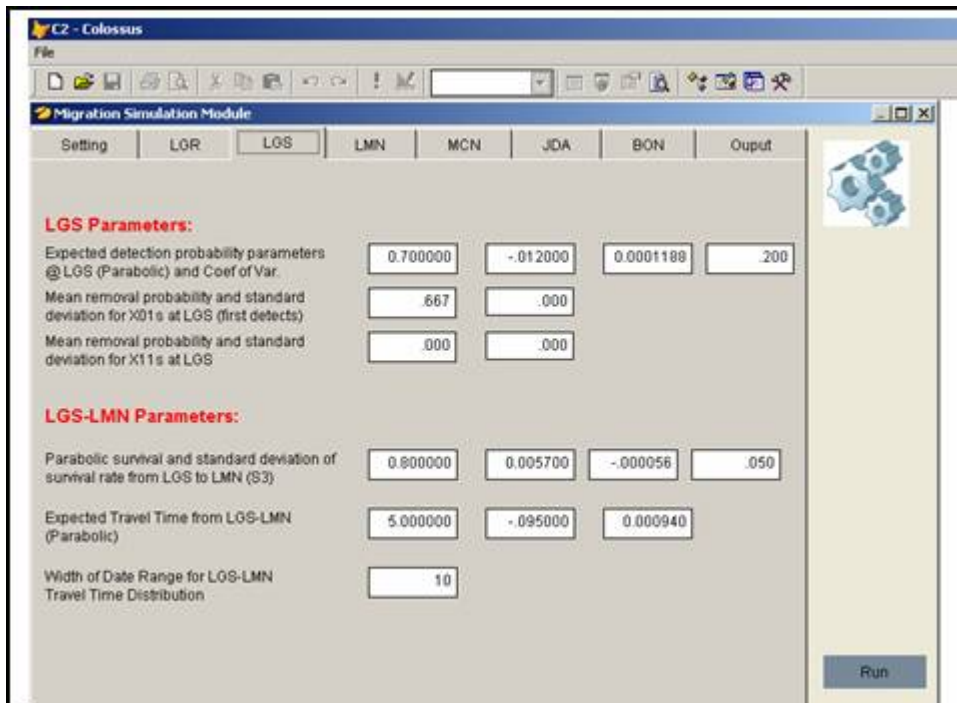


Figure 7.3. Third simulator input screen – collection efficiency and removal rates at LGS, and smolt travel time and survival to LMN.

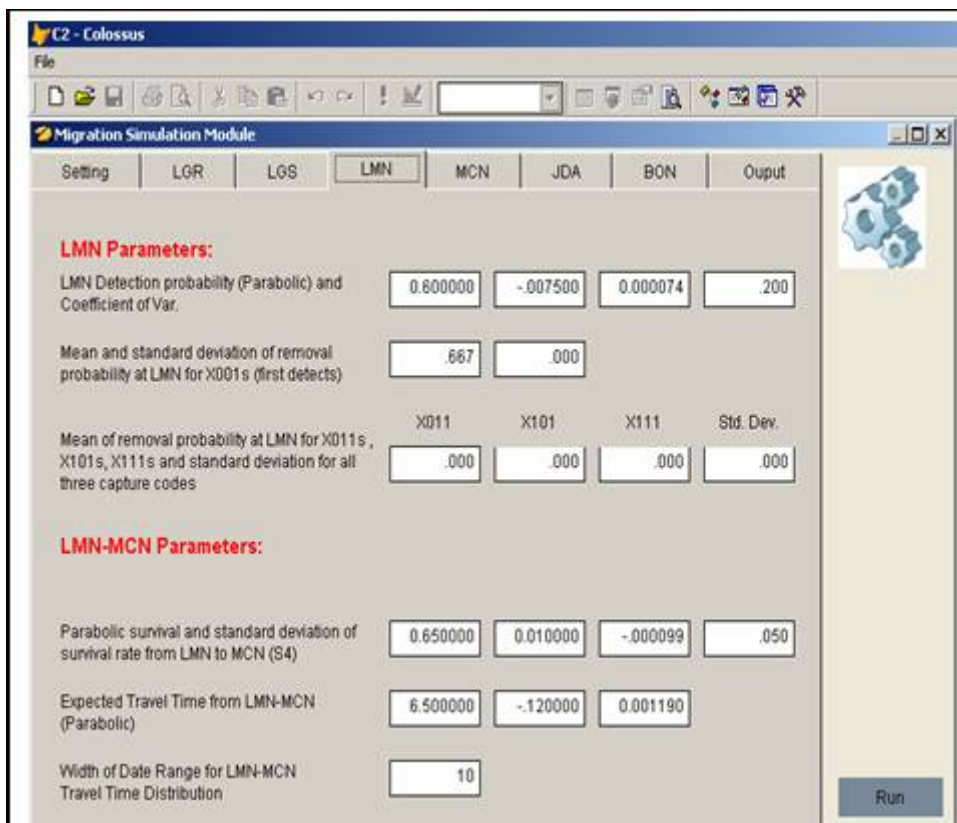


Figure 7.4. Fourth simulator input screen – collection efficiency and removal rates at LMN, and smolt travel time and survival to MCN.

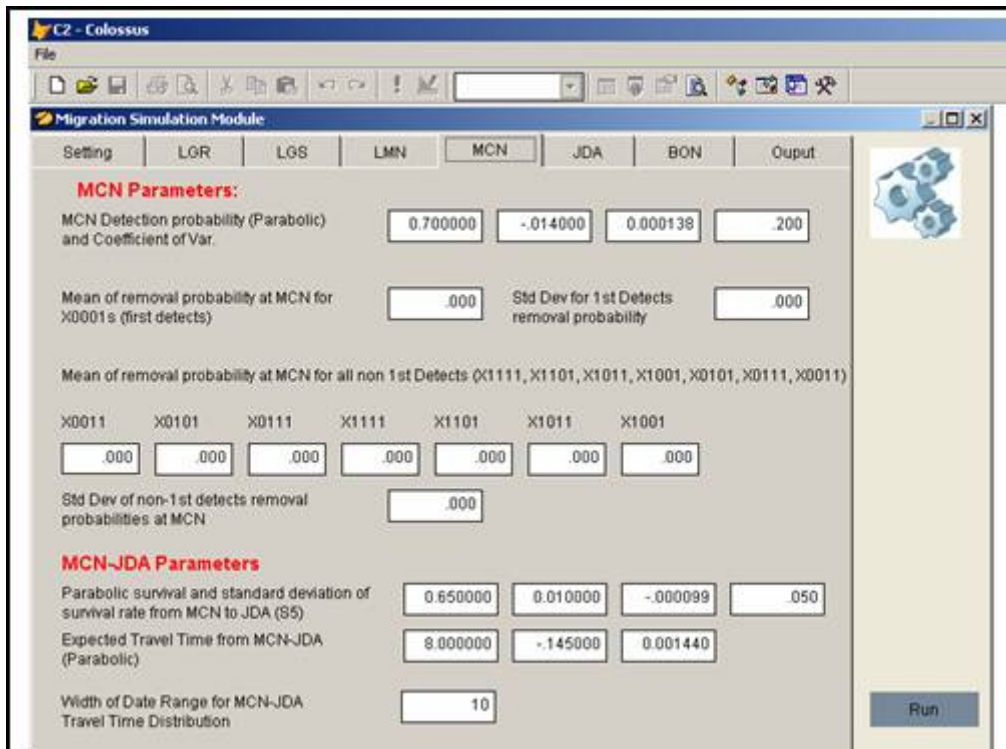


Figure 7.5. Fifth simulator input screen – collection efficiency and removal rates at MCN, and smolt travel time and survival to JDA.

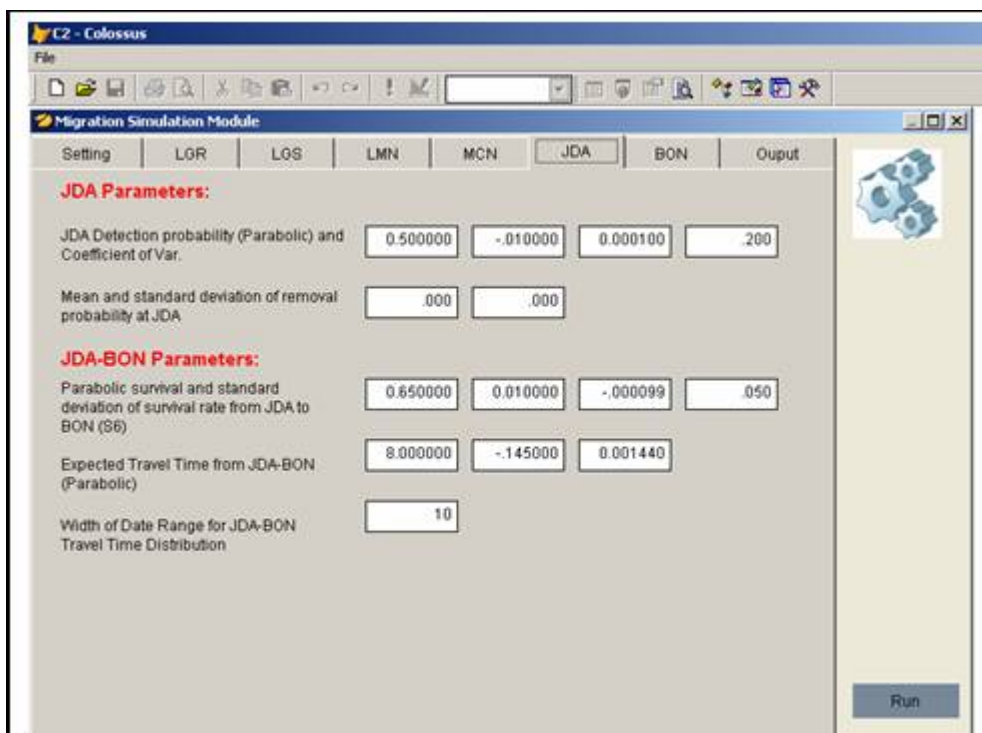


Figure 7.6. Sixth simulator input screen – collection efficiency and removal rates at JDA, and smolt travel time and survival to BON.

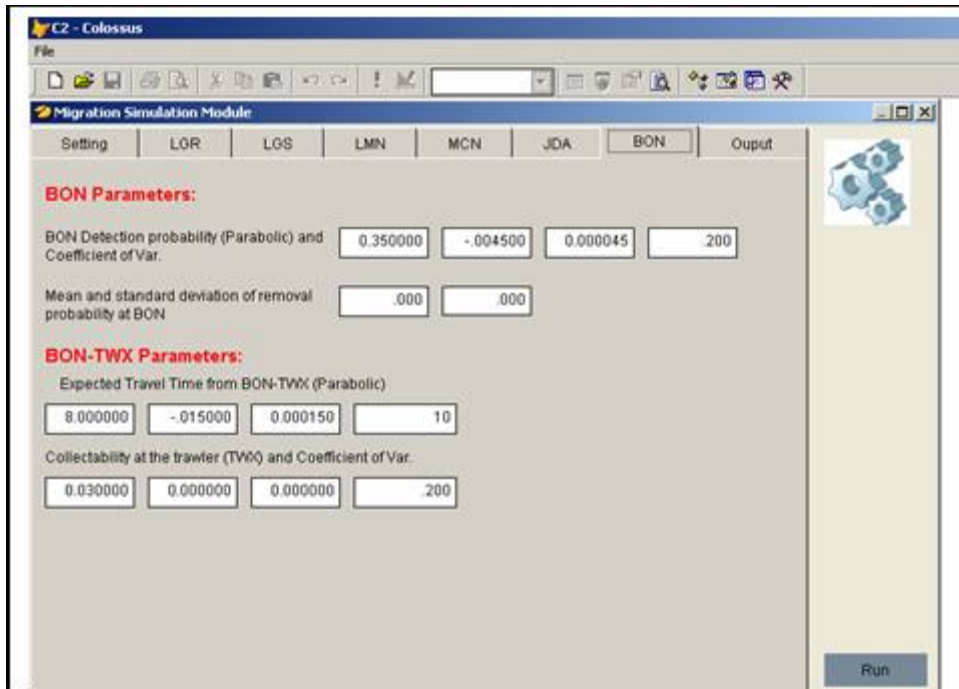


Figure 7.7. Seventh simulator input screen – collection efficiency and removal rates at BON, smolt travel time to trawl site, and trawl collection rate (joint survival-collection efficiency).

In the second input screen, there are parameters that define the mean and standard deviation of a normal timing distribution for the population of smolts arriving in the LGR forebay. This function distributes the population of smolts over a span of time similar to that observed historically for wild Chinook at LGR. On this and the subsequent six screens, there are parameters that define the travel time for smolts migrating between successive dams where PIT-tag detectors are present. At these dams, there are parameters to describe an expected daily collection efficiency that may (or may not) change over time (depending on the simulation scenario). In the river reaches between dams where PIT-tag detectors are located, there are parameters to describe an expected daily survival rate that also may (or may not) change over time. Smolt travel time, collection efficiency, and reach survival can be configured to change across the migration season to simulate a variety of potential situations, such as: 1) smolt travel time decreases as the season progress (e.g., fish may migrate faster over time with increasing smoltification); 2) collection efficiency decreases as flows and spill levels increase during the peak of the annual freshet; and 3) reach survival rates decrease as one moves further from the peak of the migration distribution. The simulator program can be configured to alter the rate of change by adjusting slopes of the linear and quadratic terms in each relation. The resulting values for travel time estimates are then fed into a gamma distribution, while the collection efficiency and reach survival rates are fed into a binomial distribution.

In order to add variability (process error), the program implements binomially-distributed probabilities of collection efficiency, survival rates, and removal probabilities at each dam. The resulting set of daily-varying parameter values is applied to the pool of smolts that have arrived in the forebay of each specific dam on each specific day. The smolts arriving on a specific day at an upstream site and continuing in-river to the next site will have their passage timing at the next downstream site spread out based on their travel times, but up to a maximum width of 10 days (a

reduced maximum width can also be configured). For the fish arriving in the forebay of a particular dam on a specific day, random draws based on the collection efficiency curve for that day will determine which fish are collected at that site and which fish pass undetected. For this dam's collected fish on that given day, random draws based on the outcome of the removal probability for that day will determine which smolts are removed for transportation or bypassed back-to-river.

As fish move downstream through the hydrosystem, their detection and transport disposition at each dam determines their capture-history code. Once they pass the trawl site, they have all the required digits in their capture-history code to define how they passed through the system, or died in route. Each fish in the simulated data set along with its associated capture history code forms the input dataset for the bootstrap program for evaluation of questions regarding the robustness of the CJS survival rate estimates under conditions of varying probability of survival and collection.

Input for Simulations

- A. The default input values for creating the simulated dataset for all of the 12 scenarios are as follows:

Simulated migration year = 2000

Release number = 32,000

Survival to LGR (S_l) = 0.95

Migration state date = 03/22/2000 and stop date = 06/30/2000 at LGR

Expected midpoint of distribution of smolts arriving LGR = 50 reflecting 05/10/2000 and std dev = 1.1

Expected Std Dev of distribution of smolts arriving LGR=8.8
and stochastic draw Std Dev factor =100

Beta parameter for Gamma distribution describing all travel times = 0.85

Std Dev for all stochastic daily travel time from random normal draw = 0.10

Width of date range for all travel time distributions =10

Expected travel time from LGR to LGS (parabolic) = $3.5 - 0.070*\text{day} + 0.00069*\text{day}^2$

Expected travel time from LGS to LMN (parabolic) = $5.0 - 0.095*\text{day} + 0.00094*\text{day}^2$

Expected travel time from LMN to MCN (parabolic) = $6.5 - 0.120*\text{day} + 0.00119*\text{day}^2$

Expected travel time from MCN to JDA (parabolic) = $8.0 - 0.145*\text{day} + 0.00144*\text{day}^2$

Expected travel time from JDA to BON (parabolic) = $8.0 - 0.145*\text{day} + 0.00144*\text{day}^2$

Expected travel time from BON to TWX (parabolic) = $8.0 - 0.150*\text{day} + 0.00015*\text{day}^2$

Adult Parameters $SAR(C_1) = SAR(C_0) = SAR(T_0) = 0.03$ and Std Dev =0

Expected juvenile detection probability Coef of Var of 0.20 for dams and expected survival Std Dev of 0.05 for inter-dam reaches provide low-level beta variability.

Expected detection probability parameters at JDA (parabolic)

$$P_6 = 0.50 - 0.0100*(\text{day}) + 0.000100*\text{day}^2$$

Expected detection probability parameters at BON (parabolic)

$$P_7 = 0.35 - 0.0045*(\text{day}) + 0.000045*\text{day}^2$$

Expected survival from JDA to BON (parabolic)

$$S_6 = 0.65 + 0.0100*(\text{day}) - 0.0000990*\text{day}^2$$

Collection at the trawler (includes survival BON to TWX) = 0.10 and Coef of Var=0
Std Dev for all mean removal probabilities = 0

Mean removal probabilities all dams except X1 (LGR), X01 (LGS), X001 (LMN) = 0
Mean removal probabilities collector dams X1 = X01 = X001 = 0.667

B. Input values of the default base case (Scenario 1) are as follows:

Expected detection probability parameters at LGR (parabolic)

$$P2 = 0.70 - 0.0120*(\text{day}) + 0.0001188*\text{day}^2$$

Expected detection probability parameters at LGS (parabolic)

$$P3 = 0.70 - 0.0120*(\text{day}) + 0.0001188*\text{day}^2$$

Expected detection probability parameters at LMN (parabolic)

$$P4 = 0.60 - 0.0075*(\text{day}) + 0.0000740*\text{day}^2$$

Expected detection probability parameters at MCN (parabolic)

$$P5 = 0.70 - 0.0140*(\text{day}) + 0.0001380*\text{day}^2$$

Expected survival from LGR to LGS (parabolic)

$$S2 = 0.80 + 0.0057*(\text{day}) - 0.0000564*\text{day}^2$$

Expected survival from LGS to LMN (parabolic)

$$S3 = 0.80 + 0.0057*(\text{day}) - 0.0000560*\text{day}^2$$

Expected survival from LMN to MCN (parabolic)

$$S4 = 0.65 + 0.0100*(\text{day}) - 0.0000990*\text{day}^2$$

Expected survival from MCN to JDA (parabolic)

$$S5 = 0.65 + 0.0100*(\text{day}) - 0.0000990*\text{day}^2$$

C. Input values that change from the default base case for creating the simulated data sets of scenarios 2 through 12 are as follows:

Scenario 2: Uses constant values over time for detection probabilities and survival probabilities.

$$P2= 0.406 \quad S2= 0.934$$

$$P3= 0.402 \quad S3= 0.913$$

$$P4= 0.414 \quad S4= 0.900$$

$$P5= 0.353 \quad S5= 0.889$$

Scenario 3: Uses survival probabilities that decrease linearly over time.

$$P2= \text{default} \quad S2= 1.10 - 0.005*(\text{day})$$

$$P3= \text{default} \quad S3= 1.10 - 0.005*(\text{day})$$

$$P4= \text{default} \quad S4= 1.05 - 0.005*(\text{day})$$

$$P5= \text{default} \quad S5= \text{default}$$

Scenario 4: Uses collection probabilities that increase linearly and survival probabilities that decrease linearly over time.

$$P2= 0.065 + 0.006*(\text{day}) \quad S2= 1.10 - 0.005*(\text{day})$$

$$P3= 0.065 + 0.006*(\text{day}) \quad S3= 1.10 - 0.005*(\text{day})$$

$$P4= 0.065 + 0.006*(\text{day}) \quad S4= 1.05 - 0.005*(\text{day})$$

$$P5= 0.050 + 0.006*(\text{day}) \quad S5= \text{default}$$

Scenario 5: Uses collection probabilities that increase linearly over time.

$$P2= 0.065 + 0.006*(\text{day}) \quad S2= \text{default}$$

$$P3= 0.065 + 0.006*(\text{day}) \quad S3= \text{default}$$

$$P4 = 0.065 + 0.006 * (\text{day}) \quad S4 = \text{default}$$

$$P5 = 0.050 + 0.006 * (\text{day}) \quad S5 = \text{default}$$

Scenario 6: Uses collection probabilities and survival probabilities that both increase linearly over time.

$$P2 = 0.065 + 0.006 * (\text{day}) \quad S2 = 0.55 + 0.005 * (\text{day})$$

$$P3 = 0.065 + 0.006 * (\text{day}) \quad S3 = 0.55 + 0.005 * (\text{day})$$

$$P4 = 0.065 + 0.006 * (\text{day}) \quad S4 = 0.50 + 0.005 * (\text{day})$$

$$P5 = 0.050 + 0.006 * (\text{day}) \quad S5 = \text{default}$$

Scenario 7: Uses collection probabilities and survival probabilities that both increase linearly, but at faster rates than Scenario 6.

$$P2 = -0.220 + 0.012 * (\text{day}) \quad S2 = 0.33 + 0.010 * (\text{day})$$

$$P3 = -0.220 + 0.012 * (\text{day}) \quad S3 = 0.33 + 0.010 * (\text{day})$$

$$P4 = -0.220 + 0.012 * (\text{day}) \quad S4 = 0.28 + 0.010 * (\text{day})$$

$$P5 = -0.270 + 0.012 * (\text{day}) \quad S5 = \text{default}$$

Scenario 8: Uses survival probabilities that increase linearly over time.

$$P2 = \text{default} \quad S2 = 0.55 + 0.005 * (\text{day})$$

$$P3 = \text{default} \quad S3 = 0.55 + 0.005 * (\text{day})$$

$$P4 = \text{default} \quad S4 = 0.50 + 0.005 * (\text{day})$$

$$P5 = \text{default} \quad S5 = \text{default}$$

Scenario 9: Uses collection probabilities that decrease linearly and survival probabilities that increase linearly over time.

$$P2 = 0.650 - 0.006 * (\text{day}) \quad S2 = 0.55 + 0.005 * (\text{day})$$

$$P3 = 0.650 - 0.006 * (\text{day}) \quad S3 = 0.55 + 0.005 * (\text{day})$$

$$P4 = 0.650 - 0.006 * (\text{day}) \quad S4 = 0.50 + 0.005 * (\text{day})$$

$$P5 = 0.605 - 0.006 * (\text{day}) \quad S5 = \text{default}$$

Scenario 10: Uses collection probabilities that decrease linearly over time.

$$P2 = 0.6514 - 0.006 * (\text{day}) \quad S2 = \text{default}$$

$$P3 = 0.6514 - 0.006 * (\text{day}) \quad S3 = \text{default}$$

$$P4 = 0.6514 - 0.006 * (\text{day}) \quad S4 = \text{default}$$

$$P5 = 0.6053 - 0.006 * (\text{day}) \quad S5 = \text{default}$$

Scenario 11: Uses collection probabilities and survival probabilities that both decrease linearly over time.

$$P2 = 0.650 - 0.006 * (\text{day}) \quad S2 = 1.10 - 0.005 * (\text{day})$$

$$P3 = 0.650 - 0.006 * (\text{day}) \quad S3 = 1.10 - 0.005 * (\text{day})$$

$$P4 = 0.650 - 0.006 * (\text{day}) \quad S4 = 1.05 - 0.005 * (\text{day})$$

$$P5 = 0.605 - 0.006 * (\text{day}) \quad S5 = \text{default}$$

Scenario 12: Uses collection probabilities and survival probabilities that both decrease linearly at a greater rate than Scenario 11.

$$P2 = 0.980 - 0.012 * (\text{day}) \quad S2 = 1.33 - 0.010 * (\text{day})$$

$$P3 = 0.980 - 0.012 * (\text{day}) \quad S3 = 1.33 - 0.010 * (\text{day})$$

$$P4 = 0.980 - 0.012 * (\text{day}) \quad S4 = 1.28 - 0.010 * (\text{day})$$

$$P5 = 0.930 - 0.012 * (\text{day}) \quad S5 = \text{default}$$

In Scenarios 3 through 12, any changes from the defaults for collection probability and/or survival probabilities are described by a linear trend. Early in this analysis, we observed that the use of a parabola limited the user's ability to make any substantial changes over time due to its symmetrical nature. Effectively, the default parabola inputs define a relatively flat range of parameter values over the range of dates in the middle 80% of each dam's simulated passage distribution. The default parabolas and linear increasing and decreasing trends in survival rates and collection probabilities over time simulated at LGR, with population distribution of fish arriving there, are illustrated in Figures 7.8 to 7.9. These figures illustrate the rate of temporal changes for survival and collection probabilities being covered in the 12 simulation scenarios.

Parameters estimated in simulations

The primary parameters of interest in the CSS are smolt-to-adult survival rates (SARs) for fish migrating through the hydrosystem under different conditions, as well as ratios of these SARs (termed *TIR*) and a measure of delayed differential mortality between transported and in-river migrants (termed *D*). Key to obtaining valid estimates of SARs, *TIRs* and *D* is having available reliable estimates of survival rates and collection probabilities, which are integral components in the estimation of the above parameters. Survival rates and collection probabilities are estimated using the CJS model, which has a set of assumptions necessary for obtaining valid estimates. In this set of simulations, we investigated the impacts of time-varying survival rates and collection probabilities. When either survival rates or collection probabilities or both were changing over time, and a single population parameter is to be estimated within reaches and at dams of interest, then assumption #2 (equality of survival rates and collection probabilities for the group of tagged individuals) of the CJS model was violated. The purpose of this simulation exercise was therefore to determine whether the violation of this assumption would result in biased parameter estimates and/or the degree of the potential bias.

Under the simulated variation in underlying survival rates and collection probabilities, we obtained average known values for survival rates and collection probabilities for each reach and dam, from time of release until passage at Bonneville Dam. The averages were based on tallies of smolts in the forebays, tallies of collected fish removed for transportation, and remaining fish in the tailraces of each dam. We assumed all fish are distributed with identical probabilities of survival and collection on a given day at a given location, but that these probabilities may trend

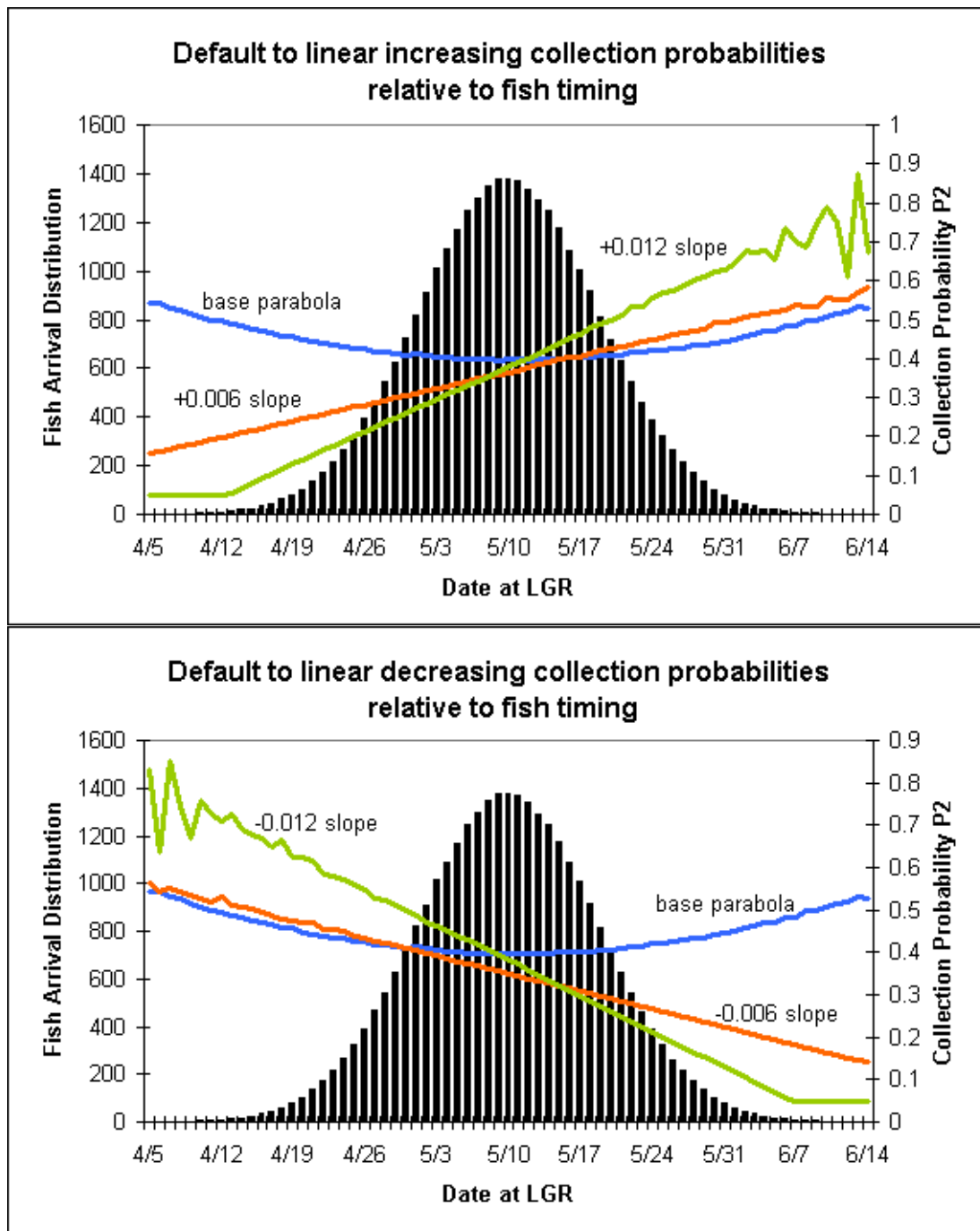


Figure 7.8. Default base parabola of collection probabilities compared to linear trend of increasing (top plot) and decreasing (bottom plot) collection probabilities used at LGR with corresponding fish passage timing. Linear trend lines will be similar at LGS and LMN and shifted slightly lower at MCN; corresponding fish passage distributions will shift later at these downstream dams as a function of fish travel time.

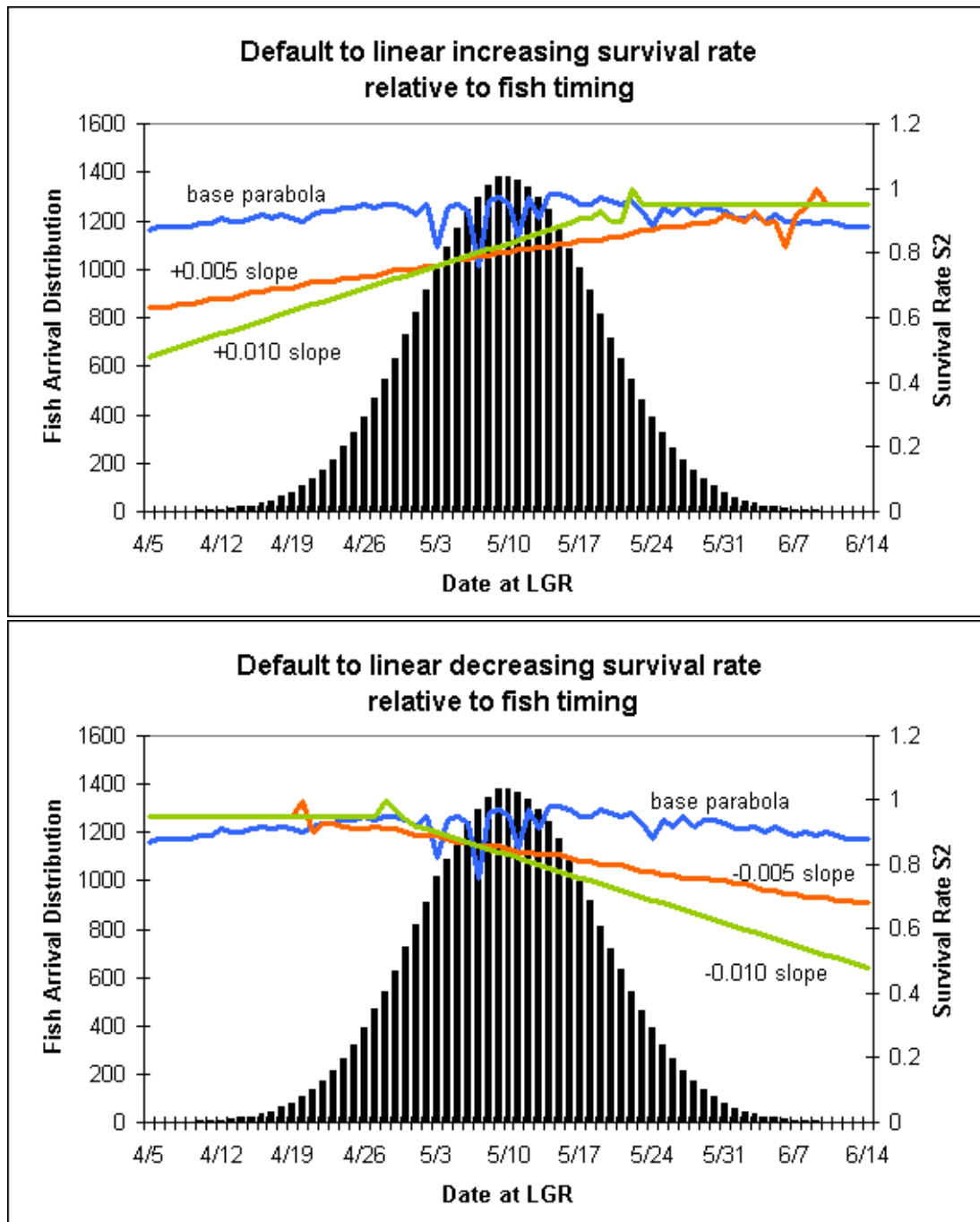


Figure 7.9. Default base parabola of survival rates compared to linear trend of increasing (top plot) and decreasing (bottom plot) survival rates from LGR to LGS with corresponding fish passage timing at LGR. Linear trend lines will be similar for the LGS to LMN reach and shifted slightly lower for the LMN to MCN reach; corresponding fish passage distributions will shift later at these downstream dams as a function of fish travel time.

over time as defined by the time-varying functions. A total of twelve scenarios were run including two base-case scenarios with no or minimal change allowed over time (Scenarios 1 and 2), four scenarios with either survival rates or collection probabilities allowed to vary separately (Scenarios 3, 5, 8, and 10), and six scenarios with both survival rates and collection probabilities allowed to vary together (Scenarios 4, 6, 7, 9, 11, 12).

From the tallies of smolts in the tailrace of LMN with particular capture histories, we obtained known counts of smolts reaching the tailrace of LMN that belonged to each of groups C_0 and C_1 . Dividing the survivors of each group by the known reach survival rates, S_2S_3 , from LGR to LMN, we converted these counts to their respective known smolt number in LGR-equivalents. Likewise, the sum of expanded capture histories $X_{12}+X_{102}/S_2+X_{1002}/(S_2S_3)$ gave the known number of transported smolts in LGR-equivalents (Eq. 7.2 below). In most years covered in the CSS, the tagged fish in groups T_0 and C_0 closely reflected the experience of the untagged run-at-large. Incorporating the known smolt numbers for these two groups into their respective SARs, TIR (ratio of $sarT_0/sarC_0$) and D (computed as $TIR \cdot [S_R/S_T]$, Appendix B) defined the known values for these parameters as well.

Using the same equations as those defined in Appendix B, we calculated the number of smolts in each study category using both the computation and expectation formulas (Equations 7.1-7.3 below). To evaluate whether resulting estimates differed between the two sets of equations, we compared the estimates from both computational methods. In the simulations, we allowed removals at LGR, LGS, and LMN for purposes of transportation only, and no removals at any other sites. Therefore, the d_0 and d_1 components in Appendix B equations 15 and 16 were both zero. The survival rates and collection probabilities were estimated with the CJS equations as illustrated in Figure 1 of Appendix B. The formulas (computation and expectation, respectively) used in the simulations for the respective numbers of smolts estimated in each study category (C_0 , T_0 , and C_1) are:

$$\begin{aligned} C_0 &= R_1S_1 - (m_{12} + m_{13}/S_2 + m_{14}/S_2S_3) \\ E(C_0) &= R_1S_1 \cdot (1 - p_2) \cdot (1 - p_3) \cdot (1 - p_4) \end{aligned} \quad [7.1]$$

$$\begin{aligned} T_0 &= X_{12} + X_{102}/S_2 + X_{1002}/S_2S_3 \\ E(T_0) &= R_1S_1 \cdot p_2 \cdot (X_{12}/m_{12}) + R_1S_1 \cdot (1 - p_2) \cdot p_3 \cdot (X_{13}/m_{13}) + R_1S_1 \cdot (1 - p_2) \cdot (1 - p_3) \cdot p_4 \cdot (X_{14}/m_{14}) \end{aligned} \quad [7.2]$$

$$\begin{aligned} C_1 &= (m_{12} - X_{12}) + (m_{13} - X_{102})/S_2 + (m_{14} - X_{1002})/S_2S_3 \\ E(C_1) &= R_1S_1 \cdot p_2 \cdot (1 - X_{12}/m_{12}) + R_1S_1 \cdot (1 - p_2) \cdot p_3 \cdot (1 - X_{13}/m_{13}) + R_1S_1 \cdot (1 - p_2) \cdot (1 - p_3) \cdot p_4 \cdot (1 - X_{14}/m_{14}) \end{aligned} \quad [7.3]$$

Evaluating parameter bias

For each scenario, we used the simulator program to generate 1,000 simulated data sets. The simulation program tracked the numbers of fish arriving in the forebay, the number collected, the number removed for transportation, and the number alive in the tailrace of each dam for each simulated data set. From these tallies, we obtained the known values for survival rates and collection probabilities, along with the known values for the three CSS study categories (C_0 , C_1 , and T_0), S_R , SAR, TIR , and D . The mean values for each parameter of interest across the 1,000 simulations constituted our “known” values for comparison with the CJS estimates.

Then for each of the 1,000 data sets within each scenario, we used the CJS methodology on each data set to estimate detection and survival probabilities. From these estimates, we calculated the number of smolts in each of the three CSS study categories (C_0 , C_1 , and T_0), S_R , SAR, TIR , and D using the CSS methodology described in Appendix B. The mean of the values

for each parameter of interest across the 1,000 simulations constituted our “CJS” estimates for each parameter. To measure bias, we calculated the relative percent difference:

$$\text{Relative percent difference} = \frac{\theta_{CJS} - \theta_{known}}{\theta_{known}} \cdot 100\% \quad [7.4]$$

where θ_{CJS} is the mean CJS estimate for the parameter of interest and θ_{known} is the mean known value for the parameter of interest.

Results

Across all of the scenarios simulated, the relative percent differences between the average smolt numbers based on the computational formulas and the average based on the expectation formula were less than 1.5%, and most were less than 0.5% (Table 7.1). In simulation runs with either seasonally decreasing or increasing collection probabilities, CJS estimates of smolt numbers were slightly higher for group C_0 and slightly lower for groups C_1 and T_0 when using computational formulas instead of their expectations. As anticipated, differences were greatest for group C_0 . This is due to the fact that estimation of C_0 requires more parameters in

Table 7.1. Comparison of smolt numbers and the relative percent differences estimated for each study category using the computational and expectation formulas, across the twelve scenarios investigated. Reported smolt numbers are averages across the 1,000 simulated data sets.

Run	Test Condition ¹	C_0 (CJS)	EC_0 (CJS)	Relative % Diff.	C_1 (CJS)	EC_1 (CJS)	Relative % Diff.	T_0 (CJS)	ET_0 (CJS)	Relative % Diff.
1	default PS	6,309	6,310	-0.02 %	8,021	8,021	0.00 %	16,078	16,078	0.00 %
2	constant PS	6,356	6,363	-0.11 %	7,998	7,996	0.03 %	16,031	16,027	0.02 %
3	default P+decr S	6,294	6,299	-0.08 %	8,029	8,028	0.01 %	16,079	16,076	0.02 %
4	incr P+decr S	7,988	7,935	0.67 %	7,507	7,524	-0.23 %	15,032	15,067	-0.23 %
5	incr P+default S	7,657	7,616	0.54 %	7,495	7,509	-0.19 %	15,014	15,041	-0.18 %
6	incr P+incr S	7,189	7,171	0.25 %	7,482	7,488	-0.08 %	14,997	15,008	-0.07 %
7	incr PS steep	5,719	5,618	1.80 %	7,504	7,537	-0.44 %	15,041	15,108	-0.44 %
8	default P+incr S	6,257	6,263	-0.10 %	8,024	8,022	0.02 %	16,071	16,067	0.02 %
9	decr P+ incr S	8,824	8,779	0.51 %	7,212	7,227	-0.21 %	14,464	14,494	-0.21 %
10	decr P+default S	8,391	8,352	0.47 %	7,242	7,255	-0.18 %	14,516	14,542	-0.18 %
11	decr P+decr S	8,037	8,013	0.30 %	7,223	7,231	-0.11 %	14,473	14,489	-0.11 %
12	decr PS steep	6,036	5,945	1.53 %	7,383	7,413	-0.40 %	14,777	14,838	-0.41 %

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

comparison to C_1 and T_0 . These patterns had also been observed with the empirical data for wild and hatchery Chinook and steelhead (Figure 7.10). Because there were only minor differences between the smolt estimates obtained with the computational and the expectation formulas, as well as for the reasons discussed below, hereafter we present only those smolt numbers obtained with the computation formulas.

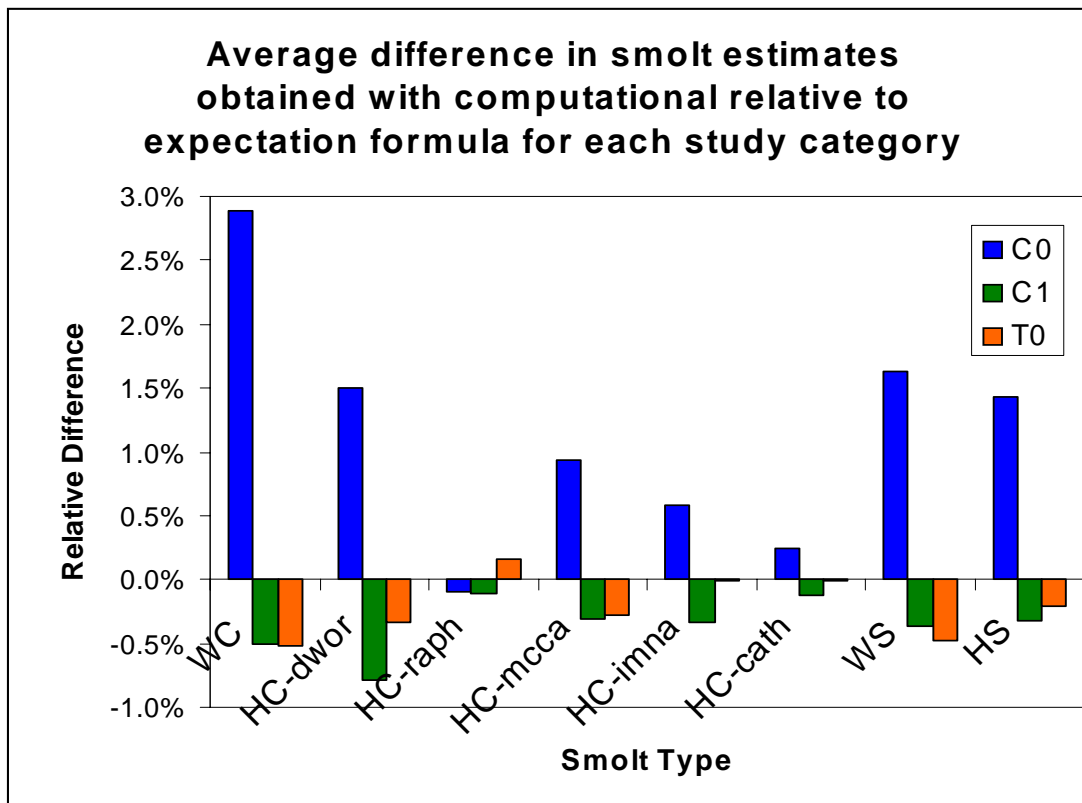


Figure 7.10. Average percent difference in smolt numbers estimated in LGR-equivalents using the computational formula relative to the expectation formula for each CSS study category (wild Chinook [WC] is average of 1994-2004; hatchery Chinook [HC] from Dworshak [dwor], Rapid River [raph], McCall [mcca], and Imnaha [imna] hatcheries are average of 1997-2004, and Catherine Ck is average of 2001-2004; wild [WS] and hatchery [HS] steelhead are average of 1997-2003).

Smolt numbers estimated by CJS methods for group C_0 differed more from the known values than did those for groups C_1 and T_0 (Table 7.2). The direction of these differences when collection probabilities were increasing or decreasing over time was toward a group C_0 estimate that was lower than the known value. As previously shown, the CJS smolt estimates for group C_0 were higher using the computation formula than when using the expectation formula under the conditions simulated (Table 7.1). Therefore, the computation formula produces closer agreement of group C_0 smolt estimates to the known values than the expectation formulas. Since both the computation and expectation formulas gave close estimates of smolt numbers for either group C_1 or group T_0 , the overall use of the computation formulas for all study groups was preferable.

Two interesting patterns are illustrated in Table 7.2. First, estimated smolt numbers appeared to diverge more from known values when collection probability changed over time rather than when survival rate changed over time. When the default collection probability case (i.e., minimal change over time) is combined with survival rates that were either linearly increasing or decreasing, the absolute differences between the CJS estimates of smolt numbers and the known values were negligible (0.3% or less). However, when a default survival rate case (i.e., minimal change over time) was combined with collection probabilities that were either

linearly increasing or decreasing, the absolute differences between the estimated smolt numbers and the known values increased from 0.1% to 0.3% for groups C_1 and T_0 and from 0.3% to 2.1-2.6% for group C_0 .

Secondly, when the linear changes in collection efficiency and survival rates were in opposite directions, there appeared to be a dampening effect on the difference between the CJS estimates and the known smolt numbers for group C_0 , resulting in less of a difference than when the default survival rate case was used. When both collection probabilities and survival rates changed in the same linear direction, smolt estimates were 5.5 to 6.3% lower than the known smolt numbers for group C_0 . When the steepness of the slopes was doubled and maintained in the same direction for collection probabilities and survival rates, the impact was greatly increased to around a 20% difference in the CJS estimates from known values. Under these extreme conditions, CJS estimates for both groups C_1 and T_0 were also reduced from the known values, but to a lesser extent (underestimating by around 6% for group C_1 and by less than 2% for group T_0). In real-world situations, we do not expect linear trends as extreme as modeled in Scenarios 7 and 12. The conditions in these scenarios may be viewed as a maximum boundary for assessing impacts of differences in estimated smolt numbers from known values on the key parameters of SARs, TIR , and D .

Table 7.2. Comparison of smolt numbers and the relative percent differences estimated for each study category using the computational formulas, across the twelve scenarios investigated. Reported smolt numbers are averages across the 1,000 simulated data sets.

Run	Test Condition ¹	C_0 known	C_0 (CJS)	Rel. % Diff.	C_1 known	C_1 (CJS)	Rel. % Diff.	T_0 known	T_0 (CJS)	Rel. % Diff.
1	default_PS	6,280	6,309	0.5%	8,028	8,021	-0.1%	16,089	16,078	-0.1%
2	constant_PS	6,334	6,356	0.4%	8,013	7,998	-0.2%	16,051	16,031	-0.1%
3	default_P+decr_S	6,275	6,294	0.3%	8,036	8,029	-0.1%	16,087	16,079	-0.1%
4	incr_P+decr_S	7,969	7,988	0.2%	7,413	7,507	1.3%	15,022	15,032	0.1 %
5	incr_P+default_S	7,823	7,657	-2.1%	7,519	7,495	-0.3%	15,057	15,014	-0.3%
6	incr_P+incr_S	7,669	7,189	-6.3%	7,638	7,482	-2.0%	15,092	14,997	-0.6
7	incr_PS_steep	7,080	5,719	-19.2%	7,992	7,504	-6.1%	15,325	15,041	-1.9%
8	default_P+incr_S	6,275	6,257	-0.3%	8,036	8,024	-0.2%	16,084	16,071	-0.1%
9	decr_P+ incr_S	8,839	8,824	-0.2%	7,110	7,212	1.4%	14,445	14,464	0.1%
10	decr_P+default_S	8,611	8,391	-2.6%	7,254	7,242	-0.2%	14,533	14,516	-0.1%
11	decr_P+decr_S	8,506	8,037	-5.5%	7,353	7,223	-1.8%	14,540	14,473	-0.5%
12	decr_PS_steep	7,555	6,036	-20.1%	7,853	7,383	-6.0%	14,993	14,777	-1.4%

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

The average SARs across the 1,000 datasets for each study group and for each simulation condition are shown in Table 7.3. In each simulation run, the number of adults for a study group was obtained by a binomial draw with binomial probability of $SAR_{LGR-LGR}$ set to 3% and n equal to the simulated “raw” number of smolts in each respective group. Expanding smolt numbers to LGR-equivalents caused resulting SARs to vary across study groups and among the twelve simulation conditions. The SARs for group C_0 were lower than 3% because all undetected fish surviving to LMN tailrace needed to be expanded to LGR-equivalents, whereas only first-time detected fish at LGS and LMN needed this expansion (i.e., LGR detected fish were already included) for groups C_1 and T_0 . Therefore, the comparisons of interest in Table 7.3 (and again

later in Table 7.4) are limited to differences between the CJS estimate of SAR and the known value for each study group, and how these differences changed across the 12 simulation scenarios.

Table 7.3. Comparison of estimated SARs for each study category with the known simulated values across the twelve scenarios investigated. The SAR values are averages across the 1,000 simulated data sets. Differences $\leq \pm 0.0001$ are considered trivial, and denoted with “=”.

Run	Test Condition ¹	sarC ₀ known	sarC ₀ (CJS)	Rel. % Diff.	sarC ₁ known	sarC ₁ (CJS)	Rel. % Diff.	sarT ₀ known	sarT ₀ (CJS)	Rel. % Diff.
1	default PS	0.0260	0.0259	=	0.0287	0.0287	=	0.0286	0.0286	=
2	constant PS	0.0254	0.0253	=	0.0285	0.0285	=	0.0285	0.0285	=
3	default P+decr S	0.0217	0.0216	=	0.0271	0.0272	=	0.0271	0.0272	=
4	incr P+decr S	0.0216	0.0215	=	0.0273	0.0269	-1.5%	0.0270	0.0269	=
5	incr P+default S	0.0259	0.0264	1.9%	0.0285	0.0286	=	0.0286	0.0286	=
6	incr P+incr S	0.0194	0.0207	6.7%	0.0257	0.0262	1.9%	0.0261	0.0262	=
7	incr PS steep	0.0206	0.0255	23.8%	0.0254	0.0270	6.3%	0.0266	0.0271	1.9%
8	default P+incr S	0.0196	0.0197	=	0.0262	0.0262	=	0.0262	0.0262	=
9	decr P+ incr S	0.0196	0.0197	=	0.0266	0.0262	-1.5%	0.0261	0.0261	=
10	decr P+default S	0.0260	0.0266	2.3%	0.0285	0.0286	=	0.0285	0.0286	=
11	decr P+decr S	0.0214	0.0227	6.1%	0.0266	0.0271	1.9%	0.0269	0.0270	=
12	decr PS steep	0.0199	0.0249	25.1%	0.0254	0.0270	6.3%	0.0265	0.0269	1.5%

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

The average CJS parameter values across simulations and for each scenario for parameters TIR , S_R , and D are shown in Table 7.4. The relative percent difference between the CJS TIR and known TIR followed a similar pattern over the 12 simulation scenarios as was observed previously for the SAR of group C_0 . With TIR computed as $SAR(T_0)/SAR(C_0)$ and little difference between CJS estimates of $SAR(T_0)$ and the known values, it is not unexpected that the TIR parameter would track the pattern of $SAR(C_0)$. Since the S_T fluctuated only over a small range (typically between 0.88 and 0.98), most of the variation in the parameter D arose from variation in TIR and S_R . Values of S_R tended to follow a pattern different from parameter TIR across the 12 simulation runs. When CJS estimates of TIR showed little differences from known values, there were greater differences for S_R . When the estimated TIR showed larger differences from known values, then the estimated S_R also showed larger differences from the known values, but in the opposite direction. The result was that CJS estimates of D were closer to the known values than was observed for parameter TIR .

Table 7.4. Comparison of estimated *TIR* (i.e., $\text{sar}T_0/\text{sar}C_0$), S_R , and *D* values with the known simulated values across the twelve scenarios investigated. Parameter values are averages across the 1,000 simulated data sets.

Run	Test Condition ¹	<i>TIR</i> known	<i>TIR</i> (CJS)	Rel. % Diff.	S_R known	S_R (CJS)	Rel. % Diff.	<i>D</i> known	<i>D</i> (CJS)	Rel. % Diff.
1	default_PS	1.109	1.115	0.5%	0.606	0.597	-1.5%	0.718	0.710	-1.1%
2	constant_PS	1.129	1.134	0.4%	0.597	0.589	-1.3%	0.724	0.716	-1.1%
3	default_P+decr_S	1.262	1.267	0.4%	0.445	0.441	-0.9%	0.634	0.632	-0.3%
4	incr_P+decr_S	1.256	1.258	0.2%	0.450	0.443	-1.6%	0.642	0.633	-1.4%
5	incr_P+default_S	1.110	1.090	-1.8%	0.608	0.607	-0.2%	0.723	0.706	-2.4%
6	incr_P+incr_S	1.352	1.275	-5.7%	0.391	0.402	2.8%	0.623	0.599	-3.9%
7	incr_PS_steep	1.298	1.069	-17.6%	0.441	0.494	12.0%	0.660	0.597	-9.5%
8	default_P+incr_S	1.349	1.347	-0.1%	0.395	0.392	-0.8%	0.621	0.615	-1.0%
9	decr_P+incr_S	1.338	1.334	-0.3%	0.398	0.392	-1.5%	0.624	0.613	-1.8%
10	decr_P+default_S	1.105	1.078	-2.4%	0.603	0.606	0.5%	0.714	0.698	-2.2%
11	decr_P+decr_S	1.260	1.196	-5.1%	0.438	0.451	3.0%	0.629	0.611	-2.9%
12	decr_PS_steep	1.342	1.087	-19.0%	0.385	0.441	14.5%	0.596	0.546	-8.4%

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

Discussion

The analyses conducted using the simulator program for the 2006 Annual Report using fixed values for collection efficiency and survival indicated that the number of smolts in each study category was well-estimated using the CJS methodology. There was close agreement between the CJS estimates and known values for number of smolts in the CSS study categories. In the present study, we examined a wide range of alternative scenarios that imposed within-season variation in survival and collection probabilities, leading to a more rigorous test of the CJS methodology under a departure from the strict CJS assumptions.

Only under the most extreme conditions of steep linear trends in collection and survival probabilities was substantial bias in SAR, *TIR*, or *D* estimates evident. Trends as steep as those simulated have rarely been observed during the study period (Figures 7.11 and 7.12). Estimated smolt numbers appeared to diverge more from known values when collection probability changed over time rather than when survival probability changed over time. Under the simulated negative and positive linear slopes of 0.005 per day for survival probabilities and 0.006 per day for collection probabilities, the differences between CJS estimates of key parameters and their known values remained small, with few simulated scenarios exceeding a 5% difference. These rates of change were greater than those actually observed for yearling Chinook in most years (Figures 7.11 and 7.12). The interplay between trends in collection probability and survival rate appeared to influence the degree of bias in CJS parameter estimates, with greater impact when both survival rate and collection probability change in the same direction over time. There appeared to be greater bias caused by trends in collection probabilities than by trends in survival rates.

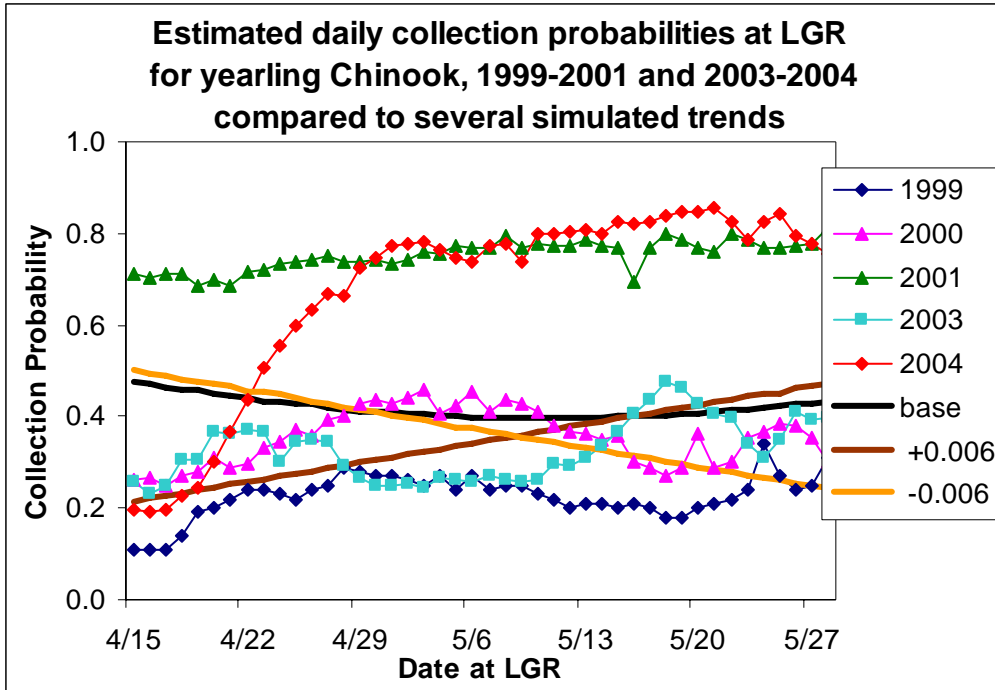


Figure 7.11. Estimated daily LGR collection probabilities for combined PIT-tagged hatchery and wild Chinook for five migration years, along with simulated trends (default parabola and lines of -0.006 and +0.006 slope).

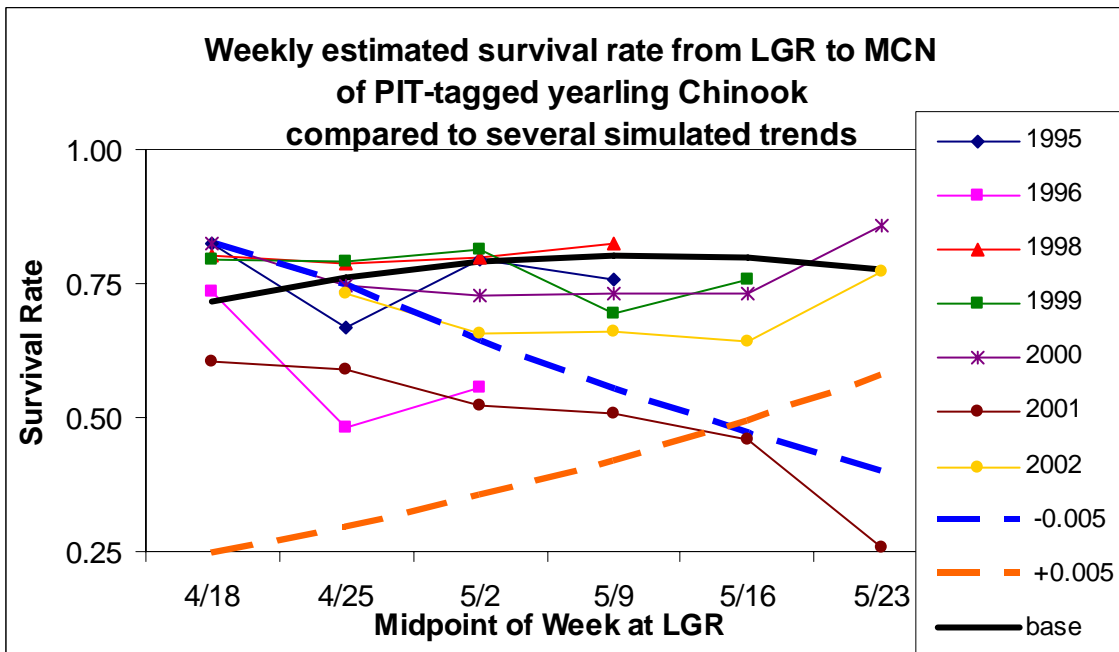


Figure 7.12. Estimated survival rates from LGR tailrace to MCN tailrace for combined PIT-tagged hatchery and wild Chinook during weekly intervals for 7 migration years; comparison with simulated trends (default parabola and lines of -0.005 and +0.005 slope) for LGR to LGS reach extrapolated on a per mile basis to MCN.

When both collection probabilities and survival rates changed in the same linear direction, the greatest effect was a negative bias in CJS estimates of group C_0 fish. Because TIR is computed as $SAR(T_0)/SAR(C_0)$ and little bias was evident in $SAR(T_0)$ values, bias in TIR tended to track the pattern in $SAR(C_0)$. Bias in S_R estimates tended to follow a different pattern from TIR across the 12 simulation runs. When the bias in TIR was relatively large, the bias in S_R also tended to be relatively large but in the opposite direction. Consequently, CJS estimates of D exhibited lower bias across the simulation runs than TIR . Overall, the results of the simulations provide confidence that bias due to CJS estimation of survival rates and collection probabilities when these parameters are changing over time is low enough to give reasonably accurate estimates of SAR for each study group, and for TIR , S_R , and D , which utilize these CJS estimates in their derivation.

Chapter 8

Accomplishments, Conclusions and Future Direction

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

Accomplishments

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

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

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

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

- a. Approximately 2,010,000 spring/summer Chinook have been PIT-tagged and released from hatcheries above LGR and approximately 143,300 at Carson NFH

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

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

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

- a. Over 976,000 PIT-tagged juvenile hatchery spring/summer Chinook CSS study fish have been estimated to arrive at LGR, from 1997 through 2004. In addition, the CSS has used 231,720 PIT-tagged juvenile wild spring/summer Chinook that have been estimated to arrive at LGR, from 1994 through 2004.
- b. From the CSS aggregate of PIT-tagged wild Chinook that outmigrated as smolts from 1994 to 2004, there have been 2,013 PIT-tagged returning adults detected at LGR through return year 2006. In the four hatcheries where Chinook have been PIT-tagged for the CSS, a total of 8,695 PIT-tagged returning adults were detected at LGR.
- c. The adult detection system at Bonneville Dam was completed in 2002; we are now able to use these detections to estimate SARs back to Bonneville Dam.
- d. Over 162,000 PIT-tagged juvenile hatchery steelhead have been estimated to arrive at LGR, from 1997 through 2003. In addition, the CSS has used 72,000 PIT-tagged juvenile wild spring/summer Chinook that have been estimated to arrive at LGR, from 1994 through 2004.
- e. From the CSS aggregate of PIT-tagged wild steelhead that outmigrated as smolts from 1997 to 2003, there have been 632 PIT-tagged returning adults detected at LGR through return year 2005. From the CSS hatchery aggregate 903 PIT-tagged hatchery steelhead that outmigrated during this same time, were detected as adults at LGR.

Chapter Specific Conclusions

Chapter 2

- a. Developed estimates of within-season reach fish travel times, survivals, and instantaneous mortality rates for Snake River hatchery and wild Chinook groups, and a composite steelhead group
- b. Simple models incorporating water travel times average percent spill, and Julian day explained 79-95% of the variation in median fish travel time.
- c. Variation in instantaneous mortality rates in the LGR-MCN reach for Chinook were explained by Julian Day and water travel time. For steelhead, variation was explained by Julian Day, flow⁻¹, and average percent spill. Variation in the MCN-BON reach was explained by Julian day for Chinook and temperature for steelhead.
- d. For both species, instantaneous mortality rates in the MCN-BON reach were roughly double those in the LGR-MCN reach. Within both reaches, instantaneous mortality rates of steelhead were roughly double those of yearling Chinook.
- e. Models that integrated predictions of median fish travel time and instantaneous mortality explained 54-80% of the variation in survival rates in the LGR-MCN reach and 51-71% of the variation in the MCN-BON reach for both Chinook and steelhead. This two-step approach outperformed modeling survival rates directly as functions of the same environmental variables.

Chapter 3

- a. The annual SARs (LGR smolts-to-LGR adults) for wild Snake River spring/summer Chinook have been highly variable, and far below the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003).
- b. Transportation provided little or no benefit (over fish that migrated in-river) to wild spring/summer Chinook during the conditions experienced in most years during 1994-2004, except during the severe drought year 2001.
- c. Delayed mortality of transported wild spring/summer Chinook smolts was substantial most years relative to that of in-river migrants, based on a 10-yr geometric mean *D* estimate (excluding 2001) of 0.49, indicating transported smolts died at twice the rate as in-river migrants once they passed BON tailrace.
- d. SARs (LGR-to-LGR) for hatchery Snake River spring/summer Chinook have shown similar patterns as wild Chinook during 1997-2004, although the actual survival rates have differed among hatcheries and between spring and summer runs. SARs of most hatchery Chinook (except Dworshak) have equaled or exceeded the SARs of wild Chinook in migration years 1997-2004.
- e. In general, transportation provided benefits (over fish that migrated in-river) most years to Snake River hatchery spring/summer Chinook 1997-2004, however; benefits varied among hatcheries.
- f. Delayed mortality of transported hatchery spring and summer Chinook smolts was evident most years relative to that of in-river migrants, based on estimated values of *D* less than 1.
- g. While wild and hatchery spring and summer Chinook populations demonstrated

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

- h. Wild steelhead from the Snake River basin had higher estimated annual SARs (indexed LGR to LGR) than hatchery steelhead in 6 of the 7 migration years (1997 to 2003). Wild steelhead had four years with annual SARs greater than the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003).
- i. Transportation seems to provide benefit (over fish that migrated in-river) to wild and hatchery Snake River steelhead; the geometric mean *TIR* (1997-2000, 2002-2003) was 1.72 wild stocks and 1.46 for hatchery stocks. Migration year 2001 had very high, but imprecise *TIR*s, for both wild and hatchery steelhead.
- j. Delayed mortality was evident with transported wild and hatchery steelhead relative to in-river migrants as the geometric mean *D* for 1997-2003 (excluding 2001) was 0.80 for wild stocks and 0.64 for hatchery stocks. Confidence intervals were wide due to small sample size.
- k. Given small sample sizes and wide confidence intervals for both wild and hatchery steelhead, it is premature to conclude whether hatchery steelhead can serve as surrogates for wild steelhead. However, trends in S_R (in-river survival from LGR to BON) and *TIR*s were similar between wild and hatchery steelhead.

Chapter 4

- a. Distributions of SAR of transported and in-river (C_0) migrants suggest that inter-annual variation in SAR is large for both Chinook and steelhead.
- b. The transport, in-river (C_0), and overall distributions suggest realized SARs have been considerably below the minimum 2% recommended in the NPCC Fish and Wildlife Program mainstem amendments (NPCC 2003) for Chinook, and generally below this level for steelhead.
- c. *TIR* distributions suggest that on average, transportation as currently implemented is not of benefit (over fish that migrated in-river (C_0)) for wild Chinook, regardless of transport project, as the bulk of the distributions for all projects is less than 1.
- d. Transportation, particularly from LGR, appears to provide a benefit to wild steelhead compared to in-river (C_0) migration under the current system. The benefits of transportation appear to decline lower in the system.
- e. Derived *D* distributions suggest substantial delayed mortality of transported wild Chinook. *D* estimates for steelhead are higher than for Chinook, suggesting that delayed mortality from transport is lower, compared to transporting Chinook.
- f. The analysis for wild spring/summer Chinook demonstrated relatively high SARs early in the season, and severe declines later in the season in SARs of in-river (C_1) fish. Similar patterns in in-river SARs within the season are seen for wild steelhead.
- g. The decline in SAR of in-river (C_1) fish of both species as the season progresses is consistent with the hypothesis that the protracted migration and late arrival in the estuary is in part responsible for elevated levels of post-Bonneville mortality as a consequence of the hydrosystem experience.

Chapter 5

- a. SARs of Snake River wild spring/summer Chinook were less than NPCC interim objectives (2% minimum, 4% average) in most years, achieving the minimum in only 1 of 11 years during 1994-2004. Snake River wild steelhead SARs averaged less than NPCC the minimum of 2%, but met the minimum in 4 of 7 years during 1997-2003.
- b. SARs of hatchery spring/summer Chinook tracked closely with those of the aggregate Snake River wild population during 1997-2004, indicating similar factors were influencing survival during the smolt migration and in the estuary and ocean life stage. The patterns observed in overall hatchery SARs appear useful for augmenting wild SAR data, as well as providing important management information for these specific hatcheries.
- c. Multiple linear regression analysis indicated that SARs of Snake River wild spring/summer Chinook were positively correlated with faster water travel time experienced during the smolt migration, cooler phases of the PDO index (primarily in May or September) and stronger down-welling in the fall (November) during the first year of ocean residence.
- d. SARs of downriver wild spring Chinook from the John Day River (migrate through 5 fewer dams) averaged about four times greater than those from the Snake River during migration years 2000-2004. The difference in SARs between upriver and downriver wild Chinook is consistent with previous findings of differential mortality between upriver and downriver population groups based on spawner and recruit data before and after FCRPS completion (Schaller et al. 1999, 2000, Deriso et al. 2001; Schaller and Petrosky 2007).
- e. Upriver and downriver hatchery spring/summer Chinook SARs did not show the same level of differential mortality as was apparent from the wild populations.
- f. Our comparison of upriver and downriver wild Chinook salmon population-specific life history attributes found no evidence for a consistent and/or systematic difference in size-at-migration, timing distributions, and migration rates in the hydrosystem. Thus, while our use of an upriver-downriver comparison relies on a 'natural experiment' approach and therefore has some design limitations, the analysis we present here illustrates that the potential confounding effects due to life history differences are probably negligible.
- g. The CSS PIT-tag results clearly demonstrate delayed estuary entry of Snake River in-river smolts due to the presence and operation of the FCRPS.
- h. SARs of Snake River were also lower than those of downriver wild Chinook when they arrived to the lower Columbia River in the same time window (April 16 - May 31). The disparity between SARs for Snake River wild Chinook and downriver smolts provides additional support for mechanisms of delayed hydrosystem mortality beyond the simple alteration of estuary entry timing.

Chapter 6

- a. The CSS project has routinely estimated survival of hatchery Chinook smolts from release to LGR for each hatchery and year. Dworshak Hatchery has typically had the highest survival through this life stage, but lowest overall SARs and poorest response to transportation compared to other hatcheries in the study.

- b. A portion of the SAR survival difference observed in the *TIR* estimates between Chinook salmon with different juvenile outmigration histories (transportation or in-river) is manifested through mortality and/or straying during the adult upstream migration. Adults that were transported from LGR as smolts survived the upstream migration at a 10% lower rate than those with either an in-river smolt history or those that were transported from LGS or LMO. Use of project specific PIT-tag detections has become the standard for estimating inter-dam conversion rates for use in in-season fisheries management; the CSS findings suggest such estimates may be positively biased if transportation history is not considered in the estimation process. The consequences of increased straying due to transportation may also extend beyond the Snake River populations in these analyses, for instance by creating situations with undesirably high of-of-basin strays in mid-Columbia steelhead (listed) and spring Chinook (unlisted) populations.
- c. This difference in upstream migrant mortality between different juvenile outmigration routes was not apparent upstream of the hydrosystem, based on relative proportions of detected adults at the hatcheries. Obtaining absolute survival estimates from LGR to the hatcheries has been problematic, due in part to difficulties in accounting for fish which may stray or spawn below the hatchery racks, uncertainties in harvest accounting, and possible issues with tag loss or detection inefficiencies at the hatchery racks. These accounting issues are beyond the present scope of CSS, but may be addressed with future directed studies.
- d. The CSS transportation evaluations based on LGR smolts and LGR adults appear to reasonably describe the relative performance of transported and in-river migrants, based on our finding of no apparent survival difference upstream of the hydrosystem. This result should be tested in future CSS evaluations.

Chapter 7

- a. We developed a simulation model to evaluate the influence of violating key assumptions for the Cormack-Jolly-Seber (CJS) model on CSS parameters of interest.
- b. Specifically, we investigated the impact that violations of the CJS model assumption (that all fish are independent and identically distributed with common reach specific and dam specific collection probabilities) has on our ability to obtain accurate estimates of reach survival rates and other study parameters.
- c. Our simulation results indicate that CJS-based estimation of parameters of SARs by study group ($sarC_0$, $sarC_1$, and $sarT_0$), *TIRs* ($sarT_0/sarC_0$), S_R and D (delayed differential mortality between T_0 and C_0 groups) are robust to population changes in survival rates and collection probabilities over time.

Overall Conclusions

We conclude that the CSS study successfully met the four primary objectives: 1) develop long term indices of transport and in-river SARs for Snake River hatchery and wild Spring/summer Chinook and Steelhead; 2) develop long term indices of survival rates from

release of yearling Chinook smolts at hatcheries to return of adults at hatchery; 3) compute and compare overall SARs for selected upriver and downriver spring/summer Chinook hatchery and wild stocks; and 4) begin a time series of SARs for use in regional long-term monitoring and evaluation.

The above CSS study objectives focused on the question of whether collecting juvenile fish and transporting them downstream in barges and trucks and releasing them below Bonneville Dam was compensating for the effects of the Federal Columbia River Power System (FCRPS) on survival of Snake Basin spring/summer Chinook and steelhead migrating through the hydrosystem (Mundy et al. 1994).

The CSS results indicated that the survival of transported fish relative to in-river groups varied across species and between wild and hatchery groups. Wild spring/summer Chinook showed little relative benefit from transportation most years ($TIR \sim 1.0$), except in severe drought years. Wild spring/summer Chinook exhibited substantial differential delayed transport mortality ($D < 1.0$). Responses of hatchery spring/summer Chinook to transportation were more positive (TIR averages across hatcheries $\sim 1.1-1.5$) than those of wild, but hatchery Chinook still exhibited substantial differential delayed mortality relative to in-river migrants ($D < 1.0$). Wild and hatchery steelhead responded more positively to transportation (TIR wild mean of 1.7, TIR hatchery mean of 1.5) than wild spring/summer Chinook, however differential delayed mortality ($D < 1.0$) of transported steelhead was also sometimes evident.

Overall SARs for wild spring/summer Chinook (geometric mean 0.9%, range 0.3% - 2.4%) fell short of the NPCC SAR objectives (2% minimum, 4% average for recovery), and were only 1/4 that of similar downriver populations which migrated through fewer dams. Overall SARs of wild steelhead (geometric mean 1.6%, range 0.3%-2.9%) also fell short of NPCC SAR objectives, although they exceeded those of wild Chinook. The above lines of evidence for Snake River reach survivals, SARs by passage route, overall SARs and downriver SARs relative to the NPCC objectives, indicate that collecting and transporting juvenile spring/summer Chinook and steelhead at Snake River Dams did not compensate for the effects of the FCRPS. Compared to regional broad sense recovery goals which include providing harvestable surplus for wild Snake Basin spring/summer Chinook and steelhead; the estimated CSS SARs are insufficient to also meet these goals.

The CSS project evaluated hydrosystem management actions as they occurred during the past decade, with primary emphasis on juvenile transportation operations. The FCRPS configuration and operations changed during the study period. Hydrosystem management and system configuration will undoubtedly continue to evolve into the future, which will require a long-term monitoring and evaluation program such as CSS to track its effectiveness.

We have demonstrated that the implementation of the CSS study and the accompanying analyses have provided the region with long-term indices of survival rates to assess the performance of in-river and transport groups of spring/summer Chinook and steelhead. In addition, we performed assessments that evaluated the relationship of these various survival rates to hydrosystem operational conditions while considering the influence of varying environmental conditions. These findings appear to have important implications for operation of the hydrosystem and provide the building blocks needed to develop tools to evaluate various hydrosystem operational alternatives to ensure protection, restoration and mitigation of anadromous salmonids. Specifically, the CSS study results provide information on past hydrosystem conditions that have optimized survival of fish migrating in-river.

An important management question during the migration season is when to initiate transportation. The Biological Opinion operations are presently designed to change with the anticipated environmental conditions to meet the competing uses of the hydrosystem. The CSS results provide information on seasonal effects of transportation in comparison to in-river (C_1) fish. It should be noted that seasonal *TIRs* derived from seasonal C_1 SARs may contain some positive bias because the in-river migrant most like the untagged fish (C_0), which migrate through spill and turbine routes at collector dams, have shown higher SARs than fish bypassed at one or more of the collector dams. The integration of the reach survival estimates (Chapter 2) and seasonal transport SARs from the CSS results (Chapter 4) have the potential to inform decisions on when to initiate transportation.

The CSS design and future results will provide the information to assess the response of the populations to any implemented set of management actions. A key element of the CSS design is marking fish above the hydrosystem so that we: 1) have known origin fish; 2) minimize handling effects on the study fish; and 3) better represent the run-at-large. Given the long-term nature of the CSS (consistent marking levels and study approach), there will be the ability to gauge population response to future management actions to the historical population performance of past actions.

Future Direction

CSS SAR estimates provide a time series for status and trend monitoring and these time series of SAR estimates and reach survival estimates provide key information to assess action effectiveness for some the hydrosystem management actions. In addition these time series of CSS survival estimates provide a baseline to assess future management actions. Given these conclusions, the following is a list of recommended activities for the continuation of the CSS and to guide the future direction:

- a. Extend the time series of PIT-tag information to the levels necessary to provide reach survivals, annual and seasonal transport SARs, in-river SARs, and overall SARs for hatchery and wild Snake River spring/summer Chinook and steelhead. Expand the time series of PIT-tag information to the levels necessary to provide overall SARs for John Day spring Chinook and steelhead and Carson hatchery spring Chinook. Also, augment hatchery and wild Snake River spring/summer Chinook PIT-tag groups to improve reach survival estimates for the McNary to Bonneville reach.
- b. Identify additional downriver wild and hatchery Chinook populations to PIT-tag and provide additional downriver overall SARs.
- c. Identify additional Snake River hatchery steelhead populations to PIT-tag at levels necessary to provide reach survivals, annual and seasonal transport SARs, in-river SARs, and overall SARs.
- d. Identify downriver wild and hatchery steelhead populations to PIT-tag and provide downriver overall SARs.
- e. Augment existing PIT-tag groups of Snake River hatchery and wild steelhead populations to levels necessary to provide reach survivals (particularly in the McNary to Bonneville reach), annual and seasonal transport SARs, in-river SARs, and overall SARs.
- f. Investigate how to improve adult LGR to hatchery rack return estimates.

- g. Continue to evaluate the key assumptions of the CJS model in relation to constraints placed on the experimental design given limitations for hydrosystem operations, with continued diligence to minimize bias.
- h. Continue to evaluate the relationships between reach survivals and environmental conditions within hydrosystem.
- i. Continue to evaluate the relationships between population overall SARs and environmental conditions within and outside the hydrosystem.
- j. Evaluate the relationships between seasonal SARs and environmental conditions within and outside the hydrosystem.
- k. Develop techniques to evaluate the relationships between overall SARs and recruit/spawner information.
- l. Continue to coordinate the CSS with other research and monitoring programs in the Columbia Basin to provide and improve efficiencies for PIT-tagging, tag detections, data management, and data accessibility.

References

- Akçakaya, H.R. 2002. Estimating the variance of survival rates and fecundities. *Animal Conservation* 5:333-336
- Berggren, T.J. and L.R. Basham. 2000. Comparative Survival Rate Study (CSS) of Hatchery PIT Tagged Chinook, Status Report for Migration Years 1996 – 1998. Mark/Recapture Activities. BPA Contract #8712702.
- Berggren, T.J., and M.J. Filardo. 1993. An analysis of variables influencing the migration of juvenile salmonids in the Columbia River Basin. *North American Journal of Fisheries Management* 13:48-63.
- Berggren, T., H. Franzoni, L. Basham, P. Wilson, H. Schaller, C. Petrosky, K. Ryding, E. Weber, and R. Boyce. 2005. Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook. 2003/04 Annual Report, Migration Years 1997-2002 Mark/Recapture Activities and Bootstrap Analysis. BPA Contract # 19960200.
- Berggren, T., H. Franzoni, L. Basham, P. Wilson, H. Schaller, C. Petrosky, E. Weber, and R. Boyce. 2005. Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and PIT-tagged Summer Steelhead. 2005 Annual Report, BPA Contract # 19960200.
- Berggren, T., H. Franzoni, L. Basham, P. Wilson, H. Schaller, C. Petrosky, E. Weber, R. Boyce and N. Bouwes. 2003. Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook. 2002 Annual Report, Migration Years 1997-2000. Mark/Recapture Activities and Bootstrap Analysis. BPA Contract # 8712702.
- Berggren T., P. McHugh, P. Wilson, H. Schaller, C. Petrosky, E. Weber, and R. Boyce. 2006. Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and Summer Steelhead. 2006 Annual Report. BPA Contract # 19960200.
- Blumenfeld, D.E. 2001. Operations research calculations handbook. CRC Press, Boca Raton, FL.
- Bouwes, N., C. Petrosky, H. Schaller, P. Wilson, E. Weber, S. Scott, and R. Boyce. 2002. Comparative Survival Study (CSS) of PIT Tagged Spring/Summer Chinook, Status Report for Migration Years 1997 – 2000. Mark/Recapture Activities. BPA Contract #8712702.
- Budy, P., and H. Schaller. 2007. Evaluating Tributary Restoration Potential for Pacific Salmon Recovery. *Ecological Applications*.
- Budy, P., G.P. Thiede, N. Bouwes, C.E. Petrosky, and H. Schaller. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. *North American Journal of Fisheries Management* 22:35-51.

- Bugert, R.M., G.W. Mendel, and P.R. Seidel. 1997. Adult returns of subyearling and yearling fall Chinook salmon released from a Snake River hatchery or transported downstream. *North American Journal of Fisheries Management* 17:638-651.
- Burnham, K.P. and D.R. Anderson. 2002. *Model selection and inference – a practical information-theoretic approach*. Second edition. Springer-Verlag. New York.
- Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. *Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture*. American Fisheries Society Monograph 5, Bethesda, Maryland.
- Čada, G.F., M.D. Deacon, S.V. Mitz, and M.S. Bevelhimer. 1997. Effects of water velocity on the survival of downstream-migrating juvenile salmon and steelhead: a review with emphasis on the Columbia River Basin. *Reviews in Fisheries Science* 5(2):131-183.
- Catalani, M. 2002. Sampling from a couple of positively correlated beta variates. <http://arxiv.org/abs/math.PR/0209090>
- Carmichael, R., G. Clair, J. Seals, S. Onjukka, J. Ruzycski, and W. Wilson. 2002. Fish Research Project Oregon, John Day Basin Spring Chinook Salmon Escapement and Productivity Monitoring. Report to BPA #DOE/BP-00000498-2.
- Chapman, C., C. Carlson, D. Weitkamp, G. Matthews, J. Stevenson, and M. Miller. 1997. Homing in sockeye and Chinook salmon transported around part of their smolt migration route in the Columbia River. *North American Journal of Fisheries Management* 17:101-113.
- Copeland, T., J. Johnson and P.R. Bunn. 2005. Idaho Natural Production Monitoring and Evaluation. Annual Progress Report. July 1, 2004—June 30, 2005. BPA Project 199107300. Idaho Department of Fish and Game Report 05-38.
- Cormack, R.M. 1964. Estimates of survival from the sightings of marked animals. *Biometrika* 51:429-438.
- Dauble, D.D., and R.P. Mueller. 2000. Upstream passage monitoring: difficulties in estimating survival for adult Chinook salmon in the Columbia and Snake rivers. *Fisheries* 25:24-34.
- Deriso, R.B., D.R. Marmorek and I.J. Parnell. 2001. Retrospective patterns of differential mortality and common year-effects experienced by spring and summer Chinook (*Oncorhynchus tshawytscha*) of the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences* 58:2419-2430.
- Ebel, W.J., D.L. Park, and R.C. Johnsen. 1973. Effects of transportation on survival and homing of Snake River Chinook salmon and steelhead trout. *Fishery Bulletin* 71:549-563.

- Efron, B. and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman & Hall, NY.
- Fish Passage Center. 2006. Fish Passage Center 2005 Annual Report. www.fpc.org.
- Giorgi, A.E., T.W. Hillman, J.R. Stevenson, S.G. Hays, and C.M. Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the Mid-Columbia River Basin. *North American Journal of Fisheries Management* 17:268-282.
- Gould, W.R. & Nichols, J.D. 1998. Estimation of temporal variability of survival in animal populations. *Ecology* 79: 2531-2538.
- Hare, S. R., Mantua, N. J., & Francis, R. C. (1999). Inverse production regimes: Alaskan and West Coast Salmon. *Fisheries*, 24, 6–14.
- Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences of the United States of America* 100(11):6564-6568.
- Hilborn, R. and C.J. Walters. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.
- IC-TRT (Interior Columbia Technical Recovery Team). 2003. Independent Populations of Chinook, Steelhead, and Sockeye for Listed Evolutionarily Significant Units Within the Interior Columbia River Domain. Working Draft, July 2003.
- ISAB (Independent Scientific Advisory Board). 2003. Review of Flow Augmentation: Update and Clarification. Prepared for Northwest Power and Conservation Council, Columbia River Basin Indian Tribes and National Marine Fisheries Service. ISAB 2003-1. February 10, 2003.
- ISAB (Independent Scientific Advisory Board). 2006. ISAB Review of the 2005 Comparative Survival Studies' Annual Report and Applicability of Comparative Survival Studies' Analysis Results. Prepared for Northwest Power and Conservation Council, Columbia River Basin Indian Tribes and National Marine Fisheries Service. ISAB 2006-3. March 15, 2006.
- ISG (Independent Scientific Group). 1999. Return to the river: scientific issues in the restoration of salmonid fishes in the Columbia River. *Fisheries* 24(3):10–19.
- Johnson, N. L., S. Kotz, and N. Balakrishnan. 1994. Continuous univariate distributions, volume 1. 2nd edition. John Wiley & Sons, Inc.
- Jolly, G.M. 1965. Explicit estimates from capture-recapture data with both death and immigration- stochastic model. *Biometrika* 52:225-247.

- Kareiva, P., M. Marvier, and M. McClure. 2000. Recovery and management options for spring/summer chinook salmon in the Columbia River basin. *Science* 290: 977-979.
- Keefer, M.L., C.A. Peery, and C.C. Caudill. 2006. Long-distance downstream movements by homing adult Chinook salmon. *Journal of Fish Biology* 68:944-950.
- Keefer, M.L., C.A. Peery, W.R. Daigle, M.A. Jepson, S.R. Lee, C.T. Boggs, K.R. Tolotti, and B.J. Burke. 2005. Escapement, harvest, and unknown loss of radio-tagged adult salmonids in the Columbia River – Snake River hydrosystem. *Canadian Journal of Fisheries and Aquatic Sciences* 62:930-949.
- Kendall, B. E. 1998. Estimating the magnitude of environmental stochasticity in survivorship data. *Ecological Applications* 8:184–193.
- Keyfitz, N. 1985. Applied mathematical demography- second edition. Springer-Verlag, New York.
- Malthus, T.R. 1798. An essay on the principle of population. J. Johnson, London.
- Mantua, N. J., Hare, S. R., Zhang, Y., Wallace, J. M., and Francis, R. C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society*, 78, 1069-1079.
- Marmorek, D.R., C.N. Peters and I. Parnell (eds.). 1998. PATH final report for fiscal year 1998. Compiled and edited by ESSA Technologies, Ltd., Vancouver, B.C. Available from Bonneville Power Administration, Portland, Oregon (http://www.efw.bpa.gov/Environment/PATH/reports/ISRP1999CD/PATH%20Reports/WOE_Report/).
- Marmorek, D.R., M. Porter, I.J. Parnell and C. Peters, eds. 2004. Comparative Survival Study Workshop, February 11–13, 2004; Bonneville Hot Springs Resort. Draft Report compiled and edited by ESSA Technologies Ltd., Vancouver, B.C. for Fish Passage Center, Portland, OR and the US Fish and Wildlife Service, Vancouver, WA. 137 pp.
- Marsh, D., M., Harmon, N. Paasch, K. Thomas, K. McIntyre, B. Sanford, and G. Matthews. 2005. Research related to transportation of juvenile salmonids on the Columbia and Snake rivers, 2001: final report for the 2001 spring/summer Chinook juvenile migration. Report by Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA to the Army Corp of Engineers, Walla Walla District, Delivery Order E86960099, v, 20 p.
- McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC-42, 156 p.
- Morris, W.F. and D.F. Doak. 2002. Quantitative Conservation Biology. Sinauer Associates, Sunderland, Massachusetts. 480 pp.

- Muir, W.D., D.M. Marsh, B.P. Sanford, S.G. Smith, and J.G. Williams. 2006. Post-hydropower system delayed mortality of transported Snake River stream-type Chinook salmon: unraveling the mystery. *Trans. Am. Fish. Soc.* 135: 1523:1534.
- Muir, W.D., S.G. Smith, J.G. Williams, and B.P. Sandford. 2001. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River dams. *North American Journal of Fisheries Management* 21:135-146.
- Mundy, P.R., D. Neeley, C.R. Steward, T. Quinn, B.A. Barton, R.N. Williams, D. Goodman, R.R. Whitney, M.W. Erho, and L.W. Botsford. 1994. Transportation of juvenile salmonids from hydroelectric projects in the Columbia River Basin; an independent peer review. Final Report. U.S. Fish and Wildlife Service, 911 N.E. 11th Ave., Portland, OR. 97232-4181.
- Naughton, G.P., C.C. Caudill, M.L. Keefer, T.C. Bjornn, C.A. Peery, and L.C. Stuehrenberg. 2006. Fallback by adult sockeye salmon at Columbia River dams. *North American Journal of Fisheries Management* 26:380-390.
- Nickelson, T.E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon Production Area. *Canadian Journal of Fisheries and Aquatic Sciences* 43:527-535.
- NPCC (Northwest Power and Conservation Council). 2000. Columbia River Basin Fish and Wildlife Program. Council Document 2000-19.
- NPCC (Northwest Power and Conservation Council). 2003. Mainstem Amendments to the Columbia River Basin Fish and Wildlife Program. Council Document 2003-11.
- Oehlert, G.W. 1992. A note on the delta method. *The American Statistician*, Vol. 46, No. 1, pp. 27-29.
- Olney, F., B. Heinith, R. Woodin, C. Tuss, C. Petrosky and M. Filardo. 1992. Review of salmon and steelhead transportation studies in the Columbia and Snake Rivers, 1984 to 1989. Ad Hoc Transportation Review Group report submitted to the Columbia Basin Fish and Wildlife Authority. December 31, 1992.
- Pascual, M.A., T.P. Quinn, and H. Fuss. 1995. Factors affecting the homing of fall Chinook salmon from Columbia River hatcheries. *Transactions of the American Fisheries Society* 124:308-320.
- PATH (Plan for Analyzing and Testing Hypotheses). 2000. Preliminary Evaluation of the Learning Opportunities and Biological Consequences of Monitoring and Experimental Management Actions.

- Paulsen, C.M. and T. Fisher. 2005. Do habitat actions affect juvenile survival? Information:Theoretic Approach applied to endangered Snake River Chinook salmon. Transaction of American Fisheries Society, 134: 68-85.
- Paulsen, C.M. and R.A. Hinrichsen. 2002. Experimental management for Snake River spring-summer Chinook (*Oncorhynchus tshawytscha*): trade-offs between conservation and learning for a threatened species. Canadian Journal of Fisheries and Aquatic Sciences 59:717-725.
- Peters, C.N. and D.R. Marmorek. 2001. Application of decision analysis to evaluate recovery actions for threatened Snake River spring and summer chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 58:2431-2446.
- Petrosky, C.E. and H.A. Schaller. 1992. A comparison of productivities for Snake River and Lower Columbia River spring and summer Chinook stocks. Proceedings of Salmon Management in the 21st Century: Recovering Stocks in Decline. 1992 Northeast Pacific Chinook and Coho Workshop. American Fisheries Society, Idaho Chapter, Boise, ID.
- Petrosky, C.E., H.A. Schaller, and P. Budy. 2001. Productivity and survival rate trends in the freshwater spawning and rearing stage of Snake River chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 58:1196-1207.
- Pham-Gia, T. 2000. Distributions of the ratios of independent beta variables and applications. *Comm. Statist. Theory Methods* 29 (12): 2693–2715.
- Plumb, J.M., R.W. Perry, N.S. Adams, and D.W. Rondorf. 2006. The effects of river impoundment and hatchery rearing on the migration behavior of juvenile steelhead in the Lower Snake River, Washington. *North American Journal of Fisheries Management* 26:438-452.
- Prentice, E.P., D.L. Park, T.A. Flagg, and C.S. McCutcheon. 1986. A study to determine the biological feasibility of a new fish tagging system. Report to BPA, Project 83-319, Contract DE-AI79-84BP11982. 89 pp. Project #1998-01600. 63 electronic pages.
- Pyper, B.J., F.J. Mueter, and R.M. Peterman. 2005. Across-species comparisons of spatial scales of environmental effects on survival rates of Northeast Pacific salmon. *Transactions of the American Fisheries Society* 134:86–104.
- Quinn, T.J., II, and R.B. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford University Press, New York, New York.
- Quinn, T.P. 2005. *The behavior and ecology of Pacific salmon*. University of Washington Press, Seattle, WA.
- Raymond, H.L. 1968. Migration rates of yearling Chinook salmon in relation to flows and impoundments in the Columbia and Snake Rivers. *Transactions of the American Fisheries Society* 97:356-359.

- Raymond, H.L. 1969. Effect of John Day Reservoir on the migration rate of juvenile Chinook salmon in the Columbia River. *Transactions of the American Fisheries Society* 98: 513-514.
- Raymond, H.L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966-1975. *Transactions of the American Fisheries Society* 90:58-72.
- Raymond, H.L. 1988. Effects of hydroelectric development and fisheries enhancement on spring and summer Chinook salmon and steelhead in the Columbia River Basin. *North American Journal of Fisheries Management* 8:1-24.
- Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. *Bulletin of the Fisheries Research Board of Canada* 191.
- Ryding, K. 2006. Comparative Survival Study 2006 Design and Analysis Technical Report. Washington Department of Fish and Wildlife – CSS Oversight Committee Member. BPA Contract # 19960200, Portland OR.
- Sanford, B.P. and S.G. Smith. 2002. Estimation of smolt-to-adult return percentages for Snake River Basin anadromous salmonids, 1990-1997. *Journal of Agricultural Biological and Environmental Statistics* 7:243-263.
- Schaller, H.A., and C.E. Petrosky. 2007. Assessing hydrosystem influence on delayed mortality of Snake River stream-type Chinook salmon. *North American Journal of Fisheries Management* 27:810–824.
- Schaller, H.A., C.E. Petrosky, and O.P. Langness. 1999. Contrasting patterns of productivity and survival rates for stream-type Chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia rivers. *Canadian Journal of Fisheries and Aquatic Sciences* 56:1031-1045.
- Schaller, H.A., C.E. Petrosky, and O.P. Langness. 2000. Reply to Zabel and Williams' comments on "Contrasting patterns of productivity and survival rates for stream-type Chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia rivers" by Schaller et al. (1999). *Canadian Journal of Fisheries and Aquatic Sciences* 57:1742-1746.
- Scheuerell, M.D. and J.G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). *Fisheries Oceanography* 14:448-457.
- Seber, G.A.F. 1965. A note on the multiple recapture census. *Biometrika* 52:249-259.
- Seber, G.A.F. 1982. The estimation of animal abundance and related parameters- second edition. Blackburn Press, New Jersey.

- Simms, C.W., and F.J. Ossiander. 1981. Migrations of juvenile Chinook salmon and steelhead in the Snake River, from 1973 to 1979, a research summary. Report to the U.S. Army Corps of Engineers, Contract DACW68-78-C-0038.
- Smith, S.G., W.D. Muir, J.G. Williams, and J.R. Skalski. 2002. Factors associated with travel time and survival of migrant yearling Chinook salmon and steelhead in the Lower Snake River. *North American Journal of Fisheries Management* 22:385-405.
- Solazzi, M.F., T.E. Nickelson, S.L. Johnson. 1991. Survival, contribution, and return of hatchery coho salmon (*Oncorhynchus kisutch*) released from freshwater, estuarine, and marine environments. *Canadian Journal of Fisheries and Aquatic Sciences* 48:248-253.
- Turchin, P. 2003. *Complex population dynamics: a theoretical/empirical synthesis*. Princeton University Press, New Jersey.
- U.S. v. Oregon Technical Advisory Committee. 2006. Spring /summer Chinook Biological Assessment Tables, December 11, 2006.
- Ward, D., R. Boyce, F. Young and F. Olney. 1997. A review and assessment of transportation studies for Juvenile Chinook salmon in the Snake River. *NAJFM* 17:652-662.
- White, Gary C. and Kenneth P. Burnham. Suppl. S, 1999. Program MARK: Survival estimation from populations of marked animals, *Bird Study*, 46:120-139.
- Williams, J.G., S.G. Smith, and W. Muir. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia rivers hydropower system, 1966-1980 and 1993-1999. *North American Journal of Fisheries Management* 21:310-317.
- Williams, J.G., S.G. Smith, R.W. Zabel, W.D. Muir, M.D. Scheuerell, B.D. Sandford, D.M. Marsh, R.A. McNatt, and S. Achord. 2005. Effects of the Federal Columbia River Power System on salmonid populations. NOAA Technical Memorandum NMFS-NWFSC-63. (<http://www.nwfsc.noaa.gov>).
- Wilson, P.H. 2003. Using population projection matrices to evaluate recovery strategies for Snake River spring and summer Chinook salmon.
- Zabel, R.W. 2002. Using “travel time” data to characterize the behavior of migrating animals. *American Naturalist* 159:372-387.
- Zabel, R.W., W.J. Faulkner, S.G. Smith, J.J. Anderson, C. Van Holmes, N. Beer, S. Iltis, J. Krinkie, G. Fredicks, B. Bellerud, J. Sweet, and A. Giorgi. (*in press*). Comprehensive Passage (COMPASS) Model: a model of downstream migration and survival of juvenile salmonids through a hydropower system. *Hydrobiologia*.

- Zabel, R.W., M.D. Scheuerell, M.M. McClure, and J.G. Williams. 2006. The interplay between climate variability and density dependence in the population viability of Chinook salmon. *Conservation Biology* 20:190-200.
- Zabel, R.W. and J.G. Williams. 2000. Comments on “Contrasting patterns of productivity and survival rates for stream-type Chinook salmon (*Oncorhynchus tshawytscha*) populations of the Snake and Columbia rivers” by Schaller et al. (1999). *Canadian Journal of Fisheries and Aquatic Sciences* 57:1739-1741.
- Zabel, R.W., and J.G. Williams. 2002. Selective mortality in Chinook salmon: what is the role of human disturbance? *Ecological Applications* 12:173-183.
- Zhou, S. 2002. Estimating parameters of derived random variables: comparison of the delta and parametric bootstrap method. *Transactions of the American Fisheries Society* 131: 667–675.
- Zar, J.H. 1984. *Biostatistical analysis*, 2nd Edition. Prentice-Hall, Englewood Cliffs NJ. 718 pp.

Glossary of Terms

BOA	Bonneville Dam adult fish ladder
BON	Bonneville Dam
BPA	Bonneville Power Administration
C_0	Refers to the group of in-river control PIT-tagged smolts, i.e., the PIT-tagged smolts that migrate through the hydrosystem without being bypassed at any of the Snake River collector dams. This group of fish is most representative of the untagged run of the river.
C_1	Refers to untransported PIT-tagged smolts which enter the detection/collection facility at one or more of the collector projects. Unlike untagged smolts, they are returned to the river so reach survival estimates are possible.
Capture history	The record of detections of PIT-tagged fish including date/sequence, location, and disposition.
CHH	Hatchery Chinook salmon
CHW	Wild Chinook salmon
CJS	Cormack-Jolly-Seber. The multiple mark-recapture survival estimation method that is employed using the PIT-tag detections from the array of detection sites in the Snake and Columbia Rivers.
CRITFC	Columbia River Inter-Tribal Fish Commission
CSS	Comparative Survival Study
CWT	Coded-Wire Tag
D	The estuary and ocean survival rate of Snake River transported fish relative to fish that migrate in-river through the FCRPS. It is a ratio of SARs similar to the TIR , except the starting point for juvenile outmigrating fish is below Bonneville Dam. This is an index of the post-Bonneville survival of transported and non-transported fish.
Delayed mortality	Delayed mortality is the component of mortality that takes place in the estuary and during early ocean residence that is related to earlier life stage anthropogenic impacts downstream migration. Delayed mortality is expressed after fish pass through the hydrosystem and therefore is presently
Detection history	The record of detections of PIT-tagged fish including date/sequence, location, and disposition.

Differential delayed mortality	<i>D</i> , the estuary and ocean survival rate of Snake River transported fish relative to fish that migrate in-river through the FCRPS. It is a ratio of SARs similar to the <i>TIR</i> , except the starting point for juvenile outmigrating fish is below Bonneville Dam.
Differential mortality	Difference in instantaneous mortality rates between Snake River populations and downriver populations of stream-type Chinook salmon that migrate through fewer dams. Measured as the difference in $\ln(\text{recruit}/\text{spawner})$ or $\ln(\text{SAR})$ between population groups.
Direct mortality	Mortality incurred within the hydrosystem.
FCRPS	Federal Columbia River Power System
FPC	Fish Passage Center
<i>FTT</i>	Fish Travel Time. The number of days a fish spends migrating through the reservoirs and past dams or through defined reaches.
GRA	Lower Granite Dam adult fish ladder
IDFG	Idaho Department of Fish and Game
IHR	Ice Harbor Dam
Instantaneous mortality rate	Denoted as ' <i>Z</i> ', the rate of exponential population decline.
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
JDA	John Day Dam
LGR	Lower Granite Dam
LGR equivalents	An estimate of the number of smolts at LGR for each of the three study categories (C_0 , C_1 , and T_0) that includes the fish that perish before reaching and passing Little Goose and Lower Monumental dams.
LGS	Little Goose Dam
LMN	Lower Monumental Dam
LSRCP	Lower Snake River Compensation Plan
MCA	McNary Dam adult fish ladder
MCN	McNary Dam
MPG	Major Population Group. A subgroup or stratum of populations within a salmon ESU or steelhead DPS distinguished from other populations by similar genetic and demographic characteristics.

NMFS	National Marine Fisheries Service
NOAA-Fisheries	National Oceanic and Atmospheric Administration, Fisheries
NPCC	Northwest Power and Conservation Council, present name of the Northwest Power Planning Council
NPPC	Northwest Power Planning Council, previous name of the Northwest Power and Conservation Council
ODFW	Oregon Department Fish and Wildlife
Overall SAR	The SAR that includes the survival of all outmigrating smolts weighted across their different in-river and transport route experiences; the SAR of an entire brood of smolts, irrespective of their route of passage through the hydrosystem.
Pathway probability	The probability an individual smolt faces at LGR of falling into a particular outmigration pathway. The pathways are: 1) transported at LGR; 2) transported at LGS; 3) transported at LMN; or 4) migrate in-river through the entire hydrosystem.
PIT-tag	Passive Integrated Transponder tag. Glass-encapsulated transponders, 11-12 mm in length with a unique identification code, which can be implanted into a fish's abdomen using a hand-held syringe. These tags are generally retained and function throughout the life of the fish. The tag's code can be read and recorded with an electronic scanner installed at a fixed site or hand held.
PTAGIS	PIT-tag Information System. Regional depository and clearing house for the Columbia Basin PIT-tag release and detection information.
<i>S</i>	Reach- or life-stage specific survival. Estimates can be made from hatchery of release to Lower Granite Dam, Lower Granite Dam to Little Goose Dam, Lower Granite Dam to Bonneville Dam, and so forth.
SAR	Smolt-to-Adult-Return rate. The survival rate of a population from a beginning point as smolts to an ending point as adults. SARs are calculated from LGR to LGR and can also be estimated at BON to BON or LGR, or below BON to BON. SARs for populations could be for wild only, hatchery-origin, or both combined. The populations can be defined as those being transported, being left in the river to migrate, or all smolts combined irregardless of their route of passage.
SMP	Smolt Monitoring Program
S_T	S_T is the assumed direct transportation survival rate (0.98)

	adjusted for in-river survival to the respective transportation sites for those fish transported from LGS or LMN.
S_T	S_T “dot” is the assumed direct transportation survival rate (0.98).
STH	Hatchery summer steelhead
STW	Wild summer steelhead
Survival Rate	Number of fish alive after a specific time interval or life stage, divided by the initial number.
T_0	Refers to LGR equivalent transported smolts. Fish in the transported from LGR, LGS, or LMN pathways form this category. The numbers of fish transported from LGS or LMN are expanded by the inverse of the in-river survival rates from LGR to the respective transport sites.
TIR	Transport/In-river, the ratio of SARs that relates survival of transported fish to in-river migrants. The ratio is the SAR of fish transported from LGR to BON and returning as adults, divided by the SAR of fish outmigrating from LGR to BON and returning to LGR as adults.
TWX	Trawling operation by NMFS in the lower Columbia River in the vicinity of Jones Beach that detects PIT-tagged fish.
USACE	U.S. Army Corp of Engineers
USFWS	U.S. Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife
WTT	Water Travel Time. Water velocity in the mainstem migratory corridor is generally expressed as the average time (in days) it takes for a water particle to travel through a river reach (water travel time) during a specified period.
Z	The total instantaneous mortality rate (rate of exponential population decline) of a population cohort. Mathematically, Z is the negative natural logarithm of survival divided by median fish travel time.

Appendix A

Logistical Methods

Introduction

The chronology of the logistical development for conducting the CSS is presented in Table A-1. This progression is organized by CSS Annual Report and shows the sources of PIT-tagged fish available to the CSS across the years, changes in the proportions of PIT-tagged smolts being routed to transportation, and changes to the capabilities to detect returning PIT-tagged adults as more dams were fitted with adult PIT-tag monitors in their fish ladders.

Sources of Study Fish

Fish utilized in the CSS are marked with a unique-coded passive integrated transponder (PIT) tag, which was evaluated for use on salmonids by NOAA (Prentice *et al.* 1986). The computer chips are encapsulated in glass with a 12-mm length and 0.05-mm width. PIT-tags are cylindrical in shape and impermeable to water. Individual PIT-tags are implanted into the fish's underbelly using a hand-held syringe with a 12-gauge veterinary needle (PTOC 1999 PIT-Tag Marking Procedures Manual). Tag loss and mortality of PIT-tagged fish are monitored, and the tagging files are transferred to Pacific State Marine Fisheries Commission's regional PTAGIS database in Portland, OR.

In each year of the CSS, there have been yearling spring/summer Chinook specifically PIT-tagged at key hatcheries for this program. In the Snake River, the hatcheries were selected from each of the four tributary drainages (Clearwater, Salmon, Imnaha, and Grande Ronde rivers) above Lower Granite Dam. Both spring and summer stocks were included. Hatchery programs were selected which accounted for a major portion of the Chinook production in their respective drainage in order to have sufficient numbers of smolts and returning adults for computing statistically rigorous smolt-to-adult survival rates. Since study inception, hatchery fish consistently used in the CSS include Chinook tagged at McCall, Rapid River, Dworshak, and Lookingglass hatcheries. Chinook tagged at Lookingglass Hatchery included the Imnaha River stock that continues to be released at the Imnaha River weir and the Rapid River stock that was released on-site through 1999 and discontinued thereafter in favor of Grande Ronde River basin endemic stocks. Throughout this report, we classify the Imnaha River Chinook as a summer stock (contrary to ODFW classification) due to its high return rate of jacks and later timing of its returning adults, which coincides with the summer stock from McCall Hatchery stock.

In the lower Columbia River, the CSS has PIT-tagged Chinook at Carson Hatchery since 1997 for the upstream/downstream comparisons. There was the attempt to include two additional hatchery stocks for the lower Columbia River when the CSS was initiated. Cowlitz Hatchery spring Chinook were tagged for two years, but dropped due to the biological characteristics of this stock being more ocean type than stream type. Round Butte Hatchery spring Chinook were tagged for three years, but dropped due to high BKD levels occurring during the tagging period, which for logistical constraints had to take place at or near the time fish were leaving the facility.

Table A-1. Progression of study design logistics changes through the series of annual reports prepared by the CSS in 2000 to 2006.

CSS Document	PIT-tagging and fish disposition for CSS	Source Fish	Adult Detections
<p>Annual Report 2000 Published Oct. 2000 DOE/BP-00006203-1</p> <p>Report covers 1996-1998 sp/su hatchery Chinook (HC) mark/recapture activities (adult returns to 2000)</p>	<p>Tagging was proportional to hatchery production levels in 1996 and 1997, but changed to a fixed tagging quota per hatchery in 1998 in order to allow a more similar release across hatcheries with widely differing production levels.</p> <p>In 1996, fish were tagged only for in-river migration data. Starting 1997, fish are tagged for both transportation and in-river migration data.</p> <p>In 1997, separation-by-code (SbyC) routed 80% of CSS PIT-tag HC detected at LGR to raceways (transportation); min goal of 43K transported and 64.5 K in-river tags (total of all CSS hatcheries) was missed for transport fish. So in 1998, SbyC routed 75% of CSS PIT-tag HC at LGR (all season) and first-time detected at LGS (thru May 9) to raceways (transportation); min targets were reached.</p>	<p><u>1996 - Upriver HC</u> Dworshak, Kooskia, Clearwater (Powell, Crooked R, Red R AP), McCall, Rapid R., and Lookingglass (onsite and Imnaha AP)</p> <p><u>1996 - Downriver HC</u> Cowlitz & Round Butte</p> <p><u>1997 - Upriver HC</u> Replace Clearwater H with Sawtooth H (release at Pahsimeroi) Others the same</p> <p><u>1997 - Downriver HC</u> Add Carson NFH</p> <p><u>1998 - Upriver HC</u> Drop Kooskia & Pahsimeroi H Others unchanged.</p> <p><u>1998 - Downriver HC</u> Drop Cowlitz H</p>	<p><u>Upriver HC</u> Detections at LGR adult trap for all PIT-tagged Fish</p> <p><u>Upriver return to hatchery</u> 1. McCall H returns to SF Salmon Weir 2. Lookingglass H Imnaha stock returns to Imnaha Weir 3. Lookingglass H (on-site released fish) were 100% CWT and collected at LGR adult trap and trucked to hatchery. 4. Rapid River H returns to adult trapping facility 5. Dworshak H returns to hatchery fish ladder 6. Kooskia H returns to facility</p> <p><u>Downriver HC</u> Only detection available is at hatchery facility for Carson, Round Butte, and Cowlitz H returns</p>
<p>Annual Report 2001 Published Feb. 2002 DOE/BP-00006203-2</p> <p>Report covers 1997-2000 sp/su HC mark/recapture activities with SARs thru 1999 (adult returns to 2001)</p> <p>This report adds 1994 to 1999 wild Chinook (WC) with adult returns to 2001.</p>	<p>In 1999, SbyC routed 67% of CSS PIT-tag HC at LGR (all season) and first-time detected at LGS (beginning May 10) to raceways (transportation); min targets were reached.</p> <p>Following analysis of data from the early years of the CSS, it was determined that routing the same proportion (67%) of first-time detected PIT-tagged fish to transport at each collector dam will be the preferred approach in future years (see discussion in Appendix B); this preferred approach was implement starting in 2000 for HC.</p>	<p><u>1999 – Upriver HC</u> Dworshak, McCall, Rapid R., and Lookingglass (onsite and Imnaha stock releases)</p> <p><u>1999 - Downriver HC</u> Carson NFH (drop Round Butte)</p> <p><u>1994 to 1999 – Upriver WC</u> Annual aggregate PIT-tag groups are created using all available tagged wild sp/su Chinook released above LGR for each year’s outmigration.</p> <p>Limited to timing, reach survivals, smolt #s – no SARs:</p> <p><u>2000 – Upriver HC</u> Lookingglass(on-site) stopped</p> <p><u>2000 - Downriver HC</u> Carson NFH</p>	<p><u>Upriver HC</u> Detections at LGR adult trap for all PIT-tagged Fish The CSS adults had lengths taken, sex and injury noted, and scales obtained.</p> <p><u>Upriver WC</u> Detections at LGR adult trap, but not sampled for additional data</p> <p><u>Upriver return to hatchery</u> (data collected for hatcheries listed above, but not presented in report)</p> <p><u>Downriver HC</u> (release information presented only)</p>

CSS Document	PIT-tagging and fish disposition for CSS	Source Fish	Adult Detections
<p>Annual Report 2002 Published Nov. 2003^A DOE/BP-00006203-4</p> <p>Report covers 1997-2000 sp/su HC & 1994-2000 sp/su WC (adult returns to 2002)</p>	<p>(Same as described above for migration years 1997 to 2000)</p> <p>Conditioned WC aggregate PIT-tag population on fish released between July 25 of year preceding outmigration and May 20 of year of migration in order to nearly eliminate tagged fish that outmigrate in a year later than migration year of interest.</p> <p>These tagged fish followed the default return-to-river routing except during SMP timed samples or unplanned operational events.</p>	<p>Report produces SARs for:</p> <p><u>1997 to 2000 – Upriver HC</u> Dworshak, McCall, Rapid R., and Lookingglass (onsite to 1999 and Imnaha stock releases)</p> <p><u>1994 to 2000 – Upriver WC</u> Annual aggregate PIT-tag groups are created using all available tagged wild sp/su Chinook released above LGR for each year’s outmigration.</p> <p><u>1997 to 2000 - Downriver HC</u> Carson NFH</p>	<p><u>Upriver HC</u> (unchanged)</p> <p><u>Upriver WC</u> (unchanged)</p> <p><u>Upriver return to hatchery</u> First report to present SARs (hatchery-to-hatchery) for 1997-2000 releases from hatcheries listed at left.</p> <p><u>Downriver HC</u> First report to present SARs (hatchery-to-hatchery) for 1997-2000 releases from Carson NFH</p>
<p>Annual Report 2003/04 Published Apr. 2005^B DOE/BP-00006203-5</p> <p>Report covers 1997-2002 sp/su HC & 1994-2002 sp/su WC (adult returns to 2004)</p>	<p>In drought year 2001, in-river migrants in C₁ are used to estimate annual SAR, <i>TIR</i>, and <i>D</i> due to negligible C₀ fish present since no spill at Snake River collector dams.</p> <p>In 2002, due to non-standard operations planned at LMN, the CSS did not directly route PIT-tagged fish to transport at that site.</p> <p>Beginning 2002, coordination with state and tribal tagging programs allowed 50% of their first-time detected PIT-tagged wild Chinook smolts to be routed to transport.</p>	<p><u>2001 to 2002– Upriver HC</u> Add Catherine Ck AP starting 2001 to replace the discontinued on-site release from Lookingglass H; others same as above.</p> <p><u>2001 to 2002 – Upriver WC</u> (unchanged)</p> <p><u>2001 to 2002 – Downriver HC</u> Carson NFH</p> <p><u>2000 to 2002 – Downriver WC</u> Add PIT-tagged John Day River wild Chinook starting 2000</p>	<p><u>Upriver HC and WC</u> (unchanged)</p> <p><u>Upriver return to hatchery</u> New adult detection site is the adult trapping facility on Catherine Ck. SARs from hatchery-to-hatchery presented for 1997-2001 for other hatcheries.</p> <p><u>Downriver HC and WC</u> Addition of detections from the new BON adult ladder PIT-tag detectors.</p>
<p>Annual Report 2005 Published Dec. 2005 DOE/BP-00025634-1</p> <p>Report covers sp/su HC and WC thru 2003 (adult returns to 2005)</p> <p>Report adds 1997-2002 wild steelhead (WS) & hatchery steelhead (HS) (adult returns to 2004)</p>	<p>Beginning with this annual report, existing PIT-tagged wild and hatchery steelhead are analyzed in two aggregate populations based on rearing type. These PIT-tagged fish followed the default return-to-river routing except during SMP timed samples or unplanned operational events.</p>	<p><u>2003 – Upriver HC and WC</u> (unchanged)</p> <p><u>1997 to 2002 – Upriver HS, HW</u> Annual aggregate PIT-tag group of wild steelhead (>130mm) tagged July 1 of prior year thru June 30 of migration year, plus another for hatchery steelhead, is created with all available tagged steelhead released above LGR.</p> <p><u>2003 – Downriver HC and WC</u> (unchanged)</p>	<p><u>Upriver HC, WC, HS, WS</u> Detection of PIT-tagged returning adults is possible at MCN and Ice Harbor beginning return years 2003 and 2004, respectively.</p> <p><u>Upriver return to hatchery</u> SARs (hatchery-to-hatchery) for 1997-2002</p> <p><u>Downriver HC and WC</u> (unchanged)</p>

CSS Document	PIT-tagging and fish disposition for CSS	Source Fish	Adult Detections
Annual Report 2006 ^C Published Nov. 2006 DOE/BP-00025634-2 Report covers sp/su HC and WC thru 2004 (adult returns to 2006) Report covers HS and WS thru 2003 (adult returns to 2005)	Beginning 2003, coordination with state and tribal tagging programs allowed 50% of their first-time detected PIT-tagged wild steelhead smolts to be routed to transport at Snake R. collector dams. This matches the routing rate for PIT-tagged wild Chinook, while that of PIT-tagged hatchery Chinook remains at 67% at these collector dams.	<u>2004 – Upriver HC and WC</u> (unchanged) <u>2003 – Upriver HS and WS</u> (unchanged) <u>2004 – Downriver HC and WC</u> (unchanged)	<u>Upriver HC, WC, HS, WS</u> (unchanged) <u>Upriver return to hatchery</u> (Not analyzed in report) <u>Downriver HC and WC</u> (unchanged)
Items pertinent to future CSS annual reports covering migration years 2005 to 2007 for HC/WC and 2004 to 2007 for HS/WS	1. In 2005, the rate of routing first-time detected PIT-tagged wild and hatchery steelhead and wild Chinook to transport is raised to 67% (matching that of hatchery Chinook) at the Snake R. collector dams. In this year, the routing rate for wild steelhead is also raised to 67%. 2. In 2006, the CSS adopted the NPT approach of pre-assigning a portion of the tagged fish to reflect the experience of untagged fish (which typically is transportation if collected at one of the Snake River transport site) and the remaining portion to the default return-to-river routing if collected at a Snake River dam. PIT-tagged fish in these pre-assigned groups are from state and tribal tagging activities that are cooperatively participating with the CSS.		

^A BPA cover page to CSS Report erroneously shows April 2005 as publish date instead of November 2003.

^B BPA cover page to CSS Report erroneously shows November 2003 as publish date instead of April 2005.

^C BPA cover page to CSS Report erroneously shows 2005-2006 for Annual Report # instead of just 2006.

With the exception of the additional PIT-tags provided by the CSS for use on wild Chinook tagging at Smolt Monitoring Program traps and numerous traps operated by IDFG in upper tributaries of the Clearwater and Salmon rivers, most PIT-tagged wild Chinook were obtained from all available marking efforts in the Snake River basin above Lower Granite Dam. The wild stocks included Chinook PIT-tagged as parr (late July-August) in Idaho streams, pre-smolts (September-December) in Idaho and Oregon streams, and smolts (March-May) in Idaho and Oregon streams. These wild and hatchery steelhead used in the CSS are also from other existing tagging efforts in Idaho and Oregon streams. Since 2003 an additional 2,000 PIT-tags has been budgeted specifically for CSS tagging purposes at the IDFG trap located near the mouth of the Clearwater River.

Although the individual hatchery populations are analyzed separately, this is not the case for the wild Chinook, wild steelhead, and hatchery steelhead tag groups. Aggregate of available PIT-tags for these two species by rearing type are created to obtain larger tagged populations for determinations of SARs. Ideally, the PIT-tagged wild steelhead, hatchery steelhead, and wild Chinook used to create these aggregate marked populations should be as representative of the untagged population as possible. For wild fish, the collection and tagging occurs over lengthy time periods from parr stages to smolt stages in each sub-basin located above Lower Granite Dam including the Clearwater, Grande Ronde, Salmon, and Imnaha rivers. These wild fish were PIT-tagged by various organizations over a 10 to 12-month period with varied sampling gear including incline-plane (scoop) traps, screw traps, electrofishing, hook and line, and beach seining. At the hatcheries, fish were obtained across as wide a set of ponds and raceways as

possible to allow effective representation of production. Most hatchery steelhead releases have a small number of PIT-tagged fish, typically between 200 and 1000 fish per individual hatchery. The aggregate of these PIT-tag releases provided a fairly good cross-section of the hatchery production in each year, although it was not proportional to the magnitude of each hatchery production. Likewise, the number of wild fish PIT-tagged in each tributary is not expected to be proportional to the total population present; however, with PIT-tagging occurring across a wide range of the total population, the resulting SARs of this aggregate PIT-tag population should be adequately reflective of the total population.

The PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead used in the CSS were initially PIT-tagged to satisfy the goals of several different research studies. At certain times of the year, multiple age classes of fish were being PIT-tagged. To ensure that smolts in our annual aggregate groups were actually migrating out in the respective year of interest, fish detected entirely outside the migratory year of interest were excluded. This was necessary since estimates of collection efficiency and survival must reflect a single year. For wild Chinook, we found that limiting the tagging season to a 10-month period from July 25 to May 20 each year reduced the instances of overlapping age classes. In this 10-month period, few additional fish were excluded due to being detected at the dams or trawl in a year outside the migration year; this was less than 0.1% in all years except 1994 when it was 0.18%. For wild steelhead, we found that size at tagging was a useful parameter for removing a high proportion of fish that reside an extra year or two in freshwater beyond the desired migration year of study (Berggren et al. 2005). Excluding wild steelhead below 130 mm and above 299 mm reduced the instances of multiple age classes and allowed the tagging season to be a full 12-months from July 1 to June 30 each year.

Detection of study fish

PIT-tagged smolts were detected at six Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA), and Bonneville (BON). In addition, PIT-tag detections were obtained at the NOAA Fisheries trawl (TWX) operated in the lower Columbia River half-way between BON and the mouth of the Columbia River.

When PIT-tagged smolts enter the bypass/collection facility of a dam from which transportation occurs, there are four potential outcomes. The tagged fish may (1) be returned-to-river under the default routing option, (2) be routed to the raceways for transportation if requested by the researcher, (3) be routed to the sample room for anesthetization and handling prior to being routed to transportation, and (4) be seen only on the separator detector coils and therefore have an unknown disposition at that site. For PIT-tagged wild steelhead, hatchery steelhead, and wild Chinook originating above LGR, the number of tagged fish specifically routed to transportation has been very small in most prior years prior to 2002 (wild Chinook) and 2003 (wild steelhead and some hatchery steelhead releases). Since the default operation has been to return PIT-tagged fish to the river at collector dams, the only reason some PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead were transported in the early years was because (1) the daily timed subsampling intervals of the Smolt Monitoring Program over-rides the default return-to-river operation for PIT-tagged fish (sampled fish are usually transported) and (2) the occurrence of periods when equipment malfunctions caused the collected PIT-tagged fish to go to the raceways. Based on the detection history of PIT-tagged smolts at the collector

dams, we are able to determine into which CSS study category (defined below) to assign these PIT-tagged fish.

PIT-tagged returning adults were detected in the Lower Granite Dam adult fish ladder (GRA) in each year. The adult fish passage facilities at LGR incorporate an adult fish trap located just off the main fish ladder. When trapping occurs, adult fish are diverted from the main fish ladder into a pool area where two false weirs, a metal flume, coded wire detectors, and PIT detectors are in line leading to the adult holding trap. Unmarked fish or fish not required to be diverted will drop back into the fish ladder, and continue up to the main fish ladder where they can exit to the forebay of the dam. In return years through 2001, the tag identification files for CSS PIT-tagged Chinook were installed in the separation-by-code program that allows the PIT-tag detector to selectively trip a gate and shunt these fish to the holding trap. This was done in order to obtain data on fish length, sex, condition (injury), and age (scale sample). Beginning in return year 2002, these data were no longer collected at LGR. Fish length, sex, and condition data will be obtained from the hatcheries. Thereafter, returning adults reaching LGR have continued upstream without any handling at that site. Adults detected at LGR are assigned to a particular study category based on the study category they belonged to as a smolt and fish with no previous detections at any dam are automatically assigned to the category of fish passing the three Snake River collector dams undetected.

Beginning in return year 2002, detectors were installed in all the adult fish ladders at Bonneville (BOA) and McNary (MCA) dams, allowing detection of returning PIT-tagged adults at these additional locations. The addition of PIT-tag detection capabilities at BOA was imperative to the upstream/downstream comparisons of the CSS. In 2003, Ice Harbor Dam (IHA to 4/1/2005 and ICH thereafter) was fitted with a PIT-tag detection system in its fish ladder. Lower Granite Dam has PIT-tag detection coils located near the adult trapping facility and at the exit section of the adult fish ladder. As noted last year, the LGR adult PIT-tag detection efficiency is $\geq 98\%$ (Berggren *et al.* 2005), so no adjustments to the number of detected adult PIT-tagged fish at LGR are necessary.

All SARs for wild and hatchery Chinook are computed with only returning adults, age 2-salt and older. In the total return, the average percent returning as jacks is higher for summer Chinook stocks than it is for the spring Chinook stocks. This highly variable jack return rate among races in hatchery Chinook and the extremely low proportion of jacks observed within the wild Chinook returns is one reason that SARs computed in the CSS report do not include jacks. All SARs for wild and hatchery steelhead are computed with returning age 1-salt and older adults. Mini's for either species returning in the same year of they outmigrated are not used in any computations.

Defining study groups and study area for SARs

A major objective of the CSS was to compute and compare overall smolt-to-adult survival rates for smolts transported through the hydro system versus smolts migrating in-river. Since 1995, the standard hydro system operation was to transport all smolts collected at LGR, LGS, and LMN throughout the spring and summer seasons, and at MCN only when the subyearling Chinook migration predominates the collections in the summer. An exception to this rule occurred in 1997 when large portions of the collections at LGS and LMN were returned to the river in a fishery agencies/tribal effort to equalize the numbers of smolts being transported and remaining in-river that year. The last year of springtime transportation at MCN occurred in

1994. Although all collected smolts were transported in 1994, there were only 42 PIT-tagged wild Chinook with first detection at MCN that were transported. With so few PIT-tagged smolts and no adult PIT-tag detections, it was not possible to estimate a SAR for yearling Chinook transported from MCN in 1994. Since then there have been too few late-migrating PIT-tagged wild yearling Chinook smolts collected and transported as first-time detections from MCN to assess SARs from there. Therefore, all CSS status reports include the transported smolts from the three Snake River collector dams.

In order to make valid comparisons between groups of smolts with different hydrosystem experiences, we must have common starting and end points for each study group. The most common life stage of study in the CSS has been from LGR as smolts and back to LGR as adults for transportation evaluations and from first-dam detected (LGR for the Snake River stocks, JDA or BON for downstream stocks) as smolts to BON as adults for the upstream/downstream comparisons. Since fish are being transported from three different dams, there is mortality in migrating in-river from LGR to the lower transportation facilities that must be taken into account. It takes a larger count of smolts starting at LGR to provide the final number being transported from LGS or LMN. This is the concept behind the term smolts “destined” for transport. Therefore, an estimated survival rate is needed to convert the actual transport numbers at LGS and LMN into what their LGR starting number would have been (*i.e.*, LGR equivalents). We define transportation at LGR, LGS, and LMN in terms of LGR equivalents, because we are in effect making our allocation into transportation at each dam from the starting number of fish at LGR. Ryding (2006) documented in an actuarial approach the necessity of accounting for the losses between dams for both the transported and in-river migrating smolts when computing SAR and ratios of SAR.

Although transportation occurs at three dams in the Snake River, the CSS did not purposely divert CSS tagged hatchery Chinook smolts into transportation at each dam until 2000. In 2000, the CSS established the protocol of routing the same proportion of the collection of first-time detected smolts at each of the three Snake River collector dams. Whereas in 1997 to 1999, the goal was to attain a fixed quota of smolts transported per hatchery group, with priority of meeting that quota with transportation from LGR first, followed by adding LGS and LMN if more fish were required. With this approach, nearly all CSS transported hatchery Chinook in the transportation group were from LGR, while in 1998 and 1999 there were sizeable numbers of smolts from LGS in the transportation study group. At LGS the CSS PIT-tagged hatchery Chinook were routed to transport for part of the seasons of 1998 and 1999 (routing PIT-tagged fish to transportation ended on May 9 in 1998 and commenced on May 10 in 1999). But this did not occur at LMN until 2000.

It was decided not to route CSS PIT-tagged hatchery Chinook to transportation at LMN in 2002 because of the non-standard operations implemented there to reduce the numbers of fish collected and transported in the absence of spill at that site. This change in project operations from other years was due to repairs being made to the stilling basin below the project. Those repairs required the curtailment of spill at LMN for the season, except for several days around May 22 when spill in excess of hydraulic capacity occurred due to a unit outage (FPC 2002 Annual Report). Spill was increased at LGR and LGS to offset the no spill operations at LMN. With larger than usual numbers of migrating salmonids expected to be collected at LMN under this no spill operation, the facility operations were modified to 2 days collection and transportation followed by a day of direct bypass (no PIT-tag detections possible) for every 3-day interval between April 30 and mid-June when subyearling Chinook began to predominate.

In addition, direct bypass occurred during most of April. All PIT-tagged fish passing the dam through the primary bypass would be undetected and would inappropriately be included in the study category on non-bypassed fish. The remaining undetected PIT-tagged fish would have passed through the turbines in the absence of spill. Under this operation, it was not possible to accurately separate bypassed and non-bypassed tagged fish at LMN during most of the 2002 migration season. Even with this change in operation, LMN still transported a higher number of fish than occurred at either LGR or LGS in 2002.

The numbers of PIT-tagged wild Chinook actually transported in migration years prior to 2002 has been relatively small due to the fact that the standard protocol in those years was to bypass PIT-tagged smolts back to the river. In these years, PIT-tagged wild Chinook, wild steelhead, and hatchery steelhead were only incidentally routed to transportation during the daily timed subsampling intervals (typically 2-6 subsamples per hour of varying duration for 24-hrs) of the Smolt Monitoring Program or when equipment malfunctions caused all collected PIT-tagged fish to be routed to the raceways. All fish collected in the sample room were subject to anesthetization and hands-on processing before being transported, whereas fish routed directly to the raceways or barges did not have this added handling affect. Beginning in 2002, the CSS coordinated with state and tribal research programs (IDFG, ODFW, and CTRUIR) to purposely route 50% of the first-time detected PIT-tagged wild Chinook smolts at Snake River transportation facilities to the raceways for transportation. This proportion was increased to 67% in 2003, and in that year the routing of PIT-tagged wild steelhead to transportation was added. This action has provided more PIT-tagged wild Chinook and wild steelhead smolts in the transportation category in recent years.

Since the PIT-tagged study groups should be representative of their non-tagged counterparts, PIT-tagged fish passing through the hydro system should mimic the experience of non-tagged fish. In the years 1997 to 2005, the CSS used separation-by-code (SbyC) capabilities at the collector dam to route a fixed ratio (1:2 or 2:3) of the collected (and detected) PIT-tagged study fish to the raceways for transportation. Since untagged smolts are nearly always transported when they enter a bypass/collector facility at the Snake River dam, it was desirable to include only the first-time detected smolts at these dams when determining numbers of PIT-tagged smolts transported. Most smolts with prior detection that are again detected downstream at another collector dam had simply followed the default return-to-river routing established for PIT-tagged fish at the upriver dam, and were not representative of the experience of the untagged fish. However, there are special instances, such as when raceways are full and no barge is available for transport, when both the untagged and PIT-tagged fish held in the raceways of an upriver dam will be returned to the river and could downriver be collected and transported from another dam. In this special case, the constraint of having to be a first-time detected PIT-tagged fish does not mimic the untagged fish affected. For this and other reasons to cover later, the CSS adopted the approach pioneered by the Nez Perce Tribe (NPT) in which one pre-assigns a proportion of their tags to a PIT-tag group that directly reflects the experience of the untagged fish. The SbyC operations at the collector dams is set so that this group of tags is routed exactly the same as the untagged fish. The remaining proportion of the tags is then pre-assigned to a PIT-tag group that will follow the default return-to-river routing at the collector dams. This second group is used in the estimation of the reach survival rates to and through the hydrosystem. In the 2006 review of the CSS by the ISAB, a recommendation for the CSS to adopt the NPT approach was made. It was successfully initiated in time for migration year 2006.

Holdovers within the hydrosystem below Lower Granite Dam

In the estimation of in-river survival rates with the Cormack(1964) – Jolly (1965) – Seber (1965) method (hereafter termed CJS), it is assumed that all PIT-tagged smolts in a group are outmigrating together in a single migration year. Any PIT-tagged fish detected as a smolt only in a year later than the expected migration year was excluded from the release group. This exclusionary clause was necessary particularly for wild Chinook and wild steelhead, because at times when multiple age classes were being PIT-tagged, our constraints of size on steelhead and tagging dates on Chinook were not enough to remove non-migratory fish for the year of interest. However, PIT-tagged fish detected at an upper dam and then holding over within the hydrosystem with subsequent detections occurring the following year, were handled as follows. The capture history code for these fish showed detections at dams only during the year they initiated their outmigration. The detections in the following year were excluded during the estimation of CJS reach survivals and project collection efficiencies. Fortunately, few yearling Chinook and steelhead delayed in the hydrosystem until the following year except for steelhead that began their migration in 2001 (Berggren et al. 2005). No additional holdovers were observed for migration years 2003 (steelhead) and 2004 (Chinook).

Special handling of the 2001 in-river migrants

Obtaining a valid estimate of the number of PIT-tagged wild and hatchery steelhead passing the three Snake River collector dams undetected in 2001 is problematic due to apparent large amount of residualism that year. This is based on the finding that most in-river migrants that returned as an adult were hold-overs. Six of the eight adult returns of PIT-tagged wild steelhead and one of three adult returns of PIT-tagged hatchery steelhead that were bypassed as a smolt at a collector dam in 2001 were actually detected in the lower river in 2002. For the three PIT-tagged wild steelhead adult returns and two PIT-tagged hatchery steelhead adults returns that had no detection anywhere in 2001, it was more likely these fish either completed their smolt migration undetected in 2002 or passed undetected into the raceways during a computer outage in mid-May at LGR than traversed the entire hydrosystem undetected in 2001. Based on estimated collection efficiencies at the Snake River collector dams with no spill in 2001, less than one percent of the wild and hatchery steelhead tagged and untagged run-at-large was estimated to pass all three Snake River collector dams through turbines. Because of the uncertainty in passage route and timing of the undetected PIT-tagged wild and hatchery steelhead smolts in 2001, the in-river SAR for comparisons with transported smolts utilized PIT-tagged smolts that had some detections (bypassed) at the collector dams. In other years, the PIT-tagged smolts undetected at the collector dams (reflective of the untagged run-at-large) formed the in-river group for comparisons with transported smolts.

Although wild and hatchery Chinook were not as affected by residualism in 2001 as their steelhead counterparts, they too had a very small proportion (1.1% for wild Chinook and 2.2-3.6% for hatchery Chinook) of smolts estimated to potentially migrate through turbines at all three consecutive Snake River collector dams in 2001. There were PIT-tagged Chinook adult returns (one wild Chinook and six hatchery Chinook from three of the five CSS hatcheries) from PIT-tagged smolts undetected anywhere (typically about half of the fish undetected at the three collector dams would still have some detections downstream at MCN, JDA, BON, or TWX). It is very unlikely that these seven adults were from smolts that actually outmigrated in-river in

2001. It is more likely that because of the large numbers of PIT-tagged fish passing through the PIT-tag detectors during the peak of the run some of these were undetected at LGR and thereby passed to the raceways along with the untagged fish. There was a short period (18 minutes) on May 21 when a computer malfunction at Lower Granite Dam may have resulted in all PIT-tagged fish passing directly to the raceways undetected (PTAGIS site log for GRJ). This added uncertainty as to how fish with no detections at any site actually passed through the hydrosystem. Therefore, just as we did with steelhead, the PIT-tagged wild and hatchery Chinook smolts that had detections (bypassed) at the collector dams in 2001 were used in the comparisons with transported smolts that year.

Appendix B

Analytical Methods: Statistical Framework and Equations of Study Parameters

Statistical Framework Introduction

The parameters generated in the CSS fall into three key areas of interest for fishery managers. These are the annual smolt-to-adult survival rates (SAR) for key salmonid populations, comparisons of SARs relative to how fish experienced passage through the hydrosystem, and assessment of delayed differential survival between the fish with different hydrosystem passage experiences. In order to compute estimates for these parameters, we must have valid estimates of in-river smolt survival rates through reaches of the hydrosystem with corresponding collection probabilities at the dams bordering these reaches. The Cormack-Jolly-Seber (CJS) method is used to estimate these reach survival and collection probabilities. This appendix will present a description of how the estimates of the various study parameters of the CSS are computed and the underlying assumptions inherent in these estimations. It covers the formulas used to estimate the parameters of reach survivals, numbers of smolts in study categories T_0 , C_0 , and C_1 , $SAR(C_0)$, $SAR(C_1)$, $SAR_1(T_0)$, $SAR_2(T_0)$, T/C and U/D ratios, and D , plus the annual SARs. Both the computation formulas and their expectations are presented for each parameter listed above. These are the basic parameters generated in the CSS. The chronology of the development of these formulas across the series of CSS annual reports and technical documents prepared through 2006 is presented in Appendix B Table-1.

Additional statistical methods used in hypothesis testing, regression analyses, and removal of stochastic error from process error will be covered directly in the chapters where these methods are being used.

Estimation of survival rates and collection probabilities

In Ryding (2006) a list and discussion of twelve assumptions that are key to tag-recapture methods of survival rate estimation and the use of T/C ratios. Eight of the twelve assumptions are directly related to the tag release-recapture methodology for reach survival estimation (assumption number corresponds to Ryding document listing):

- #1 – Tagged fish in the study are representative of the population.
- #2 – All fish in a release group have equal detection and survival probabilities.
- #3 – All fish in a release group have equal probabilities of a particular capture history.
- #4 – Fates of individual fish are independent.
- #5 – Previous detections have no influence on subsequent survival or detection probabilities.
- #6 – Release numbers, capture histories, and PIT-tag codes are accurately recorded and known.
- #8 – Tagged fish removed [for any purpose, including transportation or for use in other studies] are known and accurately recorded.

- #9 – All tagged fish in a cohort release migrate through the Snake and Columbia Rivers within the same season and while the bypass facility and transport systems are operational, *i.e.*, there is no delayed migration of tagged fish.

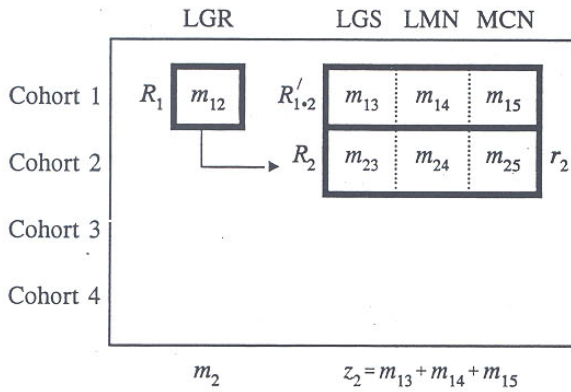
In the simulation chapter of this report, we investigated the impact that violations of Assumption #2 may have on the resulting reach survival rates and other study parameter estimates. Assumption #3 should be met whenever assumptions #2, #6, and #8 are satisfactorily satisfied. In Appendix A, we discuss how holdover fish were handled in order to minimize effect of violation of assumption #9. Plus we discussed the inability to estimate a valid C_0 study group for 2001 due to likelihood that some non-detected fish may have been transported that year, thus violating assumption #8. Assumption #1 is necessary to infer beyond the subsample of the population being tagged to the entire population. Although easier to accomplish with the hatchery Chinook tagging effort, it is felt that the cross-section of wild Chinook and steelhead, and hatchery steelhead populations included in tagging efforts will adequately reflect the overall population at the species/rear type level of resolution.

When the above assumptions #1 to #9 are satisfactorily met, then the theory of tag release/recapture models allows estimation of valid in-river reach survival rates and collection probabilities, which are necessary for expanding estimated PIT-tagged smolt numbers to LGR-equivalents, as noted in the Appendix A, and in the component of in-river survival rate through the hydrosystem, which is used in estimating delay differential mortality between transported and in-river study groups.

PIT-tagged smolts can be detected in the bypass/collection facilities at Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA) and Bonneville (BON) dams, and in trawls equipped with PIT-tag detectors deployed near Jones Beach (TWX). This array of detection sites is analogous to multiple recaptures of tagged individuals allowing for standard multiple mark-recapture survival estimates over several reaches of the hydro system. The Cormack-Jolly-Seber (CJS) (Cormack 1964; Jolly 1965; and Seber 1965) methodology was used to obtain point estimates of survival with corresponding standard errors from release to Lower Granite Dam tailrace and up to five reaches between Lower Granite Dam tailrace and Bonneville Dam tailrace.

The CJS methodology for estimation of in-river reach survival rates and collection efficiency at monitored dams uses the reduced M-matrix (Burnham et al. 1987) as partially illustrated in Figure B-1 (shown to MCN, but same logic continues for remaining downstream detection sites). The first row of the reduce M-matrix gives the number of first-time detected fish from the initial release at LGR (m_{12}), LGS (m_{13}), LMN (m_{14}), MCN (m_{15}), JDA (m_{16}), BON (m_{17}), and TWX (m_{18}). The additional rows of the reduced M-matrix show new cohorts created by re-releasing a portion of collected fish back to river at each successive downstream dam. The notation m_{jk} represents the number of first-time detected fish at downstream dams from each new cohort's re-released fish, where the j^{th} subscript is the cohort number and the k^{th} subscript is the site (the value 1 is reserved for release site, while values 2 to 8 designate each subsequent downstream detection location). Cohort 1 is the initial release and provides the tallies by site of all possible capture histories first-detected at that site; the sum across these tallies

Survival from Primary Release to Lower Granite Tailrace

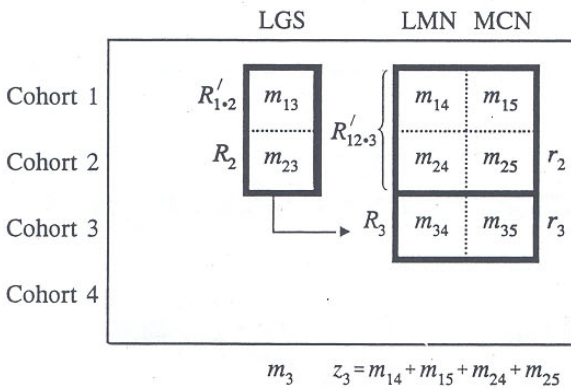


$$\phi_1 = \frac{m_2 + R'_{1\cdot 2}}{R_1}$$

where $R'_{1\cdot 2} = z_2 \frac{R_2}{r_2}$, since $\frac{z_2}{R'_{1\cdot 2}} = \frac{r_2}{R_2}$

$$\therefore \phi_1 = \frac{m_2 + z_2 \frac{R_2}{r_2}}{R_1}$$

Survival from Lower Granite Tailrace to Little Goose Tailrace

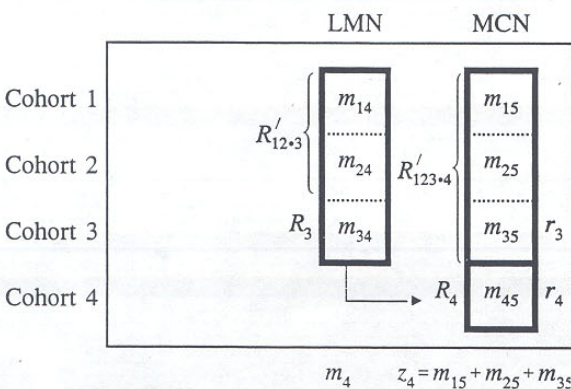


$$\phi_2 = \frac{m_3 + R'_{12\cdot 3}}{R_2 + R'_{1\cdot 2}}$$

where $R'_{12\cdot 3} = z_3 \frac{R_3}{r_3}$, since $\frac{z_3}{R'_{12\cdot 3}} = \frac{r_3}{R_3}$

$$\therefore \phi_2 = \frac{m_3 + z_3 \frac{R_3}{r_3}}{R_2 + z_2 \frac{R_2}{r_2}}$$

Survival from Little Goose Tailrace to Lower Monumental Tailrace



$$\phi_3 = \frac{m_4 + R'_{123\cdot 4}}{R_3 + R'_{12\cdot 3}}$$

where $R'_{123\cdot 4} = z_4 \frac{R_4}{r_4}$, since $\frac{z_4}{R'_{123\cdot 4}} = \frac{r_4}{R_4}$

$$\therefore \phi_3 = \frac{m_4 + z_4 \frac{R_4}{r_4}}{R_3 + z_3 \frac{R_3}{r_3}}$$

Figure B-1. Schematic of key part of reduced M-matrix used in estimation of CJS survival rates and CSS study category smolt numbers – complete reduced M-matrix of CSS includes three more sites (JDA, BON, and TWX) and three more cohorts (# 5, 6, and 7).

equating to the total number of tagged fish detected from a given initial release. Cohort 2 is made up of the fish returned-to-river at LGR and m_{2k} gives the summary tallies of these prior detected fishes' subsequent first-detection at a downstream dam. This process is continued through Cohort 7, which is made up of the fish returned-to-river at BON and the tally of its fish subsequently detected at TWX is given by m_{78} .

Figure B-1 illustrates the basic reach survival rate estimation process. At each dam, we are effecting estimating the population of undetected fish in the tailrace (shown with the notation $R'_{1:2}$ for number in LGR tailrace, $R'_{12:3}$ for number in LGS tailrace, and $R'_{123:4}$ for number in LMN tailrace). To each undetected population we are adding the associated number of detected fish at that particular dam (m_2 for LGR, m_3 for LGS, and m_4 for LMN, etc.) to obtain the total population of fish alive at each dam. The number of undetected fish alive in each dam's tailrace is unknown and must be estimated. Additional notation is need here. Let R_k = number of fish re-released at k^{th} dam, r_k = sum of first-time detections downstream of fish re-released at k^{th} dam, z_k = sum of first-time detections downstream of the undetected fish alive at k^{th} dam, and m_k = column total of the m_{jk} cells for k^{th} dam (where $k=2$ for LGR, 3 for LGS, etc.). The CJS model utilizes a basic ratio estimate to arrive at the estimated undetected fish alive in a particular dam's tailrace, which when added to that dam's detected fish, produces the estimated population alive at that dam. To illustrate this we look at LGR and the relation:

$$r_2/R_2 = z_2/ R'_{1:2} \rightarrow R'_{1:2} = (z_2/ r_2) \cdot R_2$$

Thus, the estimated population at LGR is $m_2 + (z_2/ r_2) \cdot R_2$. This is the value that goes into the numerator of the survival rate equation shown in Figure B-1. This process is repeated at each downstream dam. To obtain reach survival rates for downstream migrating smolts, we divide the estimated population at the lower dam by the estimated population alive in the tailrace of the upper dam.

Recall that Figure B-1 is only a partial depiction of all sites and cohorts, so the various tallies of m_k , z_k , and r_j will span more cohorts and sites than shown in this figure (e.g., $z_2 = m_{13} + m_{14} + m_{15} + m_{16} + m_{17} + m_{18}$ and $r_2 = m_{23} + m_{24} + m_{25} + m_{26} + m_{27} + m_{28}$). The estimate of collection efficiency for the k^{th} site is obtained by dividing the numerator from the Φ_{k-1} survival estimate in Figure 1 into the m_k tally. This methodology produces maximum likelihood estimates of the survival rate and collection efficiency parameters from the reduced M-matrix.

The computer program computed the in-river survival and associated bootstrapped confidence intervals with two methodologies. The first methodology used the CJS directly on the total PIT-tagged release group of interest, producing survival estimates for up to six reaches between release site and tailrace of Bonneville Dam (survival estimates S_1 through S_6). The total number of reaches to estimate was a function of the number of smolts in the initial release and recovery effort available in that year. Prior to 1998, there was only limited PIT-tag detection capability at John Day Dam and the NMFS trawl. Therefore, reliable survival estimates in those years were only possible to the tailrace of Lower Monumental Dam or McNary Dam. An estimate of survival was considered unreliable when its coefficient of variation exceeded 25%. From 1998 onwards, it has been possible to obtain reliable survival estimates to at least the tailraces of John Day Dam or Bonneville Dam. Estimates of individual reach survival

(e.g. LGR-LGS) can exceed 100%; however, this is often associated with an underestimate of survival in preceding or subsequent reaches. Therefore, when computing an overall multi-reach survival estimate (the product of individual reach estimates), we allow individual reach survival estimates to exceed 100%.

The second method applies the CJS method to a subset of the PIT-tagged data based on dates of detection at Lower Granite Dam. The PIT-tagged passage distribution is stratified into a series of similarly-sized smolt subcohorts, and reach survival estimates S_2 to S_6 were obtained for each separate subcohort using the CJS from Lower Granite Dam tailrace to the tailrace of the lowest dam determined when applying the first method above. For the j^{th} individual reach ($j = 2, 3, \dots, 6$), a weighted average of the survival estimates S_j across the set of subcohorts was computed, where the weight was the product of inverse relative variance and proportion of the total wild Chinook passage index that occurred during the same timeframe as the subcohort's passage dates at Lower Granite Dam. Weighting by the inverse relative variance gives cohorts with more precise survival estimates greater representation (Sandford and Smith 2002). Weighting by the passage index gives greater representation to cohorts migrating during periods when the largest proportion of the non-tagged smolts are migrating (Bouwes et al. 2002). With specific hatchery releases, the weight used with subcohorts is simply the inverse relative variance. The weighted estimates of S_2 to S_6 were then multiplied together to create the overall reach survival estimate for a given year and group of smolts.

In the computation of the total Lower Granite Dam tailrace to Bonneville Dam tailrace reach survival, termed V_C , an extrapolation was necessary whenever less than the full set of survivals S_2 to S_6 was available. The method was to take the survival estimated over the upstream portion of the overall reach, convert this survival to a "per mile" survival rate, and then apply this survival rate to the remaining miles of the overall reach. This approach has a drawback in that the per mile survival rates generated in the Snake River are generally lower than the per mile survival rates observed in the lower Columbia River based on data from migration years when survival components in the lower Columbia River are directly computable. Therefore, direct estimates of in-river survival over the longest reach possible are preferable.

Over the years of study it was found that the potential benefits desired by using the "subcohort" approach were outweighed by the penalty of having fewer fish available (since fish had to be detected at LGR first in order to make the temporal cohorts) for computing reach survival estimates over the longest reach possible. Therefore, in recent CSS annual reports, only the full sample CJS reach survival rates were used in all computations of study parameters.

Estimation of PIT-tagged smolts in study categories

The population of PIT-tagged study fish arriving at LGR is partitioned into three categories of smolts related to the manner of subsequent passage through the hydro system. Fish may either: (1) pass in-river through the Snake River collector dams in a non-bypass channel route (spillways or turbines); (2) pass in-river through the dam's bypass channel; or (3) pass in a truck or barge to below BON. Since nearly all collected untagged smolts are transported from the Snake River collector dams, we utilize only first-time detected PIT-tagged fish that are transported in order to be most reflective of

the untagged smolts. These three ways of hydro system passage define the study categories C_0 , C_1 and T_0 , respectively, of the CSS. How the in-river fish surviving to the tailrace of LMN (last Snake River collector dam) pass through the dams below LMN do not affect whether they belong to Category C_0 or C_1 . In most years, fish in categories T_0 and C_0 mimic the untagged population, although in 1997 a portion of the in-river migrants were of Category C_1 due to bypass protocols implemented on collected fish during April and May at LGS and LMN in that year. Estimation of the number of smolts in each study category is presented below.

In the reduced M-matrix as stated previously, the m_{jk} 's are tallies of capture histories reflecting whether the tagged fish are detected or not detected. An eight-digit binary code represents the status of detection (1) or non-detection (0) at each recovery site following initial release (1 in code's first position), so that code 10010001 would show detections at LMN (4th digit) and TWX (8th digit). The notation $X_{10010001}$ is used to represent the tally of fish with the capture history shown in the subscript. If a detected fish is not returned-to-river at a given site, it will receive in place of the digit 1, either the digit 2 if transported or digit 3 if "other" removal types such as taken for use in other studies (e.g., sacrificed for physiological research [Congleton 1999 to 2003] or inadvertently collected during NOAA tagging activities LMN or JDA and re-released elsewhere with those fish in some years). A shorthand capture history notation will be used for first-time detected fish that are transported at LGR ("12"), LGS ("102"), and LMN ("1002").

The sums of PIT-tagged fish across capture histories for first-time detected fish detected at LGR, LGS, and LMN are m_{12} , m_{13} , and m_{14} , respectively. The sums of PIT-tagged that are first-time detected and transported are X_{12} , X_{102} , and X_{1002} for LGR, LGS, and LMN, respectively. Ryding's (2006) assumption #7 stating "only detected fish are subject to transport" applies here. PIT-tagged fish that are first-time detected and returned-to-river at the k th site are tallied as " $m_{1k} - d_k$ ", where d_k is the sum of fish removed at the k th site (substitute $k=2$ for LGR, $3=LGS$, and 4 for LMN). The removal sum d_k includes transported (at collector dams) and "other" removal fish. The key tallies for each dam with associated expectations are summarized here:

1. Observed first-time detection tally at Lower Granite Dam (LGR) is m_{12} and expectation of $E(m_{12}) = R_1 \cdot S_1 \cdot p_2$
2. Observed first-time detection tally at Little Goose Dam (LGS) is m_{13} and expectation of $E(m_{13}) = R_1 \cdot S_1 \cdot (1 - p_2) \cdot S_2 \cdot p_3$
3. Observed first-time detection tally at Lower Monumental Dam (LMN) is m_{14} and expectation of $E(m_{14}) = R_1 \cdot S_1 \cdot (1 - p_2) \cdot S_2 \cdot (1 - p_3) \cdot S_3 \cdot p_4$
4. Observed transportation tally of PIT-tag smolts at LGR is $n_2 = X_{12}$ and expectation of $E(n_2) = E(m_{12}) \cdot P_{n2}$ where P_{n2} is the proportion of collected PIT-tagged smolts transported at LGR
5. Observed transportation estimate of run-at-large smolts at LGR is $t_2 = (\text{LGR run-at-large transported} / \text{LGR run-at-large collected}) \cdot m_{12}$ and

expectation of $E(t_2) = E(m_{12}) \cdot P_{12}$ where P_{12} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LGR

6. Observed transportation tally of PIT-tag smolts at LGS is $n_3 = X_{102}$ and expectation of $E(n_3) = E(m_{13}) \cdot P_{n3}$ where P_{n3} is the proportion of collected PIT-tagged smolts transported at LGS
7. Observed transportation estimate of run-at-large smolts at LGS is $t_3 = (\text{LGS run-at-large transported} / \text{LGS run-at-large collected}) \cdot m_{13}$ and expectation of $E(t_3) = E(m_{13}) \cdot P_{13}$ where P_{13} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LGS
8. Observed transportation tally of PIT-tag smolts at LMN is $n_4 = X_{1002}$ and expectation of $E(n_4) = E(m_{14}) \cdot P_{n4}$ where P_{n4} is the proportion of collected PIT-tagged smolts transported at LMN
9. Observed transportation estimate of run-at-large smolts at LMN is $t_4 = (\text{LMN run-at-large transported} / \text{LMN run-at-large collected}) \cdot m_{14}$ and expectation of $E(t_4) = E(m_{14}) \cdot P_{14}$ where P_{14} is the proportion of run-at-large (total fish at level of species and rearing type from Smolt Monitoring Program) transported at LMN
10. Observed return-to-river tally of PIT-tag smolts at LGR is $m_{12}-d_2 = m_{12} \cdot (1-P_{d2})$ and expectation of $E(m_{12}-d_2) = E(m_{12}) \cdot (1-P_{d2})$ where P_{d2} is proportion of collected PIT-tagged smolts not returned-to-river at LGR
11. Observed return-to-river tally of PIT-tag smolts at LGS is $m_{13}-d_3 = m_{13} \cdot (1-P_{d3})$ and expectation of $E(m_{13}-d_3) = E(m_{13}) \cdot (1-P_{d3})$ where P_{d3} is proportion of collected PIT-tagged smolts not returned-to-river at LGS
12. Observed return-to-river tally of PIT-tag smolts at LMN is $m_{14}-d_4 = m_{14} \cdot (1-P_{d4})$ and expectation of $E(m_{14}-d_4) = E(m_{14}) \cdot (1-P_{d4})$ where P_{d4} is proportion of collected PIT-tagged smolts not returned-to-river at LMN

In order to have a common starting point such as LGR for estimating the numbers of PIT-tagged smolts in each study category, it is necessary to expand the tallies of detected fish at the downstream sites of LGS and LMN into their LGR-equivalents. Simulating known probabilities of survival, collection efficiency, and transportation when collected, Ryding (2006) illustrates the need for accounting for in-river mortality during the migration to LGS and LMN for smolts detected and transported at those sites. This also true for the first-time detected fish bypassed at those sites. The resulting estimated number of PIT-tagged smolts for each CSS study category is given in LGR equivalents. The estimated number of PIT-tagged smolts transported, along with the

transport number projected had the PIT-tagged fish been transported in the same proportion as the untagged run-at-large population, and associated expectations are:

13. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are transported from the three Snake River collector dams

$$T_0 = X_{12} + X_{102}/S_2 + X_{1002}/S_2S_3 \text{ and expectation of}$$

$$E(T_0) = E(n_2) + E(n_3)/S_2 + E(n_4)/S_2S_3$$

14. Estimated number of PIT-tag smolts expanded to LGR-equivalents that would have been transported if the PIT-tag smolts had been transported at the same proportion as the run-at-large from the three Snake River collector dams

$$T_0^* = t_2 + t_3/S_2 + t_4/S_2S_3 \text{ and expectation of}$$

$$E(T_0^*) = E(t_2) + E(t_3)/S_2 + E(t_4)/S_2S_3$$

Lastly, there is a small adjustment made to the estimated numbers of smolts in C_0 and C_1 categories to reflect known removals occurring at monitoring sites downstream of Lower Monumental Dam. Fish were considered removed (not returned-to-river) at McNary Dam when detected on raceway or sample room monitors or only on the separator monitor during the summer transportation season, or when collected and removed at John Day or Bonneville Dam for other research purposes. For example, samples of CSS hatchery Chinook from Rapid River, McCall, and Dworshak hatcheries were collected and sacrificed at John Day and/or Bonneville dams during migration years 1999 to 2003 for physiological (blood chemistry) evaluation (Dr. Congleton, University of Idaho Fish and Wildlife Unit). Because most removals occurred at John Day and Bonneville dams for other research purposes, we settled on a fixed 50% Lower Granite to Bonneville Dam survival rate for each removed fish in order to subtract these fish in LGR-equivalents from the estimated number of smolts in Categories C_0 and C_1 . The 50% survival rate was the average of 1995 to 2004 (excluding drought year 2001) survival rates between Lower Granite Dam and Bonneville Dam. In 1994, the wild Chinook in-river survival rate from Lower Granite Dam to McNary Dam was estimated at 47%, with most removals occurring at McNary Dam due to no operational return-to-river diversion route present that year. Therefore, in equations 15 and 16 below, the number of PIT-tagged fish of categories C_1 and C_0 , respectively, removed downstream of LMN (*i.e.*, d_1 and d_0) are multiplied by a factor 2 to account for this average survival rate.

15. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are return-to-river at each collector dam and remain in-river to below LMN

$$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/S_2 + (m_{14} - d_4)/S_2S_3 - 2 \cdot d_1 \text{ and expectation of}$$

$$E(C_1) = E(m_{12}) \cdot (1 - P_{d2}) + [E(m_{13}) \cdot (1 - P_{d3})]/S_2 + [E(m_{14}) \cdot (1 - P_{d4})]/S_2S_3 - 2 \cdot d_1$$

16. Estimated number of PIT-tag smolts expanded to LGR-equivalents that are not detected at any of the three Snake River collector dams (note: detection at downstream sites is permitted)

$$C_0 = R_1 S_1 - (m_{12} + m_{13}/S_2 + m_{14}/S_2 S_3) - 2 \cdot d_0 \text{ and expectation of}$$

$$E(C_0) = R_1 S_1 - [E(m_{12}) + E(m_{13})/S_2 + E(m_{14})/S_2 S_3] - 2 \cdot d_0$$

$$E(C_0) = R_1 \cdot S_1 \cdot (1 - p_2) \cdot (1 - p_3) \cdot (1 - p_4) - 2 \cdot d_0$$

Estimation of SARs for study categories

As stated earlier, we only used first-time detections for transported smolts in order to represent the non-tagged smolts. Since springtime transportation occurs at three Snake River collector projects, we needed to have the number of PIT-tagged smolts transported at each dam be reflective of the proportion of the untagged smolt population likewise being transported from each facility. But since most PIT-tagged wild Chinook were returned to river at the collector dams in year prior to 2002 and the fact that the CSS was transporting a higher proportion of its PIT-tagged hatchery Chinook at LGR in the early years of this study, the number of PIT-tagged smolts transported at some projects did not adequately reflect the untagged run-at-large. Therefore, the first formula used in the CSS to estimate the overall transportation SAR weighted the dam-specific SAR estimates (times any in-river survival to reach a transportation site below LGR) by the estimated number of PIT-tags (expanded to LGR-equivalents) that would have been transported at each dam if the PIT-tags had been transported in the same proportion as the untagged run-at-large (details in Berggren *et al.* 2002).

However, hatchery Chinook PIT-tagged for the CSS in 1997 were routed to transport only at LGR, whereas in 1998, 1999, and 2002 the CSS hatchery tagged fish were routed to transport at both LGR and LGS, but not LMN. Likewise, from 1995 to 2001, the collection of PIT-tagged wild Chinook at LGS or LMN was less than 10% transported, resulting in few (none to 2) adults returning from which to estimate a dam-specific SAR. Under those conditions using the SAR₁(T₀) estimator was less desirable than using the more simple estimator SAR₂(T₀) introduced in the 2003/04 CSS Annual Report (Berggren *et al.* 2005). In order to take advantage of self-weighting across the three Snake River collector dams, we now use a common annual routing rate to the raceways for transportation at each collector dam. With a common routing rate, the two estimators are basically identical (producing only slight differences due to rounding). This approach was started with hatchery Chinook in 2000 (except 2002 at LMN), wild Chinook in 2002, and wild steelhead in 2003.

In the 2005 and 2006 CSS annual report (Berggren *et al.* 2006a, 2006b), the estimate of SAR₂(T₀) was presented for each year, while the SAR₁(T₀) estimate was presented only for those years when non-zero dam-specific SAR estimates were available for comparison purposes of the two methods. Because the estimator SAR₂(T₀) does not rely on site-specific SARs, it has been more reliable method to use over the full 1994 to 2004 time frame. Likewise, subsequent ratios of SARs and *D* computation have utilized only SAR₂(T₀) in recent CSS reports.

The SARs for Category C₀ and C₁ smolts do not require the same type of adjustment as was needed for Category T₀ smolts. The SAR formula is simply the number of adults divided by number of smolts (in LGR equivalents) for each respective study category. In this report, the adult count is the sum of 2-salt and older returning

wild and hatchery Chinook and 1-salt and older returning wild and hatchery steelhead for each study category.

The formulas for SARs for each study category are summarized here:

17. Numbers of returning adults used in SAR estimates are tallies of PIT-tag adults (age 2-salt and older for Chinook; age 1-salt and older for steelhead) detected at Lower Granite Dam adult monitors (GRA), which have near 100% detection efficiency. Some analyses use Bonneville Dam adult detections (BOA), which have been expanded by estimated detection efficiency at that site.

AT_{LGR} = tally of adults of smolts transported at LGR (capture history “12”)

AT_{LGS} = tally of adults of smolts transported at LGS (capture history “102”)

AT_{LGR} = tally of adults of smolts transported at LGR (capture history “1002”)

Letting shorthand $A = 0$ if not detected and 1 if detected and returned to river (but not including returning adults having $A > 1$ at any site, which signifies a removal):

AC_0 = tally of adults of smolts that passed the three Snake River collector dams undetected (capture histories “1000AAAA”)

AC_1 = tally of adults of smolts that passed the three Snake River collector dams with at least one detection (capture histories “11AAAAAA” or “101AAAAA” or “1001AAAA”).

18. Site-specific transportation SAR (n_k is observed number smolts at k^{th} dam that is not expanded to LGR-equivalents):

$$\begin{aligned} SAR(T_{LGR}) &= AT_{LGR} / n_2 \\ SAR(T_{LGS}) &= AT_{LGS} / n_3 \\ SAR(T_{LMN}) &= AT_{LMN} / n_4 \end{aligned}$$

19. Overall transportation SAR where site-specific SARs are weighed by the proportion of PIT-tag smolts that would have been transported from each site (expanded in LGR-equivalents) if the PIT-tag smolts had been transported in the same proportion as the run-at-large at each collector dam

$$SAR_1(T_0) = \{t_2 \cdot SAR(T_{LGR}) + (t_3/S_2) \cdot [S_2 \cdot SAR(T_{LGS})] + t_4/S_2S_3 \cdot [S_2S_2 \cdot SAR(T_{LMN})]\} / \{t_2 + (t_3/S_2) + (t_4/S_2S_3)\}$$

$$SAR_1(T_0) = \{t_2 \cdot SAR(T_{LGR}) + t_3 \cdot SAR(T_{LGS}) + t_4 \cdot SAR(T_{LMN})\} / \{t_2 + (t_3/S_2) + (t_4/S_2S_3)\}$$

20. Overall transportation SAR where site-specific SARs are weighed by actual proportion of PIT-tag smolts transported at each collector dam (expanded in LGR-equivalents)

$$\text{SAR}_2(T_0) = \{n_2 \cdot \text{SAR}(T_{\text{LGR}}) + (n_3/S_2) \cdot [S_2 \cdot \text{SAR}(T_{\text{LGS}})] + n_4/S_2S_3 \cdot [S_2S_2 \cdot \text{SAR}(T_{\text{LMN}})]\} / \{n_2 + (n_3/S_2) + (n_4/S_2S_3)\}$$

$$\text{SAR}_2(T_0) = \{n_2 \cdot (AT_{\text{LGR}}/n_2) + (n_3 \cdot (AT_{\text{LGS}})/n_3) + n_4 \cdot (AT_{\text{LMN}}/n_4)\} / \{n_2 + (n_3/S_2) + (n_4/S_2S_3)\}$$

$$\text{SAR}_2(T_0) = \{AT_{\text{LGR}} + AT_{\text{LGS}} + AT_{\text{LMN}}\} / \{n_2 + (n_3/S_2) + (n_4/S_2S_3)\}$$

21. In-river SAR for smolts not detected at the Snake River collector dams

$$\text{SAR}(C_0) = AC_0 / C_0$$

22. In-river SAR for smolts detected at one or more Snake River collector dam

$$\text{SAR}(C_1) = AC_1 / C_1$$

Annual estimates of overall SARs

Annual estimates of overall SAR_{LGR-to-LGR} reflective of the run-at-large for wild steelhead, hatchery steelhead, wild Chinook, and hatchery Chinook that outmigrated in 1997 to 2003 are computed by weighting the SARs computed with PIT-tagged fish for each respective study category by the proportion of the run-at-large transported and remaining in-river. The proportions of the run-at-large reflected by each of the CSS study categories C₀, C₁ and T₀ were estimated as follows. First, we estimated the number of PIT-tagged smolts t_j that would have been transported at each of the three Snake River collector dams (j=2 for LGR, j=3 for LGS, and j=4 for LMN) if these fish had been routed to transportation in the same proportion as the run-at-large. This estimation uses run-at-large collection and transportation data for these dams from the FPC Smolt Monitoring Program. The total estimated number transported across the three Snake River collector dams in LGR equivalents equals T₀^{*} = t₂+t₃/S₂+t₄/(S₂S₃). When a portion of the collected run-at-large fish is being bypassed as occurred in 1997, then there will be a component of the PIT-tagged fish also in that bypass category (termed C₁^{*} in this discussion). In most years, the C₁^{*} is at or near zero. When run-at-large bypassing occurs, C₁^{*} = (T₀ + C₁) – T₀^{*}. The sum of estimated smolts in categories C₀, T₀^{*}, and C₁^{*} is divided into each respective category's estimated smolt number to provide the proportions to be used in the weighted SAR computation. The proportion of the run-at-large that each category of PIT-tagged fish represents is then multiplied by its respective study category-specific SAR estimate, i.e., SAR(C₀), SAR(C₁), and SAR₂(T₀), and summed to produce the overall weighted SAR (LGR-to-LGR) for each migration year except 2001 as follows:

23. Estimate of overall SARs computed by weighting each study category SAR by the estimated proportion of the run-at-large (in LGR-equivalents) each represents

$$SAR_{OVERALL} = w(T_0^*) \cdot SAR_2(T_0) + w(C_0) \cdot SAR(C_0) + w(C_1^*) \cdot SAR(C_1)$$

where $T_0^* = t_2 + (t_3/S_2) + (t_4/S_2S_3)$ and $C_1^* = (T_0 + C_1) - T_0^*$ reflect number of PIT-tag smolts in transport and bypass categories, respectively, if collected PIT-tag smolts were routed to transportation in the same proportion as run-at-large; and

$w(T_0^*) = T_0^* / (T_0^* + C_0 + C_1^*)$ is transported smolt proportion

$w(C_0) = C_0 / (T_0^* + C_0 + C_1^*)$ is non-detected (LGR, LGS, LMN) smolt proportion

$w(C_1^*) = 1 - [w(T_0^*) + w(C_0)]$ is bypass (LGR, LGS, LMN) smolt proportion

Estimation of the TIR and D

The *TIR* (formerly T/C ratio) is a common parameter used to illustrate differences between the SARs of transported and in-river migrating smolts. It is simply measured as:

$$24. TIR = SAR_2(T_0) / SAR(C_0)$$

Assessments that these differences are the result of the collection and transportation of the PIT-tagged smolts relative to the baseline effects of migrating in-river through the hydrosystem relies on the following assumptions from Ryding (2006):

#10 – Transported fish and in-river migrants experience the same estuary and ocean conditions.

#11 – Harvest survival [rate] is the same for transported and in-river categories.

#12 – River conditions for same-age returns of a cohort are the same for the T_0 and C_0 categories.

Assumption #10 from Ryding (2006) should be limited to the ocean conditions, since it is expected that arrival timing in the estuary of the transported PIT-tagged smolts will be from one to two weeks earlier than that of the smolts completing their migration in-river through the hydrosystem. The timing of smolt entry into the estuary may have a real influence on the subsequent SARs. There is evidence of higher levels of straying of adult returns from the transported smolts (particularly for steelhead). Delays and greater levels of straying into lower Columbia River tributaries may make more returning adults of transported smolts available for tributary harvest, in spite of assumption 11 that the harvest rate is independent of whether fish had been transported or not as a smolt. These assumptions and comments apply to both parameters *TIR* and *D*.

Parameter *D* is the ratio of post-BON survival rate of transported fish to that of in-river migrating fish. Basically, *D* is computed as:

$$25. D = [SAR_2(T_0) / S_T] / [SAR(C_0) / S_R]$$

where $S_T = 0.98 * [t_2 + t_3 + t_4] / [t_2 + (t_3/S_2) + (t_4/S_2S_3)]$ and

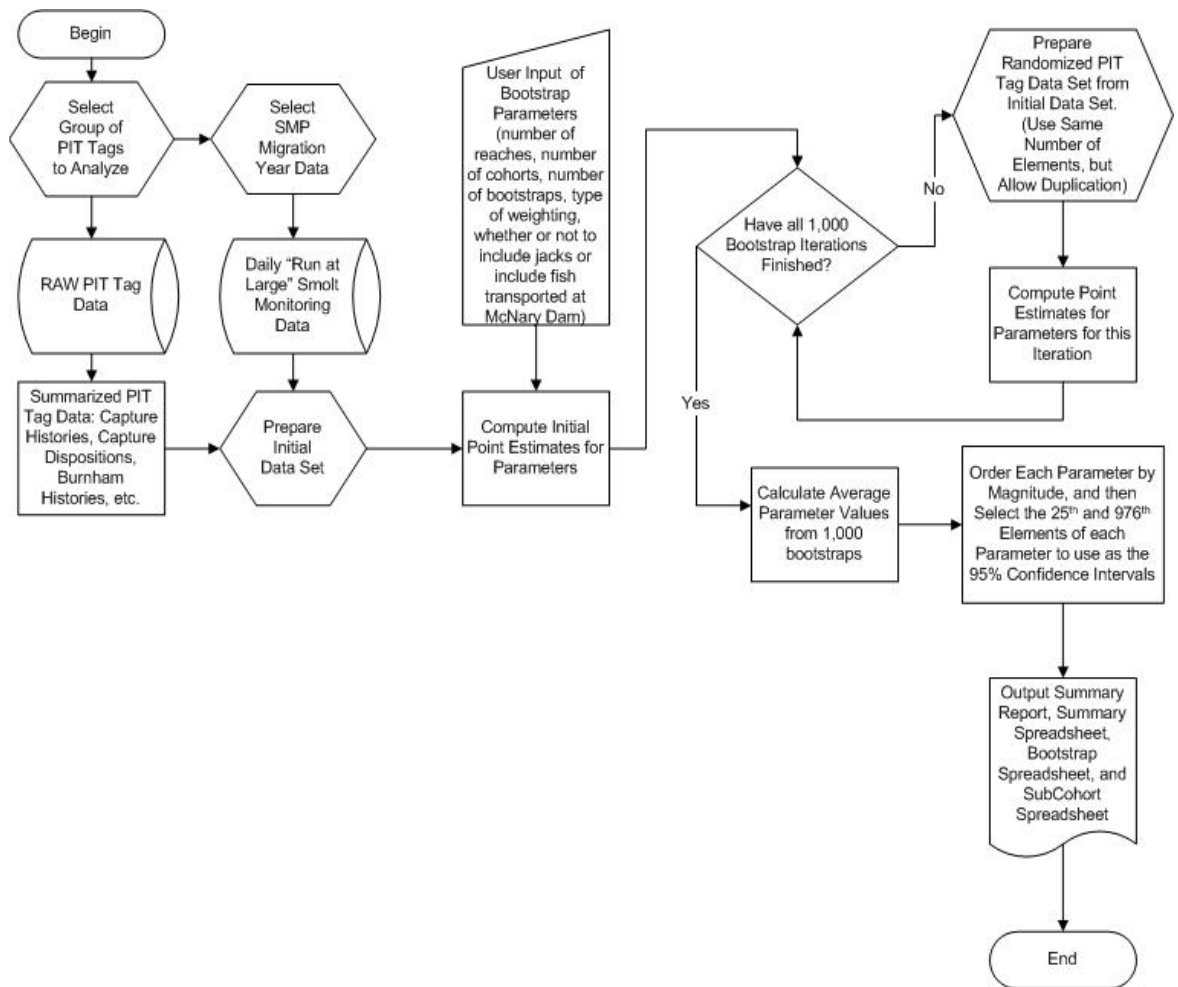
$$S_R = S_2 \cdot S_3 \cdot S_4 \cdot S_5 \cdot S_6$$

In this equation, parameter S_R (formerly V_C) is the overall reach survival from LGR to BON of fish in Category C_0 . Although the S_R in pre-1998 years is less reliable due to the expansion of a “per/mile” survival rate to over 50% of the full reach distance, the variation in the S_R estimates follows variation in hydroproject operations in that S_R estimates were lowest in 1994 and 2001, the two years with limited or no spill provided at the Snake River collector dams.

Parameter S_T (formerly V_T) is the overall in-river survival from LGR to the transportation sites and on barges or trucks until released below BON for fish in Category T_0 . Regardless of whether $SAR_1(T_0)$ or $SAR_2(T_0)$ is used in the computation of D , the estimate of S_T should be computed as $0.98 \cdot (t_2 + t_3 + t_4) / (t_2 + t_3/S_2 + t_4/S_2S_3)$. This is because the same in-river survival exists from LGR to these two downstream collector dams regardless of which transport SAR estimator is utilized. When $SAR_2(T_0)$ was first introduced in the 2003/2004 Annual Report, the associated S_T was simply programmed as a constant 98%, which resulted in a slight under-estimate of parameter D . This was corrected in time for the 2005 CSS Annual Report. Estimated S_T has ranged between 88 and 98% (Berggren *et al.* 2006a) across the years, species, and rear types.

Program for Parameter Estimation and Confidence Intervals

A computer program was written to compute the in-river survivals, SARs, ratios of selected SARs, and D indices along with associated bootstrapped confidence intervals. The confidence intervals were produced using nonparametric bootstrapping methods (Efron and Tibshirani 1993). During a bootstrapped iteration, the computer program obtained a random sample of PIT-tags with replacement from the full set of PIT-tags in the particular group of interest. During each iteration, all relevant study parameters were computed, while retaining the raw data used in the computations. From a set of iterations (typically 1,000 runs), non-parametric 80%, 90%, and 95% confidence intervals were computed for each parameter of interest. The 90% confidence intervals were chosen for reporting in the recent CSS annual reports in an attempt to better balance the making of Type I (failure to reject a false null hypothesis) and Type II (failure to accept a true alternative hypothesis) errors in comparisons study groups of fish for the various parameters of interest. Appendix B Figure 2 is a flowchart overview of the bootstrapping methodology used by this computer program.



Appendix B Figure 2. Schematic of bootstrap program for estimating initial values, averages, and confidence intervals for study parameters.

Appendix B Table-1. Progression of methods of estimating study-specific SARs and *D* through the series of annual reports and design & analysis technical documents prepared by the CSS in 2000 to 2006 (see definitions of symbols in text).

CSS Document	Transport SARs	In-river SARs	Parameter <i>D</i>
<p>Annual Report 2000 Published Oct. 2000 DOE/BP-00006203-1</p> <p>Report covers 1996-1998 sp/su hatchery Chinook (HC) mark/recapture activities (adult returns to 2000)</p>	<p>HC smolt numbers: $T_0 = t_1 + t_2/s_2 + t_3/s_2s_3$ where $t_1 = X_{12}$; $t_2 = X_{102}$; and $t_3 = X_{1002}$</p> <p>$SAR(T_0) = \text{adult}(T_0)/T_0$</p> <p>Point estimates only; No confidence intervals</p> <p>Note: CSS PIT-tagged HC were not routed to transport in 1996, so only in-river SARs available for that migration year.</p>	<p>HC smolt numbers: $C_0 = m_{12}/p_2 - (m_{12} + m_{13}/s_2 + m_{14}/s_2s_3)$ $C_1 = m_{12} + m_{13}/s_2 + m_{14}/s_2s_3 - (T+U+M)$ where $T = T_0$; U = separator only; most at LGR so no expansion made; M = study fish sacrificed at any dam (no split in morts between C_0 and C_1 groups)</p> <p>$SAR(C_0) = \text{adult}(C_0)/C_0$ $SAR(C_1) = \text{adult}(C_1)/C_1$</p> <p>Point estimates only; No confidence intervals</p>	<p>Not computed.</p>
<p>Annual Report 2001 Published Feb. 2002 DOE/BP-00006203-2</p> <p>Report covers 1997-2000 sp/su HC mark/recapture activities with SARs thru 1999 (adult returns to 2001)</p> <p>This report adds 1994 to 1999 wild Chinook (WC) with adult returns to 2001.</p>	<p>HC smolt numbers: $T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2s_3$</p> <p>$SAR(T_0) = \text{adult}(T_0)/T_0$</p> <p>A <i>Monte Carlo</i> 95% confidence interval is generated in same manner as described at right for in-river groups.</p> <p>WC smolt numbers: $T_0 = X_{12} + X_{102}/s_2 + X_{1002}/s_2s_3 + X_{10002}/s_2s_3s_4$ (MCN included here)</p> <p>$SAR_T = \frac{\sum W_J \cdot LGR_{A,J}}{\sum W_J \cdot LGR_{S,J}}$ where subscript J=dam, A=adults, S=smolts, LGR = # in LGR-equiv., and $W_J = PA_J/PO_J / \sum PA_J/PO_J$ with PA = actual # (includes untagged) and PO = tagged only.</p> <p>SAR_T has no computed confidence intervals.</p>	<p>HC & WC smolt numbers: $C_0 = R \cdot s_1 - (m_{12} + m_{13}/s_2 + m_{14}/s_2s_3) - 2\Delta_0$ since $R \cdot s_1 = m_{12}/p_2$ $C_1 = (m_{12} - \delta_2) + (m_{13} - \delta_3)/s_2 + (m_{14} - \delta_4)/s_2s_3 - 2\Delta_1$ where δ_j is total removals at J^{th} dam (include transport, morts, and separator only fish); and Δ is removals below LMN split between C_0 and C_1 groups (a factor of 2 used to offset an approx. survival rate of 50% from LGR since most of these removals are at JDA or BON)</p> <p>$SAR(C_0) = \text{adult}(C_0)/C_0$ $SAR(C_1) = \text{adult}(C_1)/C_1$</p> <p>A <i>Monte Carlo</i> 95% confidence interval is generated for these SARs by applying a binomial draw of adults for the numerator and Gaussian draw of survival rates for computing the denominator within each of 1000 iterations of SAR formulas above. The rank order 25th and 976th positions values provided a 95% CI.</p>	<p>Parameter <i>D</i> is computed as:</p> <p>$\frac{[SAR(T_0)/V_T]}{[SAR(C_0)/V_C]}$</p> <p>where $V_T = 0.98$ and $V_C =$ survival rate from LGR to BON which is either obtained directly from the product of 5 reach survival rates or an expanded (per mile) estimate.</p> <p>Note: symbols V_T and V_C have been replaced by S_T and S_R, respectively, in the 10-yr report.</p>

CSS Document	Transport SARs	In-river SARs	Parameter <i>D</i>
<p>Design & Analysis Tech Report Apr. 2002 DOE/BP-00006203-3</p> <p>Derivation of formulas to estimate smolt #'s, SARs, & <i>D</i></p>	<p>Demonstrated that equation SAR_T used with wild Chinook in previous annual report is equivalent to formula</p> $SAR(T_0) = [t_2 \cdot SAR(T_{LGR}) + t_3 \cdot SAR(T_{LGS})/s_2 + t_4 \cdot SAR(T_{LMN})/s_2s_3 + t_5 \cdot SAR(T_{MCN})/s_2s_3s_4] / [t_2 + t_3/s_2 + t_4/s_2s_3 + t_5/s_2s_3s_4]$ <p>where <i>t_j</i> is estimated # of PIT-tagged smolts transported if done at rate of untagged fish. Note: this <i>t_j</i> is not the same used in AR 2000.</p>	<p>No changes from description of smolt numbers and SARs for groups C₀ and C₁ described in previous annual report.</p>	<p>Demonstrated that V_T in computing <i>D</i> needs to account for in-river mortality of fish transported at dams below LGR as:</p> $V_T = 0.98 \cdot \frac{\{(t_2 + t_3 + t_4 + t_5) / (t_2 + t_3/s_2 + t_4/s_2s_3 + t_5/s_2s_3s_4)\}}$ <p>where <i>t_j</i> is estimated # of PIT-tagged smolts transported if done at rate of untagged fish.</p>
<p>Annual Report 2002 Published Nov. 2003^A DOE/BP-00006203-4</p> <p>Report covers 1997-2000 sp/su HC & 1994-2000 sp/su WC (adult returns to 2002)</p>	<p>With 1994 the last year of springtime transport from MCN and only 42 first-time detected PIT-tagged wild Chinook transported, it was not possible to obtain a site-specific SAR for MCN. Therefore, SAR(T₀) =</p> $[t_2 \cdot SAR(T_{LGR}) + t_3 \cdot SAR(T_{LGS})/s_2 + t_4 \cdot SAR(T_{LMN})/s_2s_3] / [t_2 + t_3/s_2 + t_4/s_2s_3]$ <p>(additional info at right)</p>	<p>Following applies to all parameters and groups (<i>i.e.</i>, T₀, C₀, and C₁): Two methods of estimating reach survival rates -- (1) "full sample CJS" & (2) "subcohort CJS." The latter approach gave weighted mean survival rates of stratified re-releases of detected PIT-tagged fish from LGR.</p> <p>Bootstrap 95% confidence intervals were computed for each SAR parameter starting in this annual report.</p>	<p>V_C computed with "subcohort CJS" method required more reaches to be estimated on "per mile" basis than "full sample CJS" method to fewer fish in stratified re-release blocks.</p> <p>First year of bootstrap 95% confidence intervals for <i>D</i></p>
<p>Annual Report 2003/04 Published Apr. 2005^B DOE/BP-00006203-5</p> <p>Report covers 1997-2002 sp/su HC & 1994-2002 sp/su WC (adult returns to 2004)</p>	<p>Reinstated the transport SAR from AR2000 and renamed it SAR₂(T₀) as alternative when a site-specific SAR was missing (<i>i.e.</i>, "0"). Renamed SAR(T₀) from AR 2002 to SAR₁(T₀).</p> <p>Overall weighted annual SAR is computed with CSS transport and in-river SARs weighted by estimated proportion of "untagged" population transported or migrating in-river each year.</p> <p>(see more info at right)</p>	<p>Following applies to all parameters and groups (<i>i.e.</i>, T₀, C₀, and C₁): estimating reach survival rates with the "subcohort CJS method was dropped; only "full sample CJS" survival rates were used in computing study parameters including transport and in-river SARs, TIRs, and <i>D</i>.</p>	<p>V_C computed with "full sample CJS."</p> <p>In <i>D</i> computation, V_T is correct with SAR₁(T₀), but not with SAR₂(T₀), where only 0.98 is erroneously used.</p>

CSS Document	Transport SARs	In-river SARs	Parameter <i>D</i>
Annual Report 2005 Published Dec. 2005 DOE/BP-00025634-1 Report covers sp/su HC and WC thru 2003 (adult returns to 2005) Report adds 1997-2002 wild steelhead (WS) & hatchery steelhead (HS) (adult returns to 2004)	SAR ₂ (T ₀) is primary transport SAR used in computing other study parameters. With equal proportions of PIT-tagged smolts routed to transport at the collector dam in recent years, SAR ₂ (T ₀) equals SAR ₁ (T ₀) in expected value. (see more info at right)	The method of Akçakaya (2002) was used to estimate the variance in PIT-tag SAR estimates from sampling error, and remove it from the total variance in the time series. This produced estimates of process error (inter-annual variation in survival rates), which were used in computing probability density functions of transport and in-river SARs for wild Chinook (as well as <i>TIRs</i>).	The correct V _T as shown above (see D&A 2002 Tech Report) is used with SAR ₂ (T ₀) in the <i>D</i> computation.
Annual Report 2006 ^C Published Nov. 2006 DOE/BP-00025634-2 Report covers sp/su HC and WC thru 2004 (adult returns to 2006) Report covers HS and WS thru 2003 (adult returns to 2005)	No changes. Simulator program was completed during this reporting period; and simulation runs using default input values are conducted to illustrate comparisons between estimates of s ₂ , s ₃ , V _C , and smolt numbers in T ₀ , C ₀ , and C ₁ .	No changes from description of smolt numbers and SARs for groups C ₀ and C ₁ used in annual reports 2001 to present. The method of Akçakaya (2002) was not used in this annual report.	No changes.
Design & Analysis Tech Report Dec. 2006 DOE/BP-none ^D	Using formulas for expectation of smolt #s in groups T ₀ and C ₀ and returning adults under two scenarios, report demonstrated why expanding estimated smolt numbers to LGR-equivalents is necessary to obtain unbiased <i>TIRs</i> .	(see description at left)	Not addressed.

^A BPA cover page to CSS Report erroneously shows April 2005 as publish date instead of November 2003.

^B BPA cover page to CSS Report erroneously shows November 2003 as publish date instead of April 2005.

^C BPA cover page to CSS Report erroneously shows 2005-2006 for Annual Report # instead of just 2006.

^D BPA does not have this report on BPA publication website; however, it has two identical copies of the CSS Annual Report 2006 with different numbers -- DOE/BP-00025634-2 and DOE/BP-00025634-4.

Appendix C
2006 Design and Analysis Report

Comparative Survival Study (CSS)

2006 Design and Analysis Report:

Methodology for Obtaining Unbiased T/C Ratio Estimates

BPA Contract #19960200

Prepared by

Kristen Ryding

Washington Department of Fisheries

Comparative Survival Study Oversight Committee Member

Project Leader:

Michele DeHart, Fish Passage Center

Final

December 31, 2006

Preface

A primary goal of the Comparative Survival Study (CSS) is to provide reliable (*i.e.*, unbiased, reasonably precise, and transparent) estimates of parameters describing the relative survival benefits due to various management strategies. In particular, the CSS estimates smolt-to-adult survival rates (SARs) for groups of fish (hatchery and wild spring/summer Chinook salmon, *Oncorhynchus tshawytscha*, and summer steelhead, *O. mykiss*) that out-migrate as juveniles via in-river and transportation passage routes, as well as the ratio of these SAR estimates (*i.e.*, transport:inriver ratio or T/C). Reviewers of the 2005 CSS Annual Report (see Appendix D in Berggren *et al.* 2005) suggested that the CSS estimators are inherently biased in their formulation and poorly documented. To address these concerns, the following document was prepared by Washington Department of Fish and Wildlife's Comparative Survival Oversight Committee member Kristen Ryding. While a description of the quantitative methods used to estimate CSS study parameters appears elsewhere (see Appendix A in Berggren *et al.* 2006), the purpose of this document is two fold: i) to provide a derivation of the main study parameters used by the CSS and ii) to describe their behavior, relative to a 'true' value, under various circumstances (*e.g.*, with and without actual transportation benefits).

The document is structured to build from a description of basic elements (*i.e.*, parameter definition and notation) to the theoretical expectation of key study parameters (*i.e.*, SARs and T/C) and their analogous estimators. Additionally, the main assumptions underlying the described estimators will be identified and discussed in brief. Finally, using a set of simple examples based on the derived estimators and a set of assumed inputs, this document illustrates that both SARs and T/C , as used in the CSS, are both accurate (*i.e.*, unbiased) and robust.

Table of Contents	<u>Page</u>
List of Tables	ii
List of Figures	iii
Introduction	1
Notation and Definitions	2
Basic Metrics	4
Derivation of the smolt-to-adult return estimators: $SAR(C_0)$ and $SAR(T_0)$	6
Calculation of in-river (Control) SAR	14
Calculation of the transport SAR	16
T/C Ratio, behavior under the null hypothesis [$H_0 : (T / C) = 1$] and numerical examples	23
Estimation	47
Assumptions	53

List of Tables	<u>Page</u>
Table 1. Hypothetical survival, detection, and transport probabilities for a cohort of 50,000 tagged fish	26
Table 2. Numbers of fish comprising each migration category sub-categories, e.g., C_0^1 , for a hypothetical release of 50,000 fish and the probabilities given in Table 1. Shaded boxes correspond to the shaded sub-categories in Figure 2.	27
Table 3. Hypothetical reach survival and site-specific detection and transport probabilities for Example 1b.	36
Table 4. Hypothetical numbers of fish in each category and sub-category (intermediate calculations) for Example 1b. Shaded cells corresponds to sub-categories in Figure 2. Release size is 50,000 fish.	36
Table 5. Hypothetical reach survival and site-specific detection and transport probabilities:used in Example 2.	46
Table 6. Number of fish in each category and sub-group calculated from the probabilities in Table 5 and a release size of 50,000 tagged fish. Shaded cells correspond to sub-categories in Figure 2.	46
Table 7. Hypothetical survival, detection, and transport probabilities for Example 3.	52

List of Figures	<u>Page</u>
Figure 1. Diagram of a hypothetical river to illustrate the concept of “destined to be in a route of passage” in the CSS study.	8
Figure 2. Schematic of the Lower Snake and Columbia River system with focus on the three transport sites, the migration routes, and the sub-categories or possible fates within each group.	13

Introduction

This section focuses on the derivation of the estimator used to assess the efficacy of transporting fish around dams on the Lower Snake and Columbia rivers versus migration using in-river routes. Fish are collected and put into the transport barges at one of three dams on the Lower Snake River. In order of occurrence, the three transport sites are Lower Granite Dam (LGR), Little Goose Dam (LGS), and Lower Monumental Dam (LMN). The transport system is considered to start at the first site, Lower Granite Dam and end at the barge release site below Bonneville Dam. Performance of the transportation system is assessed by comparing relative rate of adult returns back to Lower Granite Dam between juveniles that were transported and those that migrated in-river (control) through the hydro-system. Transport and control returns are compared by use of the transport-control or T/C ratio, the focus of this study.

The CSS study does not divide a cohort into transport and in-river groups before release, but rather at the first transport site, LGR. Fish pass a dam through either detected through bypass system and then possibly transported, or through other routes undetected. Essential to understanding the derivation of the T/C ratio are three elements of the study. First only fish not previously detected at a dam are barged. Second, probabilities of adult return back to LGR are based on the numbers of juveniles at LGR in each group. Third, fish passing undetected at LGR are considered to be in a transport or in-river migration route upon egress from the dam. This last condition owes to the fact that even in a river system where fish are subject to only transportation should they be detected, some mortality will

occur in-river on the way to the barge site. Any loss associated with getting to the barge is part of the total mortality of transportation. Subsequently, fish are considered routed for either transportation at LGS or LMN prior to the onset of survival processes associated with downstream travel to these sites. All of these elements will be discussed further.

We outline the derivation of the T/C ratio from first principles. We begin by defining the notation and basic metrics used in the analysis. Derivation of the equations for calculating the numbers of juveniles and returning adults in each category follows. Next, we present the T/C ratio as a function of survival, detection, and transport probabilities and discuss its properties under the null condition analytically and through numerical examples. We conclude with a discussion of parameter estimation and associated assumptions of analytical methods.

Notation and Definitions

Unless otherwise indicated, the following subscripts are used to identify site-specific probabilities and observations following the convention of previous CSS reports;

1 = release site;

2 = Lower Granite Dam (LGR);

3 = Little Goose Dam (LGS);

4 = Lower Monumental Dam (LMN).

The following notation will be used in this section to show the derivation of the T/C estimator. Define the number of tagged fish released, survival, detection, and transport probabilities, and observations as follows,

N_0 = the number of tagged fish released;

S_1 = survival from release to Lower Granite Dam tailrace;

S_i^R = survival probability from the tailrace of site i to $i + 1$ for fish passing in-river e.g.,

S_2^R = in-river survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam;

S_i^T = survival probability from the i to $i + 1$ transport site for fish transported in the

barge e.g., S_2^T = in-barge survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam;

S_L^x = the probability of surviving from the tailrace of LMN, the last transport site,

through the Lower Snake and Columbia Rivers to the transport release site for

group x , e.g., $S_L^{C_0}$ is the lower river survival probability for the in-river migration group;

S_O^x = the probability of surviving from the transport release site as juveniles back to

Bonneville dam as adults for group x (includes estuary and marine survival);

S_A^x = the probability of surviving adult migration from Bonneville dam back to LGR;

p_i = detection probability (collection efficiency) at the i th site;

τ_i = the probability that a tagged, detected fish is transported at the i th site;

T_i = the number of juveniles in the transportation route (pathway) of the i th site;

T_0 = the total number of juveniles that entered the transport system, i.e., $\sum_i T_i$;

C_0 = the number of juveniles that migrated undetected at the transportation sites through
the Lower Snake River hydro system, i.e., the in-river migration route;

$A_j^{T_i}$ = the number of age j adults returning to LGR out of T_i juveniles;

$A_j^{C_0}$ = the number of age j adults returning to LGR out of C_0 juveniles;

$SAR(T_0)$ = the proportion of fish that return as adults out of T_0 juveniles;

$SAR(T_i)$ = the proportion of fish that return as adults out of T_i juveniles, i.e., a site
specific SAR ;

$SAR(C_0)$ = the proportion of fish that return as adults out of C_0 juveniles.

Basic Metrics

Transportation effectiveness is measured against in-river migration by comparing smolt-to-adult return (SAR) proportion for the two groups as follows,

$$\frac{T}{C} = \frac{SAR(T_0)}{SAR(C_0)} \quad (1)$$

where $SAR(T_0)$ and $SAR(C_0)$ are defined as above. Because the transportation system is regarded as starting at Lower Granite Dam (LGR), SAR s are the proportion of fish in a

cohort that survive from LGR as a juvenile back to LGR as an adult. The T/C ratio [Eq. (1)] is a measure of the relative rate of adult returns between the transportation group, (T_0), and in-river migrants, (C_0). Equation 1 will be greater than one when the number of adult returns relative to the number of juveniles in the transport group is greater than that of the in-river fish.

For the purposes of this study, *SARs* are defined as the proportion of fish passing LGR as juveniles that return to LGR as adults and for control and transported fish are expressed in terms of adult returns and juveniles, as follows,

$$SAR(C_0) = \frac{A^{C_0}}{C_0} \quad (2)$$

and

$$SAR(T_0) = \frac{A^{T_0}}{T_0} \quad (3)$$

respectively. Numerators in Eq. (2) and (3) are the sums of adult returns from all age classes, e.g., $A^{T_0} = \sum_j A_j^{T_0}$. The *SAR* is a joint probability of surviving through several life stages that

include migration from LGR through the Snake and Columbia Rivers (S_2, S_3, S_L), estuary migration and ocean residence (S_o), and adult return upstream back to LGR (S_A).

Subsequently, an *SAR* can be expressed entirely as a function of independent survival probabilities.

Derivation of the smolt-to-adult return estimators: $SAR(C_0)$ and $SAR(T_0)$

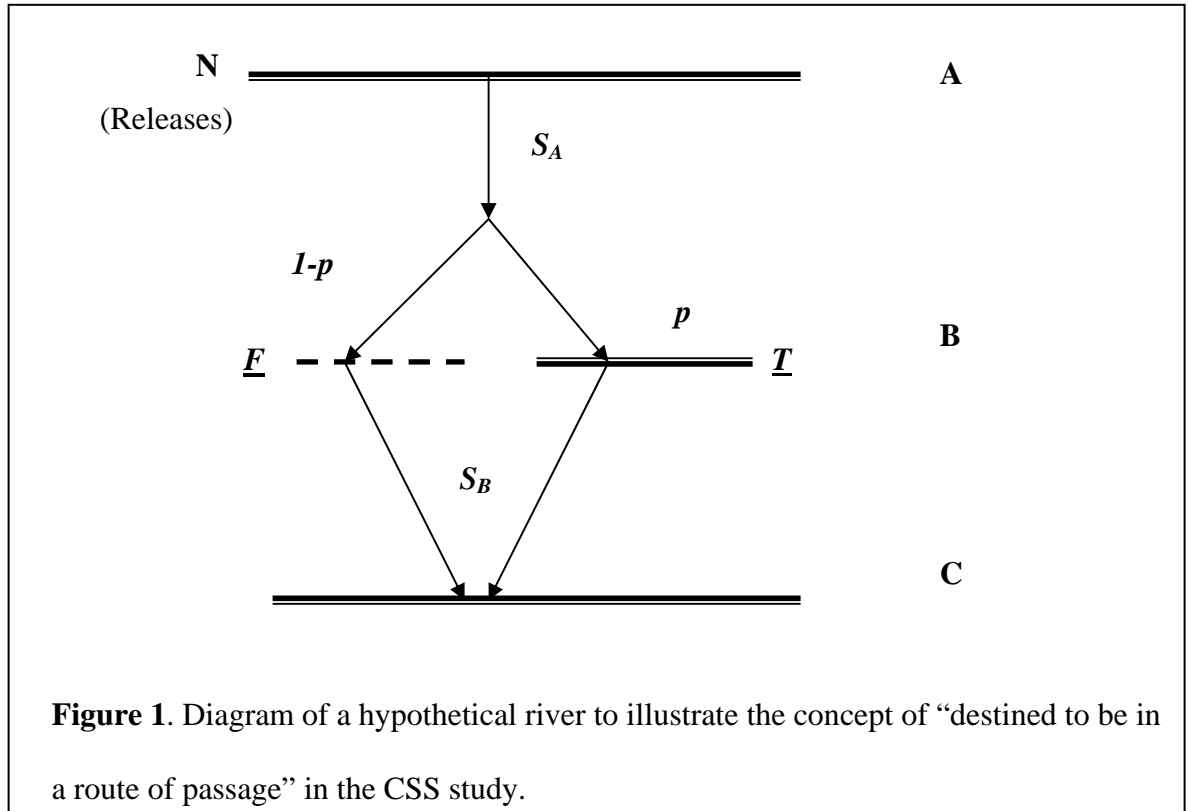
Estimating the *SARs* for in-river (control) and transported fish requires first calculating the numbers of juveniles (C_0 and T_0) and adults (A^{C_0} and A^{T_0}) comprising each group. Calculating the numbers of juveniles in each study group, C_0 and T_0 , is the more complex part of the study and thus requires the most explanation. Central to understanding the methods used to arrive at C_0, T_0, A^{C_0} , and A^{T_0} are three elements of the study mentioned in the introduction,

1. Smolt-to-adult return ratios are measured as the proportion of juveniles in each group at LGR that return as adults to LGR.
2. Only fish not previously detected at a dam are transported.
3. Fish are considered routed to transport at a particular dam or in-river passage before mortality occurs.

Juveniles migrating downstream encounter the start of the hydro system at Lower Granite Dam, the first transport site. Comparing *SARs* between the two groups starting at LGR fully incorporates the experience of both groups. That only previously undetected fish are transported is meant to mimic the experience of the run-at-large, i.e., tagged and untagged fish. The last element of the study, that fish are considered as entering either one of four possible migration pathways at LGR, three transport and one control, is because we are interested in the survival of fish before and after the treatment is applied. Assigning routes before the survival process occurs gives an estimate of survival from beginning of the study

at LGR to the end, also at LGR. Further, losses en route to a transport site are part of total transport mortality.

Conceptually, the “destined to be transported” part or third element of the CSS study can be difficult to convey. Consider a hypothetical river with two groups of fish, a treatment and control, and a dam, weir, or other obstacle in the middle (Figure 1). We are interested in studying the effect of the “treatment” (going through an obstacle), on survival from release to a point somewhere downstream of the treatment. In this study, logistics prevent assigning groups to the treatment ahead of time. A group of size N fish is released upstream at location A (Figure 1) and at location B, some fish go through the obstacle or treatment, at random, with probability p . Other fish do not encounter the obstacle, again at random, and pass freely down the river with probability $1 - p$. The effect of the treatment on survival is measured by comparing total survival from release at location A to C, $S_A S_B$, for treatment fish and against that of the control group (**T** and **F** respectively).



Based on the branch diagram in Figure 1, one can estimate of the number of group **T** fish by considering survival *then* passage route. The number in group **T** is comprised of those that first survived with probability S_A *then* passed through the treatment with probability p and is expressed mathematically as follows,

$$T = NS_A p.$$

The number of treatment fish surviving from treatment application (passing the obstacle) to the end of the study at point **C** is as follows,

$$T_C = NS_A p S_B.$$

By use of the expression for the number of treatment fish above, the estimate of the proportion of fish surviving to the last point, is as follows,

$$\frac{T_C}{T} = \frac{NS_A p S_B}{NS_A p} = S_B,$$

This is not the original metric of interest, $S_A S_B$.

Now consider assigning a route of passage prior to the onset of survival processes between **A** and **B**. Any released fish can pass through the treatment with probability p (because they have not died yet). The expected number of released fish passing through the treatment is Np . Some of these fish will die along the way with probability $(1 - S_A)$, and the remainders survive with probability S_A . After the survivors pass through the treatment at **B**, some mortality will occur on the way to point **C** with probability $1 - S_B$, and the rest of the fish will survive to **C** with probability S_B . The total number in the treatment group is then comprised of those that died between **A** and **B**, and between **B** and **C**, plus the survivors from **A** to **C**, expressed mathematically as follows,

$$T = \underbrace{Np(1 - S_A)}_{\text{Died between A and B}} + \underbrace{NpS_A(1 - S_B)}_{\text{Died between B and C}} + \underbrace{NpS_AS_B}_{\text{Survived to C}}$$

$$T = Np.$$

The proportion of fish surviving to site **C** out of T fish is now estimated as follows,

$$\frac{T_C}{T} = \frac{NS_A p S_B}{Np} = S_A S_B.$$

This is the original metric of interest. Hence, the idea of a destined route of passage is perhaps more accurately considered as the expected number of fish taking a particular route prior to mortality, where expectation is defined statistically as the number of trials (fish released) times the probability of being in a particular passage category.

Alternatively, one could partition site-to-site mortality between the two groups. The number of fish dying between points **A** and **B** is $N(1 - S_B)$ (Figure 1). The expected number of treatment (**T**) and control (**F**) mortalities is $N(1 - S_A)p$ and $N(1 - S_A)(1 - p)$, respectively. The expected number of fish surviving to site **B** but not to site **C** is $NS_A(1 - S_B)$. The expected number of mortalities between sites **B** and **C** in the treatment and control groups is $NS_A(1 - S_B)p$ and $NS_A(1 - S_B)(1 - p)$, respectively. The total number of fish in each group is the sum of the mortalities in each river section, plus the number surviving to site **C**. The total number of fish in control group **F** is calculated as follows,

$$F = N(1 - S_A)(1 - p) + NS_A(1 - S_B)(1 - p) + NS_A S_B(1 - p)$$

$$F = N(1 - p),$$

and the total number of fish in the treatment group (**T**) calculated as above.

This simple example is analogous to the process encountered in the CSS study where the treatment for some groups is applied after the start of the experiment. Whether we pre-assign a route of passage, divide mortalities proportionally among the different groups, or divide by survival, e.g., $T = \frac{NS_A p}{S_A}$, the results are the same. In all cases, we would arrive

at an estimate of the number in each group that will allow us to estimate survival from the beginning to the end of the experiment. We will continue with the idea of taking into account particular “fates” and apportioning mortality among groups to further motivate the derivation of the T/C ratio as the system becomes more complex.

The fish release site, the three transportation sites in the Lower Snake River, and possible passage routes under consideration in this study are as in Figure 2. We present passage routes for the three transport dams, LGR, LGS, and LMN in detail because this is where juvenile fish are routed to transport or in-river passage. The river system can be considered as two separate sections. Below LNM, fish are in transport around the remaining dams or migrate in-river through the hydro system. Above Lower Monumental Dam fish are classified between the two main study groups, transport and control. It is here that mortality associated with potential passage routes is taken into account as described above.

At the start of a migration season a cohort of tagged fish is released into the Snake River above LGR (Figure 2). The expected number of tagged fish arriving at LGR regardless of eventual passage route is the number of tagged releases, N_0 , multiplied by the probability of surviving to LGR, expressed as follows,

$$N_0 S_1^R.$$

At LGR, fish pass through the juvenile bypass system with probability p_2 (also called “collected”) or through other routes with probability $1 - p_2$. Fish entering the bypass system can be transported with probability τ_2 (Figure 2). Fish exiting LGR via non-detect routes

can be transported at LGS or LMN, or migrate in-river undetected. Post LGR passage and the associated fates within the routes under consideration in the CSS are shown using a branch diagram (Figure 2).

The derivation of each of the metrics used to compare in-river migration to transportation performance will refer back to Figure 2. We derive mathematical expressions for the basic metrics T/C , $SAR(T_0)$, and $SAR(C_0)$, and present numerical examples from a deterministic perspective, i.e., no variance. Estimation of survival, detection, and transport parameters is discussed briefly. Estimators for $SARs$ and the T/C ratio are then expressed as functions of estimable parameters. We conclude by listing the assumptions of the methods and their importance in making inferences to the population.

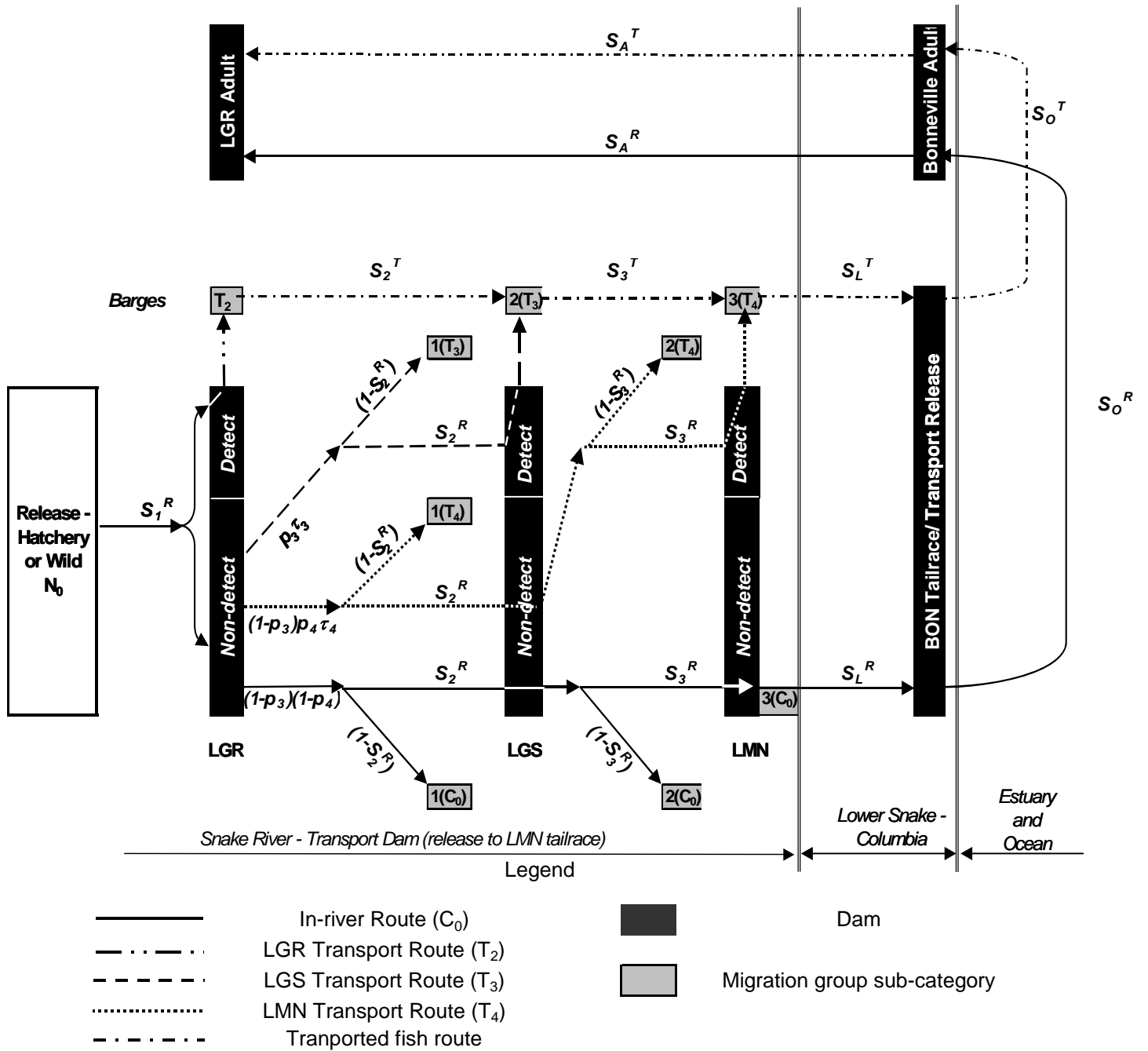


Figure 2. Schematic of the Lower Snake and Columbia River system with focus on the three transport sites, the migration routes, and the sub-categories or possible fates within each group.

Calculation of in-river (Control) SAR

Calculation of the number of juveniles for the undetected in-river passage group is the simplest among the three possible post LGR routes to describe (solid line, Figure 2). A fish passing undetected through the three transport sites is first undetected through LGR with probability $1 - p_2$. Of the number of fish in the tailrace in LGR, an expected proportion of $(1 - p_3)(1 - p_4)$ will be in the in-river migration route or C_0 group.

Fish in this undetected pathway are comprised of three groups each representing a possible fate. First, a fish could die in-river between LGR and LGS with probability $(1 - S_2^R)$ (C_0^1 , Figure 2). Expressed as a function of cohort release size N_0 , detection, and survival probabilities the number of C_0^1 juveniles is written as follows,

$$C_0^1 = N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4)(1 - S_2^R).$$

The two other possible fates are represented by juveniles that survive to LGS but die between LGS and LMN with probability $S_2^R(1 - S_3^R)$ (C_0^2 , Figure 2) and fish that survive to the tailrace of LMN with probability $S_2^R S_3^R$ (C_0^3 , Figure 2). The total number of fish in the undetected category, C_0 , is the sum of the three groups and is expressed mathematically as follows,

$$C_0 = \left[\underbrace{N_0 S_1^R (1-p_2)(1-p_3)(1-p_4)(1-S_2^R)}_{C_0^1} \right] + \left[\underbrace{N_0 S_1^R (1-p_2)(1-p_3)(1-p_4) S_2^R (1-S_3^R)}_{C_0^2} \right] + \left[\underbrace{N_0 S_1^R (1-p_2)(1-p_3)(1-p_4) S_2^R S_3^R}_{C_0^3} \right],$$

or more simply,

$$C_0 = N_0 S_1^R (1-p_2)(1-p_3)(1-p_4). \quad (4)$$

A returning adult that migrated undetected through the Lower Snake River as a juvenile would have had to survive undetected from the LGR tailrace to the LMN tailrace with probability $(1-p_3)(1-p_4)S_2^R S_3^R$ and survive in-river to the Bonneville tailrace with probability S_L^R . Subsequent to in-river migration as a juvenile, a fish would then need to survive migration through estuary, then ocean residence back to Bonneville with probability S_O^R , and finally survive adult migration back to LGR with probability S_A^R (solid line, Figure 2). Under the assumption of independent probabilities, the number of fish in the C_0 group that return as adults, A^{C_0} , is expressed as a function of release numbers, detection, and survival as follows,

$$A_{C_0} = N_0 S_1^R (1-p_2)(1-p_3)(1-p_4) S_2^R S_3^R S_L^R S_O^R S_A^R. \quad (5)$$

By the definition of Eq. (2) and use of the juvenile and adult numbers (Eq. (4) and (5), respectively), the *SAR* for fish migrating in-river is as follows,

$$SAR(C_0) = \frac{A_{C_0}}{C_0},$$

or,

$$SAR(C_0) = \frac{N_0 S_1^R (1-p_2)(1-p_3)(1-p_4) S_2^R S_3^R S_L^R S_O^R S_A^R}{N_1 S_1^R (1-p_2)(1-p_3)(1-p_4)}.$$

Simplifying the above equation leads to an expression for $SAR(C_0)$ that is a function exclusively of survival probabilities through each life stage from LGR as a juvenile to LGR as an adult

$$SAR(C_0) = S_2^R S_3^R S_L^R S_O^R S_A^R. \quad (6)$$

Calculation of the transport SAR

Although conceptually similar, determining the number of fish in the transport system is more complex than calculating juvenile numbers passing in-river. The total number of T_0 juveniles is the sum of the number transported from each of the three barge sites, LGR, LGS, and LNM or T_2 , T_3 , and T_4 , respectively. The derivation for the numbers of juveniles in each transport group is similar to that of the C_0 group where the possible fates of fish en route to the barge site are considered. Expressions for adult returns are more easily calculated than juvenile numbers. We derive the smolt-to-adult return rate for transported fish by considering site-specific transport route and adult return numbers.

Calculation of transported juveniles, returning adults, and SAR: Lower Granite Dam

The number of fish transported from LGR is the most easily calculated of all the transport groups (Figure 2). Fish survive from release to LGR with probability, S_1^R , are detected with probability p_2 , and are transported with probability τ_2 . The total number of fish transported from LGR, T_2 , is expressed mathematically as follows,

$$T_2 = N_0 S_1^R p_2 \tau_2. \quad (7)$$

A fish transported as a juvenile at LGR returning as an adult to LGR has to first survive past LGS and LMN in the barge with joint probability $S_2^T S_3^T$, then survive transport through the lower Snake and Columbia rivers to the transport release site with probability S_L^T (Figure 2). Upon release, the same fish would have to survive estuary migration and ocean residence back to Bonneville with probability S_O^T and finally survive upstream migration to LGR with probability S_A^T (Figure 2). The total number of adults returning to LGR that were transported as juveniles, A_{T_2} , is expressed in terms of release numbers, detection, transport, and survival probabilities as follows,

$$A_{T_2} = N_0 S_1^R p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T. \quad (8)$$

By the definition of Eq. (3), the site-specific return probability for fish transported from LGR, $SAR(T_2)$, is written as,

$$SAR(T_2) = \frac{A_{T_2}}{T_2} = \frac{N_0 S_1^R p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T}{N_0 S_1^R p_2 \tau_2}$$

or, more simply,

$$SAR(T_2) = S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2}. \quad (9)$$

Hence, the SAR for fish transported from LGR can be expressed solely as a joint survival probability through several life stages.

Calculation of transported juveniles, returning adults, and SAR: Little Goose Dam

The expected number of fish not detected at LGR is expressed as follows, $N_0 S_1^R (1 - p_2)$. Juveniles in this group are routed to one of three pathways, transport at LGS, transport at LMN, or in-river passage (Figure 2). The probability of being in the LGS transport group is $p_3 \tau_3$. Of these fish, some will die in-river on the way to LGS with probability $(1 - S_3^R) (T_3^1)$, and the rest survive with probability $S_2^R (T_3^2)$. The expected number of fish in this route, T_3 , can therefore be expressed as

$$T_3 = \underbrace{N_0 S_1^R (1 - p_1) p_3 \tau_3 (1 - S_2^R)}_{T_3^1} + \underbrace{N_0 S_1^R (1 - p_1) p_3 \tau_3 S_2^R}_{T_3^2},$$

or

$$T_3 = N_0 S_1^R (1 - p_1) p_3 \tau_3. \quad (10)$$

Fish returning to LGR as adults that were in the LGS transport pathway as juveniles in the tailrace of LGR (dotted line, Figure 2) would have had to survive in-river to the transport site with probability S_2^R . Subsequent to entering the barge at LGS, a fish would

have had to survive in the barge past LMN to the transport release site with joint probability, $S_3^T S_L^T$, survive in the estuary migration, ocean residence and back to BON with probability S_O^T , and finally survive in-river migration as an adult back to LGR with probability S_A^T (dotted-dashed line, Figure 2). Hence, the number of fish in the LGS pathway surviving from LGR as a juvenile back to LGR as an adult can be written as,

$$A_{T_3} = N_0 S_1^R (1 - p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T, \quad (11)$$

Following the definition of Eq. (3), the site specific smolt-to-adult return proportion for fish in the LGS transport route, $SAR(T_3)$, is as follows,

$$SAR(T_3) = \frac{N_0 S_1^R (1 - p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T}{N_0 S_1^R (1 - p_2) p_3 \tau_3}$$

or more simply,

$$SAR(T_3) = S_2^R S_3^T S_L^T S_O^T S_A^T. \quad (12)$$

Again, the SAR for fish transported at LGS is a function of the probability of surviving from LGR as a juvenile back to LGR as an adult through all associated life stages. The $SAR(T_3)$ also includes S_2^R , the survival through that portion of the river traveled by juveniles to the transport site.

Calculation of transported juveniles, returning adults, and SAR: Lower Monumental Dam

The number of juveniles on the transport route to LMN, T_4 , can meet three possible fates; not survive between LGR and LGS with probability $(1 - S_2^R)(T_4^1)$, survive to LGS tailrace and die on the way to LMN with probability $S_2^R(1 - S_3^R)(T_4^2)$, or survive to the transport site with probability $S_2^R S_3^R(T_4^3)$. The total number of fish in the LMN transport route is the sum of the number of fish in these groups and is expressed mathematically as,

$$T_4 = \left[\underbrace{N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 (1 - S_2^R)}_{T_4^1} \right] + \left[\underbrace{N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R (1 - S_3^R)}_{T_4^2} \right] + \left[\underbrace{N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R}_{T_4^3} \right].$$

Simplifying the above equation gives the number of fish in the LMN transport route as a function of tag release numbers, survival, detection, and transport probabilities as follows,

$$T_4 = N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4. \quad (13)$$

The number of fish surviving the LMN transport route and returning to LGR as adults is expressed mathematically as

$$A_{T_4} = N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T. \quad (14)$$

By use of the definition in Eq. 3, the site-specific SAR for fish in the LMN transport route, $SAR(T_4)$, is expressed as,

$$SAR(T_4) = \frac{N_0 S_1^R (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T}{N_0 S_1^R (1-p_2)(1-p_3) p_4 \tau_4},$$

or more simply,

$$SAR(T_4) = S_2^R S_3^R S_L^T S_O^T S_A^T \quad (15)$$

Again, the SAR for fish in this passage route is a function of survival probabilities only, including some in-river survival associated with traveling to the transport site, i.e., $S_2^R S_3^R$.

Transport smolt-to-adult return rate, $SAR(T_0)$

The SAR for transported fish is, by definition [Eq. (3)], the number of returning adults divided by the number of juveniles in the transport system. Total juveniles in the transport system, T_0 , are calculated from the numbers each transport sub-group [Eqs. (7), (10), and (13)] as follows,

$$T_0 = N_0 S_1^R (p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4). \quad (16)$$

The expected number of returning adults, A_{T_0} , out of T_0 transported juveniles is calculated by the sum of Eqs. (8), (11), and (14) as follows,

$$A_{T_0} = N_0 S_1^R (p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T + (1-p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T + (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T)$$

The smolt-to-adult return proportion for fish in the transport system [Eq. 3] is expressed as follows,

$$SAR(T_0) = \frac{A_{T_0}}{T_0},$$

or

$$SAR(T_0) = \frac{p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T + (1-p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T + (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T}{p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4} \quad (17)$$

Alternatively, the transport SAR can be expressed as a weighted average across all transport groups, with weights equal to the proportion of fish transported from each site. The transport SAR as a weighted average is written as follows,

$$SAR(T_0) = \sum_{i=2}^4 w_i SAR(T_i), \quad (18)$$

where $w_i = \frac{T_i}{T_0}$, the proportion of fish in each of the i transport routes [Eqs. (7), (10), and

(13) for T_2, T_3 , and T_4 , respectively] and $SAR(T_i)$, the site specific $SARs$ defined in Eqs. (9),

(12), and (15).

T/C Ratio, behavior under the null hypothesis [$H_0 : (T/C) = 1$] and numerical

examples

The transport to in-river survival ratio can be written in terms of site-specific adult return probabilities [Eq. (1)] as follows,

$$T/C = \frac{p_2 \tau_2 S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2} + (1-p_2) p_3 \tau_3 S_2^R S_3^{T_3} S_L^{T_3} S_O^{T_3} S_A^{T_3} + (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^{T_4} S_O^{T_4} S_A^{T_4}}{p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4} \frac{S_2^R S_3^R S_L^R S_O^R S_A^R}{S_2^R S_3^R S_L^R S_O^R S_A^R}$$

or,

$$\frac{T}{C} = \frac{p_2 \tau_2 S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2} + (1-p_2) p_3 \tau_3 S_2^R S_3^{T_3} S_L^{T_3} S_O^{T_3} S_A^{T_3} + (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^{T_4} S_O^{T_4} S_A^{T_4}}{S_2^R S_3^R S_L^R S_O^R S_A^R [p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4]} \quad (19)$$

Using the convention of Sanford and Smith (1991) and Buchanan (2005), the site-specific

T/C ratios can be expressed as $R_i = \frac{SAR(T_i)}{SAR(C_0)}$ and Eq. (19) re-expressed as,

$$\frac{T}{C} = \frac{R_2 \cdot p_2 \tau_2 + R_3 \cdot (1-p_2) p_3 \tau_3 + R_4 \cdot (1-p_2)(1-p_3) p_4 \tau_4}{[p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4]},$$

or

$$\frac{T}{C} = \sum_{i=2}^4 w_i R_i \quad (20)$$

where w_i is defined as in Eq. (18). The overall T/C ratio can be written as an average of site specific ratios, R_i weighted by the probability of being transported from each site. However, Eqs. (19) and (20) are specific to the design elements of the CSS study and not a general T/C ratio for all possible situations.

Behavior of T/C under the null

One of the ways to check the properties of an equation is to observe the behavior under the null hypothesis, the only condition under which the outcome is known. For the T/C ratio, the null hypothesis means that there is no difference in the rate of relative adult returns between transported and in-river migrating juveniles. No difference in relative survival between transported and control fish could be satisfied under the following set conditions,

$$S_2^{T_i} = S_2^R; S_3^{T_i} = S_3^R; S_4^{T_i} = S_4^R; S_L^{T_i} = S_L^R; S_O^{T_i} = S_O^R; \text{ and } S_A^{T_i} = S_A^R, \forall i.$$

If true, then $R_i = 1$ for all i and Eq. (20), the T/C ratio is equal to one. Note that the result does not depend on detection and transport probabilities but only on survival.

Numerical example 1a: Equal return rates between transport and control groups (Null model), 100% transport

To further illustrate the calculations to arrive the T/C ratio for a cohort of fish, we consider a year in which the rates of return are the same for both groups, i.e., the null condition of no difference between the transport and control group with regard to smolt-to-adult return ratios. Illustrating the properties of the T/C ratio is easiest under this scenario. Moreover, examining conditions under the null hypothesis is one way to verify that a particular estimator behaves as expected. In this example, probabilities of survival are the same for fish in the transport group and control groups (Table 1). For simplicity, detection probabilities are equal among the three sites and all detected fish are transported, i.e., $\tau_2 = \tau_3 = \tau_4 = 1$. We relax these last conditions in the next example. Numbers of fish comprising transport and control groups are presented in Table 2, given a fixed cohort release size and the stated probabilities. Starting from the release site to eventual return as an adult, we follow a cohort of fish through a simplified life history to illustrate the calculation of the T/C ratio (Eq. (19)).

Table 1. Hypothetical survival, detection, and transport probabilities for a cohort of 50,000 tagged fish.

Segment	Segment designation (<i>i</i>)	In River Survival S_i^R	Transport Route Survival S_i^T	Location (<i>i</i>)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.3	1.00
LGR to LGS	2	0.8	0.8	LGS (3)	0.3	1.00
LGS to LMN	3	0.8	0.8	LMN (4)	0.3	1.00
LMN-BON (L)	L	0.5	0.5			
BON-BON (Ocean)	O	0.05	0.05			
BON-LGR	A	0.8	0.8			

Table 2. Numbers of fish comprising each migration category sub-categories, e.g., C_0^1 , for a hypothetical release of 50,000 fish and the probabilities given in Table 1. Shaded boxes correspond to the shaded sub-categories in Figure 2.

Segment	Fish Surviving to Site, In-river (Bold) (Undetected in Snake R.)			Total Mortalities Between Sites	In River Mortalities to C_0 category	In River Mortalities to T_0 category	Fish Added to Barge At Site (Bold)	Fish in Barge At Site (Bold)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to LGR	28000						12000 (T_2)	12000	
LGR to LGS	15680	10976 ($C_0^2 + C_0^3$)	4704 ($T_4^2 + T_4^3$)	5600	2744 (C_0^1)	1680 (T_3^1) 1176 (T_4^1)	6720 (T_3^2)	16320	2400
LGS to LMN	8781	8781 (C_0^3)		3136	2195 (C_0^2)	941 (T_4^2)	3763 (T_4^3)	16819	3264
LMN-BON	4390							8410	
BON-BON (Ocean residence)	220							420	
BON-LGR	176							336	

We begin by calculating the numbers of juveniles in each passage group, i.e., C_0 and T_0 . At a hatchery above Lower Granite Dam, 50,000-tagged fish are released ($N_1 = 50,000$). Of this tag release group, 12,000 juveniles are put to the barge at LGR T_2 , (Figure 2) calculated by Eq. (7) as follows,

$$\begin{aligned} T_2 &= N_0 S_1^R p_2 \tau_2 \\ &= 50000(0.8)(0.3)(1) \\ T_2 &= 12,000 \end{aligned}$$

Fish surviving to LGR pass undetected are comprised of the C_0, T_3 , and T_4 groups, calculated as,

$$\begin{aligned} C_0 + T_3 + T_4 &= N_0 S_1^R (1 - p_2) \\ C_0 + T_3 + T_4 &= 50000(0.8)(1 - 0.3). \\ C_0 + T_3 + T_4 &= 28,000 \end{aligned}$$

Of the number of fish in the tailrace of LGR, $(1 - S_2^R)$ % of each group will not make it to the next site (Figure 2). Because getting to an eventual passage route will have associated mortality, we apportion number of mortalities within the reach (segment of the river) according to the probability a fish will be in a particular route of passage among three groups. The total number of mortalities, $28000 \cdot (1 - S_2^R)$, between LGR and LGS are comprised of the C_0^1, T_3^1 , and T_4^1 groups (Figure 2), each calculated as follows,

$$\begin{aligned} C_0^1 &= N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4)(1 - S_2^R) \\ &= 50000(0.8)(0.7)(0.7)(0.7)(0.2) \\ C_0^1 &= 2744, \end{aligned}$$

$$\begin{aligned}
T_3^1 &= N_0 S_1^R (1 - p_2) p_3 \tau_3 (1 - S_2^R) \\
&= 50000(0.8)(0.7)(0.3)(1)(0.2) \\
T_3^1 &= 1680,
\end{aligned}$$

and

$$\begin{aligned}
T_4^1 &= N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 (1 - S_2^R) \\
&= 50000(0.8)(0.7)(0.7)(0.3)(1)(0.2) \\
T_4^1 &= 1176.
\end{aligned}$$

The second fate for fish in the LGS transport path is survival to the barge. The number of fish in the T_3^2 group that is eventually added to the T_2 surviving fish already in the barge is calculated by,

$$\begin{aligned}
T_3^2 &= N_0 S_1^R (1 - p_2) p_3 \tau_3 S_2^R \\
&= 50,000(0.8)(0.7)(0.3)(1)(0.8) \\
T_3^2 &= 6720.
\end{aligned}$$

All of the T_3 transport group, those on the LGS transport pathway (route) are accounted for at this site. The total number of T_3 fish is $T_3^1 + T_3^2 = 1,680 + 6,720 = 8,400$.

Arriving at the tailrace of LGS are the remainder of the fish in the C_0 and T_4 groups. Juveniles that will eventually migrate in-river (C_0 group) and have survived the second river segment (LGR to LGS) plus those that will be transported at LMN (T_4) and survived through this reach comprise the 15,680-tagged fish in the tailrace of LGS. Of these fish, $(1 - S_3^R)$ percent, or 3,136 juveniles, will meet the second fate of not surviving to LMN,

groups C_0^2 and T_4^2 (Figure 2). The numbers in each group are calculated as follows, respectively,

$$\begin{aligned} C_0^2 &= N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R (1 - S_3^R) \\ &= 50000(0.8)(0.7)(0.7)(0.7)(0.8)(0.2) \\ &= 2195 \end{aligned}$$

and

$$\begin{aligned} T_4^2 &= N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R (1 - S_3^R) \\ &= 50,000(0.8)(0.7)(0.7)(0.3)(1)(0.8)(0.2) \\ T_4^2 &= 941. \end{aligned}$$

The third fate for the C_0 fish is survival to the tailrace of LMN and eventual passage through the hydro system. The number in the group is calculated as

$$\begin{aligned} C_0^3 &= N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R S_3^R \\ &= 50,000(0.8)(0.7)(0.7)(0.7)(0.8)(0.8) \\ C_0^3 &= 8781 \end{aligned}$$

The third fate for the fish in the LGS transport group, T_4^3 , is eventual survival to the barge for downstream passage. The number of fish in this group is calculated as follows,

$$\begin{aligned} T_4^3 &= N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R \\ &= 50,000(0.8)(0.7)(0.7)(0.3)(1)(0.8)(0.8) \\ T_4^3 &= 3763 \end{aligned}$$

The total number of fish in the control group is the sum of the C_0 mortalities between LGR and LMN plus the number of fish surviving to LNM tailrace is computed as,

$$\begin{aligned}
C_0 &= C_0^1 + C_0^2 + C_0^3 \\
C_0 &= 2744 + 2195 + 8781 \\
C_0 &= 13720
\end{aligned}$$

This is equivalent to calculating the expected number of C_0 fish by Eq. (4) as follows,

$$\begin{aligned}
C_0 &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) \\
&= 50,000(0.8)(0.7)(0.7)(0.7) \\
C_0 &= 13720.
\end{aligned}$$

The total number of fish in the T_0 group is the sum of all possible fates between LGR and LMN for fish in the transport routes, calculated as follows,

$$\begin{aligned}
T_0 &= T_2 + (T_3^1 + T_4^1) + T_3^2 + T_4^2 + T_4^3 \\
&= 12000 + (2856) + 6720 + 941 + 3763 \\
T_0 &= 26280
\end{aligned}$$

Of the 8781 fish in the C_0 group that survived to LMN, 4,390 juveniles survived migration through the rest of the system to the tailrace of Bonneville with $8781 \cdot S_L^R$, and 220 eventually returned as adults to Bonneville Dam (BON). Of these adult returns, 176 fish were eventually observed at LGR. The expected number of adults in the control group returning to LGR is calculated by Eq. (5) as follows,

$$\begin{aligned}
A_{C_0} &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R S_3^R S_L^R S_O^R S_A^R \\
&= 50,000(0.8)(0.7)(0.7)(0.7)(0.8)(0.8)(0.5)(0.05)(0.8) \\
A_{C_0} &= 176
\end{aligned}$$

The smolt-to-adult return proportion for control fish is calculated by the definition in Eq. (2) as follows,

$$\begin{aligned} SAR(C_0) &= \frac{A_{C_0}}{C_0} \\ &= \frac{176}{13720} \\ SAR(C_0) &= 0.0128 \end{aligned}$$

Alternatively, the SAR can be calculated as the product of survival probabilities [Eq. (6)] as follows,

$$\begin{aligned} SAR(C_0) &= S_2^R S_3^R S_L^R S_O^R S_A^R \\ &= (0.8)(0.8)(0.5)(0.05)(0.8) \\ SAR(C_0) &= 0.0128. \end{aligned}$$

The number of adults returning to LGR of the transported fish is again slightly more complex. Of the 12,000 T_2 juveniles put in the barge, 9600 survived to LGS and 2400 died on the way, i.e., $S_2^T = 0.8$. At the second transport site, LGS, 6,720 of the T_3 fish were added. A total of 16,320 juveniles were alive in the barge upon leaving LGS. Between LGS and LMN, 3,264 juveniles died, i.e., $S_3^T = 0.8$ and 3,763 T_4 surviving juveniles were added at LMN. Subsequently, there were 16,819 live fish in the barge upon entering the lower hydro system. Survival in the barge through the lower river, S_L^T was 50% , hence only 8,410 were released alive below BON. Of these, 420 survived to adult return (sum of all age classes; $S_O^T = 0.05$) at BON, and 336 were observed at LGR. From these data, the smolt-to-

adult return proportion for fish in the T_0 group is calculated according to the definition of an SAR [Eq. (3)] as follows,

$$\begin{aligned} SAR(T_0) &= \frac{A_{T_0}}{T_0} \\ &= \frac{336}{26208} \\ SAR(T_0) &= 0.0128. \end{aligned}$$

The $SAR(T_0)$ can also be computed using site specific SARs Eq (18) as follows,

$$\begin{aligned} SAR(T_2) &= S_2^{T_2} S_3^{T_2} S_L^{T_2} S_O^{T_2} S_A^{T_2} \\ &= (0.8)(0.8)(0.5)(0.05)(0.8) \\ SAR(T_2) &= 0.0128 \end{aligned}$$

and for T_3 and T_4 , $SAR(T_3) = 0.0128$ and $SAR(T_4) = 0.0128$, respectively. The proportions of T_0 fish transported from each site, w_2, w_3 , and w_4 , are calculated as follows,

$$w_2 = \frac{12000}{26280} = 0.456, w_3 = \frac{8400}{26280} = 0.320, \text{ and } w_4 = \frac{5880}{26280} = 0.224,$$

respectively. Then, using Eq. (18) $SAR(T_0)$ is,

$$SAR(T_0) = w_2 SAR(T_2) + w_3 SAR(T_3) + w_4 SAR(T_4)$$

$$SAR(T_0) = 0.456(0.0128) + 0.320(0.0128) + 0.224(0.0128)$$

$$SAR(T_0) = 0.0128.$$

By use of the definition in Eq. 1, the T/C ratio is calculated as follows,

$$\begin{aligned} T/C &= \frac{SAR(T_0)}{SAR(C_0)} \\ &= \frac{0.0128}{0.0128} , \\ T/C &= 1 \end{aligned}$$

or by Eq. (20) where $R_i = \frac{SAR(T_i)}{SAR(C_0)}$, as

$$\begin{aligned} T/C &= w_2R_2 + w_3R_3 + w_4R_4 \\ &= 0.456(1) + 0.320(1) + 0.224(1) \\ T/C &= 1. \end{aligned}$$

In the next example, not all collected (detected) fish are transported.

Numerical example 1b: Equal return rates between transport and control groups (Null model), differential detection and survival probabilities among transport sites.

In this example, all survival probabilities are as in example 1a, however, each transport site has a different detection (collection) probability (Table 3). Furthermore, transport probabilities are less than one and differ among the three sites (Table 3). Again, we follow a cohort of 50,000 tagged fish from release to eventual return as an adult to LGR and compute the number of fish in each category and at each stage of migration through the three transport dams (Table 4), the SARs for each group and T/C ratio.

As in Example 1a, 40,000 fish survive to LGR, 24,000 of which are undetected (Table 4). However, this time only 10,560 of 16,000 collected (detected) juveniles are

transported, i.e., $T_2 = 10,560$, Eq. (7). The remaining 5,440 juveniles that were detected (collected) are returned to the river for the purposes of estimating survival and detection probabilities. Because these fish have a prior detection history, they are not subject to transport, nor can they be included in the C_0 category. Thus, they are no longer part of the study except for purposes of parameter estimation.

Table 3. Hypothetical reach survival and site-specific detection and transport probabilities for Example 1b.

Segment	Segment designation (<i>i</i>)	In-river Survival S_i^R	Transport Route Survival S_i^T	Location (<i>i</i>)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.4	0.66
LGR to LGS	2	0.8	0.8	LGS (3)	0.35	0.5
LGS to LMN	3	0.8	0.8	LMN (4)	0.5	0.6
LMN-BON (L)	L	0.5	0.5			
BON-BON (Ocean)	O	0.05	0.05			
BON-LGR	A	0.8	0.8			

Table 4. Hypothetical numbers of fish in each category and sub-category (intermediate calculations) for Example 1b. Shaded cells correspond to sub-categories in Figure 2. Release size is 50,000 tagged fish.

Segment	Fish Surviving to Site (Bold), In-river (Undetected in Snake R.)			Total Mortalities In-river Between Sites	In-river Mortalities to C_0 category	In-river Mortalities to T_0 category	Fish Added to Barge At Site (Bold)	Fish in Barge At Site (Bold)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to LGR	24000						10560 (T_2)	10560	
LGR to LGS	12480	6240 ($C_0^2 + C_0^3$)	3744 ($T_4^2 + T_4^3$)	4800	1560 (C_0^1)	840 (T_3^1) 936 (T_4^1)	3360 (T_3^2)	11808	2112
LGS to LMN	4992	4992 (C_0^3)		2496	1248 (C_0^2)	749 (T_4^2)	2995 (T_4^3)	12442	2362
LMN-BON		2496						6221	
BON-BON		125						311	
BON-LGR		100						249	

Of the 24,000 undetected fish in the tailrace of LGR, 4,800 die within the next river reach and include 1,560 C_0 fish (C_0^1 , Figure 2; Table 1), 840 T_3 fish (T_3^1 , Figure 2 and Table 4), and 936 T_4 fish (T_4^1 , Figure 2; Table 4). The numbers in each of these sub-categories are calculated as follows, respectively,

$$\begin{aligned} C_0^1 &= N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4)(1 - S_2^R) \\ &= 50000(0.8)(0.6)(0.65)(0.5)(0.2) \\ C_0^1 &= 1,560, \end{aligned}$$

$$\begin{aligned} T_3^1 &= N_0 S_1^R (1 - p_2) p_3 \tau_3 (1 - S_2^R) \\ &= 50000(0.8)(0.6)(0.35)(0.5)(0.2) \\ T_3^1 &= 840, \end{aligned}$$

and

$$\begin{aligned} T_4^1 &= N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 (1 - S_2^R) \\ &= 50,000(0.8)(0.6)(0.65)(0.5)(0.6)(0.2) \\ T_4^1 &= 936. \end{aligned}$$

The 1,464 unaccounted for mortalities in the LGR-LGS reach ($4,800 - C_0^1 - T_3^1 - T_4^1 = 1,464$) are part of the group of juveniles that are detected in the Snake River at least once but are not transported and thus are no longer part of the study.

Surviving to transport at LGS are 3,360 juveniles ($T_3^2 = 3,360$). The number of juveniles placed in transport at LGS is calculated as follows,

$$\begin{aligned}
T_3^1 &= N_0 S_1^R (1 - p_2) p_3 \tau_3 S_2^R \\
&= 50000(0.8)(0.6)(0.35)(0.5)(0.8) \\
T_3^1 &= 3,360.
\end{aligned}$$

The total number of fish in the LGS transport group is the sum of the two T_3 sub-groups, those dying in the second river reach (LGR to LGS) and those that survive to actual transport, or $T_3 = T_3^1 + T_3^2 = 4,200$. This is equivalent to the result obtained by computing the expected number fish in the LGS transport group by use of Eq. (10).

Entering the river reach below LGS are 6,240 and 3,744 fish remaining in the C_0 , and T_4 migration routes, respectively. Of the control fish, 1,248 do not survive to the next dam (C_0^2), and 4,992 arrive at the tailrace of LMN (C_0^3). The numbers in each sub-category are calculated as,

$$\begin{aligned}
C_0^2 &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R (1 - S_3^R) \\
&= 50,000(0.8)(0.6)(0.65)(0.5)(0.8)(0.2) \\
C_0^2 &= 1,248
\end{aligned}$$

and

$$\begin{aligned}
C_0^3 &= N_1 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_2^R S_3^R \\
&= 50,000(0.8)(0.6)(0.65)(0.5)(0.8)(0.8) \\
C_0^3 &= 4,992.
\end{aligned}$$

Of the 3,744 remaining fish in the LMN transport pathway, 749 die in the reach below LGS ($T_4^2 = 749$; Figure 2; Table 4), and 2,995 survive to actual transport ($T_4^3 = 2,995$). The numbers of fish in each of the T_4 sub-categories, T_4^2 and T_4^3 , are estimated as follows,

$$\begin{aligned} T_4^2 &= N_1 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R (1 - S_3^R) \\ &= 50,000(0.8)(0.6)(0.65)(0.5)(0.6)(0.8)(0.2) \\ T_4^2 &= 749 \end{aligned}$$

and

$$\begin{aligned} T_4^3 &= N_1 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R \\ &= 50,000(0.8)(0.6)(0.65)(0.5)(0.6)(0.8)(0.8) \\ T_4^3 &= 2,995. \end{aligned}$$

The total number of fish in the LNM transport group (pathway) is the sum of fish experiencing one of three possible fates on the way to the barge: dying in the 2nd river reach (the T_4^1 group); surviving to the tailrace of LGS but not to LMN (the T_4^2 group); and arriving to actual transport at LMN (the T_4^3 fish). The total number of T_4 fish is,

$$\begin{aligned} T_4 &= T_4^1 + T_4^2 + T_4^3 \\ &= 936 + 749 + 2995 \\ T_4 &= 4,680. \end{aligned}$$

The total number of fish in the transport group, T_0 , can be calculated by either summing the totals of the individual pathways as follows,

$$\begin{aligned}
T_0 &= T_2 + T_3 + T_4 \\
&= 10,590 + 4200 + 4680 \\
T_0 &= 19,440,
\end{aligned}$$

or by use of Eq.(16),

$$\begin{aligned}
T_0 &= N_1 S_1^R [p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4] \\
&= 50,000(0.8) [(0.4)(0.66) + (0.6)(0.35)(0.5) + (0.6)(0.65)(0.5)(0.6)] \\
T_0 &= 19,440
\end{aligned}$$

The total number of juveniles in the control groups is calculated by use of subgroups as follows,

$$\begin{aligned}
C_0 &= C_0^1 + C_0^2 + C_0^3 \\
&= 1560 + 1248 + 4992 \\
C_0 &= 7800
\end{aligned}$$

or by use of Eq. (4)

$$\begin{aligned}
C_0 &= N_1 S_1^R (1-p_2)(1-p_3)(1-p_4) \\
&= 50,000(0.8)(0.6)(0.65)(0.5) \\
C_0 &= 7,800.
\end{aligned}$$

The adults that return out of the T_0 juveniles in the transport routes are calculated by considering the 10,560 fish that were transported at LGR (Table 4). Of these fish, 80% survive to LGS where 3,360 fish are added (Table 3 and Table 4). Upon leaving LGS, 11,808 juveniles are in transport, i.e., $10,560(0.8) + 3,360 = 11,808$, with 80% surviving to LMN ($S_3^T = 0.8$; Table 3). At the final transport site, 2995 T_4^3 fish are added. Twelve-thousand four hundred forty-two (12,442) juveniles are then barged downstream past the

dams on the Columbia River. Survival in the barge through the lower river reaches to the release site below Bonneville Dam is 50%. Hence, only 6,221 live fish are released from the barge. Survival from transport release back to Bonneville as an adult for the T_0 fish is 5%, and 311 adults are observed at BON. Adult in-river survival is 80% and 249 adult fish return out of the 19,440 in the T_0 group leaving LGR as juveniles. The SAR for the transport category is calculated by Eq. (3) as follows,

$$\begin{aligned} SAR(T_0) &= \frac{A_{T_0}}{T_0} \\ &= \frac{249}{19440} \\ SAR(T_0) &= 0.0128. \end{aligned}$$

Alternatively, $SAR(T_0)$ can be calculated use of Eq. (18). The SAR s for each transport group are the same as in Example 1a , $SAR(T_2) = 0.0128$, $SAR(T_3) = 0.0128$ and $SAR(T_4) = 0.0128$. The proportion of T_0 fish in each of the three transport groups, w_2, w_3 , and w_4 , are calculated as,

$$w_2 = \frac{10590}{19440} = 0.5448, w_3 = \frac{4200}{19440} = 0.2160, \text{ and } w_4 = \frac{4680}{19440} = 0.2407,$$

respectively, and $SAR(T_0)$ estimated as,

$$SAR(T_0) = \sum_{i=2}^4 w_i SAR(T_i)$$

$$SAR(T_0) = 0.5448(0.0128) + 0.2160(0.0128) + 0.2407(0.0128)$$

$$SAR(T_0) = 0.0128.$$

Although not all detected fish were transported and detection probabilities differed among sites, $SAR(T_0)$ is the same as in Example 1a, indicating that the calculation for the smolt-to-adult return proportion depends only on survival probabilities.

The number of adults returning to LGR out of the 7,800 juveniles in the C_0 first must survive to the LMN tailrace. Out of the 4992 C_0 juveniles in the tailrace of LMN (Table 4), only half survive through the hydro system from below LNM to the tailrace of BON, or 2,496 fish. Survival back to BON as an adult is 5%. Hence, 125 C_0 fish are observed at BON as a returning adult, and 100 survive upstream migration to LGR. The $SAR(C_0)$ is calculated by Eq. (2) as follows,

$$SAR(C_0) = \frac{A_{C_0}}{C_0}$$

$$= \frac{100}{7800}$$

$$SAR(C_0) = 0.0128,$$

or by Eq. (6) as in Example 1a. The $SARs$ for both groups are the same as in the previous example and the T/C ratio is also the same, i.e., $T/C = 1$. The only change between the two examples is the detection and transport probabilities. Because the transport SAR does not depend on detection and transport probabilities when site-specific $SARs$ are the same, the

T/C ratio as calculated by Eq. (19) (or Eq. (20)) is independent of these parameters under the null hypothesis, as expected.

Numerical example 2: Estimating the T/C ratio using survival, detection and transport probabilities under Eq. (19)

The last two examples focused on the behavior of the T/C ratio under the null hypothesis. In addition, the examples demonstrated how mortality between the groups can be partitioned by apportioning survival among possible routes of passage. The numerical examples further motivate the derivation of the T/C ratio from first principles. In this next example, we examine a cohort release for which there was a clear benefit of transportation. However, we calculate the T/C ratio entirely from survival, detection, and transport probabilities by use of Eq. (19).

Consider a cohort with survival, detection, and transport probabilities listed in Table 5. From these data $SAR(T_0)$ is estimated by use of Eq. (17) written as follows,

$$SAR(T_0) = \frac{p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T + (1-p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T + (1-p_2)(1-p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T}{p_2 \tau_2 + (1-p_2) p_3 \tau_3 + (1-p_2)(1-p_3) p_4 \tau_4} \cdot$$

The numerator is calculated by the probabilities in Table 5 as,

$$\begin{aligned}
Num. &= p_2 \tau_2 S_2^T S_3^T S_L^T S_O^T S_A^T \\
&+ (1 - p_2) p_3 \tau_3 S_2^R S_3^T S_L^T S_O^T S_A^T \\
&+ (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R S_L^T S_O^T S_A^T
\end{aligned}$$

$$\begin{aligned}
Num. &= (0.4)(0.5)(0.9)(0.8)(0.6)(0.075)(0.8) \\
&+ (0.6)(0.6)(0.66)(0.8)(0.8)(0.6)(0.075)(0.8) \\
&+ (0.6)(0.4)(0.5)(0.6)(0.8)(0.9)(0.6)(0.075)(0.8) \\
Num. &= 0.0125,
\end{aligned}$$

the denominator calculated as,

$$\begin{aligned}
Denom. &= p_2 \tau_2 + (1 - p_2) p_3 \tau_3 + (1 - p_2)(1 - p_3) p_4 \tau_4 \\
&= (0.4)(0.5) + (0.6)(0.6)(0.66) + (0.6)(0.4)(0.5)(0.6) \\
Denom. &= 0.5096,
\end{aligned}$$

and the $SAR(T_0)$ calculated as,

$$\begin{aligned}
SAR(T_0) &= \frac{Num.}{Denom.} \\
&= \frac{0.0125}{0.5096} = 0.0246
\end{aligned}$$

The SAR for the control group is calculated by Eq. (6) as follows,

$$\begin{aligned}
SAR(C_0) &= S_2^R S_3^R S_L^R S_O^R S_A^R \\
&= (0.8)(0.9)(0.3)(0.075)(0.9)
\end{aligned}$$

$$SAR(C_0) = 0.0146$$

By the definition of Eq. (1), the T/C ratio is,

$$\begin{aligned} T/C &= \frac{SAR(T_0)}{SAR(C_0)} \\ &= \frac{0.0246}{0.0146} \end{aligned}$$

$$T/C = 1.69$$

Calculating the T/C ratio from the numbers of fish in each of the C_0 and T_0 sub-categories

(Table 6) is presented as a check of the above equation as follows,

$$T/C = \frac{\left(\frac{A_{T_0}}{T_0} \right)}{\left(\frac{A_{C_0}}{C_0} \right)} = \left(\frac{\frac{501}{(8000 + 1901 + 7603 + 576 + 230 + 2074)}}{\frac{70}{(960 + 384 + 3456)}} \right)$$

$$T/C = 1.69.$$

Table 5. Hypothetical reach survival and site-specific detection and transport probabilities:used in Example 2.

Segment	Subscript (i)	In River Survival S_i^R	Transport Route Survival S_i^T	Location (i)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8		LGR (2)	0.4	0.5
LGR to LGS	2	0.8	0.9	LGS (3)	0.6	0.66
LGS to LMN	3	0.9	0.8	LMN (4)	0.5	0.6
LMN-BON (L)	L	0.3	0.6			
BON-BON	O	0.08	0.07			
BON-LGR	A	0.9	0.8			

Table 6. Number of fish in each category and sub-group calculated from the probabilities in Table 5 and a release size of 50,000 tagged fish. Shaded cells correspond to sub-categories in Figure 2.

Segment	Fish Surviving to Site, In-river (Bold) (Undetected in Snake R.)			Total Mortalities Between Sites	In River Mortalities to C_0 category	In River Mortalities to T_0 category	Fish Added to Barge At Site (Bold)	Fish in Barge At Site (Bold)	Mortalities in Barge Between Sites
	Total	Control Group C_0	Transport Group T_0						
Rel to LGR	28000						8000 (T_2)	8000	
LGR to LGS	7680	3840 ($C_0^2 + C_0^3$)	2304 ($T_4^2 + T_4^3$)	4800	960 (C_0^1)	1901 (T_3^1) 576 (T_4^1)	7603 (T_3^2)	14803	800
LGS to LMN	3456	3456 (C_0^3)		768	384 (C_0^2)	230 (T_4^2)	2074 (T_4^3)	13916	2961
LMN- BON		1037						8350	
BON- BON		78						626	
BON- LGR		70						501	

Estimation

We derived expressions for calculating $SAR(T_0)$, $SAR(C_0)$ and T/C from first principles. We started by defining each metric then applied the definitions to arrive at a mathematical expression for them. An unbiased estimator of any of the above metrics should result in an appropriate expressions presented earlier, i.e., Eq 1, 2 or 3 for T/C , $SAR(C_0)$, and $SAR(T_0)$, respectively. An unbiased estimator of T/C should reduce Eqs. (1), (19), or (20) given that only fish with no previous detection are transported, that survival is measured from LGR as juveniles to LGR as adults, that comparisons are made to a control group as defined earlier, and that no T_0 returning adults were un-transported (migrated in-river). To explain the derivation and concepts of the CSS study we used sub-categories that are not directly observable. In this section, we re-write the equations as functions of parameters that are estimable from detections of tagged fish.

Estimates of reach survival, and site-specific detection and transport probabilities are obtained by use of maximum likelihood methods described earlier. The numbers of juveniles in the transport and control groups are estimated by use of the maximum likelihood estimators (MLEs) of the survival parameters. The estimators for T_0 and C_0 are written as follows, respectively,

$$\hat{T}_0 = N_1 \hat{S}_1^R (\hat{p}_2 \hat{t}_2 + (1 - \hat{p}_2) \hat{p}_3 \hat{t}_3 + (1 - \hat{p}_2)(1 - \hat{p}_3) \hat{p}_4 \hat{t}_4)$$

and

$$\hat{C}_0 = N \hat{S}_1^R (1 - \hat{p}_2)(1 - \hat{p}_3)(1 - \hat{p}_4),$$

where the symbol $\hat{\cdot}$ denotes an MLE of a parameter. The estimators for T_0 and C_0 will be unbiased if the MLEs are unbiased.

Once juveniles enter a transport barge they are not observed again until they return to Bonneville as adults. Hence, the survival probabilities S_2^T , S_3^T , S_L^T and S_O^T are not separately estimable for any of the T_i transport groups. Rather, we use the joint probability of surviving in the transport barge (from detection to release in the estuary) and subsequent marine residence to return at BON. By use of the joint probability, the expected number of adults observed at BON that were transported from LGR as juveniles is expressed as follows,

$$A_{T_2} = N_0 S_1^R p_2 \tau_2 \left(S_2^T S_3^T S_L^T S_O^T \right) S_A^T$$

$$A_{T_2} = N_0 S_1^R p_2 \tau_2 S_{BON}^{T_2} S_A^T$$

The *SAR* for fish in the LGR transport route is expressed as a function of estimable parameters as follows,

$$SAR(T_2) = S_{BON}^{T_2} S_A^T$$

and estimated by,

$$\widehat{SAR}(\hat{T}_2) = \hat{S}_{BON}^{T_2} \hat{S}_A^T \quad (21)$$

where $\hat{S}_{BON}^{T_2}$ is the estimator for the joint probability $(S_2^T S_3^T S_L^T S_O^T)$.

The expected number of adult returns for juveniles that were in the LGS transport pathway is expressed as,

$$A_{T_3} = N_0 S_1^R (1 - p_3) p_3 \tau_3 S_2^R (S_3^T S_L^T S_O^T) S_A^T$$

$$A_{T_3} = N_0 S_1^R (1 - p_3) p_3 \tau_3 S_2^R S_{BON}^{T_3} S_A^T,$$

and the *SAR* for T_3 written as,

$$SAR(T_3) = S_2^R S_{BON}^{T_3} S_A^T,$$

and estimated by

$$\widehat{SAR}(\hat{T}_3) = \hat{S}_2^R \hat{S}_{BON}^{T_3} \hat{S}_A^T \quad (22)$$

where $\hat{S}_{BON}^{T_3}$ is the estimator for the joint the probability that a T_3 fish returns to BON as an adult. The number of adults and the *SAR* for T_4 fish, the LMN transport route are expressed as follows, respectively

$$A_{T_4} = N_0 S_1^R (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R S_{BON}^{T_4} S_A^T$$

and

$$SAR(T_4) = S_2^R S_3^R S_{BON}^{T_4} S_A^T$$

with an associated estimator for the *SAR*,

$$\widehat{SAR}(\hat{T}_4) = \hat{S}_2^R \hat{S}_3^R \hat{S}_{BON}^{T_4} \hat{S}_A^T \quad (23)$$

where $\hat{S}_{BON}^{T_4}$ is the estimator for the joint probability $S_L^T S_O^T$. Hence, all of the site-specific transport *SARs* are probabilities of making a round trip from LGR as a juvenile back to LGR as an adult.

The fish in the control group are never observed at any of the Snake River transport dams. Unlike the T_0 group, there are no direct observations of fish in the C_0 group and the

number must be calculated from the estimated survival and detection probabilities. These fish may be detected in the Columbia River and will be observed upon adult return. Reach specific survival probabilities between transport sites, S_2^R and S_3^R , are estimable from detections of transported fish and non-transported fish passing through detection routes. However, for simplicity we will express the number of adult returns as follows,

$$A_{C_0} = N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) (S_2^R S_3^R S_L^R S_O^R) S_A^R$$

$$A_{C_0} = N_0 S_1^R (1 - p_2)(1 - p_3)(1 - p_4) S_{BON}^{C_0} S_A^R$$

where $S_{BON}^{C_0}$ is the joint probability ($S_2^R S_3^R S_L^R S_O^R$). The $SAR(C_0)$ is then written as,

$$SAR(C_0) = S_{BON}^{C_0} S_A^R$$

and estimated by,

$$\widehat{SAR}(\hat{C}_0) = \hat{S}_{BON}^{C_0} \hat{S}_A^R, \quad (24)$$

where $\hat{S}_{BON}^{C_0}$ could be calculated from the number of control group observations at Bonneville Dam and \hat{C}_0 .

Using the above joint probabilities, the T/C ratio is expressed as follows,

$$T/C = \frac{p_2 \tau_2 S_{BON}^{T_2} S_A^{T_2} + (1 - p_2) p_3 \tau_3 S_2^R S_{BON}^{T_3} S_A^{T_3} + (1 - p_2)(1 - p_3) p_4 \tau_4 S_2^R S_3^R S_{BON}^{T_3} S_A^{T_4}}{S_{BON}^R S_A^R [p_2 \tau_2 + (1 - p_2) p_3 \tau_3 + (1 - p_2)(1 - p_3) p_4 \tau_4]}$$

and estimated by,

$$\widehat{T/C} = \frac{\hat{p}_2 \hat{\tau}_2 \hat{S}_{BON}^{T_2} \hat{S}_A^{T_2} + (1 - \hat{p}_2) \hat{p}_3 \hat{\tau}_3 \hat{S}_2^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_3} + (1 - \hat{p}_2)(1 - \hat{p}_3) \hat{p}_4 \hat{\tau}_4 \hat{S}_2^R \hat{S}_3^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_4}}{\hat{S}_{BON}^R \hat{S}_A^R [\hat{p}_2 \hat{\tau}_2 + (1 - \hat{p}_2) \hat{p}_3 \hat{\tau}_3 + (1 - \hat{p}_2)(1 - \hat{p}_3) \hat{p}_4 \hat{\tau}_4]}. \quad (25)$$

Example 3: Estimation of T/C ratio using estimable survival, detection, and transport probabilities.

Consider a cohort release with estimated survival, detection, and transport probabilities listed in Table 7. The SARs and T/C ratio can be calculated from probabilities only using Eq. (25). The numerator of Eq. (25) is calculated as follows,

$$\begin{aligned}\widehat{Eq(25)}_{NUM} &= \hat{p}_2 \hat{\tau}_2 \hat{S}_{BON}^{T_2} \hat{S}_A^{T_2} + (1 - \hat{p}_2) \hat{p}_3 \hat{\tau}_3 \hat{S}_2^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_3} + (1 - \hat{p}_2)(1 - \hat{p}_3) \hat{p}_4 \hat{\tau}_4 \hat{S}_2^R \hat{S}_3^R \hat{S}_{BON}^{T_3} \hat{S}_A^{T_4} \\ &= (0.3)(0.5)(0.0292)(0.75) \\ &\quad + (0.7)(0.4)(0.66)(0.9)(0.0324)(0.75) \\ &\quad + (0.7)(0.6)(0.3)(0.6)(0.9)(0.8)(0.0405)(0.75)\end{aligned}$$

$$\widehat{Eq(25)}_{NUM} = 0.0033 + 0.004 + 0.0017 = 0.0090$$

the denominator calculated as,

$$\begin{aligned}\widehat{Eq.(25)}_{DENOM} &= \hat{S}_{BON}^R \hat{S}_A^R [\hat{p}_2 \hat{\tau}_2 + (1 - \hat{p}_2) \hat{p}_3 \hat{\tau}_3 + (1 - \hat{p}_2)(1 - \hat{p}_3) \hat{p}_4 \hat{\tau}_4] \\ &= (0.8)(0.8)(0.0638)(0.85) [(0.3)(0.5) + (0.7)(0.4)(0.66) + (0.7)(0.6)(0.3)(0.6)] \\ &= 0.03468 [0.15 + 0.1848 + 0.0756]\end{aligned}$$

$$\widehat{Eq.(25)}_{DENOM} = 0.0143$$

and the T/C ratio estimated by use of Eq. (25) as,

$$\widehat{T/C} = \frac{0.0090}{0.0143} = 0.631.$$

Table 7: Hypothetical survival, detection, and transport probabilities for Example 3.

Segment	Subscript (i)	In River Survival S_i^R	C_0 In-river route Survival	Transport Route Survival S_i^T	LGR (T_2) Transport Route Survival	LGS (T_3) Transport Route Survival	LMN (T_4) Transport Route Survival	Location (i)	Capture Probability p_i	Transport Probability τ_i
Rel to LGR	1	0.8						LGR (2)	0.3	0.5
LGR to LGS	2	0.8		0.9		0.9		LGS (3)	0.4	0.66
LGS to LMN	3	0.8		0.8			0.8	LMN (4)	0.3	0.6
LMN-BON (L)	L	0.85	0.0408	0.9	0.0292					
BON-BON (Ocean)	O	0.075		0.045		0.0324			0.0405	
BON-LGR	A	0.85	0.85	0.75	0.75	0.75	0.75			

Assumptions

Empirical results can only be inferred to a population in the context of the assumptions under which a study was conducted. Estimation of survival, detection and transport probabilities, *SARs* and *T/C* ratios require the following set of assumptions.

1. Tagged fish in the study are representative of the population.
2. All fish in a release group have equal detection and survival probabilities.
3. All fish in a release group have equal probabilities of a particular capture history.
4. Fates of individual fish are independent.
5. Previous detections have no influence on subsequent survival or detection probabilities.
6. Release numbers, capture histories, and PIT tag codes are accurately recorded and known.
7. Only detected fish are subject to transport.
8. Tagged fish removed for use in other studies are known and accurately recorded.
9. All tagged fish in a cohort release migrate through the Snake and Columbia Rivers within the same season and while the bypass facility and transport systems are operational, i.e., there is no delayed migration of tagged fish.
10. Harvest survival is the same for transported and in-river categories.

11. River conditions for same-age returns of a cohort are the same for the T_0 and C categories.

The first five assumptions are regarded as statistical in that they dictate the choice of statistical model used in parameter estimation. Assumption 1 is required when making inferences to untagged fish. If tagged fish are not representative of the run-at-large, then inferences are limited to the segment of the population most represented by tagged fish or restricted only to tagged fish. Assumptions 2 through 5 are necessary to obtain unbiased estimates of detection, survival, and transport probabilities and associated variance estimates.

Assumptions 7 through 12 are associated with elements of the CSS study and the life history characteristics fish in the study. Assumption 7 is an element of the study and was discussed earlier. Unobserved tagged fish are regarded as either mortalities or non-detects. Hence, if fish are removed for use in other studies or for monitoring, tag codes should be accurately recorded and noted so that survival and or detection probabilities are not biased. Assumption 9 is required to meet the assumption that all fish have equal detection and transport probabilities. Equations for the metrics of the CSS study were derived under this assumption and severe departures from assumption 9 will require a different set of equations. The last two assumptions are meant to assure that transport and control fish differ only with regard to the treatment, i.e., juvenile migration through transport or in-river passage. Part of the treatment includes timing of estuary and ocean entrance. However, if

fish in either group are subject to different harvest probabilities or river conditions as an adult, then differences in *SARs* will not be wholly attributable to the treatment.

Appendix D

Supporting Tables of PIT-Tag Marking Data and Estimates of Survival and Major CSS Parameters

Appendix D includes the time series of data by smolt migration year that are compiled annually by the CSS. These tables support analyses presented in Chapters 3, 4, 5, and 6. The information is organized by species (stream type Chinook salmon and steelhead) and origin (wild and hatchery) following the steps of the survival estimations and comparisons. First the numbers, origins, and release sites of PIT-tagged juvenile fish used in the study are presented. Next the estimated size of each study category is presented: numbers of smolts that are collected at Snake River dams and transported (T_0), never collected or transported (C_0), or collected and returned to the river (C_1); and counts of returning adults grouped by study category detected at Bonneville and Lower Granite dams. For each of these study categories, SARs are shown. Then the two comparative transport and in-river SAR ratios (TIR and D) are presented, as well as the in-river reach survivals (S_R) used to estimate D .

Appendix D also includes survival estimates from the CJS method of in-river migrating juvenile fish through specific reaches and the numbers and age distribution of returning adult Chinook and steelhead detected at LGR for upriver populations and BON for downriver populations. It concludes with the numbers of PIT-tagged juvenile hatchery and wild Chinook and steelhead smolts transported from each of the Snake River collector dams and the corresponding detections of adults at Bonneville and Lower Granite dams.

Tables D-1 to D-4 present PIT-tag release numbers of wild and hatchery Chinook and steelhead in locations above LGR.

Table D-1. Number of PIT-tagged wild Chinook parr/smolts from the four tributaries above Lower Granite Dam and Snake River trap used in the CSS analyses for migration years 1994 to 2004.

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

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

Table D-2. Number of PIT-tagged hatchery Chinook parr/smolts from key hatcheries located above Lower Granite Dam used in the CSS analyses for migration years 1997 to 2004.

Migr. Year	Rapid River H	Dworshak NFH	Catherine Creek AP	McCall H	Imnaha AP
1997	40,451	14,080	-----	52,652	13,378
1998	48,336	47,703	-----	47,340	19,825
1999	47,812	47,845	-----	47,985	19,939
2000	47,747	47,743	-----	47,705	20,819
2001	55,085	55,139	20,915	55,124	20,922
2002	54,908	54,725	20,796	54,734	20,920
2003	54,763	54,708	20,628	74,317	20,904
2004	51,969	51,616	20,994	71,363	20,910

Table D-3. Number of PIT-tagged wild steelhead smolts from the four tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS for migration years 1997 to 2003.

Migr. Year	Number of PIT-tagged wild steelhead (>130 mm) utilized in CSS by location of origin					
	Total PIT-tags	Clearwater River (Rkm 224)	Snake River trap ¹ (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1997	7,703	5,518	68	248	1,158	711
1998	10,512	4,131	1,032	887	1,683	2,779
1999	15,763	5,095	886	1,628	5,569	2,585
2000	24,254	8,688	1,211	3,618	6,245	4,492
2001	24,487	8,845	867	3,370	7,844	3,561
2002	25,183	10,206	2,368	3,353	6,136	3,120
2003	24,284	5,885	1,197	4,261	6,969	5,972
Average % of total		36.6%	5.8%	13.1%	26.9%	17.6%

¹ Snake River trap located at Lewiston, ID, collects wild steelhead originating in Grande Ronde, Salmon, and Imnaha rivers.

Table D-4. Number of PIT-tagged hatchery steelhead smolts from the four tributaries above Lower Granite Dam (plus mainstem Snake River) used in the CSS for migration years 1997 to 2003.

Migr. Year	Number of PIT-tagged hatchery steelhead utilized in CSS by location of origin						
	Total PIT-tags	Clearwater River (Rkm 224)	Snake River trap ¹ (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)	Snake River at Hells Canyon Dam (Rkm 397) ¹
1997	35,705	12,872	725	6,039	9,394	6,379	296
1998	30,913	8,451	4,209	4,904	8,457	4,604	288
1999	36,968	11,486	3,925	5,316	9,132	6,808	301
2000	32,000	8,488	3,290	5,348	8,173	6,436	265
2001	29,099	9,155	3,126	4,677	7,859	3,995	287
2002	26,573	7,819	4,722	3,888	7,011	2,839	294
2003	26,379	4,912	4,171	3,113	7,764	6,123	296
Average % of total		29.0%	11.1%	15.3%	26.6%	17.1%	0.9%

¹ Snake River trap located at Lewiston, ID, collects hatchery steelhead released in Grande Ronde, Salmon, and Imnaha rivers, and below Hells Canyon Dam.

Tables D-5 to D-12 present estimated number of smolts per study category with associated 90% confidence interval and number of returning adults per study category for PIT-tagged wild and hatchery Chinook and steelhead.

Table D-5. Estimated number of PIT-tagged wild Chinook (aggregate of fish tagged in 10-month period between July 25 and May 20) arriving Lower Granite Dam in each of the three study categories from 1994 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1994	(15,008 – 15,520)	T ₀	2,004	(1,922 – 2,084)	9	
		C ₀	1,801	(1,693 – 1,911)	5	
		C ₁	4,431	(4,275 – 4,618)	3	
1995	(19,950 – 20,457)	T ₀	2,283	(2,202 – 2,367)	8	
		C ₀	2,709	(2,602 – 2,812)	10	
		C ₁	14,206	(13,997 – 14,413)	36	
1996	(7,682 – 8,070)	T ₀	400	(365 – 434)	2	
		C ₀	1,917	(1,805 – 2,034)	5	
		C ₁	5,209	(5,057 – 5,366)	7	
1997	(2,784 – 3,024)	T ₀	230	(207 – 255)	4	
		C ₀	680	(614 – 757)	16	
		C ₁	1,936	(1,843 – 2,028)	18	
1998	(17,172 – 17,562)	T ₀	1,271	(1,214 – 1,330)	15	
		C ₀	3,081	(2,976 – 3,187)	42	
		C ₁	12,276	(12,111 – 12,444)	131	
1999	(33,343 – 33,988)	T ₀	1,768	(1,697 – 1,841)	43	
		C ₀	4,469	(4,339 – 4,595)	95	
		C ₁	26,140	(25,855 – 26,424)	495	
2000	(24,721 – 25,397)	T ₀	839	(790 – 890)	12	21
		C ₀	6,494	(6,321 – 6,686)	155	184
		C ₁	16,833	(16,574 – 17,087)	392	456
2001	(22,234 – 22,595)	T ₀	547	(512 – 587)	7	10
		C ₀	231	(208 – 253)	1 ^A	1 ^A
		C ₁	20,307	(20,124 – 20,491)	29	32
2002	(22,995 – 23,697)	T ₀	3,886	(3,775 – 3,995)	31	41
		C ₀	6,218	(6,042 – 6,395)	76	86
		C ₁	12,687	(12,455 – 12,922)	125	137
2003	(30,744 – 31,490)	T ₀	8,713	(8,560 – 8,873)	30	29
		C ₀	8,879	(8,660 – 9,094)	29	33
		C ₁	12,694	(12,499 – 12,910)	22	22
2004 ^B	(32,296 – 32,828)	T ₀	12,887	(12,722 – 13,058)	39	49
		C ₀	2,252	(2,168 – 2,354)	7	8
		C ₁	16,504	(16,313 – 16,725)	30	35

^A One returning adult with no detections may have inadvertently been transported so in-river SARs based solely on Category C₁ fish in 2001.

^B Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-6. Estimated number of PIT-tagged spring Chinook from Rapid River Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	15,765 (15,246 – 16,439)	T ₀	4,324	(4,224 – 4,424)	34	
		C ₀	4,176	(3,904 – 4,448)	19	
		C ₁	6,843	(6,515 – 7,187)	36	
1998	32,148 (31,801 – 32,473)	T ₀	12,876	(12,711 – 13,032)	257	
		C ₀	4,402	(4,260 – 4,537)	53	
		C ₁	13,597	(13,389 – 13,820)	91	
1999	35,895 (35,272 – 36,542)	T ₀	12,857	(12,666 – 13,050)	391	
		C ₀	7,040	(6,842 – 7,238)	167	
		C ₁	14,456	(14,157 – 14,773)	235	
2000	35,194 (34,652 – 35,769)	T ₀	16,587	(16,302 – 16,883)	349	492
		C ₀	11,046	(10,676 – 11,427)	176	201
		C ₁	5,248	(5,110 – 5,375)	70	90
2001	38,026 (37,822 – 38,211)	T ₀	19,090	(18,904 – 19,273)	207	265
		C ₀	966	(919 – 1,016)	2 ^A	2 ^A
		C ₁	15,989	(15,802 – 16,177)	8	12
2002	41,471 (40,785 – 42,099)	T ₀	11,589	(11,378 – 11,817)	117	132
		C ₀	13,625	(13,303 – 13,950)	91	106
		C ₁	14,854	(14,551 – 15,161)	94	104
2003	37,911 (37,317 – 38,562)	T ₀	13,353	(13,138 – 13,586)	33	52
		C ₀	16,858	(16,398 – 17,331)	39	41
		C ₁	7,055	(6,897 – 7,212)	11	11
2004 ^B	36,178 (35,955 – 36,406)	T ₀	19,519	(19,332 – 19,719)	50	66
		C ₀	3,484	(3,350 – 3,616)	5	5
		C ₁	12,776	(12,615 – 12,946)	11	11

^A Two returning adults with no detections may have inadvertently been transported so in-river SARs based solely on Category C₁ fish in 2001.

^B Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-7. Estimated number of PIT-tagged spring Chinook from Dworshak Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	8,175 (7,735 – 8,683)	T ₀	1,931	(1,866 – 2,000)	16	
		C ₀	2,529	(2,310 – 2,755)	13	
		C ₁	3,613	(3,370 – 3,884)	12	
1998	40,218 (39,660 – 40,742)	T ₀	14,728	(14,563 – 14,915)	132	
		C ₀	11,151	(10,882 – 11,447)	139	
		C ₁	13,128	(12,875 – 13,387)	118	
1999	40,804 (39,771 – 41,948)	T ₀	9,787	(9,608 – 9,985)	115	
		C ₀	10,484	(10,181 – 10,820)	125	
		C ₁	19,083	(18,596 – 19,612)	181	
2000	39,412 (38,782 – 40,101)	T ₀	18,317	(17,987 – 18,660)	183	296
		C ₀	13,075	(12,612 – 13,529)	132	172
		C ₁	5,416	(5,280 – 5,568)	44	56
2001	41,251 (41,068 – 41,446)	T ₀	21,740	(21,555 – 21,934)	79	96
		C ₀	886	(839 – 938)	0	0
		C ₁	16,872	(16,672 – 17,062)	7	8
2002	45,233 (44,268 – 46,304)	T ₀	9,665	(9,431 – 9,902)	60	80
		C ₀	19,008	(18,512 – 19,582)	95	113
		C ₁	14,914	(14,538 – 15,354)	74	80
2003	38,612 (37,984 – 39,274)	T ₀	13,205	(12,984 – 13,447)	34	44
		C ₀	17,697	(17,237 – 18,153)	38	45
		C ₁	6,715	(6,573 – 6,881)	12	12
2004 ^A	45,505 (42,223 – 42,788)	T ₀	21,657	(21,443 – 21,897)	46	88
		C ₀	6,280	(6,100 – 6,468)	14	18
		C ₁	14,009	(13,822 – 14,189)	22	36

^A Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-8. Estimated number of PIT-tagged spring Chinook from Catherine Creek Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 2001 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
2001	10,885 (10,747 – 11,021)	T ₀	4,790	(4,683 – 4,899)	11	18
		C ₀	379	(345 – 414)	0	0
		C ₁	4,642	(4,540 – 4,738)	2	3
2002	8,435 (8,181 – 8,709)	T ₀	2,697	(2,600 – 2,797)	24	33
		C ₀	2,445	(2,312 – 2,590)	12	11
		C ₁	3,120	(2,992 – 3,258)	10	10
2003	7,202 (6,932 – 7,487)	T ₀	2,494	(2,397 – 2,592)	9	10
		C ₀	3,201	(3,010 – 3,421)	8	8
		C ₁	1,403	(1,333 – 1,478)	5	6
2004 ^A	5,348 (5,225 – 5,465)	T ₀	2,877	(2,790 – 2,970)	10	13
		C ₀	503	(455 – 551)	1	0
		C ₁	1,869	(1,797 – 1,938)	6	7

^A Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-9. Estimated number of PIT-tagged summer Chinook from McCall Hatchery arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimate smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	22,381 (21,588 – 23,224)	T ₀	6,013	(5,888 – 6,136)	91	
		C ₀	6,761	(6,398 – 7,132)	74	
		C ₁	9,272	(8,854 – 9,738)	102	
1998	27,812 (27,474 – 28,141)	T ₀	10,142	(9,988 – 10,286)	273	
		C ₀	3,849	(3,721 – 3,983)	53	
		C ₁	12,816	(12,578 – 13,060)	94	
1999	31,571 (30,816 – 32,358)	T ₀	10,515	(10,281 – 10,742)	377	
		C ₀	8,407	(8,122 – 8,675)	202	
		C ₁	11,391	(11,062 – 11,684)	231	
2000	31,825 (31,170 – 32,466)	T ₀	12,806	(12,552 – 13,083)	497	584
		C ₀	13,064	(12,558 – 13,601)	269	299
		C ₁	4,485	(4,349 – 4,624)	91	101
2001	36,784 (36,578 – 36,994)	T ₀	16,704	(16,511 – 16,882)	206	246
		C ₀	1,000	(946 – 1,052)	3 ^A	3 ^A
		C ₁	15,536	(15,351 – 15,728)	6	7
2002	32,599 (32,042 – 33,229)	T ₀	8,842	(8,666 – 9,027)	131	164
		C ₀	10,280	(9,987 – 10,578)	106	127
		C ₁	12,315	(12,029 – 12,631)	126	154
2003	43,144 (42,527 – 43,752)	T ₀	14,006	(13,782 – 14,233)	111	124
		C ₀	19,696	(19,221 – 20,166)	107	122
		C ₁	8,669	(8,503 – 8,845)	30	32
2004 ^B	40,150 (39,912 – 40,408)	T ₀	20,858	(20,667 – 21,062)	65	92
		C ₀	2,359	(2,262 – 2,453)	6	7
		C ₁	16,297	(16,094 – 16,500)	19	31

^A Three returning adults with no detections may have inadvertently been transported so in-river SARs based solely on Category C₁ fish in 2001.

^B Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-10. Estimated number of PIT-tagged summer Chinook from Imnaha River Acclimation Pond arriving Lower Granite Dam in each of the three study categories from 1997 to 2004 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) and Bonneville (BOA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		Detected adults (2-salt & older)	
					GRA	BOA
1997	8,254 (7,814 – 8,740)	T ₀	2,147	(2,079 – 2,212)	25	
		C ₀	2,219	(2,032 – 2,433)	19	
		C ₁	3,785	(3,535 – 4,040)	26	
1998	13,577 (13,327 – 13,833)	T ₀	4,809	(4,709 – 4,910)	41	
		C ₀	1,995	(1,900 – 2,085)	11	
		C ₁	6,335	(6,194 – 6,483)	19	
1999	13,244 (12,829 – 13,687)	T ₀	4,827	(4,688 – 4,963)	130	
		C ₀	2,869	(2,733 – 3,008)	41	
		C ₁	5,084	(4,884 – 5,268)	62	
2000	14,267 (13,926 – 14,650)	T ₀	6,789	(6,597 – 6,991)	211	262
		C ₀	4,396	(4,159 – 4,672)	106	114
		C ₁	2,254	(2,166 – 2,353)	37	41
2001	15,650 (15,531 – 15,763)	T ₀	7,730	(7,609 – 7,855)	48	61
		C ₀	336	(336 – 396)	1 ^A	4 ^A
		C ₁	6,939	(6,819 – 7,055)	4	4
2002	13,962 (13,560 – 14,380)	T ₀	3,912	(3,777 – 4,041)	31	41
		C ₀	4,637	(4,429 – 4,853)	21	27
		C ₁	5,135	(4,952 – 5,333)	28	33
2003	14,948 (14,532 – 15,377)	T ₀	5,189	(5,044 – 5,345)	30	39
		C ₀	6,683	(6,358 – 6,999)	32	38
		C ₁	2,908	(2,801 – 3,015)	11	13
2004 ^B	12,867 (12,709 – 13,013)	T ₀	6,927	(6,801 – 7,049)	24	35
		C ₀	1,302	(1,221 – 1,381)	3	5
		C ₁	4,456	(4,349 – 4,554)	5	6

^A One returning adult with no detections may have inadvertently been transported so in-river SARs based solely on Category C₁ fish in 2001.

^B Migration year 2004 is incomplete with 2-salt adult returns as of 8/9/2006.

Table D-11. Estimated number of PIT-tagged wild steelhead (aggregate of tagged fish >130 mm released in 12-month period between July 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		LGR detected returning adults
1997	3,830 (3,744 – 3,920)	T ₀	275	(248 – 301)	4
		C ₀	454	(415 – 492)	3
		C ₁	2,984	(2,905 – 3,066)	7
1998	7,109 (7,010 – 7,208)	T ₀	480	(443 – 518)	1
		C ₀	750	(700 – 800)	8
		C ₁	5,150	(5,053 – 5,242)	11
1999	8,820 (8,695 – 8,960)	T ₀	391	(358 – 424)	12
		C ₀	1,113	(1,052 – 1,178)	15
		C ₁	6,992	(6,878 – 7,114)	53
2000	13,609 (13,418 – 13,818)	T ₀	466	(426 – 505)	13
		C ₀	1,871	(1,780 – 1,961)	36
		C ₁	10,616	(10,461 – 10,773)	192
2001 ^A	12,929 (12,810 – 13,066)	T ₀	201	(179 – 226)	5
		C ₀	103	(87 – 120)	3 ^B
		C ₁	11,892	(11,748– 12,014)	8
2002 ^C	13,378 (13,148 – 13,598)	T ₀	317	(289 – 346)	9
		C ₀	4,045	(3,908 – 4,197)	27
		C ₁	8,726	(8,552 – 8,891)	82
2003 ^C	12,926 (12,696 – 13,153)	T ₀	2,210	(2,140 – 2,293)	44
		C ₀	3,320	(3,185 – 3,459)	16
		C ₁	7,132	(6,979 – 7,292)	37

^A Estimates of number of smolts in study categories in 2001 are approximate due to potentially high holdover rate in lower Snake River affecting reach survival estimates and ultimately the smolt estimates in LGR-equivalents for each study category.

^B Three returning adults with no detections may have inadvertently been transported or held-over to the following year so in-river SARs based solely on Category C₁ fish in 2001

^C Migration year 2003 is incomplete until 3-salt returns occur at GRA.

Table D-12. Estimated number of PIT-tagged hatchery steelhead (aggregate of tagged fish released in 3-month period between April 1 and June 30) arriving Lower Granite Dam in each of the three study categories from 1997 to 2003 (with 90% confidence intervals), with detected adults at Lower Granite (GRA) adult ladders.

Migr. Year	Estimated smolts starting in LGR population (with 90% CI)	Study category	Estimated smolt numbers in each study category (with 90% CI)		LGR detected returning adults
1997	24,710 (24,477 – 24,933)	T ₀	1,729	(1,665 – 1,798)	9
		C ₀	3,390	(3,266 – 3,526)	8
		C ₁	19,095	(18,895 – 19,307)	32
1998	23,507 (23,325 – 23,685)	T ₀	1,365	(1,304 – 1,425)	7
		C ₀	2,926	(2,826 – 3,023)	26
		C ₁	17,958	(17,778 – 18,129)	40
1999	27,193 (26,959 – 27,426)	T ₀	1,336	(1,274 – 1,395)	12
		C ₀	3,952	(3,839 – 4,055)	41
		C ₁	20,975	(20,767 – 21,192)	124
2000	24,565 (24,280 – 24,847)	T ₀	668	(621 – 717)	14
		C ₀	4,408	(4,237 – 4,589)	42
		C ₁	18,804	(18,598 – 19,013)	197
2001 ^A	20,877 (20,739 – 21,031)	T ₀	427	(389 – 464)	4
		C ₀	372	(334 – 414)	2 ^B
		C ₁	19,132	(18,985 – 19,294)	3
2002	20,681 (20,328 – 21,037)	T ₀	284	(256 – 313)	3
		C ₀	6,129	(5,917 – 6,338)	43
		C ₁	14,038	(13,764 – 14,322)	102
2003 ^C	21,400 (21,067 – 21,732)	T ₀	4,595	(4,475 – 4,719)	83
		C ₀	6,459	(6,248 – 6,671)	44
		C ₁	10,118	(9,918 – 10,320)	37

^A Estimates of number of smolts in study categories in 2001 are approximate due to potentially high holdover rate in lower Snake River affecting reach survival estimates and ultimately the smolt estimates in LGR-equivalents for each study category.

^B Two returning adults with no detections may have inadvertently been transported or held-over to the following year so in-river SARs based solely on Category C₁ fish in 2001

^C Migration year 2003 is incomplete until 3-salt returns occur at GRA

Tables D-13 to D-20 present estimated SARs per study category with associated 90% confidence interval for wild and hatchery Chinook and steelhead.

Table D-13. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1994	NA ¹	0.45 (0.20 – 0.72)	0.28 (0.11 – 0.51)	0.07 (0.02 – 0.14)
1995	NA	0.35 (0.17 – 0.57)	0.37 (0.18 – 0.57)	0.25 (0.18 – 0.32)
1996	NA	0.50 (0.00 – 1.07)	0.26 (0.10 – 0.48)	0.13 (0.06 – 0.23)
1997	NA	1.74 (0.44 – 3.27)	2.35 (1.45 – 3.36)	0.93 (0.60 – 1.32)
1998	1.16 (0.66 – 1.68)	1.18 (0.71 – 1.70)	1.36 (1.05 – 1.70)	1.07 (0.91 – 1.22)
1999	2.50 (1.76 – 3.41)	2.43 (1.85 – 3.07)	2.13 (1.78 – 2.50)	1.89 (1.76 – 2.04)
2000	1.58 (0.83 – 2.44)	1.43 (0.74 – 2.14)	2.39 (2.08 – 2.72)	2.33 (2.12 – 2.52)
2001	NA	1.28 (0.54 – 2.14)	Assume = SAR(C ₁)	0.14 (0.10 – 0.18)
2002	0.75 (0.49 – 1.07)	0.80 (0.57 – 1.04)	1.22 (0.99 – 1.45)	0.99 (0.84 – 1.14)
2003	0.35 (0.24 – 0.46)	0.34 (0.24 – 0.45)	0.33 (0.23 – 0.43)	0.17 (0.12 – 0.24)
2004 ²	0.30 (0.22 – 0.39)	0.30 (0.22 – 0.39)	0.31 (0.13 – 0.52)	0.18 (0.13 – 0.24)
11-yr Avg. Std Error 90% CI	NA	0.98 0.209 (0.60-1.36)	1.10 0.275 (0.51-1.51)	0.74 0.236 (0.31-1.17)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-14. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	NA ¹	0.79 (0.57 – 1.01)	0.45 (0.31 – 0.63)	0.53 (0.39 – 0.68)
1998	1.68 (1.47 – 1.93)	2.00 (1.80 – 2.21)	1.20 (0.95 – 1.48)	0.67 (0.56 – 0.79)
1999	2.72 (2.47 – 3.00)	3.04 (2.78 – 3.31)	2.37 (2.07 – 2.68)	1.63 (1.46 – 1.79)
2000	2.10 (1.90 – 2.26)	2.10 (1.91 – 2.28)	1.59 (1.40 – 1.81)	1.33 (1.07 – 1.58)
2001	1.08 (0.96 – 1.21)	1.08 (0.96 – 1.21)	{Assume = SAR(C ₁)}	0.05 (0.02 – 0.08)
2002	1.00 (0.78 – 1.25)	1.01 (0.86 – 1.16)	0.67 (0.55 – 0.79)	0.63 (0.53 – 0.74)
2003	0.25 (0.17 – 0.32)	0.25 (0.17 – 0.32)	0.23 (0.17 – 0.29)	0.16 (0.08 – 0.24)
2004 ²	0.26 (0.20 – 0.31)	0.26 (0.20 – 0.31)	0.14 (0.05 – 0.26)	0.09 (0.05 – 0.13)
8-yr Avg. Std error 90% CI		1.32 0.375 (0.61-2.03)	0.84 0.289 (0.29-1.39)	0.64 0.205 (0.25-1.03)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-15. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	NA ¹	0.83 (0.52 – 1.19)	0.47 (0.26 – 0.72)	0.36 (0.21 – 0.54)
1998	NA	0.90 (0.77 – 1.02)	1.25 (1.08 – 1.42)	0.90 (0.77 – 1.04)
1999	1.07 (0.86 – 1.28)	1.18 (1.01 – 1.35)	1.19 (1.01 – 1.37)	0.95 (0.82 – 1.07)
2000	1.00 (0.88 – 1.13)	1.00 (0.88 – 1.12)	1.01 (0.87 – 1.16)	0.81 (0.62 – 1.02)
2001	0.37 (0.30 – 0.44)	0.36 (0.29 – 0.43)	{Assume =SAR(C ₁)}	0.04 (0.02 – 0.07)
2002	0.48 (0.35 – 0.63)	0.62 (0.49 – 0.75)	0.50 (0.42 – 0.58)	0.50 (0.40 – 0.58)
2003	0.26 (0.19 – 0.33)	0.26 (0.19 – 0.33)	0.21 (0.16 – 0.27)	0.18 (0.10 – 0.27)
2004 ²	0.21 (0.16 – 0.27)	0.21 (0.16 – 0.27)	0.22 (0.13 – 0.32)	0.16 (0.11 – 0.21)
8-yr Avg. Std_error 90% CI		0.67 0.129 (0.43-0.91)	0.61 0.168 (0.29-0.93)	0.49 0.127 (0.25-0.73)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-16. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 2001 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
2001	NA ¹	0.23 (0.12 – 0.35)	{Assume =SAR(C ₁)}	0.04 (0.00 – 0.09)
2002	NA	0.89 (0.59 – 1.20)	0.49 (0.28 – 0.74)	0.32 (0.18 – 0.50)
2003	NA	0.36 (0.17 – 0.59)	0.25 (0.12 – 0.41)	0.36 (0.14 – 0.64)
2004 ²	0.37 (0.17 – 0.57)	0.35 (0.17 – 0.55)	0.20 (0.00 – 0.61)	0.32 (0.11 – 0.56)
4-yr Avg. Std_error 90% CI		0.46 0.147 (0.11-0.81)	0.25 0.093 (0.03-0.47)	0.26 0.074 (0.09-0.43)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-17. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged summer Chinook from McCall Hatchery for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	1.89 (1.20 – 2.75)	1.51 (1.26 – 1.77)	1.09 (0.88 – 1.34)	1.10 (0.92 – 1.29)
1998	1.95 (1.70 – 2.22)	2.69 (2.44 – 2.96)	1.38 (1.05 – 1.69)	0.73 (0.62 – 0.87)
1999	3.58 (3.10 – 4.07)	3.59 (3.29 – 3.87)	2.40 (2.12 – 2.69)	2.03 (1.82 – 2.26)
2000	3.86 (3.60 – 4.15)	3.88 (3.60 – 4.18)	2.06 (1.84 – 2.29)	2.03 (1.68 – 2.38)
2001	1.25 (1.11 – 1.41)	1.24 (1.10 – 1.38)	{Assume =SAR(C ₁)}	0.04 (0.01 – 0.07)
2002	1.31 (0.92 – 1.74)	1.48 (1.27 – 1.70)	1.03 (0.87 – 1.20)	1.02 (0.89 – 1.18)
2003	0.79 (0.68 – 0.91)	0.79 (0.68 – 0.91)	0.54 (0.46 – 0.63)	0.35 (0.25 – 0.45)
2004 ²	NA ¹	0.31 (0.24 – 0.38)	0.25 (0.09 – 0.43)	0.12 (0.07 – 0.16)
8-yr Avg. Std_error 90% CI		1.94 0.461 (1.07-2.81)	1.10 0.294 (0.54-1.66)	0.93 0.277 (0.41-1.45)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-18. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged summer Chinook from Imnaha River AP for each study category from 1997 to 2004 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	NA ¹	1.16 (0.77 – 1.60)	0.86 (0.53 – 1.22)	0.69 (0.48 – 0.93)
1998	NA	0.85 (0.65 – 1.09)	0.55 (0.28 – 0.83)	0.30 (0.20 – 0.42)
1999	2.52 (2.07 – 3.04)	2.69 (2.28 – 3.08)	1.43 (1.08 – 1.82)	1.22 (0.98 – 1.49)
2000	3.13 (2.79 – 3.47)	3.11 (2.77 – 3.44)	2.41 (2.01 – 2.83)	1.64 (1.22 – 2.08)
2001	NA	0.62 (0.49 – 0.78)	{ Assume =SAR(C ₁) }	0.06 (0.01 – 0.11)
2002	0.98 (0.53 – 1.45)	0.79 (0.56 – 1.04)	0.45 (0.29 – 0.63)	0.55 (0.38 – 0.72)
2003	0.58 (0.41 – 0.74)	0.58 (0.41 – 0.74)	0.48 (0.34 – 0.62)	0.38 (0.20 – 0.55)
2004 ²	0.35 (0.23 – 0.47)	0.35 (0.23 – 0.47)	0.23 (0.07 – 0.46)	0.11 (0.04 – 0.20)
8-yr Avg. Std_error 90% CI		1.27 0.368 (057.1.97)	0.81 0.272 (0.29-1.33)	0.62 0.196 (0.25-0.99)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

Table D-19. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	NA ¹	1.45 (0.36 – 2.80)	0.66 (0.0 – 1.34)	0.23 (0.10 – 0.39)
1998	NA	0.21 (0.0 – 0.63)	1.07 (0.51 – 1.73)	0.21 (0.12 – 0.33)
1999	3.39 (1.75 – 5.31)	3.07 (1.74 – 4.66)	1.35 (0.80 – 1.96)	0.76 (0.60 – 0.94)
2000	3.05 (1.65 – 4.58)	2.79 (1.55 – 4.11)	1.92 (1.40 – 2.49)	1.81 (1.59 – 2.03)
2001	NA	2.49 (0.93 – 4.37)	{ Assume =SAR(C ₁) }	0.07 (0.03 – 0.10)
2002	2.75 (1.37 – 4.44)	2.84 (1.52 – 4.43)	0.67 (0.46 – 0.90)	0.94 (0.77 – 1.11)
2003 ²	2.01 (1.50 – 2.54)	1.99 (1.49 – 2.49)	0.48 (0.30 – 0.68)	0.52 (0.38 – 0.66)
7-yr Avg. Std_error 90% CI		2.12 0.382 (1.38-2.86)	0.89 0.231 (0.44-1.34)	0.65 0.227 (0.21-1.09)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

Table D-20. Estimated SAR_{LGR-to-LGR} (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2003 (with 90% confidence intervals).

Mig. Year	SAR ₁ (T ₀)	SAR ₂ (T ₀)	SAR(C ₀)	SAR(C ₁)
1997	NA ¹	0.52 (0.24 – 0.81)	0.24 (0.09 – 0.39)	0.17 (0.12 – 0.22)
1998	0.53 (0.23 – 0.90)	0.51 (0.22 – 0.84)	0.89 (0.61 – 1.19)	0.22 (0.17 – 0.28)
1999	NA	0.90 (0.51 – 1.33)	1.04 (0.79 – 1.31)	0.59 (0.51 – 0.69)
2000	2.37 (1.41 – 3.53)	2.10 (1.22 – 3.07)	0.95 (0.71 – 1.19)	1.05 (0.92 – 1.18)
2001	NA	0.94 (0.24 – 1.78)	{ Assume =SAR(C ₁) }	0.016 (0.005 – 0.03)
2002	NA	1.06 (0.32 – 2.11)	0.70 (0.54 – 0.88)	0.73 (0.61 – 0.85)
2003 ²	1.80 (1.48 – 2.13)	1.81 (1.50 – 2.14)	0.68 (0.52 – 0.85)	0.37 (0.26 – 0.47)
7-yr Avg. Std_error 90% CI		1.12 0.232 (0.67-1.57)	0.65 0.144 (0.37-0.93)	0.45 0.137 (0.18-0.72)

¹ Not applicable since some sites have no adult returns for estimating a site-specific SAR.

² Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

Tables D-21 to D-28 present estimated S_R (in-river survival LGR to BON denoted as V_C in prior CSS reports), TIR (ratio of $SAR_2(T_0)/SAR(C_0)$, and D parameters with associated 90% confidence interval for wild and hatchery Chinook and steelhead.

Table D-21. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged wild Chinook for migration years 1994 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1994	0.20 (0.17-0.22; x77%) ^A	1.62 (0.62 – 5.05)	0.36 (0.13 – 1.09)
1995	0.41 (0.32-0.56; x51%)	0.95 (0.39 – 2.14)	0.42 (0.17 – 1.09)
1996	0.44 (0.35-0.55; x77%)	1.92 (0.00 – 6.80)	0.92 (0.00 – 3.24)
1997	0.51 (0.34-0.82; x77%)	0.74 (0.17 – 1.58)	0.40 (0.08 – 0.95)
1998	0.61 (0.54-0.69; x25%)	0.87 (0.50 – 1.35)	0.55 (0.31 – 0.87)
1999	0.59 (0.53 – 0.68)	1.14 (0.82 – 1.51)	0.72 (0.52 – 0.98)
2000	0.48 (0.41 – 0.58)	0.60 (0.32 – 0.92)	0.32 (0.17 – 0.51)
2002	0.61 (0.52 – 0.76)	0.65 (0.45 – 0.94)	0.44 (0.29 – 0.68)
2003	0.60 (0.52 – 0.69)	1.05 (0.69 – 1.67)	0.68 (0.43 – 1.09)
2004 ^B	0.40 (0.33 – 0.51)	0.97 (0.53 – 2.37)	0.40 (0.21 – 1.03)
Geomean	0.46 (0.25 - 0.86)	0.99 (0.50 – 1.94)	0.49 (0.26 - 0.92)
2001 ^C	0.23 (0.20 – 0.27)	8.96 (3.61 – 16.8)	2.16 (0.87 – 4.16)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied, denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the $SAR(C_1)$ value is used in the denominator of the TIR ratio.

Table D-22. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged Rapid River Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.33 (0.24-0.45; x77%) ^A	1.73 (1.08 – 2.85)	0.61 (0.37 – 1.09)
1998	0.59 (0.52-0.66; x25%)	1.66 (1.32 – 2.16)	1.01 (0.80 – 1.36)
1999	0.57 (0.49 – 0.67)	1.28 (1.11 – 1.51)	0.79 (0.65 – 0.99)
2000	0.58 (0.48 – 0.83)	1.32 (1.13 – 1.55)	0.82 (0.66 – 1.25)
2002	0.71 (0.60 – 0.84)	1.51 (1.20 – 1.91)	1.14 (0.87 – 1.52)
2003	0.66 (0.57 – 0.79)	1.07 (0.70 – 1.60)	0.75 (0.48 – 1.18)
2004 ^B	0.35 (0.27 – 0.52)	1.79 (0.94 – 5.25)	0.65 (0.32 – 2.09)
Geometric mean	0.52 (0.29 - 0.94)	1.46 (1.01 – 2.10)	0.81 (0.52 – 1.25)
2001 ^C	0.33 (0.28 – 0.40)	21.7 (13.3 – 54.1)	7.33 (4.40 – 16.9)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the $SAR(C_1)$ value is used in the denominator of the TIR ratio.

Table D-23. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged Dworshak Hatchery spring Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.49 (0.31-0.80; x77%) ^A	1.75 (0.92 – 3.46)	0.88 (0.40 – 2.01)
1998	0.51 (0.44–0.58; x25%)	0.72 (0.59 – 0.88)	0.37 (0.30 – 0.47)
1999	0.54 (0.47 – 0.65)	0.99 (0.81 – 1.24)	0.60 (0.47 – 0.81)
2000	0.48 (0.40 – 0.65)	0.99 (0.82 – 1.19)	0.53 (0.42 – 0.75)
2002	0.62 (0.54 – 0.72)	1.24 (0.93 – 1.61)	0.84 (0.61 – 1.12)
2003	0.68 (0.59 – 0.80)	1.20 (0.82 – 1.80)	0.87 (0.58 – 1.36)
2004 ^B	0.50 (0.40 – 0.69)	0.95 (0.60 – 1.72)	0.49 (0.29 – 0.96)
Geometric mean	0.54 (0.42 - 0.70)	1.08 (0.63 – 1.85)	0.62 (0.33 – 1.20)
2001 ^C	0.24 (0.20 – 0.30)	8.76 (5.04 – 20.4)	2.21 (1.23 – 5.30)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the T/C ratio.

Table D-24. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged Catherine Creek AP spring Chinook for 2001 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
2002	0.65 (0.44 – 1.06)	1.81 (1.02 – 3.43)	1.23 (0.59 – 2.79)
2003	0.62 (0.52-0.76; x25%) ^A	1.44 (0.60 – 3.56)	0.93 (0.38 – 2.29)
2004 ^B	0.33 (0.20 – 0.89)	1.75 (0.0 – 2.31)	0.59 (0.0 – 1.34)
Geometric mean	0.51 (0.17 – 1.54)	1.66 (1.15-2.40)	0.88 (0.30-2.59)
2001 ^C	0.25 (0.18 – 0.37)	5.33 (0.0 – 13.6)	1.38 (0.03 – 3.79)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-25. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged McCall Hatchery summer Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.43 (0.52-0.76; x77%) ^A	1.38 (1.06 – 1.80)	0.64 (0.43 – 0.93)
1998	0.56 (0.50-0.64; x25%)	1.96 (1.54 – 2.56)	1.16 (0.89 – 1.54)
1999	0.52 (0.46 – 0.61)	1.49 (1.29 – 1.73)	0.87 (0.72 – 1.07)
2000	0.61 (0.51 – 0.83)	1.89 (1.67 – 2.15)	1.24 (0.98 – 1.81)
2002	0.58 (0.51 – 0.68)	1.44 (1.18 – 1.79)	0.87 (0.68 – 1.14)
2003	0.70 (0.63 – 0.79)	1.46 (1.17 – 1.81)	1.08 (0.85 – 1.39)
2004 ^B	0.44 (0.35 – 0.58)	1.23 (0.66 – 2.98)	0.55 (0.30 – 1.31)
Geometric mean	0.54 (0.39 – 0.76)	1.53 (1.11 – 2.13)	0.88 (0.49 - 1.59)
2001 ^C	0.27 (0.22 – 0.34)	31.9 (17.9 – 88.4)	8.95 (4.87 – 24.1)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-26. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged Imnaha AP summer Chinook for 1997 to 2004 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.31 (0.21-0.49; x77%) ^A	1.36 (0.83 – 2.37)	0.45 (0.24 – 0.92)
1998	0.53 (0.46-0.62; x25%)	1.55 (0.93 – 3.15)	0.87 (0.51 – 1.72)
1999	0.54 (0.42 – 0.75)	1.89 (1.40 – 2.51)	1.11 (0.75 – 1.72)
2000	0.57 (0.43 – 0.83)	1.29 (1.06 – 1.58)	0.82 (0.56 – 1.25)
2002	0.50 (0.41 – 0.66)	1.75 (1.07 – 3.03)	0.95 (0.54 – 1.78)
2003	0.70 (0.62-0.80; x25%)	1.21 (0.79 – 1.89)	0.91 (0.58 – 1.42)
2004 ^B	0.37 (0.24 – 0.71)	1.50 (0.48 – 4.80)	0.58 (0.15 – 2.19)
Geometric mean	0.49 (0.29 – 0.83)	1.49 (1.09 - 2.04)	0.78 (0.42 - 1.44)
2001 ^C	0.37 (0.27 – 0.61)	10.8 (4.94 – 39.8)	4.15 (1.83 – 15.3)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2004 is incomplete with Age 2-salt adult returns through 8/9/2006.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-27. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged wild steelhead for migration years 1997 to 2003 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.52 (0.28-1.45; x25%) ^A	2.20 (0.0 – 8.16)	1.18 (0.0 – 5.74)
1998	0.54 (0.48-0.62; x25%)	0.20 (0.0 – 0.70)	0.11 (0.0 – 0.41)
1999	0.45 (0.38 – 0.54)	2.28 (1.15 – 4.38)	1.07 (0.53 – 2.09)
2000	0.30 (0.28-0.35; x25%)	1.45 (0.77 – 2.40)	0.50 (0.27 – 0.82)
2002	0.52 (0.41 – 0.69)	4.25 (2.12 – 7.67)	2.24 (1.09 – 4.25)
2003 ^B	0.37 (0.31 – 0.44)	4.13 (2.62 – 6.80)	1.64 (1.01 – 2.72)
Geometric Mean	0.44 (0.27 – 0.71)	1.72 (0.18 – 16.73)	0.80 (0.09 – 7.20)
2001 ^C	0.038 (0.027 – 0.059)	37.0 (10.6 – 94.6)	1.46 (0.40 – 4.40)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Table D-28. Estimated in-river survival LGR to BON (S_R), TIR, and D of PIT-tagged hatchery steelhead for migration years 1997 to 2003 (with 90% confidence intervals).

Mig. Year	S_R	TIR	D
1997	0.40 (0.28-1.45; x25%) ^A	2.21 (0.99 – 5.66)	0.92 (0.36 – 2.67)
1998	0.64 (0.47 – 1.02)	0.58 (0.23 – 1.05)	0.39 (0.16 – 0.85)
1999	0.45 (0.39 – 0.53)	0.87 (0.48 – 1.41)	0.41 (0.22 – 0.70)
2000	0.22 (0.19-0.26; x25%)	2.20 (1.22 – 3.58)	0.55 (0.30 – 0.93)
2002	0.37 (0.29 – 0.49)	1.51 (0.38 – 3.33)	0.60 (0.14 – 1.38)
2003 ^C	0.51 (0.43 – 0.62)	2.65 (1.99 – 3.74)	1.43 (1.02 – 2.10)
Geometric Mean	0.41 (0.20 – 0.85)	1.46 (0.43 - 4.93)	0.64 (0.23 – 1.75)
2001	0.038 (0.023 – 0.082)	59.7 (0.0 – 215.6)	2.40 (0.0 – 10.05)

^A Expansion shows percent of reach with a constant “per/mile” survival rate applied denoted as x#%.

^B Migration year 2003 is incomplete until 3-salt adult returns occur at GRA.

^C For migration year 2001, the SAR(C_1) value is used in the denominator of the TIR ratio.

Tables D-29 to D-30 present annual pathway survival estimates (S) and contributions to overall SAR for wild Chinook and steelhead used in Chapter 4

Table D-29. Annual wild Chinook pathway survival estimates (S) and contributions to overall SAR (Path S_i * π_i), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate in-river. The resulting covariances used to estimate parameters for Figure 3.3 are Cov(1,2) = 2.59E-06; Cov(1+2,3) = 2.75E-06; and Cov(1+2+3,4) = 7.07E-06.

Year	Path1 S (%)	Path2 S (%)	Path3 S (%)	Path4 S (%)	Path1 contr	Path2 contr	Path3 contr	Path4 contr	1+2 contr	1+2+3 contr	Total S (%)
1994	0.67	0.42	0.00	0.28	0.30	0.07	0.00	0.06	0.37	0.37	0.43
1995	0.41	0.25	0.00	0.37	0.21	0.06	0.00	0.05	0.27	0.27	0.32
1996	0.37	1.07	0.00	0.26	0.13	0.26	0.00	0.06	0.39	0.39	0.45
1997	1.08	6.15	0.00	2.35	0.41	1.39	0.00	0.56	1.80	1.80	2.36
1998	1.34	0.84	1.08	1.36	0.64	0.20	0.12	0.23	0.84	0.97	1.19
1999	2.53	2.70	1.85	2.13	0.66	1.21	0.30	0.27	1.87	2.17	2.44
2000	1.22	2.21	0.83	2.39	0.41	0.64	0.10	0.62	1.05	1.15	1.77
2001	1.33	1.29	0.00	0.43	1.10	0.18	0.00	0.00	1.28	1.28	1.29
2002	0.61	0.97	0.54	1.22	0.15	0.30	0.10	0.32	0.44	0.54	0.87
2003	0.31	0.46	0.13	0.33	0.13	0.11	0.01	0.09	0.24	0.25	0.34

Table D-30. Annual wild steelhead pathway survival estimates (S) and contributions to overall SAR (Path S_i * π_i), used to estimate covariance between pathways. Pathway 1 = transport from LGR; Pathway 2 = migrate to and transport from LGS; Pathway 3 = migrate to and transport from LMN; Pathway 4 = migrate in-river. The resulting covariances used to estimate parameters for Figure 3.4 are Cov(1,2) = -5.86E-06; Cov(1+2,3) = 6.72E-06; and Cov(1+2+3,4) = 1.86E-06.

Year	Path1 S (%)	Path2 S (%)	Path3 S (%)	Path4 S (%)	Path1 contr	Path2 contr	Path3 contr	Path4 contr	1+2 contr	1+2+3 contr	Total S (%)
1997	1.87	0.00	0.00	0.66	1.05	0.00	0.00	0.08	1.05	1.05	1.13
1998	0.34	0.00	0.00	1.07	0.21	0.00	0.00	0.11	0.21	0.21	0.32
1999	2.69	4.33	2.65	1.35	0.96	1.64	0.40	0.16	2.59	2.99	3.15
2000	3.50	2.66	1.96	1.92	1.81	0.65	0.20	0.26	2.46	2.66	2.92
2001	3.09	0.00	0.00	2.91	2.76	0.00	0.00	0.02	2.76	2.76	2.78
2002	3.91	1.52	2.44	0.67	1.24	0.36	0.33	0.21	1.60	1.93	2.14

Tables D-31 to D-38 present annual reach survival rates estimated with CJS method for PIT-tagged wild and hatchery Chinook and steelhead

Table D-31. In-river smolt survival rate estimates through hydrosystem for the PIT-tag aggregate of wild spring/summer Chinook in migration years 1994 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1994	S2 (lgr-lgs)	0.822	0.796	0.846
	S3 (lgs-lmn)	0.836	0.807	0.866
1995	S2 (lgr-lgs)	0.895	0.880	0.911
	S3 (lgs-lmn)	0.951	0.924	0.978
	S4 (lmn-mcn)	0.764	0.659	0.923
1996	S2 (lgr-lgs)	0.908	0.869	0.946
	S3 (lgs-lmn)	0.911	0.850	0.977
1997	S2 (lgr-lgs)	0.922	0.859	0.990
	S3 (lgs-lmn)	0.931	0.822	1.057
1998	S2 (lgr-lgs)	1.003	0.986	1.021
	S3 (lgs-lmn)	0.850	0.824	0.874
	S4 (lmn-mcn)	0.940	0.889	0.993
	S5 (mcn-jda)	0.854	0.763	0.965
1999	S2 (lgr-lgs)	0.958	0.948	0.967
	S3 (lgs-lmn)	0.924	0.914	0.934
	S4 (lmn-mcn)	0.889	0.869	0.908
	S5 (mcn-jda)	0.889	0.854	0.927
	S6 (jda-bon)	0.845	0.734	1.000
2000	S2 (lgr-lgs)	0.897	0.880	0.915
	S3 (lgs-lmn)	0.868	0.842	0.893
	S4 (lmn-mcn)	0.977	0.934	1.022
	S5 (mcn-jda)	0.734	0.674	0.804
	S6 (jda-bon)	0.866	0.708	1.097
2001	S2 (lgr-lgs)	0.930	0.925	0.936
	S3 (lgs-lmn)	0.772	0.762	0.782
	S4 (lmn-mcn)	0.684	0.670	0.698
	S5 (mcn-jda)	0.714	0.669	0.763
	S6 (jda-bon)	0.663	0.553	0.827
2002	S2 (lgr-lgs)	0.901	0.883	0.920
	S3 (lgs-lmn)	0.996	0.975	1.016
	S4 (lmn-mcn)	0.810	0.785	0.837
	S5 (mcn-jda)	0.873	0.826	0.927
	S6 (jda-bon)	0.967	0.780	1.268
2003	S2 (lgr-lgs)	0.893	0.877	0.910
	S3 (lgs-lmn)	0.878	0.852	0.905
	S4 (lmn-mcn)	0.990	0.955	1.023
	S5 (mcn-jda)	0.798	0.759	0.841
	S6 (jda-bon)	0.962	0.803	1.146
2004	S2 (lgr-lgs)	0.970	0.960	0.979
	S3 (lgs-lmn)	0.830	0.810	0.849
	S4 (lmn-mcn)	0.878	0.841	0.917
	S5 (mcn-jda)	0.744	0.667	0.843
	S6 (jda-bon)	0.756	0.581	1.021

Table D-32. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Rapid River Hatchery spring Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.390	0.376	0.406
	S2 (lgr-lgs)	0.964	0.903	1.027
	S3 (lgs-lmn)	0.803	0.746	0.867
1998	S1 (rel-lgr)	0.665	0.658	0.672
	S2 (lgr-lgs)	1.005	0.986	1.024
	S3 (lgs-lmn)	0.847	0.826	0.869
	S4 (lmn-mcn)	0.982	0.924	1.045
	S5 (mcn-jda)	0.798	0.713	0.897
1999	S1 (rel-lgr)	0.751	0.738	0.765
	S2 (lgr-lgs)	0.923	0.901	0.943
	S3 (lgs-lmn)	0.957	0.937	0.977
	S4 (lmn-mcn)	0.906	0.875	0.939
	S5 (mcn-jda)	0.945	0.882	1.022
	S6 (jda-bon)	0.750	0.622	0.923
2000	S1 (rel-lgr)	0.737	0.724	0.752
	S2 (lgr-lgs)	0.846	0.813	0.882
	S3 (lgs-lmn)	1.127	1.016	1.255
	S4 (lmn-mcn)	0.823	0.721	0.937
	S5 (mcn-jda)	0.945	0.760	1.250
	S6 (jda-bon)	0.782	0.546	1.171
2001	S1 (rel-lgr)	0.690	0.686	0.694
	S2 (lgr-lgs)	0.958	0.951	0.965
	S3 (lgs-lmn)	0.856	0.843	0.867
	S4 (lmn-mcn)	0.698	0.683	0.715
	S5 (mcn-jda)	0.924	0.854	1.013
	S6 (jda-bon)	0.618	0.497	0.802
2002	S1 (rel-lgr)	0.755	0.741	0.769
	S2 (lgr-lgs)	0.947	0.923	0.972
	S3 (lgs-lmn)	0.981	0.959	1.004
	S4 (lmn-mcn)	0.841	0.819	0.863
	S5 (mcn-jda)	0.953	0.895	1.018
	S6 (jda-bon)	0.951	0.770	1.191
2003	S1 (rel-lgr)	0.692	0.680	0.706
	S2 (lgr-lgs)	0.916	0.881	0.950
	S3 (lgs-lmn)	0.875	0.809	0.949
	S4 (lmn-mcn)	0.964	0.885	1.050
	S5 (mcn-jda)	0.902	0.834	0.976
	S6 (jda-bon)	0.947	0.788	1.195
2004	S1 (rel-lgr)	0.696	0.691	0.702
	S2 (lgr-lgs)	0.999	0.985	1.013
	S3 (lgs-lmn)	0.754	0.709	0.807
	S4 (lmn-mcn)	0.880	0.812	0.950
	S5 (mcn-jda)	0.766	0.667	0.897
	S6 (jda-bon)	0.696	0.478	1.120

Table D-33. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Dworshak Hatchery spring Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.581	0.547	0.613
	S2 (lgr-lgs)	1.047	0.959	1.148
	S3 (lgs-lmn)	0.810	0.725	0.908
1998	S1 (rel-lgr)	0.843	0.832	0.855
	S2 (lgr-lgs)	1.071	1.043	1.098
	S3 (lgs-lmn)	0.765	0.740	0.790
	S4 (lmn-mcn)	0.931	0.891	0.976
	S5 (mcn-jda)	0.782	0.696	0.891
1999	S1 (rel-lgr)	0.853	0.832	0.873
	S2 (lgr-lgs)	0.887	0.862	0.914
	S3 (lgs-lmn)	0.952	0.935	0.968
	S4 (lmn-mcn)	0.875	0.848	0.901
	S5 (mcn-jda)	0.899	0.849	0.959
	S6 (jda-bon)	0.816	0.684	1.010
2000	S1 (rel-lgr)	0.825	0.809	0.843
	S2 (lgr-lgs)	0.807	0.777	0.839
	S3 (lgs-lmn)	1.036	0.955	1.124
	S4 (lmn-mcn)	0.834	0.754	0.920
	S5 (mcn-jda)	0.944	0.804	1.145
	S6 (jda-bon)	0.730	0.543	1.007
2001	S1 (rel-lgr)	0.748	0.744	0.752
	S2 (lgr-lgs)	0.941	0.934	0.947
	S3 (lgs-lmn)	0.839	0.828	0.849
	S4 (lmn-mcn)	0.694	0.681	0.707
	S5 (mcn-jda)	0.693	0.654	0.739
	S6 (jda-bon)	0.636	0.510	0.839
2002	S1 (rel-lgr)	0.827	0.803	0.849
	S2 (lgr-lgs)	0.917	0.884	0.953
	S3 (lgs-lmn)	0.978	0.950	1.007
	S4 (lmn-mcn)	0.810	0.787	0.834
	S5 (mcn-jda)	0.931	0.877	0.995
	S6 (jda-bon)	0.910	0.758	1.086
2003	S1 (rel-lgr)	0.706	0.692	0.722
	S2 (lgr-lgs)	0.905	0.874	0.933
	S3 (lgs-lmn)	0.897	0.854	0.947
	S4 (lmn-mcn)	0.983	0.934	1.038
	S5 (mcn-jda)	0.856	0.804	0.908
	S6 (jda-bon)	0.990	0.833	1.217
2004	S1 (rel-lgr)	0.823	0.817	0.830
	S2 (lgr-lgs)	0.977	0.964	0.990
	S3 (lgs-lmn)	0.969	0.912	1.031
	S4 (lmn-mcn)	0.779	0.723	0.839
	S5 (mcn-jda)	0.790	0.701	0.910
	S6 (jda-bon)	0.858	0.640	1.270

Table D-34. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Catherine Creek Acclimation Pond spring Chinook in migration years 2001 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
2001	S1 (rel-lgr)	0.520	0.513	0.528
	S2 (lgr-lgs)	0.945	0.931	0.961
	S3 (lgs-lmn)	0.814	0.787	0.840
	S4 (lmn-mcn)	0.659	0.624	0.699
	S5 (mcn-jda)	0.768	0.654	0.901
	S6 (jda-bon)	0.639	0.419	1.101
2002	S1 (rel-lgr)	0.406	0.391	0.421
	S2 (lgr-lgs)	0.949	0.899	0.998
	S3 (lgs-lmn)	1.013	0.954	1.073
	S4 (lmn-mcn)	0.808	0.743	0.887
	S5 (mcn-jda)	0.928	0.779	1.125
	S6 (jda-bon)	0.896	0.562	1.726
2003	S1 (rel-lgr)	0.349	0.334	0.366
	S2 (lgr-lgs)	0.972	0.894	1.056
	S3 (lgs-lmn)	0.855	0.743	1.004
	S4 (lmn-mcn)	1.093	0.937	1.282
	S5 (mcn-jda)	0.764	0.641	0.918
2004	S1 (rel-lgr)	0.255	0.248	0.262
	S2 (lgr-lgs)	0.976	0.942	1.010
	S3 (lgs-lmn)	0.921	0.827	1.047
	S4 (lmn-mcn)	0.900	0.743	1.072
	S5 (mcn-jda)	0.704	0.513	1.040
	S6 (jda-bon)	0.579	0.271	2.149

Table D-35. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged McCall Hatchery summer Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.425	0.411	0.441
	S2 (lgr-lgs)	0.935	0.889	0.987
	S3 (lgs-lmn)	0.882	0.820	0.954
1998	S1 (rel-lgr)	0.588	0.580	0.595
	S2 (lgr-lgs)	0.991	0.971	1.012
	S3 (lgs-lmn)	0.843	0.820	0.867
	S4 (lmn-mcn)	0.942	0.884	1.007
	S5 (mcn-jda)	0.824	0.738	0.930
1999	S1 (rel-lgr)	0.658	0.642	0.675
	S2 (lgr-lgs)	0.908	0.880	0.939
	S3 (lgs-lmn)	0.936	0.908	0.961
	S4 (lmn-mcn)	0.913	0.872	0.957
	S5 (mcn-jda)	1.086	0.989	1.206
	S6 (jda-bon)	0.622	0.514	0.766
2000	S1 (rel-lgr)	0.667	0.650	0.685
	S2 (lgr-lgs)	0.867	0.813	0.932
	S3 (lgs-lmn)	0.917	0.807	1.036
	S4 (lmn-mcn)	1.034	0.911	1.181
	S5 (mcn-jda)	1.307	0.904	2.258
	S6 (jda-bon)	0.570	0.323	0.887
2001	S1 (rel-lgr)	0.667	0.663	0.672
	S2 (lgr-lgs)	0.928	0.920	0.937
	S3 (lgs-lmn)	0.771	0.756	0.786
	S4 (lmn-mcn)	0.647	0.628	0.666
	S5 (mcn-jda)	0.862	0.784	0.954
	S6 (jda-bon)	0.674	0.531	0.924
2002	S1 (rel-lgr)	0.596	0.583	0.609
	S2 (lgr-lgs)	0.964	0.936	0.992
	S3 (lgs-lmn)	0.990	0.964	1.016
	S4 (lmn-mcn)	0.837	0.809	0.869
	S5 (mcn-jda)	1.051	0.969	1.144
	S6 (jda-bon)	0.688	0.583	0.840
2003	S1 (rel-lgr)	0.581	0.570	0.590
	S2 (lgr-lgs)	0.921	0.892	0.949
	S3 (lgs-lmn)	0.884	0.838	0.933
	S4 (lmn-mcn)	1.014	0.964	1.070
	S5 (mcn-jda)	0.907	0.858	0.960
	S6 (jda-bon)	0.929	0.804	1.082
2004	S1 (rel-lgr)	0.563	0.559	0.567
	S2 (lgr-lgs)	0.938	0.927	0.949
	S3 (lgs-lmn)	0.993	0.942	1.052
	S4 (lmn-mcn)	0.754	0.695	0.812
	S5 (mcn-jda)	0.893	0.780	1.039
	S6 (jda-bon)	0.696	0.515	0.993

Table D-36. In-river smolt survival rate estimates from hatchery to LGR and through reaches in the hydrosystem for PIT-tagged Imnaha Acclimation Pond summer Chinook in migration years 1997 to 2004.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S1 (rel-lgr)	0.617	0.586	0.654
	S2 (lgr-lgs)	0.994	0.909	1.082
	S3 (lgs-lmn)	0.768	0.693	0.856
1998	S1 (rel-lgr)	0.685	0.673	0.697
	S2 (lgr-lgs)	0.978	0.951	1.006
	S3 (lgs-lmn)	0.843	0.812	0.872
	S4 (lmn-mcn)	0.956	0.894	1.035
	S5 (mcn-jda)	0.784	0.685	0.907
1999	S1 (rel-lgr)	0.664	0.645	0.686
	S2 (lgr-lgs)	0.921	0.885	0.957
	S3 (lgs-lmn)	0.954	0.920	0.989
	S4 (lmn-mcn)	0.876	0.825	0.931
	S5 (mcn-jda)	0.944	0.840	1.075
	S6 (jda-bon)	0.740	0.548	1.103
2000	S1 (rel-lgr)	0.685	0.665	0.707
	S2 (lgr-lgs)	0.822	0.774	0.877
	S3 (lgs-lmn)	1.008	0.869	1.201
	S4 (lmn-mcn)	0.885	0.717	1.081
	S5 (mcn-jda)	0.893	0.677	1.293
	S6 (jda-bon)	1.013	0.570	2.469
2001	S1 (rel-lgr)	0.748	0.742	0.755
	S2 (lgr-lgs)	0.958	0.950	0.968
	S3 (lgs-lmn)	0.892	0.877	0.908
	S4 (lmn-mcn)	0.751	0.729	0.776
	S5 (mcn-jda)	0.853	0.763	0.958
	S6 (jda-bon)	0.678	0.462	1.226
2002	S1 (rel-lgr)	0.667	0.645	0.691
	S2 (lgr-lgs)	0.951	0.910	0.994
	S3 (lgs-lmn)	0.947	0.911	0.984
	S4 (lmn-mcn)	0.858	0.817	0.904
	S5 (mcn-jda)	0.828	0.753	0.914
	S6 (jda-bon)	0.788	0.603	1.120
2003	S1 (rel-lgr)	0.715	0.691	0.739
	S2 (lgr-lgs)	0.901	0.845	0.952
	S3 (lgs-lmn)	0.905	0.815	1.020
	S4 (lmn-mcn)	0.914	0.809	1.021
	S5 (mcn-jda)	1.027	0.913	1.163
2004	S1 (rel-lgr)	0.615	0.607	0.624
	S2 (lgr-lgs)	0.964	0.943	0.986
	S3 (lgs-lmn)	0.910	0.831	1.001
	S4 (lmn-mcn)	0.834	0.731	0.966
	S5 (mcn-jda)	0.878	0.701	1.126
	S6 (jda-bon)	0.576	0.333	1.274

Table D-37. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of wild summer steelhead in migration years 1997 to 2003.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S2 (lgr-lgs)	0.984	0.948	1.017
	S3 (lgs-lmn)	0.975	0.902	1.060
	S4 (lmn-mcn)	0.886	0.685	1.233
	S5 (mcn-jda)	0.721	0.368	2.096
1998	S2 (lgr-lgs)	0.969	0.945	0.995
	S3 (lgs-lmn)	0.843	0.807	0.879
	S4 (lmn-mcn)	0.889	0.805	1.000
	S5 (mcn-jda)	0.868	0.746	1.009
1999	S2 (lgr-lgs)	0.974	0.956	0.991
	S3 (lgs-lmn)	0.910	0.888	0.934
	S4 (lmn-mcn)	0.835	0.785	0.890
	S5 (mcn-jda)	1.040	0.937	1.148
	S6 (jda-bon)	0.580	0.473	0.761
2000	S2 (lgr-lgs)	0.790	0.771	0.807
	S3 (lgs-lmn)	0.910	0.878	0.943
	S4 (lmn-mcn)	0.860	0.800	0.931
	S5 (mcn-jda)	0.659	0.594	0.729
2001	S2 (lgr-lgs)	0.834	0.823	0.845
	S3 (lgs-lmn)	0.716	0.694	0.741
	S4 (lmn-mcn)	0.288	0.267	0.312
	S5 (mcn-jda)	0.230	0.191	0.281
	S6 (jda-bon)	0.958	0.618	1.714
2002	S2 (lgr-lgs)	0.943	0.921	0.965
	S3 (lgs-lmn)	1.164	1.122	1.215
	S4 (lmn-mcn)	0.522	0.493	0.553
	S5 (mcn-jda)	0.960	0.886	1.083
	S6 (jda-bon)	0.939	0.720	1.269
2003	S2 (lgr-lgs)	0.908	0.884	0.934
	S3 (lgs-lmn)	0.914	0.875	0.958
	S4 (lmn-mcn)	0.729	0.679	0.784
	S5 (mcn-jda)	0.913	0.826	1.21
	S6 (jda-bon)	0.664	0.552	0.818

Table D-38. In-river smolt survival rate estimates through reaches in the hydrosystem for the PIT-tag aggregate of hatchery summer steelhead in migration years 1997 to 2003.

Migr Year	Reach of Survival	Survival Estimate	95% CI Lower Limit	95% CI Upper Limit
1997	S2 (lgr-lgs)	0.954	0.937	0.972
	S3 (lgs-lmn)	0.853	0.823	0.888
	S4 (lmn-mcn)	0.938	0.814	1.104
	S5 (mcn-jda)	0.656	0.440	1.187
1998	S2 (lgr-lgs)	0.950	0.936	0.963
	S3 (lgs-lmn)	0.854	0.834	0.875
	S4 (lmn-mcn)	0.820	0.775	0.868
	S5 (mcn-jda)	1.058	0.970	1.148
	S6 (jda-bon)	0.915	0.642	1.543
1999	S2 (lgr-lgs)	0.966	0.955	0.978
	S3 (lgs-lmn)	0.895	0.880	0.909
	S4 (lmn-mcn)	0.801	0.769	0.837
	S5 (mcn-jda)	1.044	0.985	1.111
	S6 (jda-bon)	0.622	0.519	0.772
2000	S2 (lgr-lgs)	0.693	0.673	0.717
	S3 (lgs-lmn)	0.812	0.778	0.854
	S4 (lmn-mcn)	0.803	0.735	0.877
	S5 (mcn-jda)	0.705	0.614	0.820
2001	S2 (lgr-lgs)	0.693	0.682	0.705
	S3 (lgs-lmn)	0.678	0.650	0.707
	S4 (lmn-mcn)	0.284	0.262	0.311
	S5 (mcn-jda)	0.353	0.286	0.463
	S6 (jda-bon)	0.805	0.418	2.455
2002	S2 (lgr-lgs)	0.908	0.887	0.930
	S3 (lgs-lmn)	0.970	0.943	1.001
	S4 (lmn-mcn)	0.570	0.536	0.610
	S5 (mcn-jda)	0.937	0.830	1.051
	S6 (jda-bon)	0.777	0.604	1.067
2003	S2 (lgr-lgs)	0.949	0.927	0.972
	S3 (lgs-lmn)	0.935	0.900	0.971
	S4 (lmn-mcn)	0.710	0.664	0.761
	S5 (mcn-jda)	0.954	0.856	1.056
	S6 (jda-bon)	0.842	0.695	1.049

Tables D-39 to D-44 present age distribution of returning adult Chinook and steelhead detected at LGR for upriver populations and BON for downriver populations

Table D-39. Age composition of returning PIT-tagged wild Chinook jacks and adults detected at Lower Granite Dam that were PIT-tagged during the 10-month period from July 25 to May 20 for each migration year between 1994 and 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1994	1	11	11	4.3	47.8	47.8
1995	1	38	20	1.7	64.4	33.9
1996	0	11	5	0.0	68.8	31.3
1997	2	33	5	5.0	82.5	12.5
1998	17	148	47	8.0	69.8	22.2
1999	25	517	144	3.6	75.4	21.0
2000	9	259	312 (1 ^B)	1.5	44.6	53.7 (0.2 ^B)
2001	2	30	15	4.3	63.8	31.9
2002	26	197	38	10.0	75.5	14.6
2003 ^A	3	61	24	3.4	69.3	27.3
2004 ^A	3	86	NA	--	--	--
Average				4.2	66.2	29.6

^A Migration year 2004 is incomplete until 3-salt returns occur at GRA; not included in average.

^B One 4-salt adult shown in parenthesis in 3-salt column.

Table D-40. Age composition of returning PIT-tagged John Day River wild Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	3	112	31	2.1	76.7	21.2
2001	7	90	15	6.3	80.4	13.4
2002	5	86	9	5.0	86.0	9.0
2003	5	110	13	3.9	85.9	10.2
2004 ^A	5	68	NA	--	--	--
Average				4.3	82.3	13.4

^A Migration year 2004 is incomplete until 3-salt returns occur at BOA; not included in average.

Table D-41. Number of returning PIT-tagged hatchery Chinook adults and jacks detected at Lower Granite Dam that migrated as smolts in 1997 to 2004 and percent of total return.

Hatchery (run)	Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
RAPH (spring)	1997	2	86	7	2.1	90.5	7.4
	1998	32	390	23	7.2	87.6	5.2
	1999	43	787	31	5.0	91.4	3.6
	2000	8	371	256	1.3	58.4	40.3
	2001	21	206	13	8.8	85.8	5.4
	2002	60	298	5	16.5	82.1	1.4
	2003	20	75	8	19.4	72.8	7.8
	2004 ^A	4	67	NA	--	--	--
Average				8.6	81.2	10.2	
MCCA (summer)	1997	21	263	11	7.1	89.2	3.7
	1998	108	394	37	20.0	73.1	6.9
	1999	119	722	113	12.5	75.7	11.8
	2000	144	635	239 (1 ^B)	14.1	62.3	(0.1 ^B)
	2001	62	200	23	21.8	70.2	8.1
	2002	116	347	18	24.1	72.1	3.7
	2003	129	222	27	34.1	58.7	7.1
	2004 ^A	25	91	NA	--	--	--
Average				19.1	71.6	9.3	
DWOR (spring)	1997	1	36	6	2.3	83.7	14.0
	1998	51	372	23	11.4	83.4	5.2
	1999	14	393	44	3.1	87.1	9.8
	2000	3	180	197	0.8	47.4	51.8
	2001	14	79	10	13.6	76.7	9.7
	2002	52	222	8	18.4	78.7	2.8
	2003	5	73	12	5.6	81.1	13.3
	2004 ^A	1	85	NA	--	--	--
Average				7.9	76.9	15.2	
IMNA (summer)	1997	24	63	7	25.5	67.0	7.4
	1998	54	69	2	43.2	55.2	1.6
	1999	81	226	12	25.4	70.8	3.8
	2000	149	289	79	28.8	55.9	15.3
	2001	30	49	4	36.1	59.0	4.8
	2002	46	81	2	35.7	63.8	1.6
	2003	93	71	2	56.0	42.8	1.2
	2004 ^A	9	33	NA	--	--	--
Average				35.8	59.2	5.1	
CATH (spring)	2001	2	13	0	13.3	86.7	0.0
	2002	11	45	1	19.3	79.0	1.8
	2003	5	22	0	18.5	81.5	--
	2004 ^A	2	17	NA	--	--	--
Average				17.0	82.4	0.6	

^A Migration year 2004 is incomplete until 3-salt returns occur at GRA; not included in average.

^B One 4-salt adult shown in parenthesis in 3-salt column.

Table D-42. Age composition of returning PIT-tagged Carson NFH Chinook jacks and adults detected at Bonneville Dam for fish that outmigrated in 2000 to 2004.

Migration Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	5	302	124 (1 ^A)	1.2	69.9	28.7 (0.2 ^A)
2001	3	205	18	1.3	90.7	8.0
2002	5	148	3	3.2	94.9	1.9
2003	0	32	2	0	94.1	5.9
2004 ^B	4	79	NA	--	--	--
Average				1.4	87.4	11.2

^A One 4-salt adult Chinook shown in parenthesis in 3-salt column.

^B Migration year 2004 is incomplete until 3-salt returns occur at BOA; not included in average.

Table D-43. Age composition of returning PIT-tagged wild steelhead adults detected at Lower Granite Dam that were PIT-tagged during the 12-month period from July 1 to June 30 for each migration year between 1997 and 2003.

Migration Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	4	10	0	28.6	71.4	0
1998	16	8	0	66.7	33.3	0
1999	33	51	2	38.4	59.3	2.3
2000	132	131	3	49.6	49.3	1.1
2001	5	14	2	23.8	66.7	9.5
2002	59	60	1	49.2	50.0	0.8
2003 ^A	38	63	NA	(37.6)	(62.4)	--
Average				42.7	55.0	2.3

^A Migration year 2003 is incomplete until 3-salt returns occur at GRA; not included in average.

Table D-44. Age composition of returning PIT-tagged hatchery steelhead adults detected at Lower Granite Dam that migrated as smolts in 1997 to 2003.

Migration Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	34	15		69.4	30.6	0
1998	45	32		58.4	41.6	0
1999	85	96	1	46.7	52.7	0.5
2000	178	89	1	66.4	33.2	0.4
2001	3	8		27.3	72.7	0
2002	99	49	1	66.4	32.9	0.7
2003 ^A	90	77	NA	(53.9)	(46.1)	--
Average				55.8	43.9	0.3

^A Migration year 2003 is incomplete until 3-salt returns occur at GRA; not included in average.

Tables D-45 to D-47 provide the actual number of PIT-tagged smolts transported from each Snake River collector dam and corresponding number of returning adult detections.

Table D-45. Actual number of PIT-tagged juvenile hatchery spring Chinook transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.

Hat. Code ^A	Migr. Year	Smolts Transported			Adult Detections of Transported Smolts					
		X12	X102	X1002	X12		X102		X1002	
		LGR	LGS	LMN	GRA	BOA	GRA	BOA	GRA	BOA
RAPH	1997	4,138	132	38	33	---	0	---	1	---
	1998	11,290	1,362	197	239	---	16	---	2	---
	1999	7,405	4,728	290	236	---	152	---	3	---
	2000	10,369	4,182	1,213	243	357	79	101	27	34
	2001	15,404	2,851	582	182	235	21	25	4	5
	2002	5,348	5,325	576	61	73	50	53	6	6
	2003	8,391	3,887	574	27	44	5	7	1	1
	2004 ^B	13,511	5,271	550	38	50	11	15	1	1
DWOR	1997	1,864	52	15	16	---	0	---	0	---
	1998	11,113	3,577	225	110	---	22	---	0	---
	1999	4,934	3,798	484	62	---	49	---	4	---
	2000	9,806	4,912	2,030	116	198	53	74	14	24
	2001	16,580	4,091	640	60	75	18	20	1	1
	2002	4,095	4,358	734	26	37	32	39	2	4
	2003	7,031	4,345	1,113	20	25	12	18	2	1
	2004 ^B	12,725	8,154	552	16	45	28	40	2	3
CATH	2001	3,377	1,096	195	11	18	0	0	0	0
	2002	1,470	1,115	50	16	23	8	9	0	1
	2003	1,564	698	176	5	5	4	5	0	0
	2004 ^B	2,078	700	73	5	6	4	5	1	2

^A Hatchery codes are RAPH = Rapid River Hatchery, DWOR = Dworshak Hatchery, and CATH = Catherine Creek Acclimation Pond.

^B Incomplete adult return data.

Table D-46. Actual number of PIT-tagged juvenile hatchery summer Chinook transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.

Hat. Code ^A	Migr. Year	Smolts Transported			Adult Detections of Transported Smolts					
		X12	X102	X1002	X12		X102		X1002	
		LGR	LGS	LMN	GRA	BOA	GRA	BOA	GRA	BOA
MCCA	1997	5,863	105	31	87	---	3	---	1	---
	1998	9,045	901	157	263	---	9	---	1	---
	1999	4,760	5,010	204	206	---	161	---	10	---
	2000	8,555	2,835	781	386	455	92	107	19	22
	2001	13,153	2,646	500	184	217	20	26	2	3
	2002	4,314	4,160	201	70	90	59	72	2	1
	2003	8,334	4,242	866	68	76	36	41	7	7
	2004 ^B	16,455	3,877	251	54	76	11	16	0	0
IMNA	1997	2,086	45	12	25	---	0	---	0	---
	1998	4,068	608	98	37	---	4	---	0	---
	1999	2,182	2,317	114	74	---	53	---	3	---
	2000	3,914	1,831	537	154	190	45	60	12	12
	2001	5,764	1,609	246	42	54	6	7	0	0
	2002	1,627	1,967	196	12	18	16	20	3	3
	2003	3,094	1,557	299	18	26	10	10	2	3
	2004 ^B	4,754	1,916	162	15	24	7	9	2	2

^A Hatchery codes are MCCA = McCall Hatchery and IMNA = Imnaha Acclimation Pond.

^B Incomplete adult return data.

Table D-47. Actual number of PIT-tagged juvenile wild Chinook and wild/hatchery steelhead transported from Lower Granite (LGR-X12), Little Goose (LGS-X102), and Lower Monumental (LMN-X1002) dams, used in creating the CSS transport group, and corresponding number of returning adults detected in fish ladders at Lower Granite (GRA) and Bonneville (BOA) dams.

SP/ RT Code ^A	Migr. Year	Smolts Transported			Adult Detections of Transported Smolts					
		X12	X102	X1002	X12		X102		X1002	
		LGR	LGS	LMN	GRA	BOA	GRA	BOA	GRA	BOA
WCH	1994	1,052	387	330	7	---	2	---	0	---
	1995	1,702	356	156	7	---	1	---	0	---
	1996	268	85	32	1	---	1	---	0	---
	1997	185	30	11	2	---	2	---	0	---
	1998	820	359	79	11	---	3	---	1	---
	1999	1,109	319	288	28	---	9	---	6	---
	2000	327	244	187	4	9	6	10	2	2
	2001	452	72	13	6	9	1	1	0	0
	2002	1,640	1,856	167	10	15	20	25	1	1
	2003	5,098	2,548	599	16	15	13	13	1	1
	2004 ^B	8,951	2,812	834	27	35	8	10	4	4
WST	1997	214	33	26	4	---	0	---	0	---
	1998	294	100	68	1	---	0	---	0	---
	1999	223	90	67	6	---	4	---	2	---
	2000	200	89	110	7	---	3	---	3	---
	2001	162	23	7	5	---	0	---	0	---
	2002	128	62	135	5	---	1	---	3	---
	2003 ^B	1,215	655	227	21	---	18	---	5	---
HST	1997	1,521	104	81	9	---	0	---	0	---
	1998	795	358	157	5	---	1	---	1	---
	1999	779	291	221	8	---	4	---	0	---
	2000	399	73	92	12	---	1	---	1	---
	2001	331	43	16	4	---	0	---	0	---
	2002	124	64	79	3	---	0	---	0	---
	2003 ^B	2,068	1,510	829	41	---	32	---	10	---

^A SP/RT (species and rear type) codes are WCH = wild spring/summer Chinook, WST = wild summer steelhead, and HST = hatchery summer steelhead.

^B Incomplete adult return data.

Appendix E

Tables for 61 Groups of Upriver PIT-tagged Chinook and Steelhead Analyzed for SARs and Related Parameters

Appendix E contains 61 tables organized by Species and Rear-type and Migration Year. Each table lists the PIT-tag release number for the data on that page. Data include the initial values, bootstrap averages, standard deviations, coefficient of variation, and 90% parametric and non-parametric confidence intervals of key CSS parameters. For each parameter, the estimate obtained with the computational formula is presented first, followed (on next row) with the estimate obtained with the expectation formula. The data covers PIT-tagged wild Chinook 1994-2004, hatchery Chinook (individually for each facility) 1997-2004, wild steelhead 1997-2003, and hatchery steelhead 1997-2003. All fish were PIT-tagged and released in tributaries or mainstem locations above Lower Granite Dam.

Table E-1. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1994.

Wild Chinook 1994

PIT-tags released= 49,657

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	5	5	2.2636	44.18%	1	9	2	9
adult_C1	3	3	1.7117	58.12%	0	6	1	6
adult_T0	9	9	3.0205	33.67%	4	14	4	14
E(C0)	1,576	1,574	70.9889	4.51%	1,457	1,691	1,461	1,694
C0	1,801	1,800	66.4040	3.69%	1,691	1,910	1,693	1,911
E(C1)	4,529	4,531	106.6135	2.35%	4,356	4,706	4,362	4,717
C1	4,431	4,433	103.0706	2.33%	4,264	4,603	4,275	4,618
E(T0)	2,055	2,055	50.8187	2.47%	1,972	2,139	1,973	2,137
T0	2,004	2,004	49.2858	2.46%	1,923	2,085	1,922	2,084
E(sarC0)	0.0032	0.0033	0.001453	44.56%	0.0009	0.0057	0.0012	0.0059
sarC0	0.0028	0.0028	0.001266	44.44%	0.0008	0.0049	0.0011	0.0051
E(sarC1)	0.0007	0.0007	0.000380	58.37%	0.0000	0.0013	0.0002	0.0013
sarC1	0.0007	0.0007	0.000388	58.37%	0.0000	0.0013	0.0002	0.0014
E(sar ₂ T0)	0.0044	0.0044	0.001468	33.63%	0.0020	0.0068	0.0020	0.0070
sar ₂ T0	0.0045	0.0045	0.001506	33.63%	0.0020	0.0070	0.0020	0.0072
E(TIR)	1.380	1.724	1.352781	78.44%	-0.501	3.950	0.534	4.311
TIR	1.618	2.024	1.588519	78.49%	-0.589	4.637	0.619	5.054
S _R	0.196	0.197	0.014135	7.19%	0.173	0.220	0.174	0.221
S _T	0.889	0.889	0.004717	0.53%	0.881	0.897	0.881	0.896
E(D)	0.304	0.381	0.298658	78.43%	-0.110	0.872	0.115	0.934
D	0.357	0.447	0.350463	78.43%	-0.130	1.023	0.134	1.088
prop_T0'	0.863	0.863	0.004311	0.50%	0.856	0.870	0.855	0.869
prop_C0	0.137	0.137	0.004311	3.14%	0.130	0.144	0.131	0.145
E(sar_tot) ⁺⁺	0.0042	0.0042	0.001287	30.55%	0.0021	0.0063	0.0023	0.0065
sar_tot ⁺⁺	0.0043	0.0043	0.001315	30.92%	0.0021	0.0064	0.0022	0.0066

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-2. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1995.

Wild Chinook 1995

PIT tags released= 74,639

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	10	10	3.1806	31.28%	5	15	5	15
adult_C1	36	36	5.8826	16.37%	26	46	26	46
adult_T0	8	8	2.8079	35.32%	3	13	4	13
E(C0)	2,689	2,688	57.5181	2.14%	2,594	2,783	2,596	2,785
C0	2,709	2,706	62.0096	2.29%	2,604	2,808	2,602	2,812
E(C1)	14,209	14,210	121.4399	0.85%	14,011	14,410	14,010	14,408
C1	14,206	14,208	123.8471	0.87%	14,005	14,412	13,997	14,413
E(T0)	2,283	2,284	48.5894	2.13%	2,204	2,364	2,202	2,366
T0	2,283	2,284	48.7082	2.13%	2,204	2,365	2,202	2,367
E(sarC0)	0.0037	0.0038	0.001191	31.45%	0.0018	0.0057	0.0019	0.0058
sarC0	0.0037	0.0038	0.001180	31.39%	0.0018	0.0057	0.0018	0.0057
E(sarC1)	0.0025	0.0025	0.000414	16.38%	0.0018	0.0032	0.0018	0.0032
sarC1	0.0025	0.0025	0.000414	16.38%	0.0018	0.0032	0.0018	0.0032
E(sar ₂ T0)	0.0035	0.0035	0.001227	35.27%	0.0015	0.0055	0.0017	0.0057
sar ₂ T0	0.0035	0.0035	0.001227	35.27%	0.0015	0.0055	0.0017	0.0057
E(TIR)	0.942	1.049	0.691500	65.90%	-0.088	2.187	0.387	2.111
TIR	0.949	1.056	0.694282	65.76%	-0.086	2.198	0.388	2.136
S _R	0.415	0.425	0.074060	17.44%	0.303	0.547	0.321	0.556
S _T	0.936	0.936	0.002915	0.31%	0.931	0.941	0.931	0.941
E(D)	0.417	0.477	0.333587	69.93%	-0.072	1.026	0.169	1.065
D	0.420	0.480	0.335067	69.81%	-0.071	1.031	0.171	1.087
prop_T0'	0.805	0.806	0.003352	0.42%	0.800	0.811	0.800	0.811
prop_C0	0.141	0.141	0.002897	2.06%	0.136	0.146	0.136	0.146
E(sar_tot) ⁺⁺	0.0035	0.0035	0.000999	28.77%	0.0018	0.0051	0.0020	0.0052
sar_tot ⁺⁺	0.0035	0.0035	0.000999	28.80%	0.0018	0.0051	0.0020	0.0052

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-3. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1996.

Wild Chinook 1996

PIT-tags released= 21,523

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	5	5	2.3002	46.05%	1	9	2	9
adult_C1	7	7	2.5941	36.80%	3	11	3	12
adult_T0	2	2	1.3691	69.25%	0	4	0	4
E(C0)	1,920	1,922	68.7591	3.58%	1,809	2,035	1,807	2,034
C0	1,917	1,920	69.9267	3.64%	1,805	2,035	1,805	2,034
E(C1)	5,210	5,209	90.3412	1.73%	5,060	5,357	5,060	5,361
C1	5,209	5,207	91.4589	1.76%	5,057	5,358	5,057	5,366
E(T0)	400	399	20.0029	5.01%	366	432	365	433
T0	400	399	20.0452	5.02%	367	432	365	434
E(sarC0)	0.0026	0.0026	0.001201	46.15%	0.0006	0.0046	0.0010	0.0048
sarC0	0.0026	0.0026	0.001202	46.13%	0.0006	0.0046	0.0010	0.0048
E(sarC1)	0.0013	0.0014	0.000498	36.82%	0.0005	0.0022	0.0006	0.0023
sarC1	0.0013	0.0014	0.000499	36.82%	0.0005	0.0022	0.0006	0.0023
E(sar ₂ T0)	0.0050	0.0050	0.003431	69.20%	-0.0007	0.0106	0.0000	0.0107
sar ₂ T0	0.0050	0.0050	0.003425	69.19%	-0.0007	0.0106	0.0000	0.0107
E(TIR)	1.920	2.811	2.480129	88.22%	-1.268	6.891	0.000	6.794
TIR	1.917	2.804	2.474903	88.26%	-1.267	6.875	0.000	6.798
S _R	0.439	0.444	0.063629	14.33%	0.339	0.549	0.351	0.553
S _T	0.912	0.912	0.010854	1.19%	0.894	0.930	0.894	0.931
E(D)	0.924	1.370	1.233030	90.00%	-0.658	3.398	0.000	3.211
D	0.922	1.366	1.230876	90.08%	-0.658	3.391	0.000	3.236
prop_T0'	0.706	0.706	0.007645	1.08%	0.693	0.719	0.693	0.718
prop_C0	0.255	0.255	0.007650	3.00%	0.243	0.268	0.242	0.268
E(sar_tot) ⁺⁺	0.0042	0.0042	0.002461	58.35%	0.0002	0.0083	0.0006	0.0084
sar_tot ⁺⁺	0.0042	0.0042	0.002458	58.33%	0.0002	0.0083	0.0006	0.0084

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-4. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1997.

Wild Chinook 1997

PIT-tags released= 9,781

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	16	16	3.9642	24.54%	10	23	10	23
adult_C1	18	18	4.3263	23.88%	11	25	12	26
adult_T0	4	4	1.9836	50.02%	1	7	1	8
E(C0)	687	687	43.2583	6.29%	616	759	621	763
C0	680	681	43.4428	6.38%	609	752	614	757
E(C1)	1,930	1,932	56.4562	2.92%	1,839	2,024	1,840	2,021
C1	1,936	1,938	57.3881	2.96%	1,843	2,032	1,843	2,028
E(T0)	230	230	14.8622	6.45%	206	255	206	255
T0	230	231	14.8794	6.45%	206	255	207	255
E(sarC0)	0.0233	0.0236	0.005901	25.03%	0.0139	0.0333	0.0142	0.0334
sarC0	0.0235	0.0238	0.005929	24.92%	0.0140	0.0335	0.0145	0.0336
E(sarC1)	0.0093	0.0094	0.002238	23.85%	0.0057	0.0131	0.0060	0.0132
sarC1	0.0093	0.0094	0.002233	23.87%	0.0057	0.0130	0.0060	0.0132
E(sar ₂ T0)	0.0174	0.0172	0.008574	49.82%	0.0031	0.0313	0.0044	0.0329
sar ₂ T0	0.0174	0.0172	0.008561	49.81%	0.0031	0.0313	0.0044	0.0327
E(TIR)	0.747	0.801	0.456353	56.99%	0.050	1.551	0.174	1.582
TIR	0.739	0.792	0.450686	56.92%	0.050	1.533	0.172	1.581
S _R	0.514	0.536	0.151255	28.23%	0.287	0.785	0.335	0.820
S _T	0.946	0.945	0.011931	1.26%	0.926	0.965	0.926	0.966
E(D)	0.406	0.453	0.291819	64.37%	-0.027	0.933	0.079	0.975
D	0.402	0.448	0.288719	64.38%	-0.026	0.923	0.077	0.952
prop_T0'	0.572	0.571	0.010212	1.79%	0.555	0.588	0.554	0.588
prop_C0	0.239	0.239	0.012513	5.24%	0.218	0.260	0.219	0.260
E(sar_tot) ⁺⁺	0.0173	0.0172	0.005145	29.86%	0.0088	0.0257	0.0097	0.0268
sar_tot ⁺⁺	0.0173	0.0173	0.005140	29.77%	0.0088	0.0257	0.0097	0.0268

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-5. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1998.

Wild Chinook 1998

PIT-tags released= 33,836

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	42	42	6.1971	14.71%	32	52	32	53
adult_C1	131	131	11.5555	8.83%	112	150	112	150
adult_T0	15	15	3.7976	25.45%	9	21	9	22
E(C0)	2,909	2,908	56.1839	1.93%	2,815	3,000	2,813	3,006
C0	3,081	3,080	62.6143	2.03%	2,977	3,183	2,976	3,187
E(C1)	12,419	12,415	98.0264	0.79%	12,254	12,576	12,252	12,580
C1	12,276	12,272	99.0375	0.81%	12,109	12,435	12,111	12,444
E(T0)	1,283	1,284	35.5538	2.77%	1,226	1,343	1,225	1,343
T0	1,271	1,272	35.2578	2.77%	1,214	1,330	1,214	1,330
E(sarC0)	0.0144	0.0145	0.002130	14.69%	0.0110	0.0180	0.0111	0.0180
sarC0	0.0136	0.0137	0.002002	14.63%	0.0104	0.0170	0.0105	0.0170
E(sarC1)	0.0105	0.0105	0.000928	8.80%	0.0090	0.0121	0.0090	0.0121
sarC1	0.0107	0.0107	0.000938	8.79%	0.0091	0.0122	0.0091	0.0122
E(sar ₂ T0)	0.0117	0.0116	0.002945	25.35%	0.0068	0.0165	0.0070	0.0168
sar ₂ T0	0.0118	0.0117	0.002974	25.34%	0.0068	0.0166	0.0071	0.0170
E(TIR)	0.810	0.818	0.241729	29.54%	0.421	1.216	0.463	1.265
TIR	0.866	0.875	0.258027	29.48%	0.451	1.300	0.495	1.352
S _R	0.606	0.609	0.044007	7.23%	0.536	0.681	0.541	0.686
S _T	0.960	0.960	0.003343	0.35%	0.955	0.966	0.955	0.966
E(D)	0.511	0.519	0.157994	30.47%	0.259	0.778	0.289	0.809
D	0.546	0.555	0.168725	30.43%	0.277	0.832	0.309	0.866
prop_T0'	0.815	0.815	0.003389	0.42%	0.809	0.821	0.809	0.821
prop_C0	0.185	0.185	0.003350	1.81%	0.179	0.190	0.179	0.191
E(sar_tot) ⁺⁺	0.0122	0.0122	0.002450	20.17%	0.0081	0.0162	0.0083	0.0164
sar_tot ⁺⁺	0.0121	0.0121	0.002470	20.42%	0.0080	0.0162	0.0082	0.0164

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-6. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 1999.

Wild Chinook 1999

PIT-tags released= 81,493

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	95	95	9.9074	10.42%	79	111	80	112
adult_C1	495	496	22.1035	4.46%	459	532	459	532
adult_T0	43	43	6.6391	15.45%	32	54	32	54
E(C0)	4,332	4,334	62.0679	1.43%	4,232	4,436	4,233	4,435
C0	4,469	4,470	76.2852	1.71%	4,344	4,595	4,339	4,595
E(C1)	26,247	26,248	167.2458	0.64%	25,973	26,523	25,967	26,524
C1	26,140	26,142	169.9227	0.65%	25,863	26,422	25,855	26,424
E(T0)	1,775	1,776	44.1186	2.48%	1,703	1,848	1,704	1,850
T0	1,768	1,768	44.0123	2.49%	1,696	1,840	1,697	1,841
E(sarC0)	0.0219	0.0219	0.002278	10.39%	0.0182	0.0257	0.0184	0.0258
sarC0	0.0213	0.0213	0.002201	10.35%	0.0176	0.0249	0.0178	0.0250
E(sarC1)	0.0189	0.0189	0.000844	4.47%	0.0175	0.0203	0.0175	0.0203
sarC1	0.0189	0.0190	0.000847	4.47%	0.0176	0.0203	0.0176	0.0204
E(sar ₂ T0)	0.0242	0.0242	0.003690	15.25%	0.0181	0.0303	0.0184	0.0305
sar ₂ T0	0.0243	0.0243	0.003707	15.26%	0.0182	0.0304	0.0185	0.0307
E(TIR)	1.105	1.115	0.206726	18.53%	0.775	1.455	0.791	1.462
TIR	1.144	1.155	0.214379	18.55%	0.803	1.508	0.822	1.513
S _R	0.591	0.594	0.046937	7.90%	0.517	0.671	0.526	0.677
S _T	0.937	0.937	0.003216	0.34%	0.932	0.943	0.932	0.943
E(D)	0.696	0.707	0.139298	19.72%	0.477	0.936	0.502	0.947
D	0.721	0.732	0.144460	19.74%	0.494	0.970	0.521	0.983
prop_T0'	0.863	0.863	0.002134	0.25%	0.860	0.867	0.860	0.867
prop_C0	0.137	0.137	0.002134	1.56%	0.133	0.140	0.133	0.140
E(sar_tot) ⁺⁺	0.0239	0.0239	0.003197	13.38%	0.0186	0.0291	0.0189	0.0294
sar_tot ⁺⁺	0.0239	0.0239	0.003211	13.44%	0.0186	0.0292	0.0189	0.0294

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-7. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2000.

Wild Chinook 2000

PIT-tags released= 67,841

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	155	156	12.8022	8.22%	135	177	134	176
adult_C1	392	391	20.4351	5.22%	358	425	356	426
adult_T0	12	12	3.6002	29.87%	6	18	6	18
E(C0)	6,472	6,480	103.1865	1.59%	6,310	6,649	6,305	6,653
C0	6,494	6,501	108.4981	1.67%	6,323	6,680	6,321	6,686
E(C1)	16,837	16,840	150.4650	0.89%	16,592	17,088	16,594	17,086
C1	16,833	16,836	155.1701	0.92%	16,580	17,091	16,574	17,087
E(T0)	845	845	30.7411	3.64%	794	895	796	896
T0	839	839	30.6738	3.66%	789	889	790	890
E(sarC0)	0.0239	0.0241	0.001999	8.31%	0.0208	0.0273	0.0208	0.0273
sarC0	0.0239	0.0240	0.001983	8.27%	0.0207	0.0272	0.0208	0.0272
E(sarC1)	0.0233	0.0232	0.001209	5.20%	0.0212	0.0252	0.0212	0.0252
sarC1	0.0233	0.0232	0.001207	5.19%	0.0213	0.0252	0.0212	0.0252
E(sar ₂ T0)	0.0142	0.0143	0.004272	29.92%	0.0073	0.0213	0.0074	0.0213
sar ₂ T0	0.0143	0.0144	0.004302	29.93%	0.0073	0.0215	0.0074	0.0214
E(TIR)	0.593	0.597	0.182778	30.63%	0.296	0.897	0.319	0.912
TIR	0.599	0.603	0.184650	30.64%	0.299	0.906	0.323	0.922
S _R	0.483	0.490	0.051292	10.47%	0.405	0.574	0.414	0.578
S _T	0.903	0.903	0.004857	0.54%	0.895	0.911	0.895	0.911
E(D)	0.317	0.324	0.105905	32.70%	0.150	0.498	0.165	0.495
D	0.321	0.327	0.107014	32.71%	0.151	0.503	0.167	0.505
prop_T0'	0.709	0.709	0.003750	0.53%	0.703	0.715	0.703	0.715
prop_C0	0.269	0.269	0.003556	1.32%	0.263	0.275	0.263	0.275
E(sar_tot) ⁺⁺	0.0170	0.0171	0.003118	18.23%	0.0120	0.0222	0.0121	0.0223
sar_tot ⁺⁺	0.0171	0.0171	0.003136	18.29%	0.0120	0.0223	0.0122	0.0224

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-8. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2001.

Wild Chinook 2001

PIT-tags released= 47,775

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	1	1	0.9468	99.77%	-1	3	0	3
adult_C1	29	29	5.1445	17.88%	20	37	21	37
adult_T0	7	7	2.7217	38.38%	3	12	3	12
E(C0)	201	202	6.6002	3.28%	191	212	191	212
C0	231	231	13.8051	5.99%	208	253	208	253
E(C1)	20,281	20,278	114.6878	0.57%	20,090	20,467	20,090	20,472
C1	20,307	20,305	111.7906	0.55%	20,121	20,489	20,124	20,491
E(T0)	549	549	22.8995	4.17%	512	587	514	589
T0	547	547	22.8238	4.17%	510	585	512	587
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0014	0.0014	0.000254	17.91%	0.0010	0.0018	0.0010	0.0018
sarC1	0.0014	0.0014	0.000254	17.90%	0.0010	0.0018	0.0010	0.0018
E(sar ₂ T0)	0.0128	0.0129	0.004929	38.16%	0.0048	0.0210	0.0054	0.0213
sar ₂ T0	0.0128	0.0130	0.004944	38.15%	0.0048	0.0211	0.0054	0.0214
E(TIR)	8.92	9.39	3.982674	42.40%	2.84	15.95	3.58	16.66
TIR	8.96	9.44	4.000321	42.40%	2.86	16.02	3.61	16.75
S _R	0.233	0.234	0.021963	9.37%	0.198	0.271	0.202	0.273
S _T	0.965	0.965	0.000543	0.06%	0.964	0.966	0.964	0.966
E(D)	2.151	2.279	0.992153	43.54%	0.646	3.911	0.871	4.153
D	2.161	2.289	0.996515	43.54%	0.650	3.928	0.873	4.163
prop_T0'	0.989	0.989	0.000689	0.07%	0.988	0.991	0.988	0.990
prop_C0	0.011	0.011	0.000689	6.52%	0.009	0.012	0.010	0.012
E(sar_tot) ⁺⁺	0.0126	0.0128	0.004877	38.11%	0.0048	0.0208	0.0054	0.0211
sar_tot ⁺⁺	0.0127	0.0128	0.004893	38.12%	0.0048	0.0209	0.0054	0.0211

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-9. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2002.

Wild Chinook 2002

PIT-tags released= 67,286

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	16	16	3.9642	24.54%	10	23	10	23
adult_C1	18	18	4.3263	23.88%	11	25	12	26
adult_T0	4	4	1.9836	50.02%	1	7	1	8
E(C0)	687	687	43.2583	6.29%	616	759	621	763
C0	680	681	43.4428	6.38%	609	752	614	757
E(C1)	1,930	1,932	56.4562	2.92%	1,839	2,024	1,840	2,021
C1	1,936	1,938	57.3881	2.96%	1,843	2,032	1,843	2,028
E(T0)	230	230	14.8622	6.45%	206	255	206	255
T0	230	231	14.8794	6.45%	206	255	207	255
E(sarC0)	0.0233	0.0236	0.005901	25.03%	0.0139	0.0333	0.0142	0.0334
sarC0	0.0235	0.0238	0.005929	24.92%	0.0140	0.0335	0.0145	0.0336
E(sarC1)	0.0093	0.0094	0.002238	23.85%	0.0057	0.0131	0.0060	0.0132
sarC1	0.0093	0.0094	0.002233	23.87%	0.0057	0.0130	0.0060	0.0132
E(sar ₂ T0)	0.0174	0.0172	0.008574	49.82%	0.0031	0.0313	0.0044	0.0329
sar ₂ T0	0.0174	0.0172	0.008561	49.81%	0.0031	0.0313	0.0044	0.0327
E(TIR)	0.747	0.801	0.456353	56.99%	0.050	1.551	0.174	1.582
TIR	0.739	0.792	0.450686	56.92%	0.050	1.533	0.172	1.581
S _R	0.514	0.536	0.151255	28.23%	0.287	0.785	0.335	0.820
S _T	0.946	0.945	0.011931	1.26%	0.926	0.965	0.926	0.966
E(D)	0.406	0.453	0.291819	64.37%	-0.027	0.933	0.079	0.975
D	0.402	0.448	0.288719	64.38%	-0.026	0.923	0.077	0.952
prop_T0'	0.572	0.571	0.010212	1.79%	0.555	0.588	0.554	0.588
prop_C0	0.239	0.239	0.012513	5.24%	0.218	0.260	0.219	0.260
E(sar_tot) ⁺⁺	0.0173	0.0172	0.005145	29.86%	0.0088	0.0257	0.0097	0.0268
sar_tot ⁺⁺	0.0173	0.0173	0.005140	29.77%	0.0088	0.0257	0.0097	0.0268

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-10. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2003.

Wild Chinook 2003

PIT-tags released= 103,012

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	29	29	5.4046	18.61%	20	38	20	39
adult_C1	22	22	4.5458	20.52%	15	30	15	30
adult_T0	30	30	5.4159	18.05%	21	39	21	39
E(C0)	8,677	8,676	125.2999	1.44%	8,470	8,882	8,472	8,886
C0	8,879	8,878	130.9255	1.47%	8,663	9,094	8,660	9,094
E(C1)	12,790	12,795	122.6548	0.96%	12,593	12,996	12,601	12,999
C1	12,694	12,699	123.9627	0.98%	12,495	12,902	12,499	12,910
E(T0)	8,793	8,794	99.2938	1.13%	8,631	8,958	8,638	8,956
T0	8,713	8,714	98.3475	1.13%	8,552	8,876	8,560	8,873
E(sarC0)	0.0033	0.0033	0.000623	18.61%	0.0023	0.0044	0.0023	0.0044
sarC0	0.0033	0.0033	0.000610	18.63%	0.0023	0.0043	0.0023	0.0043
E(sarC1)	0.0017	0.0017	0.000356	20.53%	0.0011	0.0023	0.0012	0.0024
sarC1	0.0017	0.0017	0.000358	20.53%	0.0012	0.0023	0.0012	0.0024
E(sar ₂ T0)	0.0034	0.0034	0.000614	18.01%	0.0024	0.0044	0.0024	0.0045
sar ₂ T0	0.0034	0.0034	0.000620	18.02%	0.0024	0.0045	0.0024	0.0045
E(TIR)	1.021	1.057	0.285182	26.98%	0.588	1.526	0.663	1.612
TIR	1.054	1.092	0.295021	27.02%	0.606	1.577	0.686	1.667
S _R	0.596	0.598	0.051360	8.58%	0.514	0.683	0.518	0.685
S _T	0.924	0.924	0.003839	0.42%	0.918	0.930	0.918	0.930
E(D)	0.659	0.684	0.193153	28.23%	0.366	1.002	0.418	1.057
D	0.680	0.707	0.199753	28.27%	0.378	1.035	0.432	1.090
prop_T0'	0.694	0.694	0.003396	0.49%	0.689	0.700	0.689	0.700
prop_C0	0.293	0.293	0.003310	1.13%	0.288	0.299	0.288	0.299
E(sar_tot) ⁺⁺	0.0034	0.0034	0.000468	13.89%	0.0026	0.0041	0.0026	0.0042
sar_tot ⁺⁺	0.0034	0.0034	0.000470	13.96%	0.0026	0.0041	0.0026	0.0042

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-11. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild Chinook outmigrating in 2004.

Wild Chinook 2004

PIT-tags released= 99,743

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	7	7	2.6746	38.07%	3	11	3	12
adult_C1	30	30	5.4323	18.05%	21	39	21	39
adult_T0	39	39	6.6992	17.23%	28	50	28	50
E(C0)	2,102	2,105	42.6802	2.03%	2,034	2,175	2,036	2,181
C0	2,252	2,254	54.2249	2.41%	2,165	2,343	2,168	2,354
E(C1)	16,656	16,666	125.6095	0.75%	16,459	16,872	16,469	16,878
C1	16,504	16,512	125.9870	0.76%	16,305	16,720	16,313	16,725
E(T0)	12,928	12,927	103.1786	0.80%	12,757	13,097	12,765	13,100
T0	12,887	12,886	103.8834	0.81%	12,715	13,057	12,722	13,058
E(sarC0)	0.0033	0.0033	0.001271	38.07%	0.0012	0.0054	0.0014	0.0056
sarC0	0.0031	0.0031	0.001186	38.04%	0.0012	0.0051	0.0013	0.0052
E(sarC1)	0.0018	0.0018	0.000326	18.04%	0.0013	0.0023	0.0013	0.0024
sarC1	0.0018	0.0018	0.000329	18.04%	0.0013	0.0024	0.0013	0.0024
E(sar ₂ T0)	0.0030	0.0030	0.000518	17.24%	0.0022	0.0039	0.0022	0.0039
sar ₂ T0	0.0030	0.0030	0.000520	17.24%	0.0022	0.0039	0.0022	0.0039
E(TIR)	0.906	1.098	0.714684	65.10%	-0.078	2.273	0.494	2.242
TIR	0.974	1.179	0.763854	64.80%	-0.078	2.435	0.526	2.370
S _R	0.398	0.409	0.056611	13.86%	0.315	0.502	0.327	0.513
S _T	0.958	0.958	0.001406	0.15%	0.956	0.961	0.956	0.961
E(D)	0.376	0.467	0.307947	65.92%	-0.039	0.974	0.200	0.968
D	0.404	0.502	0.329168	65.61%	-0.040	1.043	0.215	1.025
prop_T0'	0.929	0.929	0.001709	0.18%	0.926	0.932	0.926	0.931
prop_C0	0.071	0.071	0.001662	2.34%	0.068	0.074	0.068	0.074
E(sar_tot) ⁺⁺	0.0030	0.0030	0.000491	16.18%	0.0022	0.0038	0.0022	0.0039
sar_tot ⁺⁺	0.0030	0.0030	0.000491	16.22%	0.0022	0.0038	0.0022	0.0039

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-12. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1997.

Wild Steelhead 1997

PIT-tags released= 7,703

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	3	3	1.7629	57.71%	0	6	0	6
adult_C1	7	7	2.6393	37.94%	3	11	3	12
adult_T0	4	4	2.0438	50.98%	1	7	1	8
E(C0)	454	454	21.9907	4.84%	418	491	417	491
C0	454	453	23.2436	5.13%	415	492	415	492
E(C1)	2,986	2,987	47.3972	1.59%	2,909	3,065	2,905	3,066
C1	2,984	2,986	48.0937	1.61%	2,907	3,065	2,905	3,066
E(T0)	274	275	16.0750	5.85%	248	301	248	301
T0	275	275	16.1124	5.86%	249	302	248	301
E(sarC0)	0.0066	0.0067	0.003871	57.58%	0.0004	0.0131	0.0000	0.0135
sarC0	0.0066	0.0067	0.003873	57.51%	0.0004	0.0131	0.0000	0.0134
E(sarC1)	0.0023	0.0023	0.000882	37.86%	0.0009	0.0038	0.0010	0.0039
sarC1	0.0023	0.0023	0.000882	37.86%	0.0009	0.0038	0.0010	0.0039
E(sar ₂ T0)	0.0146	0.0146	0.007371	50.53%	0.0025	0.0267	0.0036	0.0280
sar ₂ T0	0.0145	0.0146	0.007356	50.51%	0.0025	0.0267	0.0036	0.0280
E(TIR)	2.209	2.906	2.496361	85.91%	-1.201	7.012	0.000	8.180
TIR	2.201	2.893	2.482618	85.81%	-1.191	6.977	0.000	8.161
S _R	0.523	0.673	0.507979	75.46%	-0.162	1.509	0.276	1.450
S _T	0.975	0.975	0.003640	0.37%	0.969	0.981	0.969	0.981
E(D)	1.185	1.948	2.184075	112.13%	-1.645	5.541	0.000	5.827
D	1.181	1.941	2.181946	112.43%	-1.649	5.530	0.000	5.737
prop_T0'	0.715	0.715	0.007612	1.06%	0.702	0.727	0.703	0.728
prop_C0	0.122	0.122	0.005801	4.75%	0.113	0.132	0.112	0.131
E(sar_tot) ⁺⁺	0.0116	0.0116	0.005294	45.52%	0.0029	0.0203	0.0039	0.0212
sar_tot ⁺⁺	0.0116	0.0116	0.005283	45.48%	0.0029	0.0203	0.0039	0.0211

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-13. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1998.

Wild Steelhead 1998

PIT-tags released= 10,512

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	8	8	2.8008	35.19%	3	13	4	13
adult_C1	11	11	3.2375	29.22%	6	16	6	17
adult_T0	1	1	1.0069	97.28%	-1	3	0	3
E(C0)	710	708	26.5946	3.75%	665	752	665	754
C0	750	748	30.2357	4.04%	698	798	700	800
E(C1)	5,172	5,173	57.3449	1.11%	5,078	5,267	5,081	5,266
C1	5,150	5,151	57.9746	1.13%	5,055	5,246	5,053	5,242
E(T0)	484	484	22.1670	4.58%	448	520	447	522
T0	480	480	22.1809	4.62%	443	516	443	518
E(sarC0)	0.0113	0.0113	0.003995	35.50%	0.0047	0.0178	0.0054	0.0184
sarC0	0.0107	0.0107	0.003789	35.54%	0.0044	0.0169	0.0051	0.0173
E(sarC1)	0.0021	0.0021	0.000626	29.22%	0.0011	0.0032	0.0012	0.0033
sarC1	0.0021	0.0022	0.000628	29.21%	0.0011	0.0032	0.0012	0.0033
E(sar ₂ T0)	0.0021	0.0021	0.002083	97.35%	-0.0013	0.0056	0.0000	0.0063
sar ₂ T0	0.0021	0.0022	0.002101	97.35%	-0.0013	0.0056	0.0000	0.0063
E(TIR)	0.183	0.354	0.326221	92.14%	-0.183	0.891	0.000	0.657
TIR	0.195	0.377	0.347124	92.10%	-0.194	0.948	0.000	0.698
S _R	0.544	0.547	0.044147	8.07%	0.474	0.620	0.477	0.623
S _T	0.953	0.953	0.003507	0.37%	0.947	0.959	0.947	0.959
E(D)	0.105	0.204	0.191048	93.85%	-0.111	0.518	0.000	0.380
D	0.112	0.217	0.203308	93.82%	-0.118	0.551	0.000	0.406
prop_T0'	0.892	0.892	0.004120	0.46%	0.885	0.899	0.885	0.899
prop_C0	0.108	0.108	0.004120	3.81%	0.101	0.115	0.101	0.115
E(sar_tot) ⁺⁺	0.0031	0.0031	0.001903	60.92%	0.0000	0.0063	0.0008	0.0068
sar_tot ⁺⁺	0.0030	0.0031	0.001915	62.26%	-0.0001	0.0062	0.0007	0.0068

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-14. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 1999.

Wild Steelhead 1999

PIT-tags released= 15,763

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	15	15	3.9402	26.03%	9	22	9	22
adult_C1	53	53	7.3442	13.83%	41	65	42	66
adult_T0	12	12	3.5325	28.74%	6	18	7	18
E(C0)	1,025	1,025	32.0510	3.13%	972	1,078	974	1,078
C0	1,113	1,113	38.4419	3.45%	1,050	1,176	1,052	1,178
E(C1)	7,073	7,074	71.4265	1.01%	6,957	7,192	6,962	7,194
C1	6,992	6,993	73.0782	1.04%	6,873	7,114	6,878	7,114
E(T0)	394	394	20.3939	5.17%	361	428	361	427
T0	391	391	20.3920	5.21%	358	425	358	424
E(sarC0)	0.0146	0.0148	0.003846	26.04%	0.0084	0.0211	0.0086	0.0211
sarC0	0.0135	0.0136	0.003531	25.96%	0.0078	0.0194	0.0080	0.0196
E(sarC1)	0.0075	0.0075	0.001042	13.88%	0.0058	0.0092	0.0059	0.0093
sarC1	0.0076	0.0076	0.001053	13.88%	0.0059	0.0093	0.0060	0.0094
E(sar ₂ T0)	0.0305	0.0312	0.008915	28.58%	0.0165	0.0459	0.0173	0.0462
sar ₂ T0	0.0307	0.0314	0.008977	28.57%	0.0167	0.0462	0.0174	0.0466
E(TIR)	2.081	2.271	0.956618	42.13%	0.697	3.844	1.051	4.034
TIR	2.277	2.481	1.042721	42.03%	0.766	4.196	1.153	4.383
S _R	0.446	0.452	0.051132	11.30%	0.368	0.536	0.376	0.542
S _T	0.950	0.950	0.005089	0.54%	0.941	0.958	0.942	0.958
E(D)	0.978	1.085	0.487514	44.92%	0.283	1.887	0.477	1.908
D	1.070	1.186	0.531865	44.85%	0.311	2.061	0.534	2.091
prop_T0'	0.869	0.869	0.004235	0.49%	0.862	0.876	0.862	0.876
prop_C0	0.131	0.131	0.004185	3.20%	0.124	0.137	0.124	0.138
E(sar_tot) ⁺⁺	0.0284	0.0290	0.007800	26.85%	0.0162	0.0419	0.0168	0.0423
sar_tot ⁺⁺	0.0284	0.0291	0.007851	26.99%	0.0162	0.0420	0.0167	0.0424

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-15. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2000.

Wild Steelhead 2000

PIT-tags released= 24,254

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	36	36	6.1922	17.21%	26	46	26	46
adult_C1	192	191	14.1635	7.40%	168	215	169	215
adult_T0	13	13	3.7176	28.83%	7	19	7	19
E(C0)	1,832	1,833	48.3986	2.64%	1,754	1,913	1,754	1,914
C0	1,871	1,872	54.8436	2.93%	1,782	1,962	1,780	1,961
E(C1)	10,630	10,631	93.5781	0.88%	10,477	10,785	10,475	10,788
C1	10,616	10,616	95.3198	0.90%	10,459	10,773	10,461	10,773
E(T0)	471	471	23.4537	4.98%	433	510	432	510
T0	466	466	23.4765	5.04%	427	504	426	505
E(sarC0)	0.0197	0.0196	0.003410	17.36%	0.0140	0.0253	0.0144	0.0253
sarC0	0.0192	0.0192	0.003322	17.27%	0.0138	0.0247	0.0140	0.0249
E(sarC1)	0.0181	0.0180	0.001323	7.35%	0.0158	0.0202	0.0159	0.0202
sarC1	0.0181	0.0180	0.001323	7.34%	0.0159	0.0202	0.0159	0.0203
E(sar ₂ T0)	0.0276	0.0273	0.007662	28.04%	0.0147	0.0399	0.0152	0.0406
sar ₂ T0	0.0279	0.0276	0.007755	28.05%	0.0149	0.0404	0.0155	0.0411
E(TIR)	1.405	1.434	0.476566	33.24%	0.650	2.218	0.744	2.325
TIR	1.450	1.481	0.492183	33.24%	0.671	2.291	0.772	2.398
S _R	0.305	0.305	0.016693	5.47%	0.278	0.333	0.279	0.335
S _T	0.883	0.883	0.004101	0.46%	0.876	0.890	0.876	0.889
E(D)	0.485	0.495	0.165771	33.46%	0.223	0.768	0.258	0.799
D	0.500	0.512	0.171167	33.44%	0.230	0.793	0.265	0.824
prop_T0'	0.846	0.846	0.004597	0.54%	0.839	0.854	0.839	0.854
prop_C0	0.144	0.145	0.003770	2.61%	0.138	0.151	0.138	0.151
E(sar_tot) ⁺⁺	0.0264	0.0261	0.006503	24.89%	0.0154	0.0368	0.0159	0.0377
sar_tot ⁺⁺	0.0266	0.0263	0.006582	24.99%	0.0155	0.0372	0.0159	0.0378

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-16. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2001.

Wild Steelhead 2001.

PIT-tags released= 24,487

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	3	3	1.8018	61.06%	0	6	0	6
adult_C1	8	8	2.8282	34.98%	3	13	4	13
adult_T0	5	5	2.1894	44.15%	1	9	2	9
E(C0)	96	96	5.3208	5.56%	87	104	87	105
C0	103	103	10.0646	9.79%	86	119	87	120
E(C1)	11,959	11,952	81.9557	0.69%	11,817	12,087	11,809	12,087
C1	11,892	11,887	78.1062	0.66%	11,759	12,016	11,748	12,014
E(T0)	201	201	14.3397	7.13%	177	225	178	226
T0	201	202	14.4226	7.15%	178	225	179	226
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0007	0.0007	0.000236	34.96%	0.0003	0.0011	0.0003	0.0011
sarC1	0.0007	0.0007	0.000238	34.96%	0.0003	0.0011	0.0003	0.0011
E(sar ₂ T0)	0.0249	0.0247	0.010739	43.54%	0.0070	0.0423	0.0093	0.0437
sar ₂ T0	0.0249	0.0246	0.010704	43.52%	0.0070	0.0422	0.0093	0.0437
E(TIR)	37.19	42.98	30.13584	70.12%	-6.60	92.55	10.61	95.72
TIR	36.98	42.63	29.88976	70.12%	-6.54	91.80	10.59	94.56
S _R	0.038	0.040	0.010978	27.32%	0.022	0.058	0.027	0.059
S _T	0.959	0.959	0.000913	0.10%	0.958	0.961	0.958	0.961
E(D)	1.469	1.819	1.453319	79.91%	-0.572	4.209	0.401	4.440
D	1.461	1.804	1.441883	79.92%	-0.568	4.176	0.398	4.403
prop_T0'	0.992	0.992	0.000859	0.09%	0.990	0.993	0.990	0.993
prop_C0	0.008	0.008	0.000859	10.40%	0.007	0.010	0.007	0.010
E(sar_tot) ⁺⁺	0.0247	0.0245	0.010650	43.53%	0.0069	0.0420	0.0093	0.0433
sar_tot ⁺⁺	0.0247	0.0244	0.010615	43.51%	0.0069	0.0419	0.0093	0.0433

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-17. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2002.

Wild Steelhead 2002

PIT-tags released= 25,183

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	27	27	5.3222	19.52%	19	36	19	36
adult_C1	82	82	8.8753	10.81%	68	97	67	96
adult_T0	9	9	2.9166	31.83%	4	14	5	14
E(C0)	4,125	4,125	84.0974	2.04%	3,986	4,263	3,990	4,264
C0	4,045	4,045	88.4509	2.19%	3,900	4,191	3,908	4,197
E(C1)	8,669	8,667	102.0916	1.18%	8,499	8,835	8,497	8,832
C1	8,726	8,724	104.9730	1.20%	8,551	8,896	8,552	8,891
E(T0)	307	307	16.7252	5.44%	280	335	281	336
T0	317	317	17.1487	5.42%	288	345	289	346
E(sarC0)	0.0065	0.0066	0.001297	19.61%	0.0045	0.0087	0.0045	0.0088
sarC0	0.0067	0.0067	0.001324	19.63%	0.0046	0.0089	0.0046	0.0090
E(sarC1)	0.0095	0.0095	0.001024	10.81%	0.0078	0.0112	0.0078	0.0111
sarC1	0.0094	0.0094	0.001017	10.80%	0.0077	0.0111	0.0077	0.0111
E(sar ₂ T0)	0.0293	0.0298	0.009353	31.38%	0.0144	0.0452	0.0157	0.0458
sar ₂ T0	0.0284	0.0289	0.009085	31.39%	0.0140	0.0439	0.0152	0.0443
E(TIR)	4.479	4.689	1.788199	38.13%	1.748	7.631	2.229	8.059
TIR	4.253	4.466	1.707227	38.23%	1.658	7.275	2.122	7.673
S _R	0.517	0.531	0.088643	16.69%	0.385	0.677	0.408	0.691
S _T	0.982	0.982	0.007755	0.79%	0.969	0.995	0.969	0.995
E(D)	2.355	2.542	1.078549	42.43%	0.768	4.316	1.145	4.449
D	2.237	2.421	1.030207	42.55%	0.727	4.116	1.088	4.246
prop_T0'	0.675	0.675	0.005361	0.79%	0.666	0.684	0.666	0.684
prop_C0	0.309	0.309	0.005244	1.70%	0.300	0.318	0.301	0.318
E(sar_tot) ⁺⁺	0.0220	0.0223	0.006343	28.42%	0.0119	0.0328	0.0126	0.0329
sar_tot ⁺⁺	0.0214	0.0218	0.006162	28.30%	0.0116	0.0319	0.0124	0.0321

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-18. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged wild steelhead outmigrating in 2003.

Wild Steelhead 2003

PIT-tags released= 24,284

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	16	16	3.7708	23.14%	10	22	10	23
adult_C1	37	37	6.2378	16.88%	27	47	27	47
adult_T0	44	44	6.7737	15.49%	33	55	33	55
E(C0)	3,227	3,230	80.3127	2.49%	3,098	3,362	3,102	3,363
C0	3,320	3,322	83.0888	2.50%	3,186	3,459	3,185	3,459
E(C1)	7,199	7,198	93.7229	1.30%	7,044	7,353	7,044	7,358
C1	7,132	7,131	94.3116	1.32%	6,976	7,286	6,979	7,292
E(T0)	2,230	2,232	48.0907	2.15%	2,153	2,312	2,160	2,315
T0	2,210	2,212	47.7542	2.16%	2,134	2,291	2,140	2,293
E(sarC0)	0.0050	0.0050	0.001167	23.12%	0.0031	0.0070	0.0031	0.0070
sarC0	0.0048	0.0049	0.001134	23.11%	0.0030	0.0068	0.0030	0.0068
E(sarC1)	0.0051	0.0051	0.000865	16.84%	0.0037	0.0066	0.0037	0.0066
sarC1	0.0052	0.0052	0.000872	16.83%	0.0037	0.0066	0.0038	0.0066
E(sar ₂ T0)	0.0197	0.0196	0.003009	15.36%	0.0146	0.0245	0.0148	0.0247
sar ₂ T0	0.0199	0.0198	0.003036	15.36%	0.0148	0.0248	0.0149	0.0249
E(TIR)	3.980	4.119	1.305735	31.70%	1.971	6.266	2.528	6.500
TIR	4.131	4.276	1.355966	31.71%	2.045	6.506	2.622	6.795
S _R	0.367	0.372	0.039951	10.75%	0.306	0.437	0.312	0.443
S _T	0.926	0.926	0.007038	0.76%	0.914	0.937	0.914	0.938
E(D)	1.576	1.651	0.545685	33.06%	0.753	2.548	0.971	2.638
D	1.636	1.714	0.567143	33.10%	0.781	2.647	1.009	2.725
prop_T0'	0.723	0.723	0.005354	0.74%	0.714	0.732	0.714	0.732
prop_C0	0.262	0.262	0.005221	1.99%	0.254	0.271	0.254	0.271
E(sar_tot) ⁺⁺	0.0156	0.0156	0.002199	14.13%	0.0119	0.0192	0.0120	0.0193
sar_tot ⁺⁺	0.0157	0.0157	0.002218	14.17%	0.0120	0.0193	0.0121	0.0194

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-19. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1997.

Hatchery Steelhead 1997

PIT-tags released= 35,705

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	8	8	2.9282	36.48%	3	13	3	13
adult_C1	32	32	5.6325	17.60%	23	41	23	41
adult_T0	9	9	2.9336	32.29%	4	14	4	14
E(C0)	3,372	3,372	75.0108	2.22%	3,248	3,495	3,251	3,501
C0	3,390	3,391	78.1266	2.30%	3,262	3,520	3,266	3,526
E(C1)	19,113	19,121	123.5529	0.65%	18,917	19,324	18,922	19,323
C1	19,095	19,101	124.4097	0.65%	18,897	19,306	18,895	19,307
E(T0)	1,730	1,728	40.3331	2.33%	1,662	1,795	1,665	1,798
T0	1,729	1,728	40.3336	2.33%	1,662	1,794	1,665	1,798
E(sarC0)	0.0024	0.0024	0.000868	36.44%	0.0010	0.0038	0.0009	0.0039
sarC0	0.0024	0.0024	0.000862	36.40%	0.0009	0.0038	0.0009	0.0039
E(sarC1)	0.0017	0.0017	0.000295	17.61%	0.0012	0.0022	0.0012	0.0022
sarC1	0.0017	0.0017	0.000295	17.61%	0.0012	0.0022	0.0012	0.0022
E(sar ₂ T0)	0.0052	0.0053	0.001696	32.26%	0.0025	0.0080	0.0024	0.0081
sar ₂ T0	0.0052	0.0053	0.001696	32.26%	0.0025	0.0080	0.0024	0.0081
E(TIR)	2.193	2.621	1.728675	65.96%	-0.223	5.465	0.980	5.619
TIR	2.206	2.636	1.738958	65.97%	-0.225	5.497	0.985	5.657
S _R	0.401	0.432	0.149095	34.48%	0.187	0.678	0.256	0.709
S _T	0.963	0.963	0.001507	0.16%	0.960	0.965	0.961	0.966
E(D)	0.914	1.173	0.867362	73.92%	-0.253	2.600	0.353	2.637
D	0.919	1.180	0.872530	73.93%	-0.255	2.615	0.356	2.669
prop_T0'	0.608	0.608	0.003356	0.55%	0.602	0.613	0.602	0.613
prop_C0	0.140	0.140	0.002962	2.12%	0.135	0.145	0.135	0.145
E(sar_tot) ⁺⁺	0.0039	0.0040	0.001049	26.54%	0.0022	0.0057	0.0023	0.0057
sar_tot ⁺⁺	0.0039	0.0040	0.001048	26.53%	0.0022	0.0057	0.0023	0.0057

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-20. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1998.

Hatchery Steelhead 1998

PIT-tags released= 30,913

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	26	26	5.0094	19.34%	18	34	18	35
adult_C1	40	40	6.2700	15.63%	30	50	30	51
adult_T0	7	7	2.5842	37.15%	3	11	3	11
E(C0)	2,747	2,745	54.8086	2.00%	2,655	2,835	2,654	2,834
C0	2,926	2,925	61.7061	2.11%	2,823	3,026	2,826	3,023
E(C1)	18,089	18,085	99.8125	0.55%	17,921	18,249	17,919	18,253
C1	17,958	17,954	103.1793	0.57%	17,785	18,124	17,778	18,129
E(T0)	1,379	1,379	37.2211	2.70%	1,317	1,440	1,316	1,439
T0	1,365	1,365	36.7687	2.69%	1,304	1,425	1,304	1,425
E(sarC0)	0.0095	0.0094	0.001843	19.52%	0.0064	0.0125	0.0065	0.0127
sarC0	0.0089	0.0089	0.001728	19.50%	0.0060	0.0117	0.0061	0.0119
E(sarC1)	0.0022	0.0022	0.000346	15.60%	0.0016	0.0028	0.0017	0.0028
sarC1	0.0022	0.0022	0.000349	15.60%	0.0017	0.0028	0.0017	0.0028
E(sar ₂ T0)	0.0051	0.0050	0.001869	37.04%	0.0020	0.0081	0.0022	0.0083
sar ₂ T0	0.0051	0.0051	0.001888	37.05%	0.0020	0.0082	0.0022	0.0084
E(TIR)	0.536	0.555	0.237718	42.81%	0.164	0.946	0.215	0.967
TIR	0.577	0.598	0.256272	42.88%	0.176	1.019	0.231	1.045
S _R	0.644	0.683	0.169514	24.84%	0.404	0.961	0.472	1.022
S _T	0.945	0.945	0.002237	0.24%	0.941	0.949	0.942	0.949
E(D)	0.365	0.402	0.212922	52.94%	0.052	0.752	0.151	0.784
D	0.393	0.433	0.229402	52.99%	0.056	0.810	0.163	0.853
prop_T0'	0.873	0.873	0.002504	0.29%	0.869	0.878	0.869	0.877
prop_C0	0.127	0.127	0.002504	1.98%	0.122	0.131	0.123	0.131
E(sar_tot) ⁺⁺	0.0056	0.0056	0.001654	29.53%	0.0029	0.0083	0.0031	0.0085
sar_tot ⁺⁺	0.0056	0.0056	0.001670	29.99%	0.0028	0.0083	0.0030	0.0085

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-21. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 1999.

Hatchery Steelhead 1999

PIT-tags released= 36,968

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	41	41	6.3020	15.41%	31	51	31	52
adult_C1	124	125	11.1530	8.93%	107	143	107	144
adult_T0	12	12	3.3003	27.57%	7	17	7	18
E(C0)	3,693	3,691	59.6891	1.62%	3,593	3,789	3,591	3,789
C0	3,952	3,949	67.8149	1.72%	3,838	4,061	3,839	4,055
E(C1)	21,207	21,211	124.2806	0.59%	21,007	21,415	21,004	21,418
C1	20,975	20,979	126.4613	0.60%	20,771	21,187	20,767	21,192
E(T0)	1,347	1,345	37.1949	2.76%	1,284	1,407	1,284	1,405
T0	1,336	1,335	36.8470	2.76%	1,274	1,396	1,274	1,395
E(sarC0)	0.0111	0.0111	0.001713	15.46%	0.0083	0.0139	0.0084	0.0140
sarC0	0.0104	0.0104	0.001601	15.45%	0.0077	0.0130	0.0079	0.0131
E(sarC1)	0.0058	0.0059	0.000525	8.92%	0.0050	0.0068	0.0050	0.0068
sarC1	0.0059	0.0060	0.000530	8.91%	0.0051	0.0068	0.0051	0.0069
E(sar ₂ T0)	0.0089	0.0089	0.002453	27.57%	0.0049	0.0129	0.0051	0.0132
sar ₂ T0	0.0090	0.0090	0.002473	27.58%	0.0049	0.0130	0.0051	0.0133
E(TIR)	0.802	0.823	0.266136	32.34%	0.385	1.261	0.442	1.313
TIR	0.866	0.887	0.286926	32.34%	0.415	1.359	0.478	1.408
S _R	0.450	0.454	0.041465	9.13%	0.386	0.523	0.391	0.531
S _T	0.943	0.943	0.003044	0.32%	0.938	0.948	0.938	0.948
E(D)	0.383	0.397	0.134551	33.86%	0.176	0.619	0.199	0.651
D	0.413	0.428	0.145128	33.87%	0.190	0.667	0.215	0.703
prop_T0'	0.848	0.848	0.002690	0.32%	0.844	0.852	0.844	0.852
prop_C0	0.150	0.150	0.002428	1.62%	0.146	0.154	0.147	0.154
E(sar_tot) ⁺⁺	0.0092	0.0092	0.002099	22.75%	0.0058	0.0127	0.0059	0.0128
sar_tot ⁺⁺	0.0092	0.0092	0.002111	23.02%	0.0057	0.0126	0.0059	0.0128

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-22. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2000.

Hatchery Steelhead 2000

PIT-tags released= 32,000

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	42	42	6.2922	15.00%	32	52	31	53
adult_C1	197	197	14.3359	7.29%	173	220	173	221
adult_T0	14	14	3.8157	27.40%	8	20	8	21
E(C0)	4,443	4,442	101.7824	2.29%	4,274	4,609	4,278	4,615
C0	4,408	4,409	105.8305	2.40%	4,235	4,583	4,237	4,589
E(C1)	18,779	18,778	121.2988	0.65%	18,579	18,978	18,581	18,976
C1	18,804	18,802	127.1351	0.68%	18,593	19,011	18,598	19,013
E(T0)	665	666	29.0623	4.36%	618	714	619	714
T0	668	668	29.2367	4.38%	620	716	621	717
E(sarC0)	0.0095	0.0094	0.001418	15.01%	0.0071	0.0118	0.0071	0.0119
sarC0	0.0095	0.0095	0.001426	14.99%	0.0072	0.0119	0.0071	0.0119
E(sarC1)	0.0105	0.0105	0.000764	7.29%	0.0092	0.0117	0.0092	0.0118
sarC1	0.0105	0.0105	0.000762	7.28%	0.0092	0.0117	0.0092	0.0118
E(sar ₂ T0)	0.0211	0.0209	0.005647	27.02%	0.0116	0.0302	0.0123	0.0308
sar ₂ T0	0.0210	0.0208	0.005626	27.00%	0.0116	0.0301	0.0122	0.0307
E(TIR)	2.227	2.269	0.736362	32.45%	1.058	3.481	1.219	3.611
TIR	2.200	2.245	0.727372	32.40%	1.048	3.441	1.222	3.577
S _R	0.221	0.222	0.018727	8.44%	0.191	0.253	0.192	0.255
S _T	0.877	0.877	0.003749	0.43%	0.871	0.883	0.871	0.883
E(D)	0.560	0.575	0.195659	34.03%	0.253	0.897	0.306	0.942
D	0.553	0.569	0.193297	33.99%	0.251	0.887	0.302	0.925
prop_T0'	0.817	0.817	0.003812	0.47%	0.811	0.823	0.810	0.823
prop_C0	0.183	0.183	0.003812	2.08%	0.177	0.189	0.177	0.190
E(sar_tot) ⁺⁺	0.0189	0.0188	0.004615	24.54%	0.0112	0.0264	0.0117	0.0269
sar_tot ⁺⁺	0.0189	0.0188	0.004598	24.51%	0.0112	0.0263	0.0116	0.0268

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-23. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2001.

Hatchery Steelhead 2001

PIT-tags released= 29,099

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	2	2	1.4198	71.35%	0	4	0	5
adult_C1	3	3	1.7906	58.69%	0	6	0	6
adult_T0	4	4	1.9237	47.14%	1	7	1	8
E(C0)	352	353	16.2295	4.59%	327	380	327	381
C0	372	373	23.5543	6.31%	335	412	334	414
E(C1)	19,206	19,207	93.5199	0.49%	19,053	19,361	19,058	19,364
C1	19,132	19,135	93.1267	0.49%	18,982	19,288	18,985	19,294
E(T0)	426	426	21.9075	5.14%	390	462	387	462
T0	427	427	22.1585	5.19%	391	464	389	464
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0002	0.0002	0.000093	58.67%	0.0000	0.0003	0.0000	0.0003
sarC1	0.0002	0.0002	0.000094	58.67%	0.0000	0.0003	0.0000	0.0003
E(sar ₂ T0)	0.0094	0.0096	0.004496	46.94%	0.0022	0.0170	0.0024	0.0179
sar ₂ T0	0.0094	0.0096	0.004487	46.96%	0.0022	0.0169	0.0024	0.0178
E(TIR)	60.11	79.23	65.70731	82.93%	-28.85	187.32	0.00	215.97
TIR	59.74	78.76	65.34558	82.97%	-28.74	186.25	0.00	215.64
S _R	0.038	0.044	0.024339	55.01%	0.004	0.084	0.023	0.082
S _T	0.947	0.947	0.001272	0.13%	0.945	0.949	0.945	0.949
E(D)	2.412	3.639	3.582302	98.44%	-2.254	9.532	0.000	10.088
D	2.397	3.618	3.568168	98.61%	-2.251	9.488	0.000	10.049
prop_T0'	0.979	0.979	0.002366	0.24%	0.975	0.982	0.974	0.982
prop_C0	0.019	0.019	0.001189	6.35%	0.017	0.021	0.017	0.021
E(sar_tot) ⁺⁺	0.0092	0.0094	0.004400	46.92%	0.0021	0.0166	0.0024	0.0175
sar_tot ⁺⁺	0.0092	0.0094	0.004390	46.94%	0.0021	0.0166	0.0024	0.0174

⁺ When bootstrap iterations have no adults occurring for some study categories or a missing S_R, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-24. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2002.

Hatchery Steelhead 2002

PIT-tags released= 26,573

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	43	43	6.4790	14.97%	33	54	33	54
adult_C1	102	102	9.9044	9.70%	86	118	85	119
adult_T0	3	3	1.7282	56.35%	0	6	1	6
E(C0)	6,175	6,172	125.6182	2.04%	5,966	6,379	5,969	6,370
C0	6,129	6,126	128.6076	2.10%	5,914	6,338	5,917	6,338
E(C1)	13,995	13,992	161.7898	1.16%	13,726	14,258	13,723	14,268
C1	14,038	14,035	164.3276	1.17%	13,765	14,305	13,764	14,322
E(T0)	283	284	17.0974	6.03%	255	312	255	312
T0	284	285	17.1621	6.03%	256	313	256	313
E(sarC0)	0.0070	0.0070	0.001054	15.03%	0.0053	0.0088	0.0054	0.0088
sarC0	0.0070	0.0071	0.001061	15.01%	0.0053	0.0088	0.0054	0.0088
E(sarC1)	0.0073	0.0073	0.000710	9.73%	0.0061	0.0085	0.0061	0.0085
sarC1	0.0073	0.0073	0.000707	9.72%	0.0061	0.0084	0.0061	0.0085
E(sar ₂ T0)	0.0106	0.0108	0.006069	56.20%	0.0008	0.0208	0.0032	0.0213
sar ₂ T0	0.0106	0.0108	0.006046	56.19%	0.0008	0.0207	0.0032	0.0211
E(TIR)	1.522	1.650	0.885579	53.68%	0.193	3.107	0.385	3.363
TIR	1.506	1.631	0.875210	53.66%	0.191	3.071	0.382	3.331
S _R	0.365	0.375	0.062667	16.72%	0.272	0.478	0.290	0.487
S _T	0.912	0.912	0.008365	0.92%	0.899	0.926	0.899	0.926
E(D)	0.610	0.679	0.388704	57.28%	0.039	1.318	0.140	1.400
D	0.603	0.671	0.384319	57.28%	0.039	1.303	0.138	1.382
prop_T0'	0.700	0.700	0.004957	0.71%	0.692	0.708	0.692	0.708
prop_C0	0.300	0.300	0.004936	1.65%	0.291	0.308	0.292	0.308
E(sar_tot) ⁺⁺	0.0095	0.0097	0.004256	44.04%	0.0027	0.0167	0.0040	0.0172
sar_tot ⁺⁺	0.0095	0.0097	0.004242	43.94%	0.0027	0.0166	0.0040	0.0172

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-25. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged hatchery steelhead outmigrating in 2003.

Hatchery Steelhead 2003

PIT-tags released= 26,379

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	44	44	6.5431	14.94%	33	55	33	55
adult_C1	37	37	6.1461	16.66%	27	47	27	47
adult_T0	83	83	9.0975	10.91%	68	98	68	98
E(C0)	6,464	6,466	127.1300	1.97%	6,257	6,675	6,254	6,669
C0	6,459	6,462	129.2680	2.00%	6,250	6,675	6,248	6,671
E(C1)	10,114	10,110	117.4182	1.16%	9,917	10,303	9,917	10,312
C1	10,118	10,113	118.9084	1.18%	9,918	10,309	9,918	10,320
E(T0)	4,595	4,598	72.7492	1.58%	4,478	4,717	4,475	4,715
T0	4,595	4,597	73.4931	1.60%	4,476	4,718	4,475	4,719
E(sarC0)	0.0068	0.0068	0.001020	15.05%	0.0051	0.0085	0.0051	0.0085
sarC0	0.0068	0.0068	0.001020	15.04%	0.0051	0.0085	0.0052	0.0085
E(sarC1)	0.0037	0.0036	0.000610	16.72%	0.0026	0.0047	0.0026	0.0047
sarC1	0.0037	0.0036	0.000610	16.72%	0.0026	0.0047	0.0026	0.0047
E(sar ₂ T0)	0.0181	0.0181	0.001968	10.85%	0.0149	0.0214	0.0149	0.0214
sar ₂ T0	0.0181	0.0181	0.001968	10.85%	0.0149	0.0214	0.0150	0.0214
E(TIR)	2.654	2.740	0.522077	19.05%	1.882	3.599	1.993	3.731
TIR	2.652	2.739	0.521650	19.05%	1.881	3.597	1.987	3.738
S _R	0.505	0.510	0.058573	11.48%	0.414	0.607	0.427	0.623
S _T	0.939	0.939	0.007168	0.76%	0.927	0.951	0.927	0.951
E(D)	1.428	1.489	0.331154	22.24%	0.944	2.034	1.019	2.104
D	1.427	1.489	0.331075	22.24%	0.944	2.033	1.019	2.103
prop_T0'	0.690	0.690	0.004744	0.69%	0.682	0.698	0.682	0.698
prop_C0	0.305	0.305	0.004728	1.55%	0.297	0.313	0.298	0.313
E(sar_tot) ⁺⁺	0.0146	0.0146	0.001392	9.53%	0.0123	0.0169	0.0124	0.0170
sar_tot ⁺⁺	0.0146	0.0146	0.001394	9.54%	0.0123	0.0169	0.0124	0.0170

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-26. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1997.

Dworshak Hatchery Chinook 1997

PIT-tags released= 14,080

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	12	12	3.5307	29.31%	6	18	7	18
adult_C1	13	13	3.6168	27.78%	7	19	8	19
adult_T0	16	16	3.9220	24.36%	10	23	10	23
E(C0)	2,521	2,520	131.3708	5.21%	2,304	2,736	2,303	2,739
C0	2,529	2,529	132.6720	5.25%	2,311	2,748	2,310	2,755
E(C1)	3,622	3,621	155.2265	4.29%	3,365	3,876	3,378	3,890
C1	3,613	3,612	155.2431	4.30%	3,356	3,867	3,370	3,884
E(T0)	1,932	1,931	40.7599	2.11%	1,864	1,998	1,865	2,001
T0	1,931	1,931	40.7461	2.11%	1,864	1,998	1,866	2,000
E(sarC0)	0.0048	0.0048	0.001410	29.45%	0.0025	0.0071	0.0026	0.0072
sarC0	0.0047	0.0048	0.001404	29.43%	0.0025	0.0071	0.0026	0.0072
E(sarC1)	0.0036	0.0036	0.001012	28.10%	0.0019	0.0053	0.0021	0.0053
sarC1	0.0036	0.0036	0.001015	28.10%	0.0019	0.0053	0.0021	0.0054
E(sar ₂ T0)	0.0083	0.0083	0.002029	24.33%	0.0050	0.0117	0.0051	0.0119
sar ₂ T0	0.0083	0.0083	0.002029	24.33%	0.0050	0.0117	0.0051	0.0119
E(TIR)	1.740	1.917	0.820452	42.80%	0.567	3.267	0.915	3.475
TIR	1.746	1.924	0.823331	42.79%	0.570	3.278	0.921	3.463
S _R	0.490	0.521	0.157402	30.19%	0.263	0.780	0.312	0.804
S _T	0.968	0.969	0.017236	1.78%	0.940	0.997	0.940	0.996
E(D)	0.881	1.024	0.523290	51.11%	0.163	1.885	0.416	2.004
D	0.884	1.028	0.525452	51.14%	0.163	1.892	0.415	2.014
prop_T0'	0.481	0.481	0.008761	1.82%	0.467	0.496	0.467	0.496
prop_C0	0.313	0.313	0.010693	3.41%	0.296	0.331	0.296	0.331
E(sar_tot) ⁺⁺	0.0062	0.0063	0.001102	17.62%	0.0044	0.0081	0.0044	0.0082
sar_tot ⁺⁺	0.0062	0.0062	0.001101	17.62%	0.0044	0.0081	0.0044	0.0081

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-27. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1998.

Dworshak Hatchery Chinook 1998

PIT-tags released= 47,703

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	139	139	11.9725	8.61%	119	159	120	158
adult_C1	118	118	11.0740	9.35%	100	137	100	137
adult_T0	132	132	11.4577	8.67%	113	151	114	151
E(C0)	10,890	10,898	170.8940	1.57%	10,617	11,179	10,615	11,183
C0	11,151	11,156	173.7757	1.56%	10,870	11,442	10,882	11,447
E(C1)	13,345	13,350	154.3332	1.16%	13,096	13,604	13,094	13,617
C1	13,128	13,135	154.1678	1.17%	12,881	13,388	12,875	13,387
E(T0)	14,760	14,766	106.4457	0.72%	14,591	14,941	14,594	14,946
T0	14,728	14,734	106.2324	0.72%	14,559	14,909	14,563	14,915
E(sarC0)	0.0128	0.0128	0.001105	8.66%	0.0109	0.0146	0.0110	0.0146
sarC0	0.0125	0.0125	0.001078	8.65%	0.0107	0.0142	0.0108	0.0142
E(sarC1)	0.0088	0.0089	0.000827	9.33%	0.0075	0.0102	0.0075	0.0103
sarC1	0.0090	0.0090	0.000841	9.33%	0.0076	0.0104	0.0077	0.0104
E(sar ₂ T0)	0.0089	0.0089	0.000773	8.64%	0.0077	0.0102	0.0077	0.0102
sar ₂ T0	0.0090	0.0090	0.000775	8.64%	0.0077	0.0102	0.0077	0.0102
E(TIR)	0.701	0.706	0.084758	12.00%	0.567	0.846	0.577	0.861
TIR	0.719	0.724	0.086886	11.99%	0.581	0.867	0.593	0.884
S _R	0.506	0.507	0.040724	8.04%	0.440	0.574	0.443	0.577
S _T	0.972	0.971	0.005380	0.55%	0.963	0.980	0.963	0.981
E(D)	0.365	0.368	0.051449	13.98%	0.283	0.453	0.290	0.457
D	0.374	0.377	0.052738	13.97%	0.291	0.464	0.298	0.469
prop_T0'	0.713	0.713	0.003419	0.48%	0.707	0.718	0.707	0.719
prop_C0	0.286	0.286	0.003242	1.13%	0.281	0.291	0.280	0.291
E(sar_tot) ⁺⁺	0.0100	0.0100	0.000651	6.49%	0.0090	0.0111	0.0090	0.0111
sar_tot ⁺⁺	0.0100	0.0100	0.000649	6.51%	0.0089	0.0110	0.0089	0.0111

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-28. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 1999.

Dworshak Hatchery Chinook 1999

PIT-tags released= 47,845

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	125	124	11.2266	9.03%	106	143	106	143
adult_C1	181	181	13.2304	7.33%	159	202	157	202
adult_T0	115	115	10.6335	9.23%	98	133	98	132
E(C0)	10,155	10,151	186.8341	1.84%	9,843	10,458	9,866	10,474
C0	10,484	10,482	195.1845	1.86%	10,160	10,803	10,181	10,820
E(C1)	19,351	19,354	313.6939	1.62%	18,838	19,870	18,859	19,893
C1	19,083	19,085	311.2072	1.63%	18,573	19,597	18,596	19,612
E(T0)	9,817	9,823	113.7240	1.16%	9,636	10,010	9,639	10,015
T0	9,787	9,793	113.4304	1.16%	9,606	9,980	9,608	9,985
E(sarC0)	0.0123	0.0122	0.001123	9.17%	0.0104	0.0141	0.0104	0.0141
sarC0	0.0119	0.0119	0.001088	9.17%	0.0101	0.0137	0.0101	0.0137
E(sarC1)	0.0094	0.0093	0.000697	7.47%	0.0082	0.0105	0.0081	0.0105
sarC1	0.0095	0.0095	0.000706	7.46%	0.0083	0.0106	0.0082	0.0107
E(sar ₂ T0)	0.0117	0.0117	0.001081	9.21%	0.0100	0.0135	0.0100	0.0135
sar ₂ T0	0.0118	0.0118	0.001084	9.21%	0.0100	0.0135	0.0101	0.0135
E(TIR)	0.952	0.965	0.125555	13.01%	0.759	1.172	0.776	1.196
TIR	0.986	1.000	0.129941	12.99%	0.786	1.214	0.805	1.244
S _R	0.542	0.548	0.053351	9.73%	0.460	0.636	0.469	0.648
S _T	0.885	0.885	0.010523	1.19%	0.867	0.902	0.866	0.902
E(D)	0.583	0.599	0.100559	16.80%	0.433	0.764	0.449	0.781
D	0.604	0.620	0.104076	16.78%	0.449	0.791	0.465	0.807
prop_T0'	0.735	0.735	0.002988	0.41%	0.730	0.740	0.730	0.740
prop_C0	0.265	0.265	0.002988	1.13%	0.260	0.270	0.260	0.270
E(sar_tot) ⁺⁺	0.0119	0.0119	0.000854	7.20%	0.0105	0.0133	0.0105	0.0133
sar_tot ⁺⁺	0.0118	0.0118	0.000853	7.24%	0.0104	0.0132	0.0105	0.0132

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-29. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2000.

Dworshak Hatchery Chinook 2000

PIT-tags released= 47,743

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	132	132	11.3788	8.59%	114	151	114	152
adult_C1	44	44	6.4705	14.67%	33	55	33	55
adult_T0	183	183	13.3036	7.26%	161	205	161	205
E(C0)	13,100	13,100	279.7281	2.14%	12,640	13,560	12,638	13,557
C0	13,075	13,075	280.1365	2.14%	12,614	13,535	12,612	13,529
E(C1)	5,388	5,390	86.8896	1.61%	5,247	5,532	5,251	5,538
C1	5,416	5,418	87.5000	1.61%	5,274	5,562	5,280	5,568
E(T0)	18,306	18,305	208.9408	1.14%	17,961	18,649	17,963	18,650
T0	18,317	18,316	209.4240	1.14%	17,971	18,660	17,987	18,660
E(sarC0)	0.0101	0.0101	0.000901	8.91%	0.0086	0.0116	0.0086	0.0116
sarC0	0.0101	0.0101	0.000903	8.91%	0.0086	0.0116	0.0087	0.0116
E(sarC1)	0.0082	0.0082	0.001208	14.76%	0.0062	0.0102	0.0062	0.0102
sarC1	0.0081	0.0081	0.001201	14.76%	0.0062	0.0101	0.0062	0.0102
E(sar ₂ T0)	0.0100	0.0100	0.000731	7.30%	0.0088	0.0112	0.0088	0.0112
sar ₂ T0	0.0100	0.0100	0.000730	7.30%	0.0088	0.0112	0.0088	0.0112
E(TIR)	0.992	0.998	0.116232	11.65%	0.807	1.189	0.821	1.194
TIR	0.990	0.996	0.115943	11.65%	0.805	1.186	0.821	1.191
S _R	0.481	0.503	0.076473	15.22%	0.377	0.628	0.400	0.645
S _T	0.894	0.895	0.008170	0.91%	0.881	0.908	0.881	0.908
E(D)	0.533	0.561	0.107839	19.23%	0.383	0.738	0.416	0.749
D	0.532	0.559	0.107540	19.23%	0.382	0.736	0.417	0.749
prop_T0'	0.660	0.660	0.005093	0.77%	0.651	0.668	0.652	0.668
prop_C0	0.340	0.340	0.005093	1.50%	0.332	0.349	0.332	0.348
E(sar_tot) ⁺⁺	0.0100	0.0100	0.000572	5.69%	0.0091	0.0110	0.0092	0.0110
sar_tot ⁺⁺	0.0100	0.0100	0.000572	5.69%	0.0091	0.0110	0.0092	0.0110

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-30. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2001.

Dworshak Hatchery Chinook 2001

PIT-tags released= 55,139

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	0	0	0.0000		0	0	0	0
adult_C1	7	7	2.6699	38.37%	3	11	3	12
adult_T0	79	79	8.9302	11.30%	64	94	64	94
E(C0)	809	809	20.2572	2.50%	776	843	777	843
C0	886	887	29.7019	3.35%	839	936	839	938
E(C1)	16,882	16,876	121.2001	0.72%	16,677	17,075	16,685	17,077
C1	16,872	16,866	120.4106	0.71%	16,668	17,064	16,672	17,062
E(T0)	21,782	21,785	115.6745	0.53%	21,595	21,975	21,600	21,969
T0	21,740	21,742	115.8921	0.53%	21,552	21,933	21,555	21,934
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0004	0.0004	0.000158	38.38%	0.0002	0.0007	0.0002	0.0007
sarC1	0.0004	0.0004	0.000158	38.38%	0.0002	0.0007	0.0002	0.0007
E(sar ₂ T0)	0.0036	0.0036	0.000410	11.29%	0.0030	0.0043	0.0029	0.0043
sar ₂ T0	0.0036	0.0036	0.000410	11.29%	0.0030	0.0043	0.0029	0.0043
E(TIR)	8.75	10.60	6.349103	59.89%	0.16	21.05	5.04	20.36
TIR	8.76	10.62	6.358132	59.90%	0.16	21.07	5.04	20.37
S _R	0.241	0.246	0.029852	12.15%	0.197	0.295	0.202	0.300
S _T	0.959	0.959	0.000894	0.09%	0.957	0.960	0.957	0.960
E(D)	2.202	2.720	1.667824	61.31%	-0.023	5.464	1.232	5.295
D	2.205	2.724	1.670168	61.32%	-0.024	5.471	1.233	5.303
prop_T0'	0.978	0.978	0.000801	0.08%	0.976	0.979	0.976	0.979
prop_C0	0.022	0.022	0.000801	3.59%	0.021	0.024	0.021	0.024
E(sar_tot) ⁺⁺	0.0036	0.0036	0.000402	11.30%	0.0029	0.0042	0.0029	0.0043
sar_tot ⁺⁺	0.0036	0.0036	0.000402	11.30%	0.0029	0.0042	0.0029	0.0043

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-31. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2002.

Dworshak Hatchery Chinook 2002

PIT-tags released= 54,725

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	95	94	9.6254	10.19%	79	110	80	111
adult_C1	74	74	8.2925	11.26%	60	87	60	87
adult_T0	60	60	7.5081	12.60%	47	72	47	72
E(C0)	18,930	18,952	324.7759	1.71%	18,417	19,486	18,429	19,502
C0	19,008	19,029	324.9641	1.71%	18,494	19,563	18,512	19,582
E(C1)	15,008	15,024	247.5452	1.65%	14,617	15,431	14,638	15,449
C1	14,914	14,931	247.8454	1.66%	14,524	15,339	14,538	15,354
E(T0)	9,649	9,650	136.7053	1.42%	9,425	9,874	9,416	9,884
T0	9,665	9,666	137.2332	1.42%	9,440	9,892	9,431	9,902
E(sarC0)	0.0050	0.0050	0.000515	10.33%	0.0041	0.0058	0.0042	0.0059
sarC0	0.0050	0.0050	0.000513	10.34%	0.0041	0.0058	0.0042	0.0058
E(sarC1)	0.0049	0.0049	0.000557	11.36%	0.0040	0.0058	0.0040	0.0058
sarC1	0.0050	0.0049	0.000560	11.36%	0.0040	0.0059	0.0040	0.0058
E(sar ₂ T0)	0.0062	0.0062	0.000780	12.63%	0.0049	0.0075	0.0049	0.0075
sar ₂ T0	0.0062	0.0062	0.000779	12.63%	0.0049	0.0074	0.0049	0.0075
E(TIR)	1.239	1.252	0.203598	16.26%	0.917	1.587	0.932	1.602
TIR	1.242	1.255	0.204137	16.27%	0.919	1.591	0.931	1.606
S _R	0.616	0.619	0.053079	8.57%	0.532	0.707	0.538	0.715
S _T	0.911	0.911	0.010545	1.16%	0.894	0.928	0.893	0.927
E(D)	0.837	0.851	0.155003	18.21%	0.596	1.106	0.611	1.120
D	0.839	0.853	0.155476	18.23%	0.597	1.109	0.612	1.120
prop_T0'	0.569	0.569	0.003322	0.58%	0.564	0.575	0.564	0.575
prop_C0	0.431	0.431	0.003322	0.77%	0.425	0.436	0.425	0.436
E(sar_tot) ⁺⁺	0.0057	0.0057	0.000503	8.88%	0.0048	0.0065	0.0048	0.0065
sar_tot ⁺⁺	0.0057	0.0056	0.000503	8.90%	0.0048	0.0065	0.0048	0.0065

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-32. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2003.

Dworshak Hatchery Chinook 2003

PIT-tags released= 54,708

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	38	38	5.8387	15.46%	28	47	28	47
adult_C1	12	12	3.4141	28.35%	6	18	7	18
adult_T0	34	34	5.8730	17.28%	24	44	25	44
E(C0)	17,431	17,448	284.9286	1.63%	16,979	17,917	16,967	17,894
C0	17,697	17,713	286.9060	1.62%	17,241	18,185	17,237	18,153
E(C1)	6,792	6,799	94.8188	1.39%	6,643	6,955	6,648	6,956
C1	6,715	6,722	93.7435	1.39%	6,568	6,876	6,573	6,881
E(T0)	13,376	13,377	145.5377	1.09%	13,138	13,617	13,151	13,620
T0	13,205	13,207	143.2747	1.08%	12,971	13,443	12,984	13,447
E(sarC0)	0.0022	0.0022	0.000335	15.47%	0.0016	0.0027	0.0016	0.0027
sarC0	0.0021	0.0021	0.000330	15.47%	0.0016	0.0027	0.0016	0.0027
E(sarC1)	0.0018	0.0018	0.000502	28.34%	0.0009	0.0026	0.0010	0.0027
sarC1	0.0018	0.0018	0.000508	28.35%	0.0010	0.0026	0.0010	0.0027
E(sar ₂ T0)	0.0025	0.0025	0.000438	17.26%	0.0018	0.0033	0.0018	0.0033
sar ₂ T0	0.0026	0.0026	0.000444	17.25%	0.0018	0.0033	0.0019	0.0033
E(TIR)	1.166	1.205	0.302861	25.13%	0.707	1.703	0.794	1.757
TIR	1.199	1.239	0.311440	25.13%	0.727	1.752	0.816	1.800
S _R	0.676	0.682	0.064586	9.47%	0.576	0.788	0.588	0.800
S _T	0.926	0.926	0.007047	0.76%	0.914	0.938	0.914	0.937
E(D)	0.851	0.888	0.239775	27.01%	0.493	1.282	0.572	1.319
D	0.875	0.913	0.246570	27.01%	0.507	1.318	0.588	1.359
prop_T0'	0.537	0.537	0.003944	0.74%	0.530	0.543	0.530	0.543
prop_C0	0.463	0.463	0.003944	0.85%	0.457	0.470	0.457	0.470
E(sar_tot) ⁺⁺	0.0024	0.0024	0.000281	11.85%	0.0019	0.0028	0.0019	0.0028
sar_tot ⁺⁺	0.0024	0.0024	0.000282	11.90%	0.0019	0.0028	0.0019	0.0028

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-33. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Dworshak Hatchery Chinook outmigrating in 2004.

Dworshak Hatchery Chinook 2004

PIT-tags released= 51,616

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	14	14	3.6636	26.21%	8	20	8	20
adult_C1	22	22	4.5667	20.92%	14	29	15	30
adult_T0	46	46	6.9822	15.10%	35	58	35	58
E(C0)	6,078	6,077	105.2597	1.73%	5,904	6,250	5,908	6,256
C0	6,280	6,280	109.7333	1.75%	6,100	6,461	6,100	6,468
E(C1)	14,102	14,095	112.7177	0.80%	13,909	14,280	13,912	14,283
C1	14,009	14,001	112.0947	0.80%	13,817	14,185	13,822	14,189
E(T0)	21,776	21,780	134.3991	0.62%	21,559	22,001	21,571	22,010
T0	21,657	21,660	136.1629	0.63%	21,436	21,884	21,443	21,897
E(sarC0)	0.0023	0.0023	0.000602	26.18%	0.0013	0.0033	0.0013	0.0033
sarC0	0.0022	0.0022	0.000583	26.19%	0.0013	0.0032	0.0013	0.0032
E(sarC1)	0.0016	0.0015	0.000325	20.96%	0.0010	0.0021	0.0011	0.0021
sarC1	0.0016	0.0016	0.000327	20.96%	0.0010	0.0021	0.0011	0.0021
E(sar ₂ T0)	0.0021	0.0021	0.000320	15.08%	0.0016	0.0027	0.0016	0.0026
sar ₂ T0	0.0021	0.0021	0.000322	15.07%	0.0016	0.0027	0.0016	0.0027
E(TIR)	0.917	0.999	0.364610	36.48%	0.400	1.599	0.568	1.650
TIR	0.953	1.038	0.378759	36.47%	0.415	1.661	0.596	1.721
S _R	0.499	0.516	0.087825	17.03%	0.371	0.660	0.397	0.686
S _T	0.970	0.970	0.002861	0.30%	0.965	0.974	0.965	0.974
E(D)	0.472	0.532	0.213596	40.19%	0.180	0.883	0.282	0.927
D	0.491	0.552	0.221843	40.17%	0.187	0.917	0.292	0.959
prop_T0'	0.843	0.843	0.002535	0.30%	0.839	0.848	0.839	0.848
prop_C0	0.150	0.150	0.002431	1.62%	0.146	0.154	0.146	0.154
E(sar_tot) ⁺⁺	0.0021	0.0021	0.000287	13.38%	0.0017	0.0026	0.0017	0.0026
sar_tot ⁺⁺	0.0021	0.0021	0.000287	13.40%	0.0017	0.0026	0.0017	0.0026

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-34. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1997.

Rapid River Hatchery Chinook 1997

PIT-tags released= 40,451

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	19	19	4.2238	22.25%	12	26	13	26
adult_C1	36	36	6.0439	16.71%	26	46	27	46
adult_T0	34	34	5.7365	16.87%	25	43	25	44
E(C0)	4,169	4,172	163.1545	3.91%	3,903	4,440	3,901	4,430
C0	4,176	4,178	164.3075	3.93%	3,908	4,449	3,904	4,448
E(C1)	6,849	6,850	201.7659	2.95%	6,518	7,182	6,524	7,192
C1	6,843	6,843	202.2219	2.95%	6,511	7,176	6,515	7,187
E(T0)	4,324	4,325	60.9270	1.41%	4,225	4,426	4,224	4,424
T0	4,324	4,325	60.9215	1.41%	4,225	4,425	4,224	4,424
E(sarC0)	0.0046	0.0046	0.001025	22.50%	0.0029	0.0062	0.0031	0.0063
sarC0	0.0045	0.0045	0.001024	22.51%	0.0029	0.0062	0.0031	0.0063
E(sarC1)	0.0053	0.0053	0.000892	16.87%	0.0038	0.0068	0.0039	0.0068
sarC1	0.0053	0.0053	0.000892	16.86%	0.0038	0.0068	0.0039	0.0068
E(sar ₂ T0)	0.0079	0.0079	0.001325	16.85%	0.0057	0.0100	0.0057	0.0101
sar ₂ T0	0.0079	0.0079	0.001325	16.85%	0.0057	0.0100	0.0057	0.0101
E(TIR)	1.725	1.822	0.554921	30.46%	0.909	2.735	1.079	2.840
TIR	1.728	1.825	0.556171	30.48%	0.910	2.740	1.079	2.848
S _R	0.330	0.337	0.062276	18.48%	0.234	0.439	0.242	0.449
S _T	0.940	0.940	0.010450	1.11%	0.923	0.957	0.923	0.957
E(D)	0.605	0.650	0.227915	35.04%	0.275	1.025	0.364	1.083
D	0.606	0.651	0.228552	35.08%	0.276	1.027	0.365	1.085
prop_T0'	0.539	0.539	0.006780	1.26%	0.528	0.550	0.528	0.550
prop_C0	0.272	0.272	0.007188	2.64%	0.260	0.284	0.260	0.284
E(sar_tot) ⁺⁺	0.0065	0.0065	0.000781	12.06%	0.0052	0.0078	0.0052	0.0079
sar_tot ⁺⁺	0.0065	0.0065	0.000780	12.06%	0.0052	0.0078	0.0052	0.0079

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-35. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1998.

Rapid River Hatchery Chinook 1998

PIT-tags released= 48,336

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	53	53	7.0451	13.31%	41	65	42	65
adult_C1	91	91	9.6553	10.62%	75	107	76	107
adult_T0	257	258	15.9994	6.21%	231	284	232	284
E(C0)	4,338	4,335	80.6135	1.86%	4,202	4,467	4,201	4,470
C0	4,402	4,398	84.9797	1.93%	4,258	4,538	4,260	4,537
E(C1)	13,650	13,653	126.5695	0.93%	13,444	13,861	13,446	13,870
C1	13,597	13,600	128.6548	0.95%	13,389	13,812	13,389	13,820
E(T0)	12,881	12,875	98.9700	0.77%	12,712	13,038	12,713	13,035
T0	12,876	12,871	98.9748	0.77%	12,708	13,034	12,711	13,032
E(sarC0)	0.0122	0.0122	0.001629	13.34%	0.0095	0.0149	0.0096	0.0151
sarC0	0.0120	0.0120	0.001603	13.31%	0.0094	0.0147	0.0095	0.0148
E(sarC1)	0.0067	0.0067	0.000711	10.67%	0.0055	0.0078	0.0056	0.0079
sarC1	0.0067	0.0067	0.000713	10.67%	0.0055	0.0079	0.0056	0.0079
E(sar ₂ T0)	0.0200	0.0200	0.001240	6.19%	0.0180	0.0221	0.0180	0.0221
sar ₂ T0	0.0200	0.0200	0.001240	6.19%	0.0180	0.0221	0.0180	0.0221
E(TIR)	1.633	1.670	0.256372	15.35%	1.248	2.091	1.294	2.127
TIR	1.658	1.695	0.259698	15.33%	1.267	2.122	1.316	2.157
S _R	0.586	0.589	0.041622	7.07%	0.520	0.657	0.524	0.661
S _T	0.962	0.961	0.003455	0.36%	0.956	0.967	0.956	0.967
E(D)	0.995	1.022	0.170338	16.66%	0.742	1.303	0.780	1.341
D	1.010	1.038	0.172679	16.64%	0.753	1.322	0.796	1.362
prop_T0'	0.857	0.857	0.002747	0.32%	0.852	0.861	0.852	0.861
prop_C0	0.143	0.142	0.002515	1.77%	0.138	0.147	0.139	0.147
E(sar_tot) ⁺⁺	0.0188	0.0189	0.001087	5.75%	0.0171	0.0207	0.0171	0.0207
sar_tot ⁺⁺	0.0188	0.0189	0.001086	5.75%	0.0171	0.0207	0.0171	0.0207

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-36. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 1999.

Rapid River Hatchery Chinook 1999

PIT-tags released= 47,812

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	167	167	13.0666	7.82%	146	189	146	188
adult_C1	235	235	14.9550	6.36%	211	260	211	259
adult_T0	391	391	20.4083	5.21%	358	425	357	425
E(C0)	6,994	6,993	117.1136	1.67%	6,801	7,186	6,801	7,186
C0	7,040	7,039	121.7378	1.73%	6,839	7,240	6,842	7,238
E(C1)	14,502	14,504	183.6108	1.27%	14,202	14,806	14,200	14,815
C1	14,456	14,458	184.8984	1.28%	14,154	14,762	14,157	14,773
E(T0)	12,852	12,854	117.3083	0.91%	12,661	13,047	12,658	13,046
T0	12,857	12,860	117.6088	0.91%	12,667	13,053	12,666	13,050
E(sarC0)	0.0239	0.0239	0.001903	7.96%	0.0208	0.0270	0.0208	0.0270
sarC0	0.0237	0.0237	0.001888	7.95%	0.0206	0.0269	0.0207	0.0268
E(sarC1)	0.0162	0.0162	0.001034	6.37%	0.0145	0.0179	0.0145	0.0179
sarC1	0.0163	0.0163	0.001036	6.37%	0.0146	0.0180	0.0146	0.0179
E(sar ₂ T0)	0.0304	0.0305	0.001575	5.17%	0.0279	0.0330	0.0279	0.0331
sar ₂ T0	0.0304	0.0304	0.001575	5.17%	0.0279	0.0330	0.0278	0.0331
E(TIR)	1.274	1.282	0.120895	9.43%	1.083	1.481	1.102	1.500
TIR	1.282	1.290	0.121513	9.42%	1.090	1.490	1.106	1.511
S _R	0.567	0.573	0.053201	9.29%	0.485	0.660	0.493	0.666
S _T	0.924	0.924	0.006964	0.75%	0.913	0.936	0.913	0.936
E(D)	0.781	0.794	0.102800	12.94%	0.625	0.963	0.644	0.980
D	0.786	0.799	0.103406	12.94%	0.629	0.969	0.645	0.991
prop_T0'	0.797	0.797	0.002690	0.34%	0.793	0.801	0.793	0.801
prop_C0	0.203	0.203	0.002690	1.33%	0.199	0.207	0.199	0.207
E(sar_tot) ⁺⁺	0.0291	0.0291	0.001336	4.59%	0.0269	0.0313	0.0269	0.0313
sar_tot ⁺⁺	0.0291	0.0291	0.001335	4.59%	0.0269	0.0313	0.0269	0.0313

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-37. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2000.

Rapid River Hatchery Chinook 2000

PIT-tags released= 47,747

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	176	176	13.3466	7.58%	154	198	155	199
adult_C1	70	70	8.1987	11.78%	56	83	56	83
adult_T0	349	348	18.9361	5.44%	317	379	316	378
E(C0)	11,058	11,050	226.9832	2.05%	10,677	11,424	10,687	11,441
C0	11,046	11,038	228.6351	2.07%	10,662	11,414	10,676	11,427
E(C1)	5,238	5,234	79.4772	1.52%	5,103	5,364	5,099	5,366
C1	5,248	5,244	80.1633	1.53%	5,112	5,376	5,110	5,375
E(T0)	16,580	16,579	173.3141	1.05%	16,294	16,864	16,293	16,872
T0	16,587	16,587	172.8509	1.04%	16,302	16,871	16,302	16,883
E(sarC0)	0.0159	0.0159	0.001235	7.75%	0.0139	0.0180	0.0140	0.0180
sarC0	0.0159	0.0160	0.001235	7.74%	0.0139	0.0180	0.0140	0.0181
E(sarC1)	0.0134	0.0133	0.001551	11.66%	0.0107	0.0158	0.0107	0.0159
sarC1	0.0133	0.0133	0.001548	11.67%	0.0107	0.0158	0.0107	0.0158
E(sar ₂ T0)	0.0210	0.0210	0.001140	5.43%	0.0191	0.0229	0.0190	0.0228
sar ₂ T0	0.0210	0.0210	0.001140	5.43%	0.0191	0.0229	0.0190	0.0228
E(TIR)	1.323	1.326	0.127480	9.62%	1.116	1.536	1.131	1.553
TIR	1.321	1.324	0.127227	9.61%	1.114	1.533	1.130	1.551
S _R	0.580	0.630	0.108682	17.26%	0.451	0.809	0.480	0.831
S _T	0.930	0.930	0.007307	0.79%	0.918	0.942	0.918	0.942
E(D)	0.825	0.898	0.176350	19.65%	0.608	1.188	0.659	1.245
D	0.823	0.896	0.175983	19.64%	0.607	1.186	0.657	1.245
prop_T0'	0.679	0.679	0.004826	0.71%	0.671	0.687	0.671	0.687
prop_C0	0.321	0.321	0.004826	1.50%	0.313	0.329	0.313	0.329
E(sar_tot) ⁺⁺	0.0194	0.0194	0.000873	4.50%	0.0179	0.0208	0.0179	0.0208
sar_tot ⁺⁺	0.0194	0.0194	0.000872	4.50%	0.0179	0.0208	0.0179	0.0208

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-38. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2001.

Rapid River Hatchery Chinook 2001

PIT-tags released= 55,085

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	2	2	1.3356	66.52%	0	4	0	5
adult_C1	8	8	2.8390	36.02%	3	13	3	13
adult_T0	207	207	14.3047	6.91%	184	231	183	231
E(C0)	933	932	22.0001	2.36%	896	968	895	969
C0	966	967	30.0785	3.11%	917	1,016	919	1,016
E(C1)	15,975	15,975	112.6407	0.71%	15,790	16,161	15,781	16,168
C1	15,989	15,989	112.2192	0.70%	15,804	16,173	15,802	16,177
E(T0)	19,111	19,108	111.3007	0.58%	18,925	19,291	18,926	19,292
T0	19,090	19,086	111.9044	0.59%	18,902	19,270	18,904	19,273
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0005	0.0005	0.000178	36.00%	0.0002	0.0008	0.0002	0.0008
sarC1	0.0005	0.0005	0.000177	36.01%	0.0002	0.0008	0.0002	0.0008
E(sar ₂ T0)	0.0108	0.0108	0.000748	6.90%	0.0096	0.0121	0.0096	0.0121
sar ₂ T0	0.0108	0.0109	0.000748	6.90%	0.0096	0.0121	0.0096	0.0121
E(TIR)	21.63	26.49	17.58603	66.40%	-2.44	55.42	13.25	53.90
TIR	21.67	26.54	17.61808	66.39%	-2.44	55.52	13.27	54.08
S _R	0.327	0.331	0.038359	11.58%	0.268	0.394	0.276	0.403
S _T	0.966	0.966	0.000714	0.07%	0.965	0.968	0.965	0.968
E(D)	7.312	9.057	6.144707	67.84%	-1.051	19.165	4.388	16.889
D	7.326	9.075	6.156188	67.84%	-1.052	19.202	4.398	16.922
prop_T0'	0.974	0.974	0.000873	0.09%	0.972	0.975	0.972	0.975
prop_C0	0.026	0.026	0.000873	3.30%	0.025	0.028	0.025	0.028
E(sar_tot) ⁺⁺	0.0106	0.0106	0.000728	6.89%	0.0094	0.0118	0.0093	0.0118
sar_tot ⁺⁺	0.0106	0.0106	0.000729	6.89%	0.0094	0.0118	0.0094	0.0118

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-39. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2002.

Rapid River Hatchery Chinook 2002

PIT-tags released= 54,908

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	91	91	9.5271	10.43%	76	107	76	107
adult_C1	94	94	9.4784	10.12%	78	109	78	109
adult_T0	117	117	10.7385	9.16%	100	135	100	135
E(C0)	13,548	13,555	192.8311	1.42%	13,238	13,872	13,224	13,869
C0	13,625	13,633	195.5951	1.43%	13,311	13,955	13,303	13,950
E(C1)	14,980	14,984	188.6762	1.26%	14,673	15,294	14,666	15,293
C1	14,854	14,857	188.7904	1.27%	14,547	15,168	14,551	15,161
E(T0)	11,539	11,541	129.0291	1.12%	11,329	11,753	11,324	11,764
T0	11,589	11,591	130.5750	1.13%	11,376	11,806	11,378	11,817
E(sarC0)	0.0067	0.0067	0.000710	10.53%	0.0056	0.0079	0.0056	0.0079
sarC0	0.0067	0.0067	0.000706	10.53%	0.0055	0.0079	0.0056	0.0079
E(sarC1)	0.0063	0.0063	0.000636	10.17%	0.0052	0.0073	0.0052	0.0073
sarC1	0.0063	0.0063	0.000642	10.17%	0.0053	0.0074	0.0053	0.0074
E(sar ₂ T0)	0.0101	0.0102	0.000928	9.13%	0.0086	0.0117	0.0087	0.0117
sar ₂ T0	0.0101	0.0101	0.000924	9.14%	0.0086	0.0116	0.0086	0.0116
E(TIR)	1.510	1.524	0.214348	14.06%	1.172	1.877	1.197	1.904
TIR	1.512	1.527	0.214915	14.08%	1.173	1.880	1.199	1.906
S _R	0.708	0.714	0.071840	10.07%	0.596	0.832	0.604	0.835
S _T	0.939	0.938	0.007409	0.79%	0.926	0.951	0.926	0.951
E(D)	1.138	1.159	0.200676	17.31%	0.829	1.489	0.871	1.518
D	1.140	1.161	0.201133	17.32%	0.830	1.492	0.873	1.519
prop_T0'	0.665	0.665	0.003147	0.47%	0.659	0.670	0.659	0.670
prop_C0	0.335	0.335	0.003147	0.94%	0.330	0.341	0.330	0.341
E(sar_tot) ⁺⁺	0.0090	0.0090	0.000659	7.31%	0.0079	0.0101	0.0079	0.0101
sar_tot ⁺⁺	0.0090	0.0090	0.000658	7.33%	0.0079	0.0101	0.0079	0.0101

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-40. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2003.

Rapid River Hatchery Chinook 2003

PIT-tags released= 54,763

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	39	39	6.3421	16.25%	29	49	29	50
adult_C1	11	11	3.2853	29.74%	6	16	6	17
adult_T0	33	33	5.8364	17.77%	23	42	23	42
E(C0)	16,873	16,869	287.1956	1.70%	16,397	17,341	16,409	17,352
C0	16,858	16,855	287.1809	1.70%	16,382	17,327	16,398	17,331
E(C1)	7,047	7,052	96.3328	1.37%	6,893	7,210	6,895	7,206
C1	7,055	7,059	97.0470	1.37%	6,899	7,219	6,897	7,212
E(T0)	13,344	13,354	133.7669	1.00%	13,134	13,574	13,133	13,570
T0	13,353	13,362	135.1754	1.01%	13,140	13,585	13,138	13,586
E(sarC0)	0.0023	0.0023	0.000376	16.25%	0.0017	0.0029	0.0017	0.0029
sarC0	0.0023	0.0023	0.000376	16.24%	0.0017	0.0029	0.0017	0.0029
E(sarC1)	0.0016	0.0016	0.000466	29.74%	0.0008	0.0023	0.0008	0.0024
sarC1	0.0016	0.0016	0.000465	29.74%	0.0008	0.0023	0.0008	0.0024
E(sar ₂ T0)	0.0025	0.0025	0.000438	17.82%	0.0017	0.0032	0.0017	0.0032
sar ₂ T0	0.0025	0.0025	0.000438	17.82%	0.0017	0.0032	0.0017	0.0032
E(TIR)	1.070	1.094	0.277878	25.41%	0.637	1.551	0.701	1.609
TIR	1.068	1.092	0.277388	25.40%	0.636	1.548	0.697	1.604
S _R	0.660	0.668	0.069164	10.35%	0.554	0.782	0.567	0.790
S _T	0.943	0.942	0.006347	0.67%	0.932	0.953	0.932	0.952
E(D)	0.748	0.775	0.210463	27.16%	0.429	1.121	0.484	1.182
D	0.747	0.774	0.210055	27.15%	0.428	1.119	0.483	1.178
prop_T0'	0.551	0.551	0.004420	0.80%	0.544	0.559	0.544	0.558
prop_C0	0.449	0.449	0.004420	0.99%	0.441	0.456	0.442	0.456
E(sar_tot) ⁺⁺	0.0024	0.0024	0.000292	12.17%	0.0019	0.0029	0.0019	0.0029
sar_tot ⁺⁺	0.0024	0.0024	0.000292	12.17%	0.0019	0.0029	0.0019	0.0029

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-41. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Rapid River Hatchery Chinook outmigrating in 2004.

Rapid River Hatchery Chinook 2004

PIT-tags released= 51,969

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	5	5	2.2996	47.01%	1	9	2	9
adult_C1	11	11	3.5079	31.58%	5	17	6	17
adult_T0	50	50	7.0074	14.06%	38	61	39	61
E(C0)	3,740	3,738	73.7508	1.97%	3,617	3,860	3,622	3,856
C0	3,484	3,481	81.3563	2.34%	3,348	3,615	3,350	3,616
E(C1)	12,677	12,676	100.4562	0.79%	12,511	12,841	12,515	12,844
C1	12,776	12,777	102.4978	0.80%	12,608	12,946	12,615	12,946
E(T0)	19,384	19,390	114.0575	0.59%	19,203	19,578	19,202	19,576
T0	19,519	19,525	117.5290	0.60%	19,331	19,718	19,332	19,719
E(sarC0)	0.0013	0.0013	0.000614	46.93%	0.0003	0.0023	0.0005	0.0024
sarC0	0.0014	0.0014	0.000659	46.93%	0.0003	0.0025	0.0005	0.0026
E(sarC1)	0.0009	0.0009	0.000276	31.54%	0.0004	0.0013	0.0005	0.0013
sarC1	0.0009	0.0009	0.000274	31.54%	0.0004	0.0013	0.0005	0.0013
E(sar ₂ T0)	0.0026	0.0026	0.000361	14.06%	0.0020	0.0032	0.0020	0.0032
sar ₂ T0	0.0026	0.0026	0.000359	14.06%	0.0020	0.0031	0.0020	0.0031
E(TIR)	1.929	2.572	1.781283	69.27%	-0.359	5.502	1.008	5.679
TIR	1.785	2.378	1.645548	69.21%	-0.329	5.084	0.937	5.247
S _R	0.353	0.369	0.073927	20.02%	0.248	0.491	0.268	0.515
S _T	0.970	0.970	0.002166	0.22%	0.967	0.974	0.966	0.974
E(D)	0.702	0.976	0.713574	73.09%	-0.197	2.150	0.351	2.287
D	0.650	0.903	0.659511	73.06%	-0.182	1.988	0.323	2.092
prop_T0'	0.890	0.890	0.002301	0.26%	0.886	0.894	0.886	0.894
prop_C0	0.097	0.097	0.002209	2.27%	0.094	0.101	0.094	0.101
E(sar_tot) ⁺⁺	0.0024	0.0024	0.000332	13.68%	0.0019	0.0030	0.0019	0.0030
sar_tot ⁺⁺	0.0024	0.0024	0.000331	13.68%	0.0019	0.0030	0.0019	0.0030

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-42. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2001.

Catherine Creek Hatchery Chinook 2001

PIT-tags released= 20,915

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	0	0	0.0000		0	0	0	0
adult_C1	2	2	1.3947	71.20%	0	4	0	4
adult_T0	11	11	3.3319	30.25%	6	16	6	16
E(C0)	369	369	16.2996	4.42%	342	396	343	395
C0	379	379	20.7231	5.47%	345	413	345	414
E(C1)	4,636	4,634	61.7544	1.33%	4,532	4,735	4,534	4,733
C1	4,642	4,640	61.6484	1.33%	4,539	4,742	4,540	4,738
E(T0)	4,795	4,796	63.5332	1.32%	4,692	4,901	4,690	4,904
T0	4,790	4,791	63.8422	1.33%	4,686	4,896	4,683	4,899
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0004	0.0004	0.000301	71.14%	-0.0001	0.0009	0.0000	0.0009
sarC1	0.0004	0.0004	0.000300	71.14%	-0.0001	0.0009	0.0000	0.0009
E(sar ₂ T0)	0.0023	0.0023	0.000695	30.24%	0.0012	0.0034	0.0012	0.0035
sar ₂ T0	0.0023	0.0023	0.000695	30.24%	0.0012	0.0034	0.0012	0.0035
E(TIR)	5.32	6.18	3.828708	61.96%	-0.12	12.48	0.00	13.58
TIR	5.33	6.19	3.837572	61.95%	-0.12	12.51	0.00	13.63
S _R	0.249	0.258	0.061693	23.91%	0.157	0.360	0.180	0.372
S _T	0.957	0.957	0.002004	0.21%	0.954	0.960	0.954	0.960
E(D)	1.381	1.659	1.112060	67.02%	-0.170	3.489	0.000	3.784
D	1.384	1.663	1.114690	67.01%	-0.170	3.497	0.000	3.794
prop_T0'	0.964	0.964	0.001971	0.20%	0.961	0.967	0.961	0.967
prop_C0	0.036	0.036	0.001971	5.45%	0.033	0.039	0.033	0.039
E(sar_tot) ⁺⁺	0.0022	0.0022	0.000675	30.33%	0.0011	0.0033	0.0012	0.0034
sar_tot ⁺⁺	0.0022	0.0022	0.000674	30.31%	0.0011	0.0033	0.0012	0.0034

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-43. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2002.

Catherine Creek Hatchery Chinook 2002

PIT-tags released= 20,796

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	12	12	3.4483	28.50%	6	18	7	18
adult_C1	10	10	3.1305	31.11%	5	15	6	16
adult_T0	24	24	4.9840	20.91%	16	32	16	32
E(C0)	2,424	2,424	83.0831	3.43%	2,288	2,561	2,289	2,564
C0	2,445	2,446	84.3569	3.45%	2,307	2,585	2,312	2,590
E(C1)	3,132	3,134	80.4505	2.57%	3,001	3,266	3,001	3,271
C1	3,120	3,122	81.2253	2.60%	2,989	3,256	2,992	3,258
E(T0)	2,707	2,708	61.0375	2.25%	2,608	2,808	2,611	2,811
T0	2,697	2,698	61.4696	2.28%	2,597	2,799	2,600	2,797
E(sarC0)	0.0050	0.0050	0.001432	28.67%	0.0026	0.0074	0.0028	0.0075
sarC0	0.0049	0.0050	0.001418	28.64%	0.0026	0.0073	0.0028	0.0074
E(sarC1)	0.0032	0.0032	0.000995	30.98%	0.0016	0.0048	0.0018	0.0050
sarC1	0.0032	0.0032	0.000999	30.98%	0.0016	0.0049	0.0018	0.0050
E(sar ₂ T0)	0.0089	0.0088	0.001842	20.92%	0.0058	0.0118	0.0059	0.0119
sar ₂ T0	0.0089	0.0088	0.001848	20.91%	0.0058	0.0119	0.0059	0.0120
E(TIR)	1.791	1.940	0.832320	42.90%	0.571	3.309	0.997	3.386
TIR	1.813	1.964	0.841786	42.86%	0.579	3.349	1.016	3.430
S _R	0.646	0.683	0.203909	29.86%	0.347	1.018	0.440	1.063
S _T	0.953	0.953	0.014076	1.48%	0.929	0.976	0.930	0.975
E(D)	1.214	1.391	0.719077	51.69%	0.208	2.574	0.580	2.769
D	1.229	1.408	0.728150	51.70%	0.211	2.606	0.589	2.793
prop_T0'	0.706	0.706	0.007302	1.03%	0.694	0.718	0.694	0.718
prop_C0	0.294	0.294	0.007303	2.48%	0.282	0.306	0.282	0.306
E(sar_tot) ⁺⁺	0.0077	0.0077	0.001356	17.65%	0.0055	0.0099	0.0055	0.0100
sar_tot ⁺⁺	0.0077	0.0077	0.001358	17.66%	0.0055	0.0099	0.0056	0.0100

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-44. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2003.

Catherine Creek Hatchery Chinook 2003

PIT-tags released= 20,628

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	8	8	2.8520	35.63%	3	13	4	13
adult_C1	5	5	2.2243	44.27%	1	9	2	9
adult_T0	9	9	3.0066	33.19%	4	14	4	15
E(C0)	3,201	3,203	122.8879	3.84%	3,000	3,405	3,009	3,418
C0	3,201	3,202	123.1713	3.85%	2,999	3,404	3,010	3,421
E(C1)	1,403	1,404	44.3524	3.16%	1,331	1,477	1,334	1,477
C1	1,403	1,405	44.6508	3.18%	1,331	1,478	1,333	1,478
E(T0)	2,493	2,492	59.6837	2.40%	2,394	2,590	2,399	2,587
T0	2,494	2,493	60.2495	2.42%	2,394	2,592	2,397	2,592
E(sarC0)	0.0025	0.0025	0.000899	35.90%	0.0010	0.0040	0.0012	0.0041
sarC0	0.0025	0.0025	0.000899	35.90%	0.0010	0.0040	0.0012	0.0041
E(sarC1)	0.0036	0.0036	0.001583	44.23%	0.0010	0.0062	0.0014	0.0064
sarC1	0.0036	0.0036	0.001582	44.22%	0.0010	0.0062	0.0014	0.0064
E(sar ₂ T0)	0.0036	0.0036	0.001208	33.22%	0.0016	0.0056	0.0017	0.0058
sar ₂ T0	0.0036	0.0036	0.001208	33.22%	0.0016	0.0056	0.0017	0.0059
E(TIR)	1.445	1.712	1.192119	69.62%	-0.249	3.673	0.596	3.577
TIR	1.444	1.712	1.194841	69.81%	-0.254	3.677	0.598	3.556
S _R	0.618	0.626	0.076036	12.14%	0.501	0.751	0.517	0.762
S _T	0.957	0.957	0.014380	1.50%	0.933	0.981	0.933	0.980
E(D)	0.932	1.118	0.774718	69.28%	-0.156	2.393	0.385	2.299
D	0.931	1.118	0.776125	69.44%	-0.159	2.394	0.384	2.288
prop_T0'	0.552	0.552	0.009878	1.79%	0.536	0.568	0.536	0.568
prop_C0	0.448	0.448	0.009878	2.20%	0.432	0.464	0.432	0.464
E(sar_tot) ⁺⁺	0.0031	0.0031	0.000776	24.79%	0.0019	0.0044	0.0020	0.0044
sar_tot ⁺⁺	0.0031	0.0031	0.000776	24.81%	0.0019	0.0044	0.0020	0.0044

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-45. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Catherine Creek Hatchery Chinook outmigrating in 2004.

Catherine Creek Hatchery Chinook 2004

PIT-tags released= 20,994

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	1	1	1.0312	96.55%	-1	3	0	3
adult_C1	6	6	2.5085	41.15%	2	10	2	10
adult_T0	10	10	3.1740	31.66%	5	15	5	16
E(C0)	509	509	26.0388	5.11%	467	552	467	552
C0	503	504	29.3680	5.83%	456	552	455	551
E(C1)	1,856	1,855	43.2252	2.33%	1,784	1,926	1,784	1,924
C1	1,869	1,868	43.8005	2.34%	1,796	1,940	1,797	1,938
E(T0)	2,888	2,889	53.4725	1.85%	2,801	2,977	2,801	2,981
T0	2,877	2,877	53.8438	1.87%	2,789	2,966	2,790	2,970
E(sarC0)	0.0020	0.0021	0.002020	96.34%	-0.0012	0.0054	0.0000	0.0060
sarC0	0.0020	0.0021	0.002040	96.30%	-0.0012	0.0055	0.0000	0.0061
E(sarC1)	0.0032	0.0033	0.001351	41.11%	0.0011	0.0055	0.0011	0.0056
sarC1	0.0032	0.0033	0.001340	41.08%	0.0011	0.0055	0.0011	0.0056
E(sar ₂ T0)	0.0035	0.0035	0.001099	31.66%	0.0017	0.0053	0.0017	0.0055
sar ₂ T0	0.0035	0.0035	0.001103	31.66%	0.0017	0.0053	0.0017	0.0055
E(TIR)	1.763	1.323	0.666590	50.39%	0.226	2.419	0.000	2.320
TIR	1.748	1.314	0.662807	50.43%	0.224	2.405	0.000	2.306
S _R	0.330	0.440	0.266913	60.65%	0.001	0.879	0.201	0.886
S _T	0.970	0.970	0.004966	0.51%	0.962	0.978	0.961	0.978
E(D)	0.599	0.595	0.477020	80.16%	-0.190	1.380	0.000	1.338
D	0.595	0.591	0.471826	79.89%	-0.186	1.367	0.000	1.337
prop_T0'	0.898	0.898	0.005668	0.63%	0.888	0.907	0.888	0.907
prop_C0	0.096	0.096	0.005274	5.49%	0.087	0.105	0.087	0.105
E(sar_tot) ⁺⁺	0.0033	0.0033	0.001004	30.06%	0.0017	0.0050	0.0018	0.0051
sar_tot ⁺⁺	0.0033	0.0034	0.001007	30.06%	0.0017	0.0050	0.0018	0.0052

⁺ When bootstrap iterations have no adults occurring for some study categories or missing S_R , a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where $\text{prT0}'$ and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-46. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1997.

McCall Hatchery Chinook 1997

PIT-tags released= 52,652

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	74	74	8.9905	12.13%	59	89	60	90
adult_C1	102	102	9.8494	9.67%	86	118	86	118
adult_T0	91	91	9.5688	10.56%	75	106	75	106
E(C0)	6,772	6,774	218.7537	3.23%	6,414	7,134	6,416	7,142
C0	6,761	6,762	219.2886	3.24%	6,402	7,123	6,398	7,132
E(C1)	9,261	9,264	258.6387	2.79%	8,838	9,689	8,841	9,712
C1	9,272	9,275	259.7738	2.80%	8,848	9,702	8,854	9,738
E(T0)	6,013	6,010	74.0185	1.23%	5,889	6,132	5,888	6,135
T0	6,013	6,010	74.0384	1.23%	5,889	6,132	5,888	6,136
E(sarC0)	0.0109	0.0110	0.001387	12.66%	0.0087	0.0132	0.0088	0.0134
sarC0	0.0109	0.0110	0.001388	12.65%	0.0087	0.0133	0.0088	0.0135
E(sarC1)	0.0110	0.0110	0.001120	10.18%	0.0092	0.0128	0.0092	0.0129
sarC1	0.0110	0.0110	0.001118	10.17%	0.0091	0.0128	0.0092	0.0129
E(sar ₂ T0)	0.0151	0.0151	0.001583	10.50%	0.0125	0.0177	0.0126	0.0177
sar ₂ T0	0.0151	0.0151	0.001583	10.50%	0.0125	0.0177	0.0126	0.0177
E(TIR)	1.385	1.399	0.233615	16.70%	1.014	1.783	1.056	1.804
TIR	1.383	1.396	0.233017	16.69%	1.013	1.779	1.056	1.795
S _R	0.435	0.443	0.085547	19.30%	0.303	0.584	0.320	0.592
S _T	0.945	0.945	0.009547	1.01%	0.929	0.961	0.929	0.961
E(D)	0.637	0.654	0.159018	24.32%	0.392	0.916	0.431	0.931
D	0.636	0.653	0.158642	24.30%	0.392	0.914	0.429	0.927
prop_T0'	0.509	0.509	0.005820	1.14%	0.499	0.518	0.499	0.519
prop_C0	0.307	0.307	0.006356	2.07%	0.296	0.317	0.296	0.317
E(sar_tot) ⁺⁺	0.0131	0.0131	0.000949	7.26%	0.0115	0.0146	0.0115	0.0146
sar_tot ⁺⁺	0.0131	0.0131	0.000950	7.27%	0.0115	0.0146	0.0115	0.0146

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-47. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1998.

McCall Hatchery Chinook 1998

PIT-tags released= 47,340

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	53	53	7.5664	14.25%	41	66	41	66
adult_C1	94	94	9.6070	10.18%	79	110	79	111
adult_T0	273	273	15.8254	5.80%	247	299	247	299
E(C0)	3,849	3,848	77.3158	2.01%	3,721	3,975	3,723	3,976
C0	3,849	3,847	81.1022	2.11%	3,714	3,981	3,721	3,983
E(C1)	12,815	12,819	137.9374	1.08%	12,592	13,046	12,585	13,045
C1	12,816	12,820	142.2032	1.11%	12,586	13,054	12,578	13,060
E(T0)	10,143	10,138	89.4999	0.88%	9,991	10,285	9,989	10,287
T0	10,142	10,137	89.4924	0.88%	9,989	10,284	9,988	10,286
E(sarC0)	0.0138	0.0138	0.001976	14.32%	0.0105	0.0171	0.0105	0.0170
sarC0	0.0138	0.0138	0.001970	14.28%	0.0106	0.0170	0.0105	0.0169
E(sarC1)	0.0073	0.0074	0.000750	10.19%	0.0061	0.0086	0.0062	0.0087
sarC1	0.0073	0.0074	0.000750	10.19%	0.0061	0.0086	0.0062	0.0087
E(sar ₂ T0)	0.0269	0.0269	0.001544	5.74%	0.0244	0.0295	0.0244	0.0295
sar ₂ T0	0.0269	0.0269	0.001545	5.74%	0.0244	0.0295	0.0244	0.0296
E(TIR)	1.955	1.992	0.320463	16.08%	1.465	2.520	1.534	2.554
TIR	1.955	1.992	0.319695	16.05%	1.466	2.518	1.540	2.556
S _R	0.565	0.566	0.041450	7.32%	0.498	0.635	0.503	0.637
S _T	0.952	0.951	0.004355	0.46%	0.944	0.959	0.944	0.959
E(D)	1.160	1.185	0.201654	17.02%	0.853	1.517	0.891	1.541
D	1.160	1.185	0.201128	16.97%	0.854	1.516	0.893	1.538
prop_T0'	0.854	0.854	0.003029	0.35%	0.849	0.859	0.849	0.859
prop_C0	0.144	0.144	0.002704	1.88%	0.139	0.148	0.139	0.148
E(sar_tot) ⁺⁺	0.0250	0.0250	0.001349	5.40%	0.0228	0.0272	0.0228	0.0273
sar_tot ⁺⁺	0.0250	0.0250	0.001348	5.40%	0.0228	0.0272	0.0228	0.0273

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-48. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 1999.

McCall Hatchery Chinook 1999

PIT-tags released= 47,985

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	202	202	14.4175	7.14%	178	226	179	227
adult_C1	231	230	14.8532	6.45%	206	255	207	257
adult_T0	377	376	18.6869	4.97%	346	407	345	407
E(C0)	8,315	8,306	164.5704	1.98%	8,036	8,577	8,040	8,579
C0	8,407	8,399	167.5127	1.99%	8,123	8,674	8,122	8,675
E(C1)	11,481	11,473	187.2066	1.63%	11,165	11,781	11,162	11,781
C1	11,391	11,383	188.0695	1.65%	11,074	11,692	11,062	11,684
E(T0)	10,512	10,509	133.4168	1.27%	10,289	10,728	10,277	10,737
T0	10,515	10,512	133.0074	1.27%	10,293	10,731	10,281	10,742
E(sarC0)	0.0243	0.0243	0.001788	7.35%	0.0214	0.0273	0.0215	0.0273
sarC0	0.0240	0.0241	0.001762	7.32%	0.0212	0.0270	0.0212	0.0269
E(sarC1)	0.0201	0.0201	0.001312	6.53%	0.0179	0.0222	0.0180	0.0224
sarC1	0.0203	0.0202	0.001320	6.52%	0.0181	0.0224	0.0182	0.0226
E(sar ₂ T0)	0.0359	0.0358	0.001776	4.96%	0.0329	0.0387	0.0329	0.0388
sar ₂ T0	0.0359	0.0358	0.001775	4.96%	0.0329	0.0387	0.0329	0.0387
E(TIR)	1.476	1.480	0.129824	8.77%	1.266	1.693	1.275	1.703
TIR	1.492	1.496	0.130991	8.76%	1.280	1.711	1.289	1.726
S _R	0.525	0.528	0.046670	8.85%	0.451	0.604	0.456	0.610
S _T	0.906	0.906	0.010071	1.11%	0.889	0.922	0.889	0.922
E(D)	0.855	0.862	0.105780	12.28%	0.688	1.036	0.707	1.059
D	0.865	0.871	0.106814	12.26%	0.695	1.047	0.715	1.071
prop_T0'	0.725	0.725	0.003599	0.50%	0.719	0.731	0.719	0.731
prop_C0	0.275	0.275	0.003599	1.31%	0.269	0.281	0.269	0.281
E(sar_tot) ⁺⁺	0.0327	0.0327	0.001398	4.28%	0.0304	0.0350	0.0303	0.0350
sar_tot ⁺⁺	0.0326	0.0326	0.001396	4.29%	0.0303	0.0349	0.0302	0.0349

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-49. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2000.

McCall Hatchery Chinook 2000

PIT-tags released= 47,705

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	269	269	16.2451	6.05%	242	295	242	295
adult_C1	91	91	9.4400	10.42%	75	106	75	106
adult_T0	497	498	22.4200	4.50%	461	535	462	535
E(C0)	13,028	13,024	320.5083	2.46%	12,497	13,551	12,520	13,565
C0	13,064	13,061	321.3297	2.46%	12,532	13,589	12,558	13,601
E(C1)	4,492	4,492	82.0720	1.83%	4,357	4,627	4,358	4,629
C1	4,485	4,485	82.9028	1.85%	4,349	4,621	4,349	4,624
E(T0)	12,827	12,835	164.3069	1.28%	12,565	13,105	12,567	13,105
T0	12,806	12,814	163.9595	1.28%	12,544	13,084	12,552	13,083
E(sarC0)	0.0206	0.0206	0.001344	6.51%	0.0184	0.0229	0.0185	0.0230
sarC0	0.0206	0.0206	0.001338	6.50%	0.0184	0.0228	0.0184	0.0229
E(sarC1)	0.0203	0.0202	0.002097	10.40%	0.0167	0.0236	0.0167	0.0238
sarC1	0.0203	0.0202	0.002100	10.40%	0.0167	0.0236	0.0168	0.0238
E(sar ₂ T0)	0.0387	0.0388	0.001791	4.62%	0.0358	0.0417	0.0360	0.0417
sar ₂ T0	0.0388	0.0389	0.001792	4.61%	0.0359	0.0418	0.0360	0.0418
E(TIR)	1.877	1.887	0.147680	7.83%	1.644	2.130	1.664	2.139
TIR	1.885	1.895	0.148018	7.81%	1.652	2.139	1.669	2.151
S _R	0.612	0.655	0.250977	38.33%	0.242	1.068	0.505	0.828
S _T	0.928	0.928	0.009638	1.04%	0.912	0.944	0.912	0.944
E(D)	1.238	1.331	0.529438	39.77%	0.460	2.202	0.981	1.803
D	1.244	1.337	0.531759	39.77%	0.463	2.212	0.982	1.813
prop_T0'	0.580	0.580	0.006247	1.08%	0.570	0.591	0.570	0.591
prop_C0	0.420	0.420	0.006247	1.49%	0.409	0.430	0.409	0.430
E(sar_tot) ⁺⁺	0.0311	0.0312	0.001218	3.91%	0.0292	0.0332	0.0292	0.0332
sar_tot ⁺⁺	0.0312	0.0312	0.001218	3.91%	0.0292	0.0332	0.0292	0.0333

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-50. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2001.

McCall Hatchery Chinook 2001

PIT-tags released= 55,124

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	3	3	1.7161	58.71%	0	6	0	6
adult_C1	6	6	2.4806	40.94%	2	10	2	11
adult_T0	206	206	14.2972	6.93%	183	230	184	231
E(C0)	943	943	24.5810	2.61%	903	983	903	986
C0	1,000	999	31.2540	3.13%	948	1,051	946	1,052
E(C1)	15,529	15,530	117.3943	0.76%	15,337	15,723	15,338	15,720
C1	15,536	15,538	116.3091	0.75%	15,347	15,729	15,351	15,728
E(T0)	16,736	16,731	113.1878	0.68%	16,545	16,918	16,537	16,913
T0	16,704	16,700	113.3490	0.68%	16,514	16,887	16,511	16,882
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0004	0.0004	0.000160	40.93%	0.0001	0.0007	0.0001	0.0007
sarC1	0.0004	0.0004	0.000160	40.93%	0.0001	0.0007	0.0001	0.0007
E(sar ₂ T0)	0.0123	0.0123	0.000845	6.86%	0.0109	0.0137	0.0110	0.0138
sar ₂ T0	0.0123	0.0123	0.000847	6.86%	0.0110	0.0137	0.0110	0.0138
E(TIR)	31.86	39.71	27.54076	69.35%	-5.59	85.02	17.92	88.17
TIR	31.93	39.81	27.60145	69.34%	-5.60	85.21	17.95	88.36
S _R	0.269	0.271	0.037457	13.84%	0.209	0.332	0.217	0.342
S _T	0.959	0.958	0.000929	0.10%	0.957	0.960	0.957	0.960
E(D)	8.927	11.220	7.994851	71.26%	-1.932	24.371	4.858	24.064
D	8.948	11.246	8.012466	71.25%	-1.935	24.426	4.868	24.116
prop_T0'	0.972	0.972	0.000924	0.10%	0.970	0.973	0.970	0.973
prop_C0	0.028	0.028	0.000924	3.27%	0.027	0.030	0.027	0.030
E(sar_tot) ⁺⁺	0.0120	0.0120	0.000822	6.86%	0.0106	0.0133	0.0107	0.0134
sar_tot ⁺⁺	0.0120	0.0120	0.000824	6.86%	0.0107	0.0134	0.0107	0.0134

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-51. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2002.

McCall Hatchery Chinook 2002

PIT-tags released= 54,734

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	106	107	10.0639	9.45%	90	123	89	123
adult_C1	126	127	10.8151	8.55%	109	144	110	145
adult_T0	131	131	11.3635	8.66%	113	150	112	151
E(C0)	10,196	10,200	181.2380	1.78%	9,902	10,498	9,913	10,497
C0	10,280	10,286	183.0576	1.78%	9,985	10,587	9,987	10,578
E(C1)	12,379	12,386	180.7911	1.46%	12,088	12,683	12,092	12,689
C1	12,315	12,321	182.0714	1.48%	12,021	12,620	12,029	12,631
E(T0)	8,862	8,863	111.8143	1.26%	8,679	9,047	8,687	9,044
T0	8,842	8,843	112.0887	1.27%	8,659	9,027	8,666	9,027
E(sarC0)	0.0104	0.0104	0.000992	9.49%	0.0088	0.0121	0.0088	0.0121
sarC0	0.0103	0.0104	0.000983	9.49%	0.0087	0.0120	0.0087	0.0120
E(sarC1)	0.0102	0.0102	0.000876	8.57%	0.0088	0.0117	0.0088	0.0117
sarC1	0.0102	0.0103	0.000880	8.57%	0.0088	0.0117	0.0089	0.0118
E(sar ₂ T0)	0.0148	0.0148	0.001285	8.67%	0.0127	0.0169	0.0127	0.0170
sar ₂ T0	0.0148	0.0148	0.001287	8.67%	0.0127	0.0170	0.0127	0.0170
E(TIR)	1.422	1.430	0.184886	12.93%	1.126	1.734	1.167	1.778
TIR	1.437	1.446	0.186614	12.91%	1.139	1.753	1.176	1.794
S _R	0.578	0.582	0.053110	9.13%	0.495	0.669	0.505	0.679
S _T	0.952	0.952	0.008865	0.93%	0.937	0.966	0.937	0.966
E(D)	0.863	0.875	0.142057	16.23%	0.641	1.109	0.674	1.134
D	0.872	0.884	0.143526	16.23%	0.648	1.120	0.681	1.141
prop_T0'	0.678	0.678	0.003682	0.54%	0.671	0.684	0.672	0.684
prop_C0	0.322	0.322	0.003682	1.14%	0.316	0.329	0.316	0.328
E(sar_tot) ⁺⁺	0.0134	0.0134	0.000935	6.98%	0.0119	0.0149	0.0118	0.0149
sar_tot ⁺⁺	0.0134	0.0134	0.000938	7.00%	0.0119	0.0149	0.0118	0.0149

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-52. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2003.

McCall Hatchery Chinook 2003

PIT-tags released= 74,317

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	107	107	9.7728	9.13%	91	123	91	123
adult_C1	30	30	5.4196	18.12%	21	39	21	39
adult_T0	111	111	10.2377	9.25%	94	127	94	128
E(C0)	19,412	19,420	281.0994	1.45%	18,957	19,882	18,933	19,882
C0	19,696	19,704	280.8397	1.43%	19,242	20,166	19,221	20,166
E(C1)	8,764	8,764	107.0737	1.22%	8,588	8,940	8,596	8,941
C1	8,669	8,670	105.1312	1.21%	8,497	8,842	8,503	8,845
E(T0)	14,180	14,180	138.1579	0.97%	13,953	14,407	13,948	14,411
T0	14,006	14,007	137.4782	0.98%	13,781	14,233	13,782	14,233
E(sarC0)	0.0055	0.0055	0.000513	9.30%	0.0047	0.0064	0.0047	0.0064
sarC0	0.0054	0.0054	0.000505	9.29%	0.0046	0.0063	0.0046	0.0063
E(sarC1)	0.0034	0.0034	0.000616	18.05%	0.0024	0.0044	0.0024	0.0045
sarC1	0.0035	0.0034	0.000623	18.05%	0.0024	0.0045	0.0025	0.0045
E(sar ₂ T0)	0.0078	0.0078	0.000718	9.20%	0.0066	0.0090	0.0067	0.0090
sar ₂ T0	0.0079	0.0079	0.000726	9.20%	0.0067	0.0091	0.0068	0.0091
E(TIR)	1.420	1.428	0.189747	13.29%	1.115	1.740	1.140	1.770
TIR	1.459	1.466	0.194491	13.26%	1.146	1.786	1.170	1.814
S _R	0.696	0.700	0.049337	7.05%	0.619	0.781	0.628	0.787
S _T	0.940	0.940	0.005493	0.58%	0.931	0.949	0.931	0.950
E(D)	1.050	1.063	0.160077	15.06%	0.799	1.326	0.828	1.363
D	1.079	1.091	0.164280	15.05%	0.821	1.362	0.850	1.393
prop_T0'	0.539	0.539	0.003685	0.68%	0.533	0.545	0.533	0.545
prop_C0	0.461	0.461	0.003685	0.80%	0.455	0.467	0.455	0.467
E(sar_tot) ⁺⁺	0.0068	0.0067	0.000454	6.73%	0.0060	0.0075	0.0060	0.0075
sar_tot ⁺⁺	0.0068	0.0068	0.000454	6.72%	0.0060	0.0075	0.0061	0.0075

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-53. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged McCall Hatchery Chinook outmigrating in 2004.

McCall Hatchery Chinook 2004

PIT-tags released= 71,363

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	6	6	2.4308	40.09%	2	10	2	10
adult_C1	19	19	4.3799	23.00%	12	26	12	26
adult_T0	65	65	8.2796	12.78%	51	78	51	79
E(C0)	2,297	2,297	51.3482	2.24%	2,212	2,381	2,210	2,379
C0	2,359	2,360	56.8611	2.41%	2,266	2,453	2,262	2,453
E(C1)	16,335	16,332	119.7021	0.73%	16,135	16,529	16,133	16,538
C1	16,297	16,294	119.7809	0.74%	16,097	16,491	16,094	16,500
E(T0)	20,893	20,896	123.3985	0.59%	20,693	21,099	20,703	21,100
T0	20,858	20,860	124.0886	0.59%	20,656	21,064	20,667	21,062
E(sarC0)	0.0026	0.0026	0.001062	40.21%	0.0009	0.0044	0.0009	0.0045
sarC0	0.0025	0.0026	0.001033	40.19%	0.0009	0.0043	0.0009	0.0043
E(sarC1)	0.0012	0.0012	0.000268	22.99%	0.0007	0.0016	0.0007	0.0016
sarC1	0.0012	0.0012	0.000269	22.99%	0.0007	0.0016	0.0007	0.0016
E(sar ₂ T0)	0.0031	0.0031	0.000397	12.79%	0.0024	0.0038	0.0024	0.0038
sar ₂ T0	0.0031	0.0031	0.000397	12.79%	0.0025	0.0038	0.0024	0.0038
E(TIR)	1.191	1.447	0.941306	65.06%	-0.102	2.995	0.650	2.869
TIR	1.225	1.489	0.970197	65.14%	-0.107	3.085	0.665	2.976
S _R	0.437	0.449	0.068972	15.38%	0.335	0.562	0.347	0.576
S _T	0.967	0.967	0.001203	0.12%	0.965	0.969	0.965	0.969
E(D)	0.538	0.667	0.435304	65.24%	-0.049	1.383	0.288	1.283
D	0.553	0.687	0.448462	65.30%	-0.051	1.424	0.296	1.315
prop_T0'	0.929	0.929	0.001594	0.17%	0.926	0.931	0.926	0.931
prop_C0	0.060	0.060	0.001414	2.37%	0.057	0.062	0.057	0.062
E(sar_tot) ⁺⁺	0.0031	0.0031	0.000377	12.37%	0.0024	0.0037	0.0024	0.0037
sar_tot ⁺⁺	0.0031	0.0031	0.000378	12.39%	0.0024	0.0037	0.0024	0.0037

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-54. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1997.

Imnaha River Hatchery Chinook 1997

PIT-tags released= 13,378

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	19	19	4.4306	23.18%	12	26	12	27
adult_C1	26	26	5.1459	19.68%	18	35	18	36
adult_T0	25	25	5.3352	21.10%	17	34	17	34
E(C0)	2,209	2,209	117.7107	5.33%	2,016	2,403	2,024	2,423
C0	2,219	2,220	118.8177	5.35%	2,024	2,415	2,032	2,433
E(C1)	3,795	3,791	151.7201	4.00%	3,542	4,041	3,547	4,053
C1	3,785	3,781	151.8332	4.02%	3,531	4,031	3,535	4,040
E(T0)	2,147	2,146	40.4219	1.88%	2,079	2,212	2,079	2,212
T0	2,147	2,146	40.4079	1.88%	2,079	2,212	2,079	2,212
E(sarC0)	0.0086	0.0087	0.002052	23.66%	0.0053	0.0120	0.0053	0.0122
sarC0	0.0086	0.0086	0.002042	23.66%	0.0053	0.0120	0.0053	0.0122
E(sarC1)	0.0069	0.0069	0.001373	19.88%	0.0046	0.0092	0.0048	0.0093
sarC1	0.0069	0.0069	0.001376	19.87%	0.0047	0.0092	0.0048	0.0093
E(sar ₂ T0)	0.0116	0.0118	0.002463	20.91%	0.0077	0.0158	0.0077	0.0160
sar ₂ T0	0.0116	0.0118	0.002463	20.91%	0.0077	0.0158	0.0077	0.0160
E(TIR)	1.354	1.446	0.511517	35.38%	0.604	2.287	0.823	2.380
TIR	1.360	1.452	0.514224	35.40%	0.607	2.298	0.826	2.374
S _R	0.311	0.328	0.092161	28.12%	0.176	0.479	0.205	0.488
S _T	0.944	0.944	0.015198	1.61%	0.919	0.969	0.918	0.969
E(D)	0.446	0.499	0.227881	45.63%	0.125	0.874	0.241	0.913
D	0.448	0.502	0.228949	45.63%	0.125	0.878	0.243	0.915
prop_T0'	0.515	0.516	0.008477	1.64%	0.502	0.529	0.501	0.529
prop_C0	0.272	0.272	0.010306	3.78%	0.255	0.289	0.256	0.290
E(sar_tot) ⁺⁺	0.0098	0.0099	0.001411	14.26%	0.0076	0.0122	0.0076	0.0123
sar_tot ⁺⁺	0.0098	0.0099	0.001411	14.26%	0.0076	0.0122	0.0076	0.0123

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-55. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1998.

Imnaha River Hatchery Chinook 1998

PIT-tags released= 19,825

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	11	11	3.2617	29.64%	6	16	6	16
adult_C1	19	19	4.2459	22.33%	12	26	13	26
adult_T0	41	41	6.2769	15.19%	31	52	31	52
E(C0)	1,932	1,931	53.6337	2.78%	1,842	2,019	1,845	2,018
C0	1,995	1,993	58.1701	2.92%	1,898	2,089	1,900	2,085
E(C1)	6,386	6,386	88.1191	1.38%	6,241	6,531	6,252	6,533
C1	6,335	6,335	89.8526	1.42%	6,187	6,482	6,194	6,483
E(T0)	4,814	4,814	61.8363	1.28%	4,713	4,916	4,714	4,917
T0	4,809	4,809	61.8334	1.29%	4,708	4,911	4,709	4,910
E(sarC0)	0.0057	0.0057	0.001698	29.77%	0.0029	0.0085	0.0029	0.0086
sarC0	0.0055	0.0055	0.001643	29.74%	0.0028	0.0082	0.0028	0.0083
E(sarC1)	0.0030	0.0030	0.000663	22.28%	0.0019	0.0041	0.0020	0.0041
sarC1	0.0030	0.0030	0.000669	22.28%	0.0019	0.0041	0.0020	0.0042
E(sar ₂ T0)	0.0085	0.0086	0.001299	15.13%	0.0064	0.0107	0.0065	0.0109
sar ₂ T0	0.0085	0.0086	0.001300	15.13%	0.0065	0.0107	0.0065	0.0109
E(TIR)	1.496	1.678	0.720385	42.94%	0.493	2.863	0.899	3.053
TIR	1.546	1.734	0.743643	42.89%	0.510	2.957	0.934	3.154
S _R	0.530	0.536	0.046517	8.68%	0.459	0.612	0.463	0.616
S _T	0.947	0.947	0.006172	0.65%	0.937	0.957	0.937	0.958
E(D)	0.837	0.947	0.405987	42.89%	0.279	1.614	0.498	1.661
D	0.865	0.978	0.419138	42.84%	0.289	1.668	0.513	1.718
prop_T0'	0.845	0.845	0.004406	0.52%	0.837	0.852	0.837	0.852
prop_C0	0.152	0.152	0.003972	2.62%	0.145	0.158	0.145	0.158
E(sar_tot) ⁺⁺	0.0081	0.0081	0.001131	13.92%	0.0063	0.0100	0.0063	0.0100
sar_tot ⁺⁺	0.0081	0.0081	0.001131	13.95%	0.0062	0.0100	0.0063	0.0100

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-56. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 1999.

Imnaha River Hatchery Chinook 1999

PIT-tags released= 19,939

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	41	41	6.1691	14.99%	31	51	31	52
adult_C1	62	62	8.0241	12.90%	49	75	50	75
adult_T0	130	129	11.5358	8.91%	110	148	110	149
E(C0)	2,813	2,814	80.9916	2.88%	2,681	2,948	2,680	2,944
C0	2,869	2,872	83.2993	2.90%	2,735	3,009	2,733	3,008
E(C1)	5,132	5,128	115.1727	2.25%	4,939	5,318	4,943	5,313
C1	5,084	5,080	116.1048	2.29%	4,889	5,271	4,884	5,268
E(T0)	4,832	4,830	83.5370	1.73%	4,693	4,968	4,693	4,966
T0	4,827	4,826	83.8753	1.74%	4,688	4,964	4,688	4,963
E(sarC0)	0.0146	0.0146	0.002229	15.24%	0.0110	0.0183	0.0110	0.0185
sarC0	0.0143	0.0143	0.002176	15.18%	0.0108	0.0179	0.0108	0.0182
E(sarC1)	0.0121	0.0121	0.001569	12.93%	0.0096	0.0147	0.0096	0.0148
sarC1	0.0122	0.0123	0.001584	12.93%	0.0096	0.0149	0.0098	0.0149
E(sar ₂ T0)	0.0269	0.0268	0.002385	8.90%	0.0229	0.0307	0.0228	0.0308
sar ₂ T0	0.0269	0.0268	0.002388	8.90%	0.0229	0.0307	0.0228	0.0308
E(TIR)	1.846	1.875	0.337265	17.99%	1.320	2.430	1.377	2.457
TIR	1.885	1.915	0.344082	17.97%	1.349	2.481	1.396	2.506
S _R	0.538	0.555	0.102633	18.49%	0.386	0.724	0.419	0.746
S _T	0.918	0.918	0.013358	1.46%	0.896	0.940	0.896	0.939
E(D)	1.082	1.133	0.286782	25.32%	0.661	1.604	0.740	1.686
D	1.105	1.157	0.292401	25.28%	0.676	1.638	0.750	1.720
prop_T0'	0.777	0.776	0.004750	0.61%	0.769	0.784	0.768	0.784
prop_C0	0.223	0.224	0.004750	2.12%	0.216	0.231	0.216	0.232
E(sar_tot) ⁺⁺	0.0242	0.0241	0.001933	8.03%	0.0209	0.0273	0.0209	0.0274
sar_tot ⁺⁺	0.0241	0.0240	0.001930	8.03%	0.0209	0.0272	0.0209	0.0274

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-57. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2000.

Imnaha River Hatchery Chinook 2000

PIT-tags released= 20,819

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	106	106	10.5263	9.92%	89	123	89	124
adult_C1	37	37	5.9773	16.25%	27	47	27	47
adult_T0	211	211	13.9186	6.58%	188	234	190	234
E(C0)	4,414	4,419	152.0117	3.44%	4,169	4,669	4,179	4,676
C0	4,396	4,401	153.4590	3.49%	4,148	4,653	4,159	4,672
E(C1)	2,248	2,248	55.0957	2.45%	2,157	2,339	2,161	2,344
C1	2,254	2,254	55.5701	2.47%	2,163	2,346	2,166	2,353
E(T0)	6,777	6,781	120.5766	1.78%	6,582	6,979	6,582	6,975
T0	6,789	6,792	120.9273	1.78%	6,593	6,991	6,597	6,991
E(sarC0)	0.0240	0.0240	0.002461	10.24%	0.0200	0.0281	0.0200	0.0282
sarC0	0.0241	0.0241	0.002472	10.24%	0.0201	0.0282	0.0201	0.0283
E(sarC1)	0.0165	0.0164	0.002649	16.18%	0.0120	0.0207	0.0122	0.0208
sarC1	0.0164	0.0163	0.002639	16.17%	0.0120	0.0207	0.0122	0.0208
E(sar ₂ T0)	0.0311	0.0312	0.002054	6.59%	0.0278	0.0346	0.0278	0.0345
sar ₂ T0	0.0311	0.0311	0.002047	6.58%	0.0278	0.0345	0.0277	0.0344
E(TIR)	1.297	1.311	0.165380	12.61%	1.039	1.583	1.062	1.598
TIR	1.289	1.303	0.164313	12.61%	1.033	1.574	1.058	1.582
S _R	0.572	0.597	0.131976	22.11%	0.380	0.814	0.426	0.830
S _T	0.905	0.905	0.012585	1.39%	0.884	0.926	0.885	0.926
E(D)	0.819	0.864	0.217404	25.17%	0.506	1.221	0.563	1.255
D	0.815	0.859	0.216281	25.19%	0.503	1.214	0.561	1.247
prop_T0'	0.686	0.686	0.008208	1.20%	0.672	0.699	0.672	0.699
prop_C0	0.314	0.314	0.008208	2.61%	0.301	0.328	0.301	0.328
E(sar_tot) ⁺⁺	0.0289	0.0289	0.001583	5.47%	0.0263	0.0315	0.0263	0.0316
sar_tot ⁺⁺	0.0289	0.0289	0.001581	5.46%	0.0263	0.0315	0.0263	0.0315

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-58. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2001.

Imnaha River Hatchery Chinook 2001

PIT-tags released= 20,922

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	1	1	0.9968	97.53%	-1	3	0	3
adult_C1	4	4	1.9761	49.39%	1	7	1	8
adult_T0	48	48	6.8709	14.17%	37	60	38	61
E(C0)	362	362	12.4593	3.44%	341	382	342	383
C0	366	365	18.1430	4.97%	336	395	336	396
E(C1)	6,930	6,927	69.9497	1.01%	6,812	7,042	6,810	7,047
C1	6,939	6,936	70.1955	1.01%	6,821	7,052	6,819	7,055
E(T0)	7,733	7,734	74.5215	0.96%	7,611	7,856	7,611	7,857
T0	7,730	7,731	74.8642	0.97%	7,608	7,854	7,609	7,855
E(sarC0)	assume:	E(sarC1)						
sarC0	assume:	sarC1						
E(sarC1)	0.0006	0.0006	0.000285	49.42%	0.0001	0.0010	0.0001	0.0011
sarC1	0.0006	0.0006	0.000285	49.42%	0.0001	0.0010	0.0001	0.0011
E(sar ₂ T0)	0.0062	0.0063	0.000887	14.15%	0.0048	0.0077	0.0049	0.0078
sar ₂ T0	0.0062	0.0063	0.000888	14.15%	0.0048	0.0077	0.0049	0.0078
E(TIR)	10.75	14.18	9.678872	68.27%	-1.75	30.10	4.92	39.74
TIR	10.77	14.20	9.693785	68.27%	-1.75	30.15	4.93	39.77
S _R	0.372	0.401	0.111927	27.90%	0.217	0.585	0.274	0.607
S _T	0.965	0.965	0.001284	0.13%	0.963	0.967	0.963	0.967
E(D)	4.144	5.926	4.468534	75.41%	-1.425	13.276	1.829	15.274
D	4.151	5.935	4.475659	75.41%	-1.427	13.298	1.832	15.295
prop_T0'	0.976	0.976	0.001223	0.13%	0.974	0.978	0.974	0.978
prop_C0	0.024	0.024	0.001223	5.05%	0.022	0.026	0.022	0.026
E(sar_tot) ⁺⁺	0.0061	0.0061	0.000865	14.10%	0.0047	0.0076	0.0048	0.0077
sar_tot ⁺⁺	0.0061	0.0061	0.000865	14.10%	0.0047	0.0076	0.0048	0.0077

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-59. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2002.

Imnaha River Hatchery Chinook 2002

PIT-tags released= 20,920

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	21	21	4.6767	22.11%	13	29	14	29
adult_C1	28	28	5.2210	18.56%	20	37	20	37
adult_T0	31	31	5.7234	18.29%	22	41	22	41
E(C0)	4,597	4,597	127.7444	2.78%	4,387	4,807	4,389	4,809
C0	4,637	4,637	129.5525	2.79%	4,424	4,850	4,429	4,853
E(C1)	5,173	5,171	113.1926	2.19%	4,985	5,358	4,987	5,371
C1	5,135	5,134	113.5975	2.21%	4,947	5,321	4,952	5,333
E(T0)	3,914	3,915	80.5174	2.06%	3,782	4,047	3,779	4,043
T0	3,912	3,913	80.8697	2.07%	3,780	4,046	3,777	4,041
E(sarC0)	0.0046	0.0046	0.001026	22.28%	0.0029	0.0063	0.0030	0.0064
sarC0	0.0045	0.0046	0.001016	22.26%	0.0029	0.0062	0.0029	0.0063
E(sarC1)	0.0054	0.0054	0.001012	18.60%	0.0038	0.0071	0.0038	0.0071
sarC1	0.0055	0.0055	0.001019	18.60%	0.0038	0.0072	0.0038	0.0072
E(sar ₂ T0)	0.0079	0.0080	0.001457	18.23%	0.0056	0.0104	0.0056	0.0104
sar ₂ T0	0.0079	0.0080	0.001459	18.23%	0.0056	0.0104	0.0056	0.0104
E(TIR)	1.734	1.840	0.594059	32.29%	0.862	2.817	1.067	3.004
TIR	1.750	1.856	0.599028	32.27%	0.871	2.842	1.074	3.025
S _R	0.505	0.516	0.076079	14.74%	0.391	0.641	0.411	0.656
S _T	0.929	0.929	0.014383	1.55%	0.905	0.952	0.905	0.952
E(D)	0.943	1.025	0.372457	36.35%	0.412	1.637	0.539	1.750
D	0.951	1.034	0.375619	36.32%	0.416	1.652	0.544	1.775
prop_T0'	0.662	0.662	0.005698	0.86%	0.653	0.672	0.653	0.672
prop_C0	0.338	0.338	0.005698	1.69%	0.328	0.347	0.328	0.347
E(sar_tot) ⁺⁺	0.0068	0.0069	0.000998	14.57%	0.0052	0.0085	0.0052	0.0085
sar_tot ⁺⁺	0.0068	0.0068	0.000998	14.59%	0.0052	0.0085	0.0052	0.0085

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-60. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2003.

Imnaha River Hatchery Chinook 2003

PIT-tags released= 20,904

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	32	32	5.6305	17.70%	23	41	23	41
adult_C1	11	11	3.2000	29.37%	6	16	6	16
adult_T0	30	30	5.3438	18.00%	21	38	21	39
E(C0)	6,693	6,689	187.5211	2.80%	6,380	6,997	6,377	7,004
C0	6,683	6,680	187.6779	2.81%	6,372	6,989	6,358	6,999
E(C1)	2,903	2,902	65.5469	2.26%	2,794	3,010	2,797	3,011
C1	2,908	2,906	66.0936	2.27%	2,797	3,015	2,801	3,015
E(T0)	5,184	5,184	90.8600	1.75%	5,035	5,334	5,037	5,344
T0	5,189	5,189	90.8744	1.75%	5,039	5,338	5,044	5,345
E(sarC0)	0.0048	0.0048	0.000850	17.87%	0.0034	0.0062	0.0034	0.0062
sarC0	0.0048	0.0048	0.000851	17.87%	0.0034	0.0062	0.0034	0.0062
E(sarC1)	0.0038	0.0038	0.001102	29.35%	0.0019	0.0056	0.0020	0.0055
sarC1	0.0038	0.0038	0.001101	29.35%	0.0019	0.0056	0.0020	0.0055
E(sar ₂ T0)	0.0058	0.0057	0.001027	17.94%	0.0040	0.0074	0.0041	0.0074
sar ₂ T0	0.0058	0.0057	0.001026	17.93%	0.0040	0.0074	0.0041	0.0074
E(TIR)	1.210	1.246	0.344761	27.66%	0.679	1.813	0.788	1.895
TIR	1.207	1.244	0.343487	27.62%	0.678	1.809	0.785	1.887
S _R	0.701	0.706	0.056043	7.94%	0.613	0.798	0.616	0.803
S _T	0.934	0.934	0.011010	1.18%	0.915	0.952	0.915	0.952
E(D)	0.909	0.941	0.267244	28.39%	0.502	1.381	0.581	1.426
D	0.907	0.939	0.266343	28.36%	0.501	1.377	0.579	1.420
prop_T0'	0.550	0.550	0.007043	1.28%	0.538	0.561	0.539	0.562
prop_C0	0.450	0.450	0.007043	1.56%	0.439	0.462	0.438	0.461
E(sar_tot) ⁺⁺	0.0053	0.0053	0.000678	12.82%	0.0042	0.0064	0.0042	0.0064
sar_tot ⁺⁺	0.0053	0.0053	0.000679	12.83%	0.0042	0.0064	0.0042	0.0064

⁺ Adult returns exist for each study category in all bootstrap iterations, so no missing values.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Table E-61. Key parameter initial estimates, bootstrap averages, bootstrap standard deviations (population), coefficient of variations, and both parametric and non-parametric 90% confidence limits for PIT-tagged Imnaha River Hatchery Chinook outmigrating in 2004.

Imnaha River Hatchery Chinook 2004

PIT-tags released= 20,910

Parameter	Initial Estimate	Bootstrap Average	Bootstrap Std-dev.	Coeff. of Variation	Parametric CI		Non-Parametric CI ⁺	
					90% LL	90% UL	90% LL	90% UL
adult_C0	3	3	1.6807	56.34%	0	6	1	6
adult_C1	5	5	2.2219	44.76%	1	9	2	9
adult_T0	24	24	4.9665	20.65%	16	32	16	33
E(C0)	1,304	1,304	44.9018	3.44%	1,230	1,378	1,231	1,378
C0	1,302	1,302	48.5553	3.73%	1,222	1,382	1,221	1,381
E(C1)	4,455	4,450	61.9348	1.39%	4,348	4,552	4,349	4,553
C1	4,456	4,452	62.4591	1.40%	4,349	4,554	4,349	4,554
E(T0)	6,931	6,933	74.0066	1.07%	6,812	7,055	6,810	7,053
T0	6,927	6,930	74.4953	1.07%	6,807	7,052	6,801	7,049
E(sarC0)	0.0023	0.0023	0.001288	56.28%	0.0002	0.0044	0.0007	0.0046
sarC0	0.0023	0.0023	0.001291	56.30%	0.0002	0.0044	0.0007	0.0046
E(sarC1)	0.0011	0.0011	0.000499	44.75%	0.0003	0.0019	0.0004	0.0020
sarC1	0.0011	0.0011	0.000499	44.75%	0.0003	0.0019	0.0004	0.0020
E(sar ₂ T0)	0.0035	0.0035	0.000717	20.67%	0.0023	0.0046	0.0023	0.0047
sar ₂ T0	0.0035	0.0035	0.000718	20.67%	0.0023	0.0047	0.0023	0.0047
E(TIR)	1.505	1.953	1.283317	65.70%	-0.158	4.064	0.483	4.790
TIR	1.504	1.950	1.280693	65.66%	-0.156	4.057	0.484	4.802
S _R	0.370	0.416	0.208045	50.04%	0.073	0.758	0.239	0.709
S _T	0.966	0.966	0.003639	0.38%	0.960	0.972	0.960	0.972
E(D)	0.577	0.831	0.667428	80.29%	-0.267	1.929	0.147	2.187
D	0.576	0.830	0.665188	80.16%	-0.264	1.924	0.151	2.187
prop_T0'	0.888	0.888	0.003758	0.42%	0.882	0.894	0.882	0.895
prop_C0	0.103	0.103	0.003643	3.55%	0.097	0.109	0.097	0.109
E(sar_tot) ⁺⁺	0.0033	0.0033	0.000654	19.66%	0.0023	0.0044	0.0023	0.0045
sar_tot ⁺⁺	0.0033	0.0033	0.000655	19.67%	0.0023	0.0044	0.0023	0.0045

⁺ When bootstrap iterations have no adults occurring for some study categories, a missing value will be computed for some study parameters. These missing values are not included when computing parametric confidence intervals, but are considered as the “smallest” values in the rank order of data when computing non-parametric confidence intervals.

⁺⁺ Overall annual SAR are computed as:

$$\text{sar_tot} = (\text{prT0}') \cdot \text{sar}_2\text{T0} + (\text{prC0}) \cdot \text{sarC0} + (1 - \text{prT0}' - \text{prC0}) \cdot \text{sarC1}$$

$$E(\text{sar_tot}) = (\text{prT0}') \cdot E(\text{sar}_2\text{T0}) + (\text{prC0}) \cdot E(\text{sarC0}) + (1 - \text{prT0}' - \text{prC0}) \cdot E(\text{sarC1})$$

where prT0' and prC0 are estimated proportion of fish in untagged run-at-large represented by this study categories migration experience.

Appendix F

**Cumulative passage distributions (timing plots)
at Lower Granite and Bonneville dams
for PIT-tagged juvenile wild and hatchery
Chinook (1997-2004) and steelhead (1997-2003)**

Notes on Figures:

There are ten figures showing juvenile Chinook and steelhead passage timing at dams in this appendix. Each figure contains multiple timing plots that span the migration years. These timing plot shows the cumulative passage distribution obtained by dividing the daily PIT-tag detections by the proportion of flow passing through the powerhouse [*i.e.*, $PI_adjustment = PH_flow / (Spill + PH_flow)$] at Lower Granite Dam (LGR) (Table F-1) and the combined powerhouses at Bonneville Dam (BON) for in-river migrants (Table F-2). The $PI_adjustment$ accounts for varying levels of spill over the season each year, assuming a spill effectiveness of 1. It does not account for varying levels of FGE over the season.

Figure F-1 shows the passage timing distribution of each CSS PIT-tagged hatchery group at LGR, with a comparison to the PIT-tagged wild Chinook aggregate. Figure F-2 takes the PIT-tagged wild Chinook aggregate and partitions it into timing plots by drainage of origin, such as Clearwater, Grande Ronde, Salmon, and Imnaha. When plotting wild Chinook and steelhead passage timing at LGR by subbasin of origin, all smolts PIT tagged at the Snake River trap are not included, because their subbasin of origin is unknown. Figure F-3 shows the wild steelhead passage timing at LGR by subbasin of origin also. Figure F-4 shows the hatchery steelhead passage timing at LGR by subbasin of origin and run-type, whether A-run or B-run. When plotting hatchery steelhead by subbasin of origin and run-type (A or B), all smolts PIT tagged at the Snake River trap are not included (reason cited above) as well as hatchery steelhead PIT tagged at the Salmon River trap, because at the latter site the juvenile A-run and B-run Salmon River stocks are not distinguishable.

Figures F-5 to F-9 present the passage timing distributions at BON by CSS study categories C_0 (in-river migrants not detected at LGR, LGS, or LMN), C_1 (in-river migrants detected at one or more of LGR, LGS, and LMN) and T_0 (first-time detected fish transported from either LGR, LGS, or LMN). For the in-river migrating juvenile salmonids, the daily detections are $PI_adjusted$ to account for the varying spill levels at BON. The transported juvenile salmonids are assigned an approximate date of BON passage that is 2 days after first detected at the transportation site. Figure F-5 shows the passage timing of PIT-tagged juvenile wild Chinook at BON by study category. Figure F-6 shows the passage timing of PIT-tagged juvenile hatchery Chinook, based upon an aggregate hatchery Chinook group. To create this aggregate hatchery Chinook group, the hatchery-specific daily PI adjusted detections of the four to five CSS hatcheries available for a given year were weighted by the proportion of PIT tag released in the hatchery production (Table F-3). Figure F-7 shows the passage timing at BON of PIT-tagged wild steelhead by study category and figure F-8 does the same for PIT-tagged hatchery steelhead. Figure F-9 shows the hatchery Chinook passage timing at BON for the individual hatcheries used in the CSS by study category.

Figure 10a presents passage timing, distributions (non PI adjusted) at LGR for five Snake River hatchery Chinook populations aggregated over six migration years (2000 – 2005). Figure 10b presents passage timing, distributions at BON for five Snake River hatchery Chinook populations and Carson hatchery aggregated over six migration years (2000 – 2005).

Table F-1. Proportion of flow passing through powerhouse at Lower Granite Dam. Daily PIT-tag detection tallies are divided by this proportion to produce daily PIT-tag passage index values, which in turn are used in the cumulative passage distributions.

date	1997	1998	1999	2000	2001	2002	2003	2004
3/25	0.809	0.897	0.847	1.000	1.000	1.000	1.000	1.000
3/26	0.853	0.917	0.858	1.000	1.000	1.000	1.000	1.000
3/27	0.811	0.838	0.678	1.000	1.000	1.000	1.000	1.000
3/28	0.770	1.000	0.719	1.000	1.000	1.000	1.000	1.000
3/29	0.818	1.000	0.986	1.000	1.000	1.000	1.000	1.000
3/30	0.902	1.000	0.993	0.953	1.000	1.000	1.000	1.000
3/31	0.858	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4/1	0.895	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4/2	0.920	1.000	0.841	1.000	1.000	1.000	1.000	1.000
4/3	1.000	1.000	0.691	0.987	1.000	0.779	0.866	0.882
4/4	1.000	1.000	0.680	1.000	1.000	0.499	0.711	0.590
4/5	1.000	1.000	0.613	0.937	1.000	0.487	0.706	0.563
4/6	1.000	0.881	0.608	0.997	1.000	0.589	0.708	0.554
4/7	1.000	0.574	0.578	0.817	1.000	0.508	0.677	0.612
4/8	1.000	0.538	0.562	0.628	1.000	0.596	0.660	0.707
4/9	1.000	0.525	0.575	0.625	1.000	0.671	0.661	0.552
4/10	0.874	0.529	0.564	0.632	1.000	0.649	0.558	0.620
4/11	0.745	0.584	0.536	0.753	1.000	0.652	0.693	0.618
4/12	0.722	0.566	0.542	0.750	1.000	0.641	0.704	0.600
4/13	0.726	0.733	0.553	0.757	1.000	0.678	0.725	0.660
4/14	0.714	0.896	0.567	0.763	1.000	0.739	0.687	0.684
4/15	0.680	0.896	0.557	0.728	1.000	0.648	0.748	0.711
4/16	0.727	0.892	0.577	0.759	1.000	0.731	0.800	0.673
4/17	0.733	0.891	0.582	0.752	1.000	0.677	0.723	0.639
4/18	0.745	0.887	0.611	0.757	1.000	0.691	0.710	0.627
4/19	0.769	0.885	0.654	0.766	1.000	0.709	0.691	0.604
4/20	0.728	0.896	0.717	0.755	1.000	0.660	0.597	0.588
4/21	0.689	0.852	0.741	0.751	1.000	0.574	0.683	0.573
4/22	0.712	0.892	0.734	0.754	1.000	0.635	0.772	0.555
4/23	0.700	0.908	0.718	0.567	1.000	0.747	0.724	0.889
4/24	0.711	0.778	0.668	0.718	1.000	0.788	0.682	1.000
4/25	0.705	0.673	0.532	0.763	1.000	0.767	0.745	1.000
4/26	0.645	0.714	0.601	0.752	1.000	0.671	0.812	1.000
4/27	0.698	0.793	0.601	0.753	1.000	0.688	0.743	1.000
4/28	0.702	0.811	0.610	0.753	1.000	0.669	0.669	1.000
4/29	0.660	0.798	0.683	0.750	1.000	0.638	0.715	1.000
4/30	0.709	0.734	0.663	0.756	1.000	0.537	0.718	1.000
5/1	0.663	0.661	0.649	0.754	1.000	0.308	0.709	1.000
5/2	0.734	0.693	0.662	0.755	1.000	0.271	0.764	1.000
5/3	0.732	0.760	0.665	0.759	1.000	0.185	0.683	1.000
5/4	0.701	0.737	0.685	0.753	1.000	0.685	0.595	1.000
5/5	0.775	0.750	0.658	0.757	1.000	0.689	0.686	0.953
5/6	0.800	0.739	0.646	0.759	1.000	0.754	0.791	0.969
5/7	0.756	0.752	0.623	0.750	1.000	0.686	0.707	1.000
5/8	0.747	0.747	0.638	0.743	1.000	0.639	0.709	1.000
5/9	0.747	0.735	0.627	0.748	1.000	0.608	0.698	1.000
5/10	0.705	0.744	0.648	0.747	1.000	0.588	0.610	1.000
5/11	0.619	0.763	0.617	0.749	1.000	0.680	0.678	1.000
5/12	0.638	0.760	0.592	0.741	1.000	0.605	0.758	1.000
5/13	0.619	0.766	0.590	0.743	1.000	0.595	0.710	1.000
5/14	0.556	0.750	0.589	0.746	1.000	0.733	0.672	1.000
5/15	0.582	0.744	0.574	0.743	1.000	0.668	0.740	1.000
5/16	0.590	0.763	0.552	0.728	1.000	0.618	0.823	1.000
5/17	0.546	0.768	0.570	0.732	1.000	0.764	0.772	1.000
5/18	0.550	0.713	0.572	0.746	1.000	0.723	0.693	1.000
5/19	0.597	0.759	0.602	0.749	1.000	0.706	0.755	1.000
5/20	0.553	0.742	0.600	0.744	1.000	0.719	0.785	1.000
5/21	0.627	0.739	0.629	0.749	1.000	0.632	0.725	1.000

5/22	0.626	0.706	0.608	0.747	1.000	0.625	0.642	1.000
5/23	0.681	0.603	0.696	0.760	1.000	0.660	0.740	1.000
5/24	0.559	0.602	0.677	0.757	1.000	0.748	0.785	1.000
5/25	0.622	0.645	0.635	0.764	1.000	0.758	0.749	1.000
5/26	0.630	0.586	0.564	0.760	1.000	0.720	0.632	1.000
5/27	0.729	0.486	0.548	0.764	1.000	0.735	0.603	0.952
5/28	0.782	0.493	0.634	0.760	1.000	0.755	0.596	0.755
5/29	0.659	0.539	0.632	0.682	1.000	0.660	0.546	0.702
5/30	0.712	0.530	0.583	0.652	1.000	0.586	0.505	0.727
5/31	0.648	0.611	0.601	0.627	1.000	0.555	0.450	0.764
6/1	0.641	0.631	0.611	0.610	1.000	0.552	0.493	0.806
6/2	0.617	0.665	0.595	0.571	1.000	0.564	0.564	0.889
6/3	0.607	0.614	0.626	0.543	1.000	0.541	0.626	0.811
6/4	0.586	0.694	0.612	0.548	1.000	0.497	0.674	0.785
6/5	0.560	0.608	0.627	0.592	1.000	0.400	0.744	0.825
6/6	0.557	0.618	0.651	0.627	1.000	0.451	0.763	0.810
6/7	0.532	0.557	0.677	0.630	1.000	0.505	0.774	0.803
6/8	0.479	0.657	0.566	0.616	1.000	0.612	0.765	0.906
6/9	0.543	0.688	0.669	0.558	1.000	0.673	0.712	0.942
6/10	0.562	0.591	0.689	0.526	1.000	0.260	0.718	1.000
6/11	0.457	0.711	0.704	0.503	1.000	0.657	0.764	1.000
6/12	0.536	0.699	0.669	0.511	1.000	0.690	0.795	1.000
6/13	0.546	0.665	0.692	0.566	1.000	0.699	0.792	1.000
6/14	0.516	0.688	0.695	0.598	1.000	0.763	0.763	1.000
6/15	0.467	0.763	0.685	0.602	1.000	0.703	0.741	1.000
6/16	0.550	0.782	0.648	0.607	1.000	0.758	0.745	1.000
6/17	0.545	0.762	0.640	0.566	1.000	0.708	0.753	1.000
6/18	0.576	0.720	0.622	0.514	1.000	0.590	0.746	1.000
6/19	0.629	0.708	0.614	0.505	1.000	0.591	0.720	1.000
6/20	0.594	0.726	0.623	0.744	1.000	0.674	0.863	1.000
6/21	0.632	1.000	0.674	1.000	1.000	0.761	1.000	1.000
6/22	0.626	1.000	0.654	1.000	1.000	0.938	1.000	1.000
6/23	0.666	1.000	0.655	1.000	1.000	0.869	1.000	1.000
6/24	0.814	1.000	0.640	1.000	1.000	0.714	1.000	1.000
6/25	0.985	0.936	0.672	1.000	1.000	0.722	1.000	1.000
6/26	0.939	1.000	0.630	1.000	1.000	0.903	1.000	1.000
6/27	0.978	1.000	0.736	1.000	1.000	0.658	1.000	1.000
6/28	0.903	1.000	0.777	1.000	1.000	0.567	1.000	1.000
6/29	0.957	1.000	0.886	1.000	1.000	0.760	1.000	1.000
6/30	1.000	1.000	0.891	1.000	1.000	0.730	1.000	1.000
jul to end	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table F-2. Proportion of flow passing through combined powerhouses at Bonneville Dam. Daily PIT-tag detection tallies are divided by this proportion to produce daily PIT-tag passage index values, which in turn are used in the cumulative passage distributions.

date	1997	1998	1999	2000	2001	2002	2003	2004
3/27	0.609	0.622	0.620	1.000	1.000	1.000	0.991	0.987
3/28	0.528	0.778	0.656	1.000	1.000	1.000	0.991	0.984
3/29	0.528	0.932	0.728	1.000	1.000	1.000	0.991	0.985
3/30	0.548	1.000	0.723	1.000	1.000	1.000	0.989	0.985
3/31	0.608	1.000	0.730	1.000	1.000	1.000	0.990	0.986
4/1	0.635	1.000	0.777	1.000	1.000	1.000	0.988	0.985
4/2	0.603	1.000	0.821	1.000	1.000	1.000	0.990	0.984
4/3	0.692	1.000	0.861	1.000	1.000	1.000	0.989	0.982
4/4	0.655	1.000	0.810	1.000	1.000	1.000	0.990	0.981
4/5	0.715	1.000	0.811	1.000	1.000	1.000	0.989	0.981
4/6	0.837	1.000	0.840	0.919	1.000	1.000	0.990	0.982
4/7	0.853	1.000	0.908	0.807	1.000	1.000	0.989	0.983
4/8	0.827	1.000	0.946	0.822	1.000	1.000	0.989	0.983
4/9	0.809	1.000	1.000	1.000	1.000	1.000	0.989	0.983
4/10	0.813	1.000	1.000	0.893	1.000	0.928	0.990	0.983
4/11	0.814	1.000	1.000	0.776	1.000	0.751	0.989	0.982
4/12	0.839	1.000	1.000	0.900	1.000	0.670	0.989	0.899
4/13	1.000	1.000	0.999	0.829	1.000	0.658	0.988	0.700
4/14	0.933	1.000	0.833	0.761	1.000	0.690	0.634	0.705
4/15	0.902	1.000	0.780	0.772	1.000	0.666	0.528	0.730
4/16	0.823	1.000	0.751	0.747	1.000	0.604	0.357	0.694
4/17	0.797	1.000	0.718	0.782	1.000	0.555	0.286	0.630
4/18	0.761	1.000	0.774	0.731	1.000	0.497	0.398	0.545
4/19	0.676	0.998	0.767	0.654	1.000	0.505	0.319	0.598
4/20	0.670	0.466	0.648	0.667	1.000	0.607	0.482	0.591
4/21	0.641	0.402	0.679	0.685	1.000	0.638	0.491	0.620
4/22	0.506	0.396	0.671	0.547	1.000	0.410	0.365	0.529
4/23	0.463	0.520	0.661	0.618	1.000	0.437	0.412	0.456
4/24	0.448	0.579	0.670	0.633	1.000	0.603	0.561	0.472
4/25	0.463	0.618	0.675	0.617	1.000	0.579	0.519	0.519
4/26	0.474	0.542	0.669	0.683	1.000	0.564	0.619	0.515
4/27	0.477	0.601	0.658	0.709	1.000	0.587	0.549	0.506
4/28	0.484	0.595	0.599	0.675	1.000	0.279	0.385	0.508
4/29	0.459	0.596	0.572	0.600	1.000	0.319	0.389	0.511
4/30	0.450	0.641	0.657	0.561	1.000	0.598	0.452	0.505
5/1	0.447	0.689	0.679	0.597	1.000	0.597	0.484	0.517
5/2	0.450	0.677	0.685	0.642	1.000	0.474	0.590	0.459
5/3	0.472	0.724	0.689	0.672	1.000	0.530	0.600	0.486
5/4	0.478	0.696	0.692	0.677	1.000	0.600	0.521	0.573
5/5	0.500	0.703	0.689	0.730	1.000	0.588	0.491	0.635
5/6	0.533	0.660	0.678	0.728	1.000	0.265	0.625	0.616
5/7	0.522	0.611	0.667	0.708	1.000	0.346	0.634	0.581
5/8	0.520	0.596	0.639	0.672	1.000	0.433	0.546	0.576
5/9	0.521	0.598	0.628	0.705	1.000	0.301	0.589	0.559
5/10	0.539	0.601	0.672	0.662	1.000	0.485	0.305	0.571
5/11	0.544	0.653	0.660	0.705	1.000	0.573	0.280	0.625
5/12	0.452	0.644	0.616	0.708	1.000	0.515	0.546	0.631
5/13	0.414	0.662	0.612	0.673	1.000	0.572	0.530	0.602
5/14	0.418	0.630	0.645	0.645	1.000	0.323	0.430	0.559
5/15	0.452	0.617	0.619	0.677	1.000	0.405	0.426	0.581
5/16	0.477	0.659	0.647	0.651	0.916	0.410	0.426	0.524
5/17	0.441	0.634	0.641	0.659	0.706	0.463	0.378	0.587
5/18	0.435	0.609	0.655	0.687	0.713	0.610	0.596	0.565
5/19	0.430	0.636	0.636	0.670	0.623	0.618	0.601	0.566
5/20	0.389	0.642	0.655	0.592	0.585	0.645	0.303	0.608
5/21	0.405	0.626	0.662	0.640	0.641	0.679	0.387	0.604
5/22	0.422	0.650	0.646	0.642	0.639	0.592	0.614	0.562
5/23	0.411	0.627	0.659	0.713	0.698	0.430	0.632	0.589

5/24	0.369	0.617	0.643	0.710	0.776	0.440	0.482	0.595
5/25	0.422	0.554	0.681	0.712	0.674	0.458	0.450	0.567
5/26	0.447	0.628	0.654	0.626	0.636	0.612	0.648	0.582
5/27	0.471	0.561	0.604	0.608	0.611	0.613	0.665	0.642
5/28	0.457	0.536	0.584	0.615	0.566	0.637	0.607	0.645
5/29	0.432	0.491	0.605	0.598	0.659	0.579	0.625	0.661
5/30	0.473	0.486	0.625	0.641	0.705	0.566	0.585	0.593
5/31	0.453	0.505	0.639	0.656	0.699	0.607	0.591	0.650
6/1	0.447	0.485	0.620	0.699	0.703	0.607	0.622	0.631
6/2	0.416	0.492	0.610	0.616	0.610	0.442	0.662	0.642
6/3	0.381	0.485	0.578	0.542	0.550	0.522	0.533	0.635
6/4	0.371	0.522	0.585	0.478	0.642	0.434	0.518	0.640
6/5	0.363	0.566	0.596	0.545	0.664	0.417	0.692	0.661
6/6	0.366	0.573	0.587	0.644	0.669	0.434	0.688	0.626
6/7	0.364	0.579	0.618	0.635	0.634	0.514	0.511	0.645
6/8	0.353	0.648	0.605	0.594	0.676	0.473	0.541	0.622
6/9	0.353	0.630	0.624	0.559	0.686	0.520	0.673	0.605
6/10	0.378	0.674	0.621	0.580	0.554	0.603	0.686	0.614
6/11	0.311	0.671	0.645	0.545	0.649	0.535	0.540	0.627
6/12	0.349	0.664	0.657	0.560	0.692	0.606	0.521	0.638
6/13	0.365	0.672	0.697	0.616	0.678	0.607	0.653	0.609
6/14	0.355	0.670	0.646	0.657	0.616	0.653	0.665	0.617
6/15	0.330	0.676	0.705	0.630	0.594	0.638	0.391	0.594
6/16	0.360	0.581	0.632	0.589	1.000	0.627	0.360	0.616
6/17	0.356	0.584	0.575	0.417	1.000	0.585	0.662	0.552
6/18	0.360	0.638	0.620	0.407	1.000	0.630	0.650	0.587
6/19	0.402	0.627	0.654	0.431	1.000	0.556	0.440	0.578
6/20	0.402	0.656	0.652	0.492	1.000	0.536	0.253	0.475
6/21	0.409	0.624	0.635	0.530	1.000	0.544	0.509	0.576
6/22	0.396	0.594	0.661	0.607	1.000	0.583	0.512	0.674
6/23	0.430	0.530	0.647	0.594	1.000	0.667	0.213	0.759
6/24	0.488	0.606	0.621	0.535	1.000	0.645	0.229	0.722
6/25	0.519	0.673	0.658	0.557	1.000	0.671	0.303	0.723
6/26	0.571	0.644	0.662	0.529	1.000	0.670	0.409	0.596
6/27	0.517	0.668	0.671	0.466	1.000	0.617	0.587	0.495
6/28	0.538	0.646	0.718	0.416	1.000	0.534	0.512	0.660
6/29	0.585	0.628	0.714	0.481	1.000	0.522	0.525	0.720
6/30	0.666	0.612	0.685	0.450	1.000	0.632	0.482	0.622
jul to end	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table F-3. Proportion of Chinook hatchery production PIT tagged for the CSS in 1997 to 2004.

Hatchery	Migration Year	Number of PIT tags	Production Numbers	Proportion of PIT tags in production
RAPH	1997	40,451	85,838	0.4712
RAPH	1998	48,336	896,170	0.0539
RAPH	1999	47,812	2,847,283	0.0168
RAPH	2000	47,747	2,462,354	0.0194
RAPH	2001	55,085	736,601	0.0748
RAPH	2002	54,908	2,669,476	0.0206
RAPH	2003	54,763	2,330,557	0.0235
RAPH	2004	51,969	2,762,058	0.0188
DWOR	1997	14,080	53,078	0.2653
DWOR	1998	47,703	973,400	0.0490
DWOR	1999	47,845	1,044,511	0.0458
DWOR	2000	47,743	1,017,873	0.0469
DWOR	2001	55,139	333,120	0.1655
DWOR	2002	54,725	1,000,561	0.0547
DWOR	2003	54,708	1,033,982	0.0529
DWOR	2004	51,616	1,078,923	0.0478
MCCA	1997	52,652	238,647	0.2206
MCCA	1998	47,340	393,872	0.1202
MCCA	1999	47,985	1,143,083	0.0420
MCCA	2000	47,705	1,039,930	0.0459
MCCA	2001	55,124	1,076,846	0.0512
MCCA	2002	54,734	1,022,550	0.0535
MCCA	2003	74,317	1,053,660	0.0705
MCCA	2004	71,363	1,088,810	0.0655
IMNH	1997	13,378	50,911	0.2628
IMNH	1998	19,825	93,108	0.2129
IMNH	1999	19,939	184,725	0.1079
IMNH	2000	20,819	179,797	0.1158
IMNH	2001	20,922	123,014	0.1701
IMNH	2002	20,920	303,737	0.0689
IMNH	2003	20,904	268,426	0.0779
IMNH	2004	20,910	398,469	0.0525
CATH	2001	20,915	136,833	0.1529
CATH	2002	20,796	180,343	0.1153
CATH	2003	20,628	105,292	0.1959
CATH	2004	20,994	162,614	0.1291

Table F-4. Hatchery Chinook PIT-tagged and released in Snake River basin specifically for CSS, 1997-2004.

Hatchery	Migration Year	Hatchery Release	Median		When Tagged (months prior)	PIT Tags Released	PIT Tag Proportion
			Fish/lb	Length at Tagging (mm)			
RAPH	1997	85,838	20.5	100	5	40,452	0.4713
DWOR	1997	53,078	12.7	118	1.5	14,080	0.2653
MCCA	1997	238,647	17.1	128	1.5	52,652	0.2206
IMNA	1997	50,911	17	122	1.5	13,378	0.2628
RAPH	1998	896,170	20.3	117	1.5	48,336	0.0539
DWOR	1998	973,400	20.9	121	1.5	47,703	0.049
MCCA	1998	393,872	17.5	126	1.5	47,340	0.1202
IMNA	1998	93,108	21.1	122	1.5	19,825	0.2129
RAPH	1999	2,847,283	17.9	120	1.5	47,812	0.0168
DWOR	1999	1,044,511	21	116	1.5	47,845	0.0458
MCCA	1999	1,143,083	23.9	117	1.5	47,985	0.042
IMNA	1999	184,725	18.5	117	5	19,939	0.1079
RAPH	2000	2,462,354	19.2	119	1.5	47,747	0.0194
DWOR	2000	1,017,873	24	112	1.5	47,743	0.0469
MCCA	2000	1,039,930	23.3	117	1.5	47,705	0.0459
IMNA	2000	179,797	19.1	113	5	20,819	0.1158
RAPH	2001	736,601	18.8	118	1.5	55,085	0.0748
DWOR	2001	333,120	19.7	121	1.5	55,139	0.1655
CATH	2001	136,833	19.7	117	5	20,915	0.1529
MCCA	2001	1,076,846	19.4	129	1.5	55,124	0.0512
IMNA	2001	123,014	16	121	5	20,922	0.1701
RAPH	2002	2,669,476	19.8	122	1.5	54,908	0.0206
DWOR	2002	1,000,561	20.1	119	1.5	54,725	0.0547
CATH	2002	180,343	18.6	115	5	20,796	0.1153
MCCA	2002	1,022,550	23	122	1.5	54,734	0.0535
IMNA	2002	303,737	14.1	121	5	20,920	0.0689
RAPH	2003	2,330,557	18.8	119	1.5	54,763	0.0235
DWOR	2003	1,033,982	21.4	120	1.5	54,708	0.0529
CATH	2003	105,292	12.8	123	5	20,628	0.1959
MCCA	2003	1,053,660	21.1	121	1.5	74,317	0.0705
IMNA	2003	268,426	16.3	123	5	20,904	0.0779
RAPH	2004	2,762,058	24.5			51,969	0.0188
DWOR	2004	1,078,923	20.2	113	1.5	51,616	0.0478
CATH	2004	162,614	23.2	109	5	20,994	0.1291
MCCA	2004	1,088,810	20.9			71,363	0.0655
IMNA	2004	398,469	26.1	98	5	20,910	0.0525

Table F-5. Carson NFH Chinook PIT-tagged and released in lower Columbia River basin specifically for CSS, 1997-2004.

Migration Year	Dates of Release	# Release from Hatchery	Median Fork		# of PIT Tags Released	% PIT Tags in Hatchery Release
			#Fish/Lb	Length ¹ at Tagging (mm)		
1997	17-Apr	907,708	15.5	119	4,983	0.55
1998	20-Apr	1,734,188	16.6	115	7,491	0.43
1999	20-Apr	1,415,744	12.6	120	12,977	0.92
2000	20-Apr	1,430,022	15.6	116	14,992	1.05
2001	19-Apr	1,608,684	14.9	108	14,978	0.93
2002	16-Apr	1,449,361	15.6	116	14,983	1.03
2003	16-Apr	1,673,255	17.1	111	14,983	0.9
2004	14-Apr	1,417,986	17.3	111	14,973	1.06

¹ Fork length taken at time of tagging in January approximately 3 months before release.

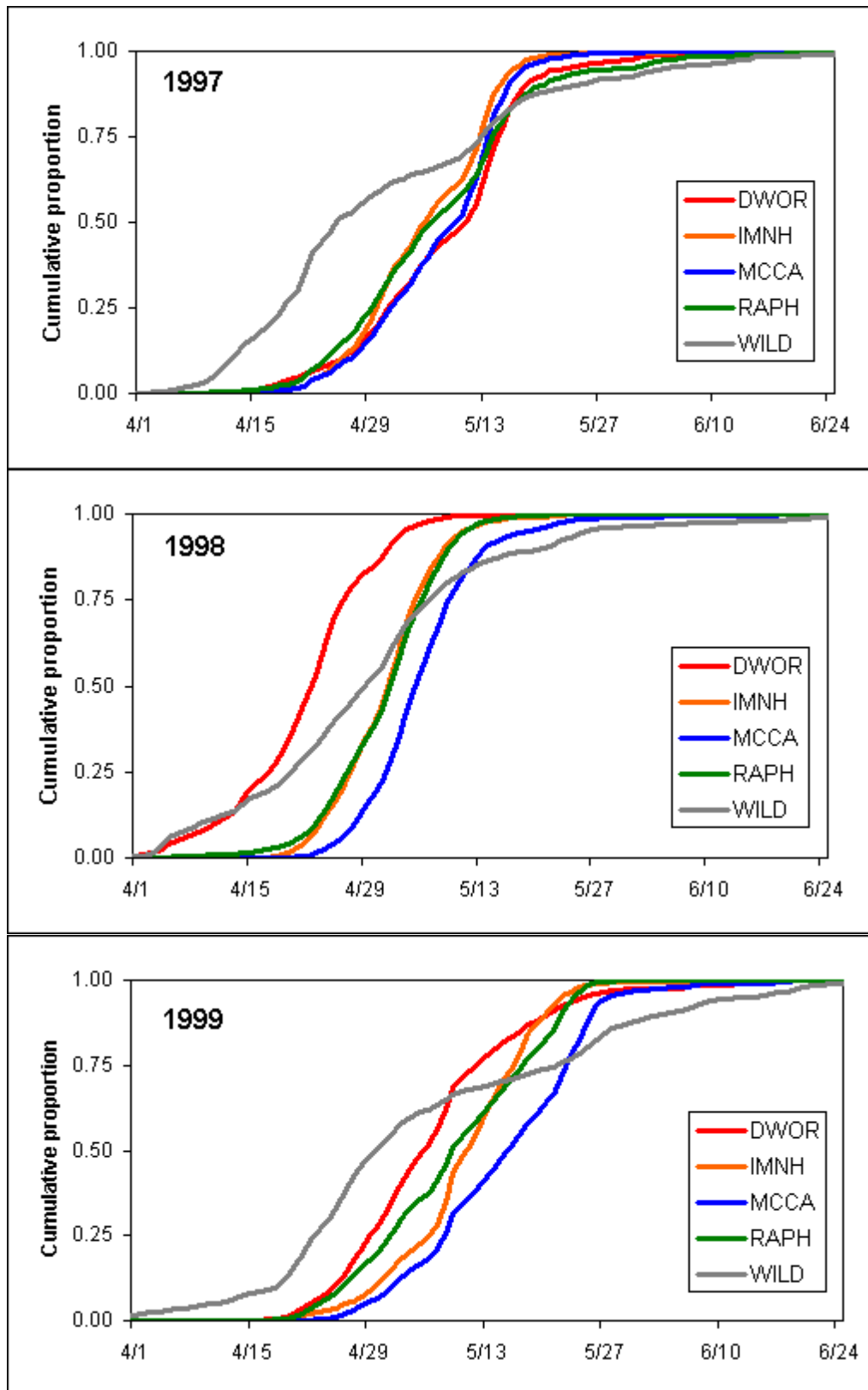


Figure F-1a. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) and aggregate wild Chinook (WILD), 1997 to 1999.

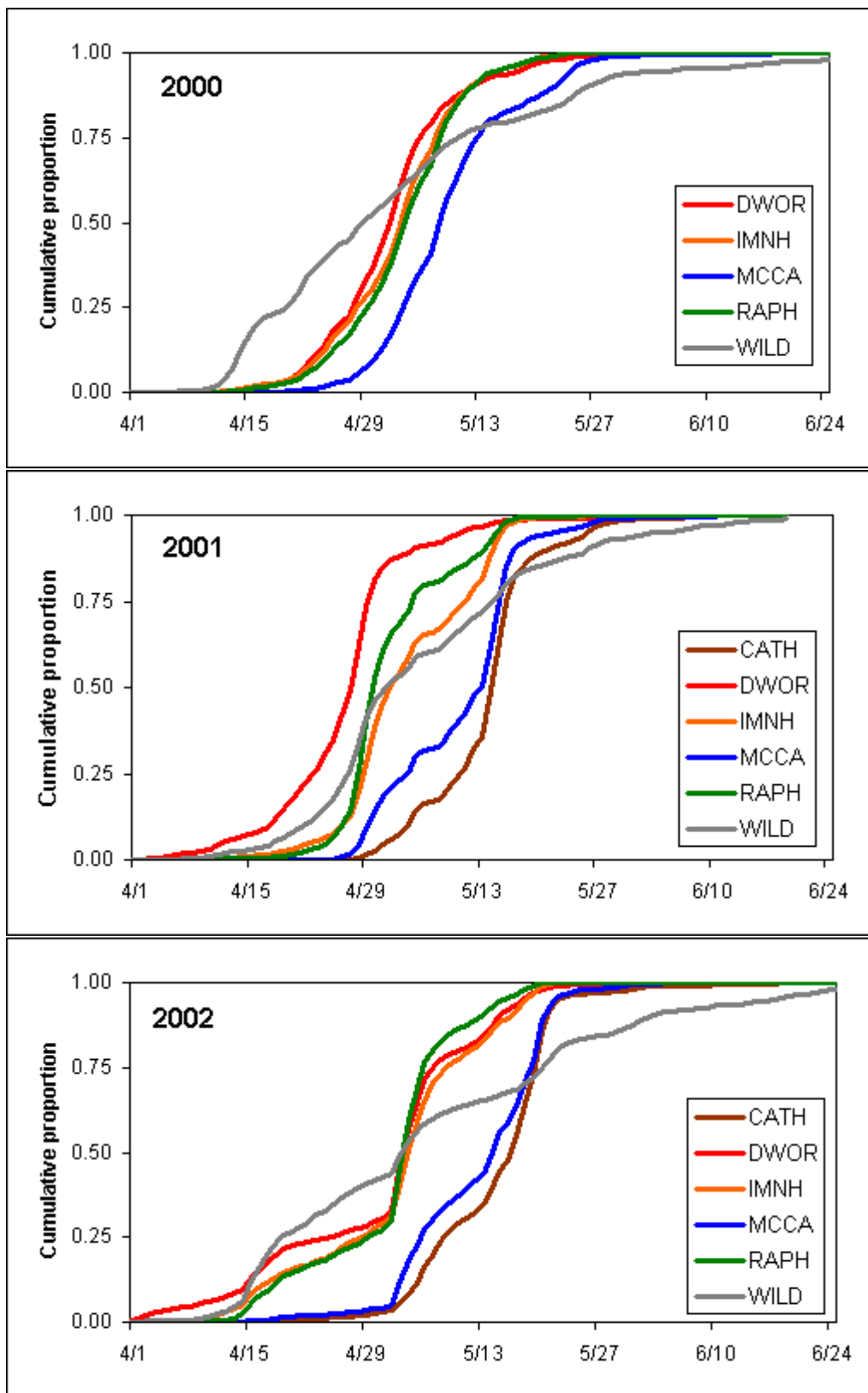


Figure F-1b. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River; CATH= Catherine Ck) and aggregate wild Chinook (WILD), 2000 to 2002.

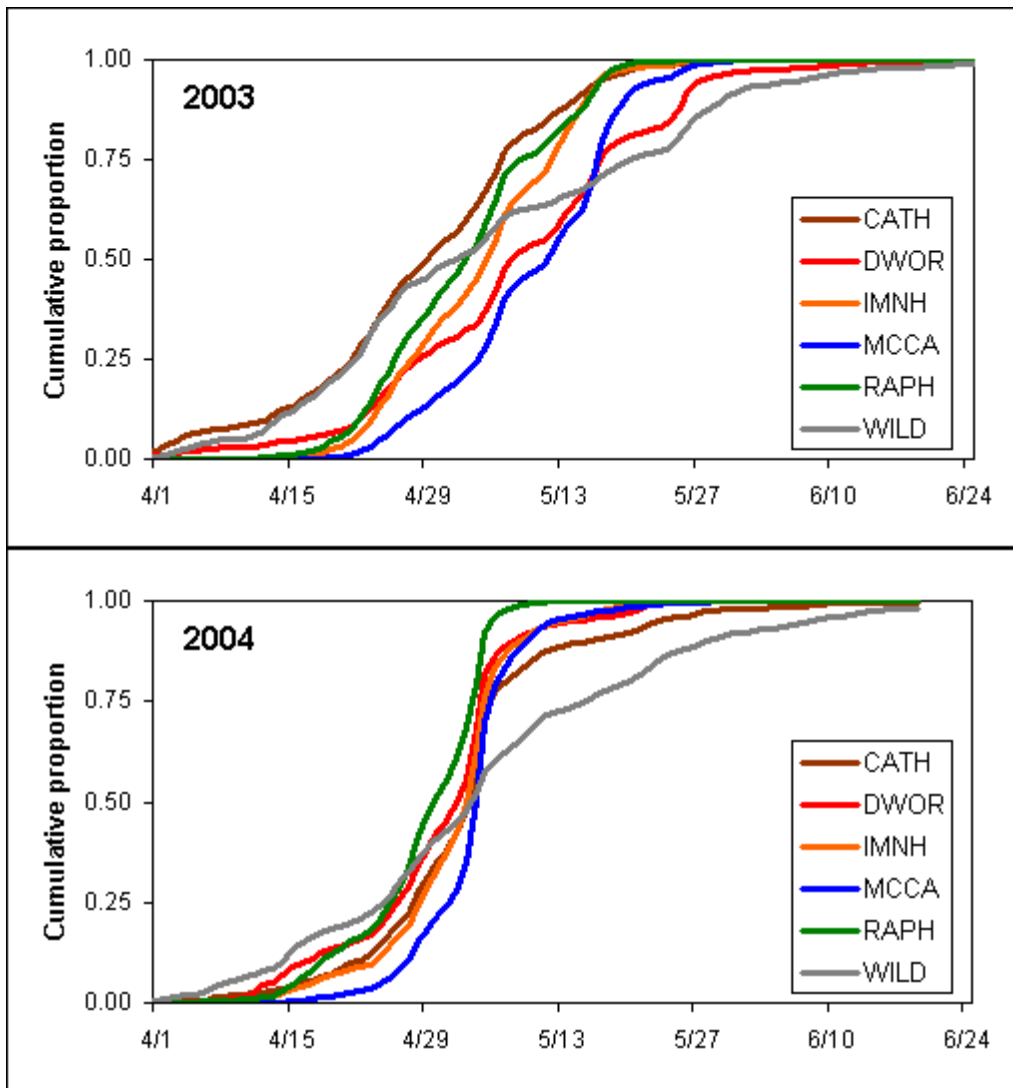


Figure F-1c. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River; CATH= Catherine CkP) and aggregate wild Chinook, 2003 to 2004.

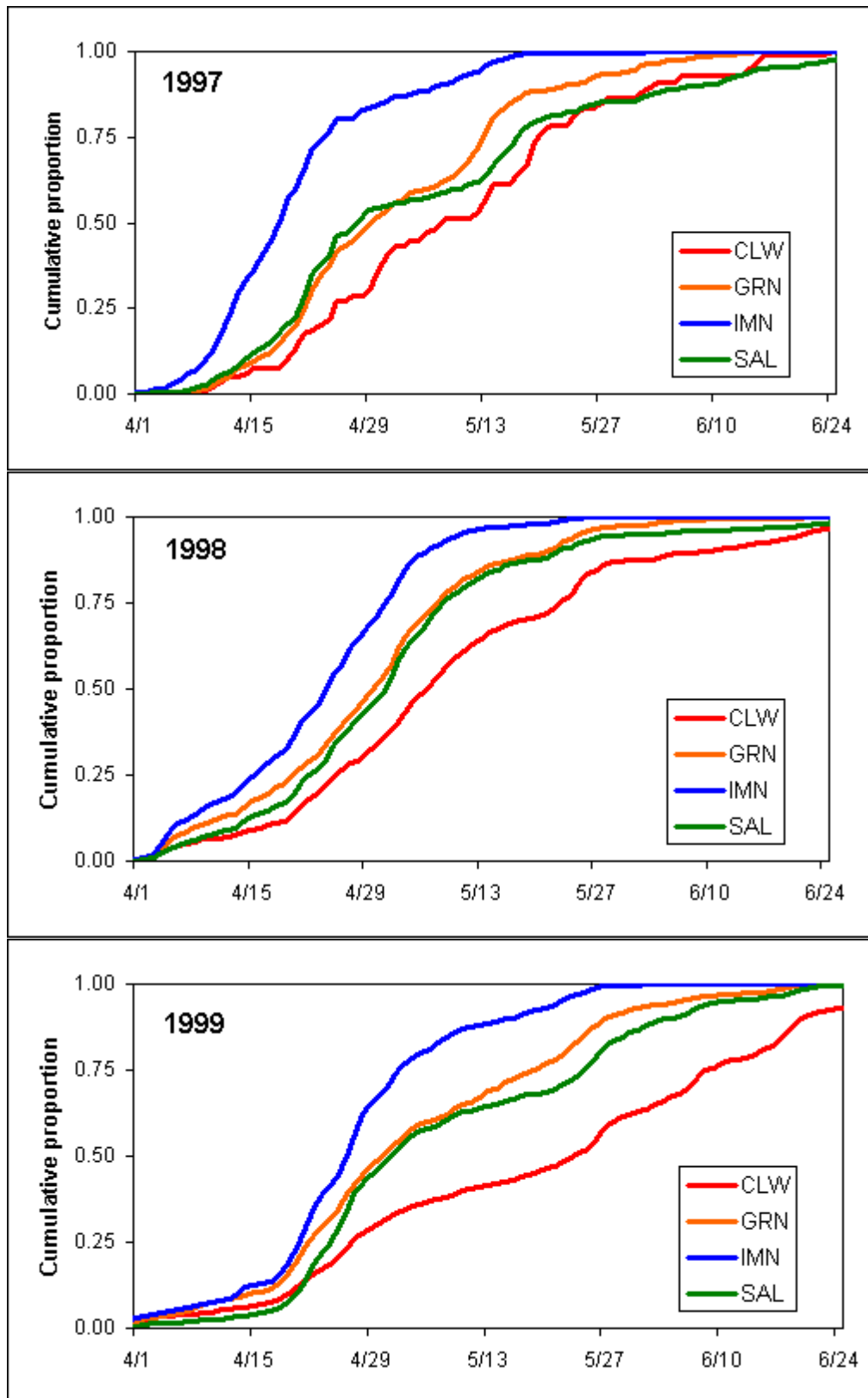


Figure F-2a. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild Chinook by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon), 1997 to 1999.

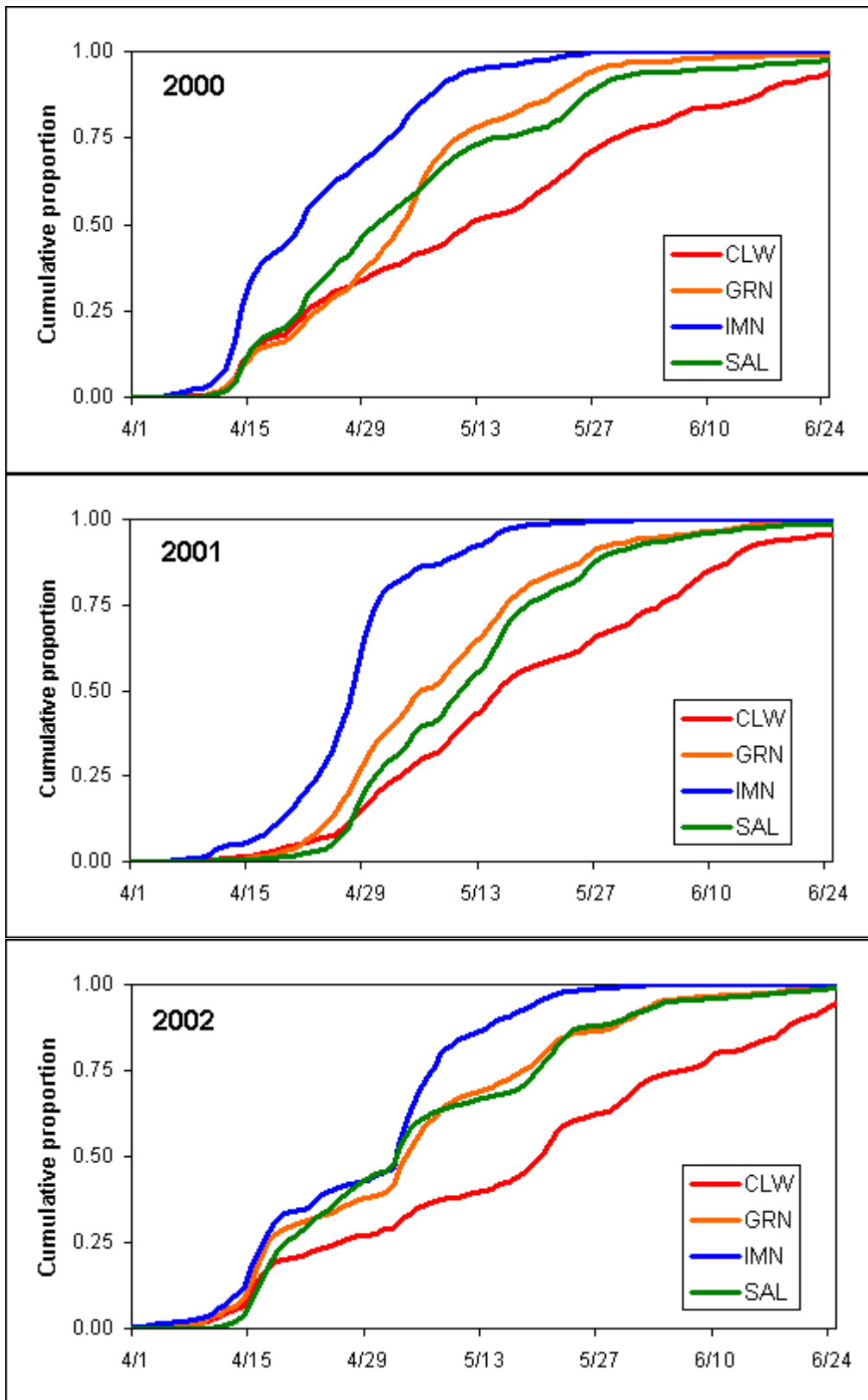


Figure F-2b. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild Chinook by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon), 2000 to 2002.

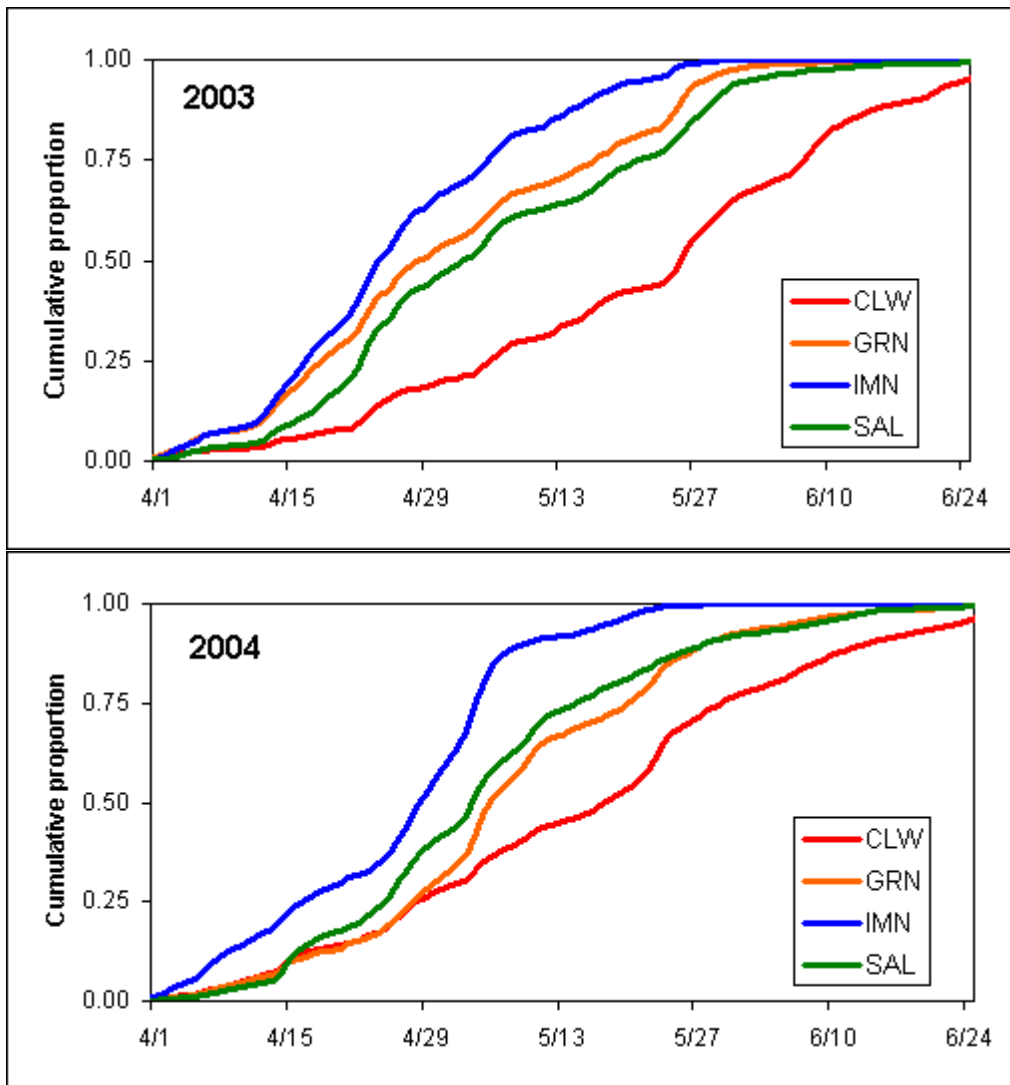


Figure F-2c. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild Chinook by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon), 2003 to 2004.

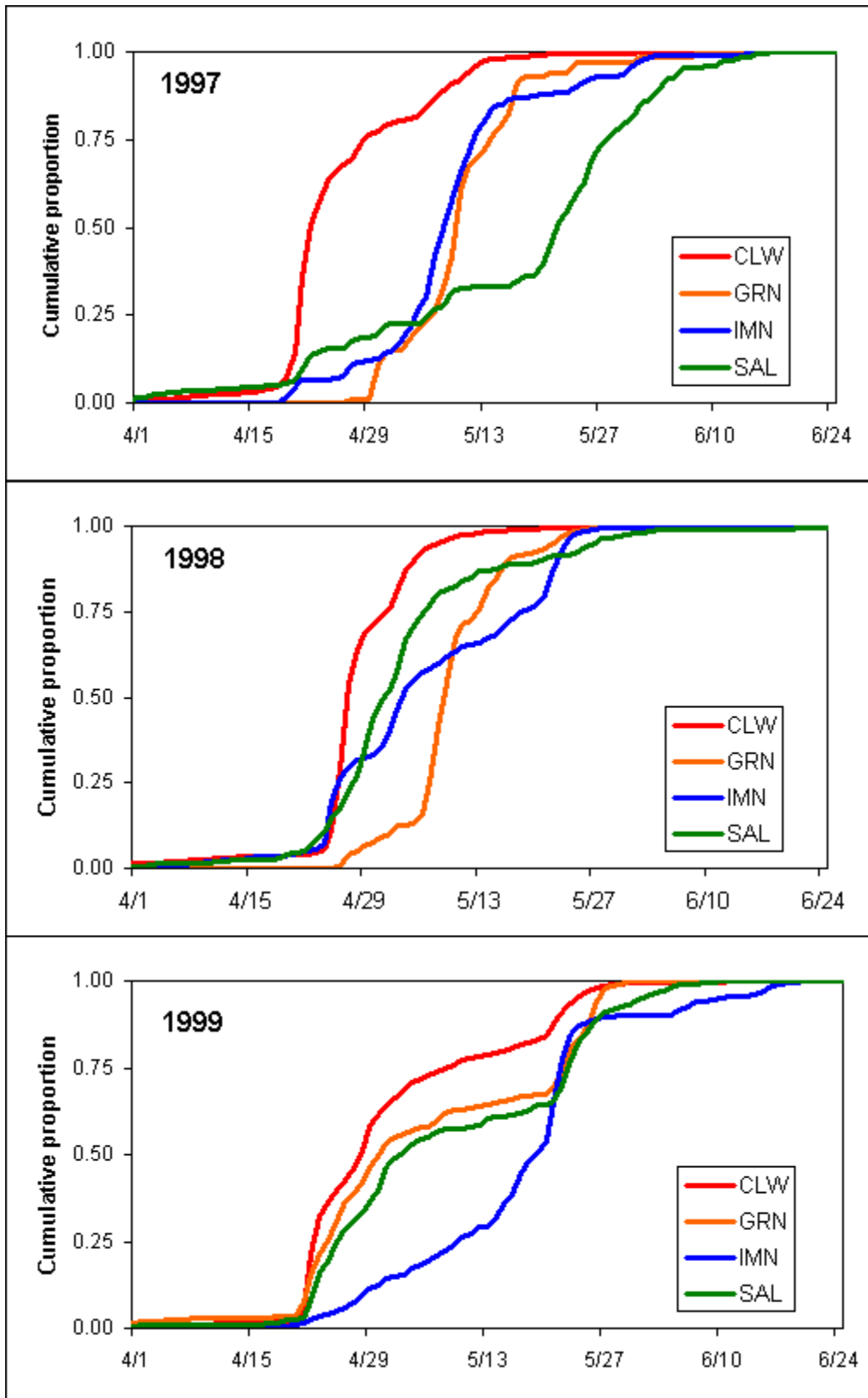


Figure F-3a. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild steelhead by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon), 1997 to 1999.

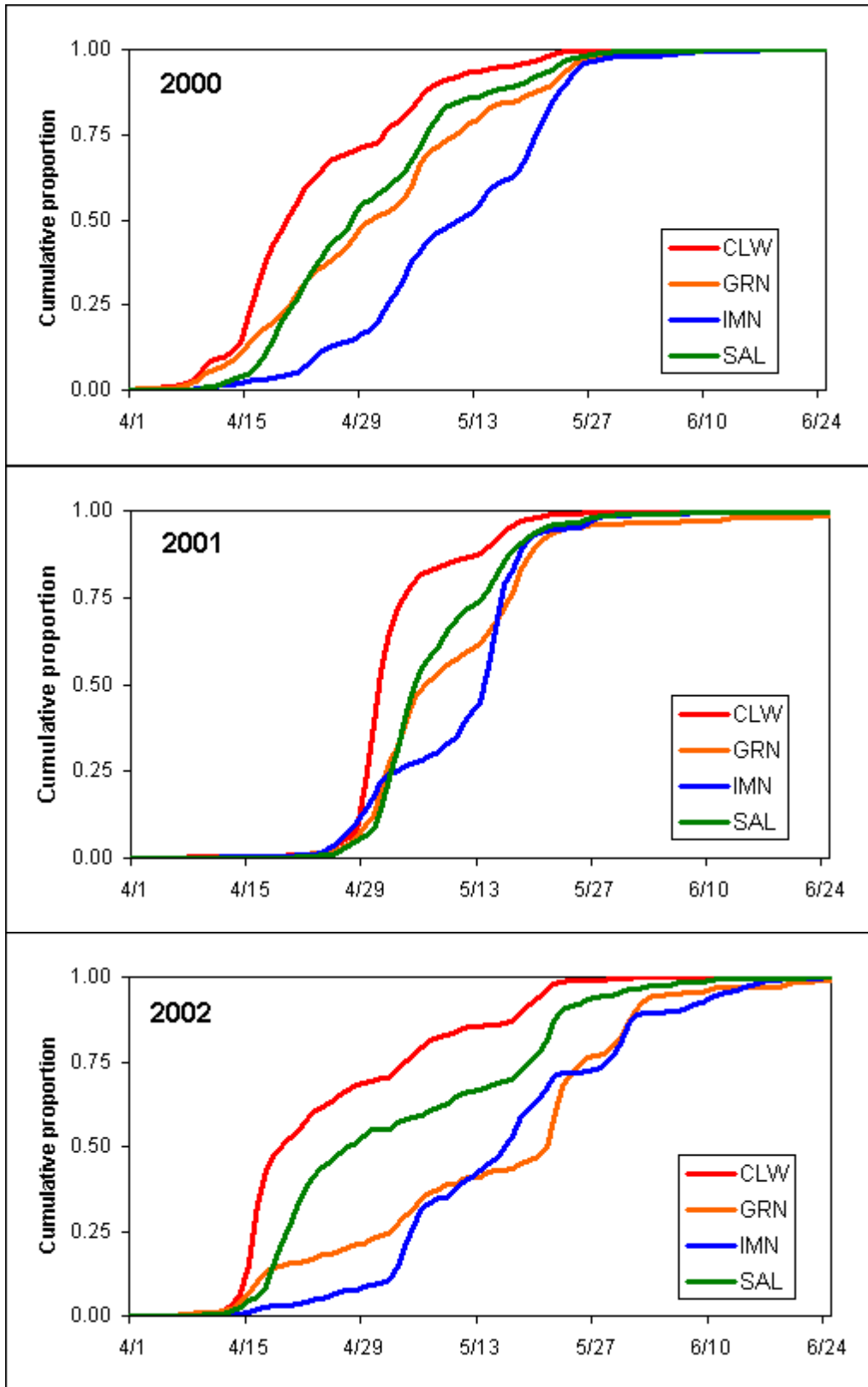


Figure F-3b. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild steelhead by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon), 2000 to 2002.

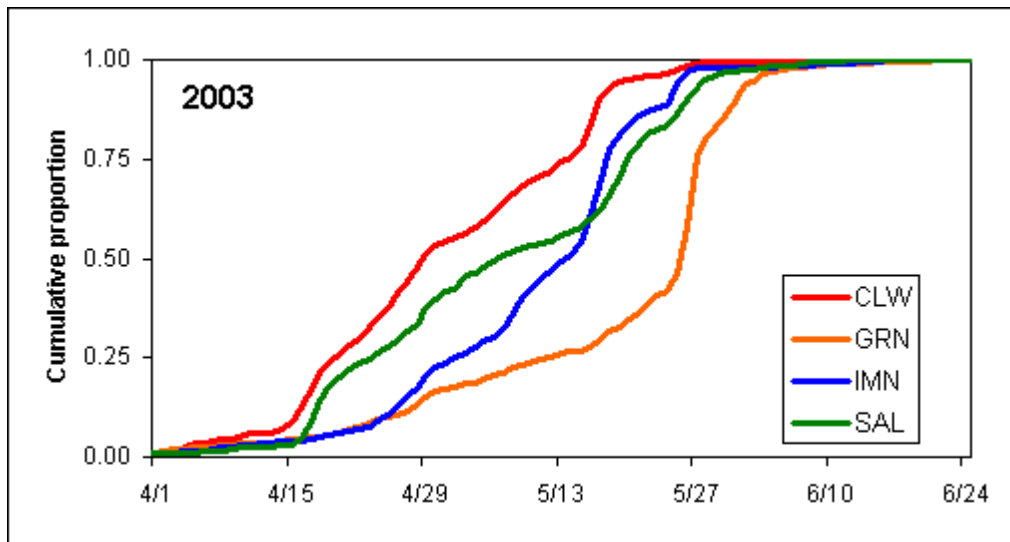


Figure F-3c. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged wild steelhead by drainage of origin (CLW= Clearwater; GRN= Grande Ronde; IMN= Imnaha; SAL= Salmon) in 2003.

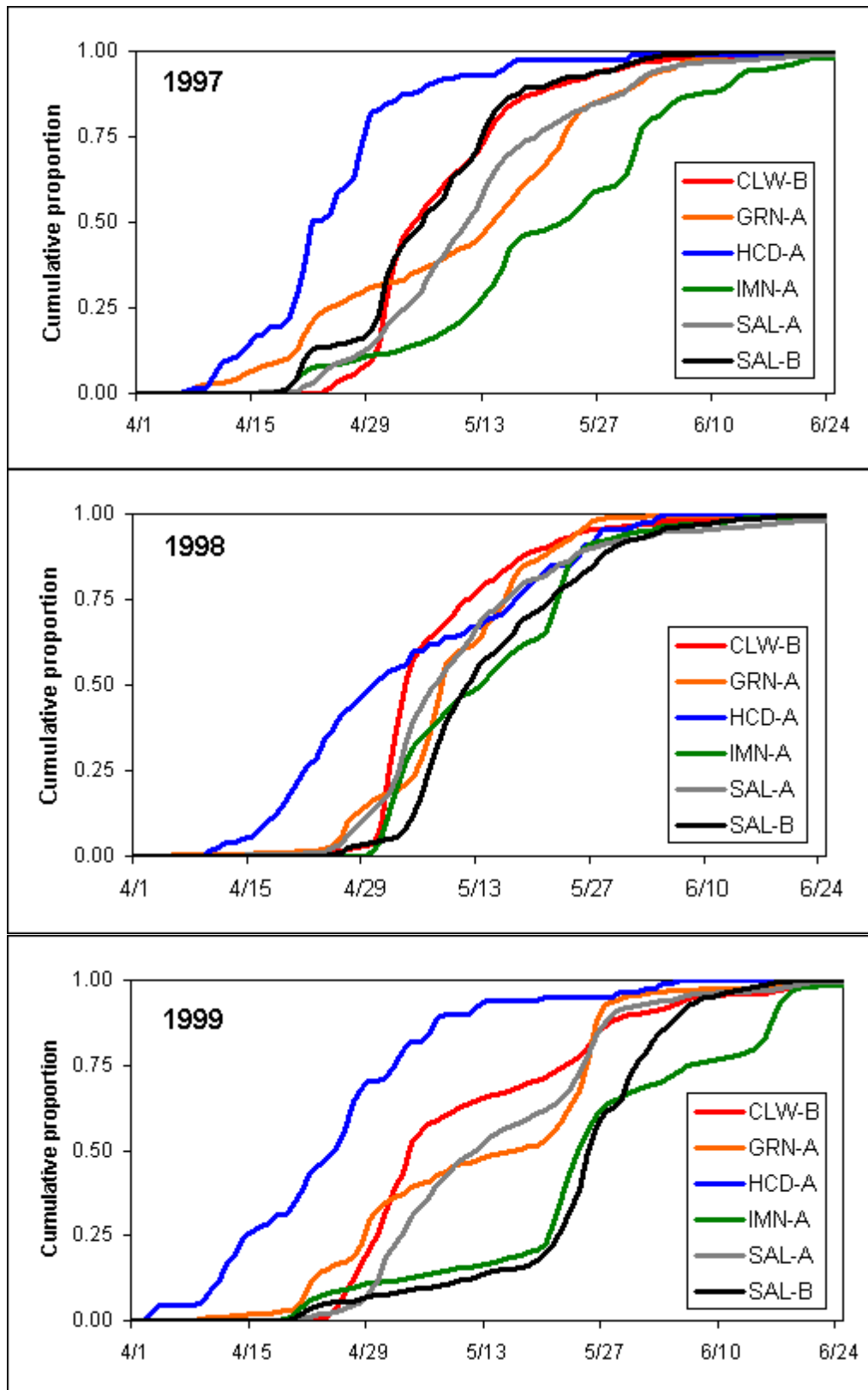


Figure F-4a. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged hatchery steelhead by drainage of origin and run type (CLW= Clearwater; GRN= Grande Ronde; HCD= below Hells Canyon Dam; IMN= Imnaha; SAL= Salmon; A-run & B-run), 1997 to 1999.

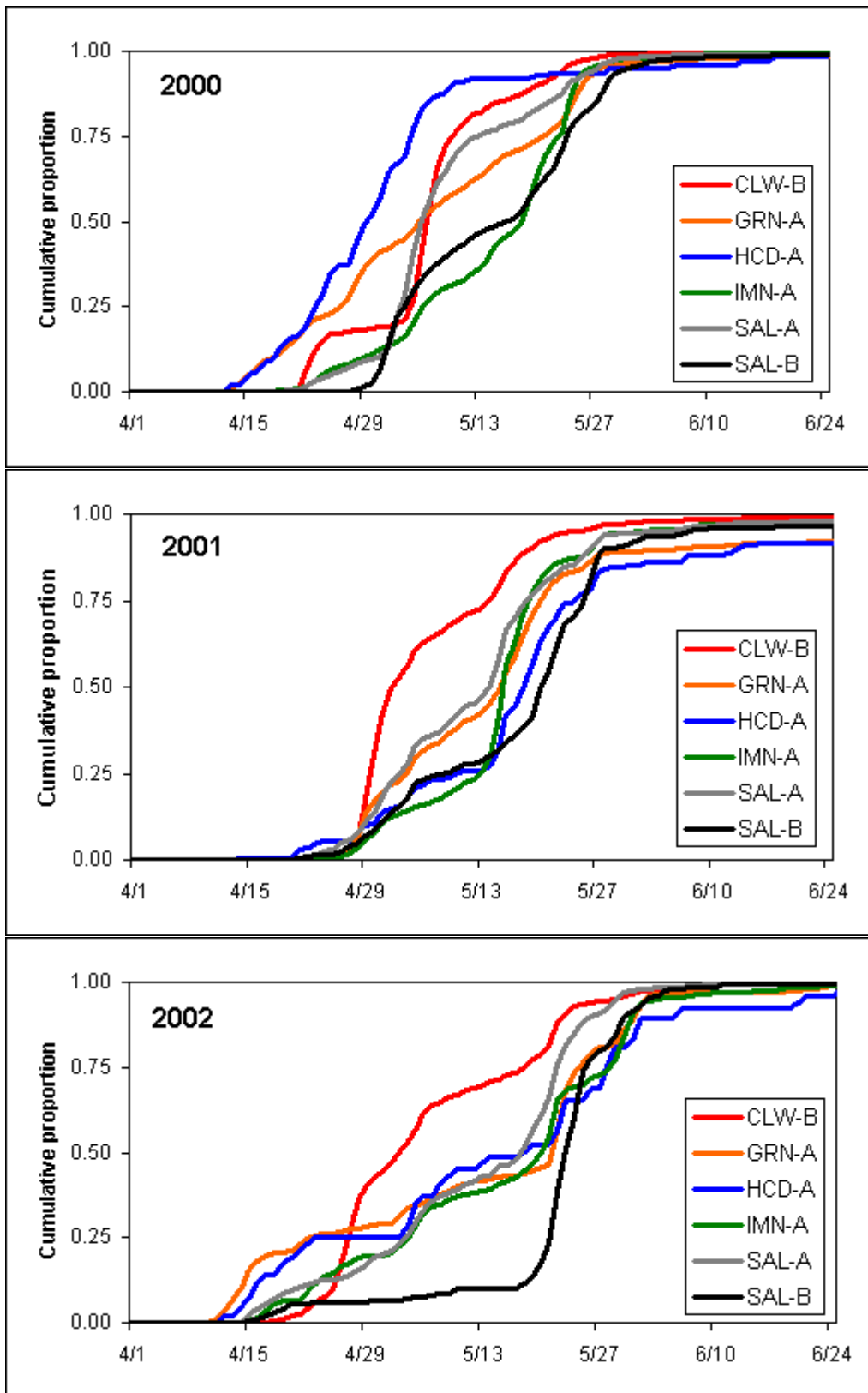


Figure F-4b. Passage timing at Lower Granite Dam of Snake River basin PIT-tagged hatchery steelhead by drainage of origin and run type (CLW= Clearwater; GRN= Grande Ronde; HCD= below Hells Canyon Dam; IMN= Imnaha; SAL= Salmon; A-run & B-run), 2000 to 2002.

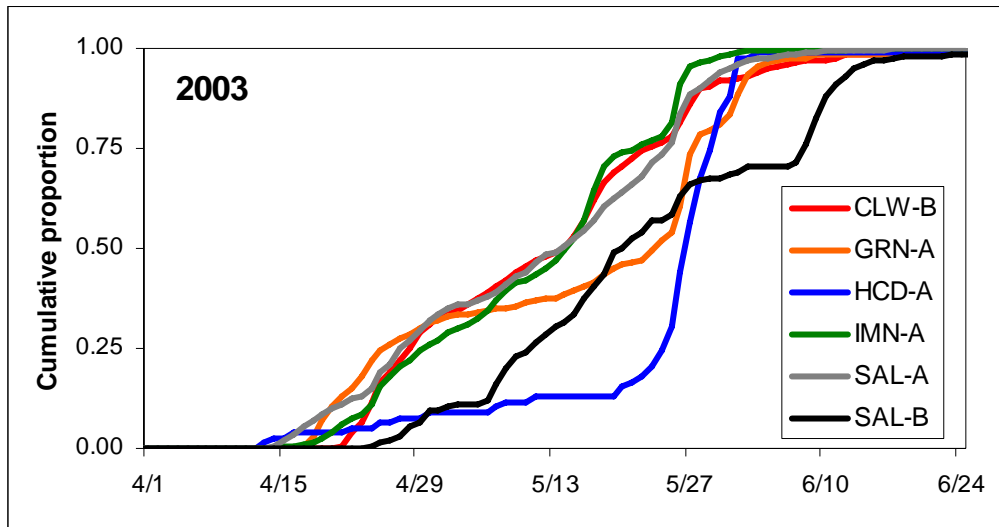


Figure F-4c. Passage timing at Lower Granite Dam of Snake River basin PIT tagged hatchery steelhead by drainage of origin and run type (CLW= Clearwater; GRN= Grande Ronde; HCD= below Hells Canyon Dam; IMN= Imnaha; SAL= Salmon; A-run & B-run) in 2003.

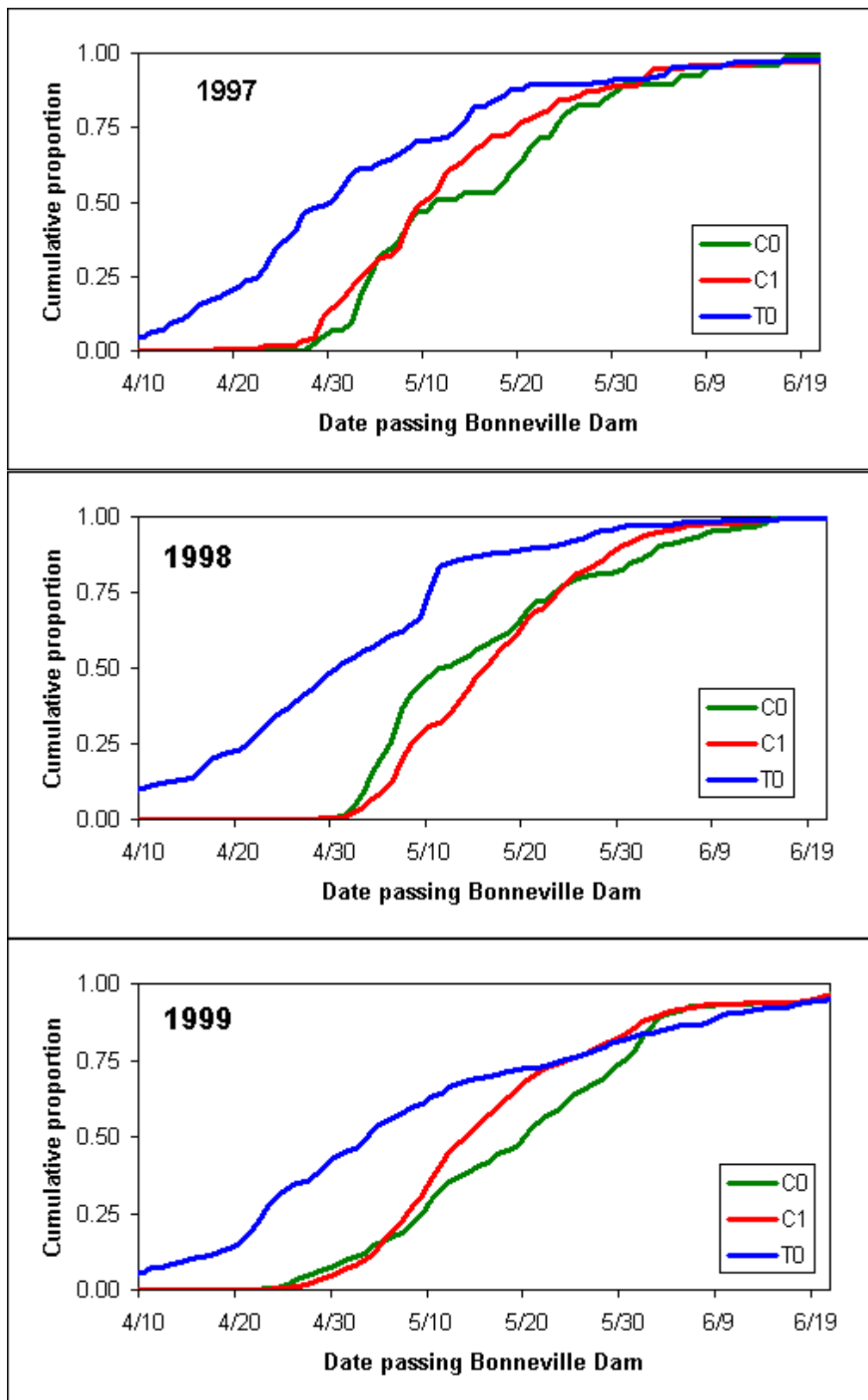


Figure F-5a. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild Chinook by CSS study group (C₀, C₁, and T₀), 1997 to 1999.

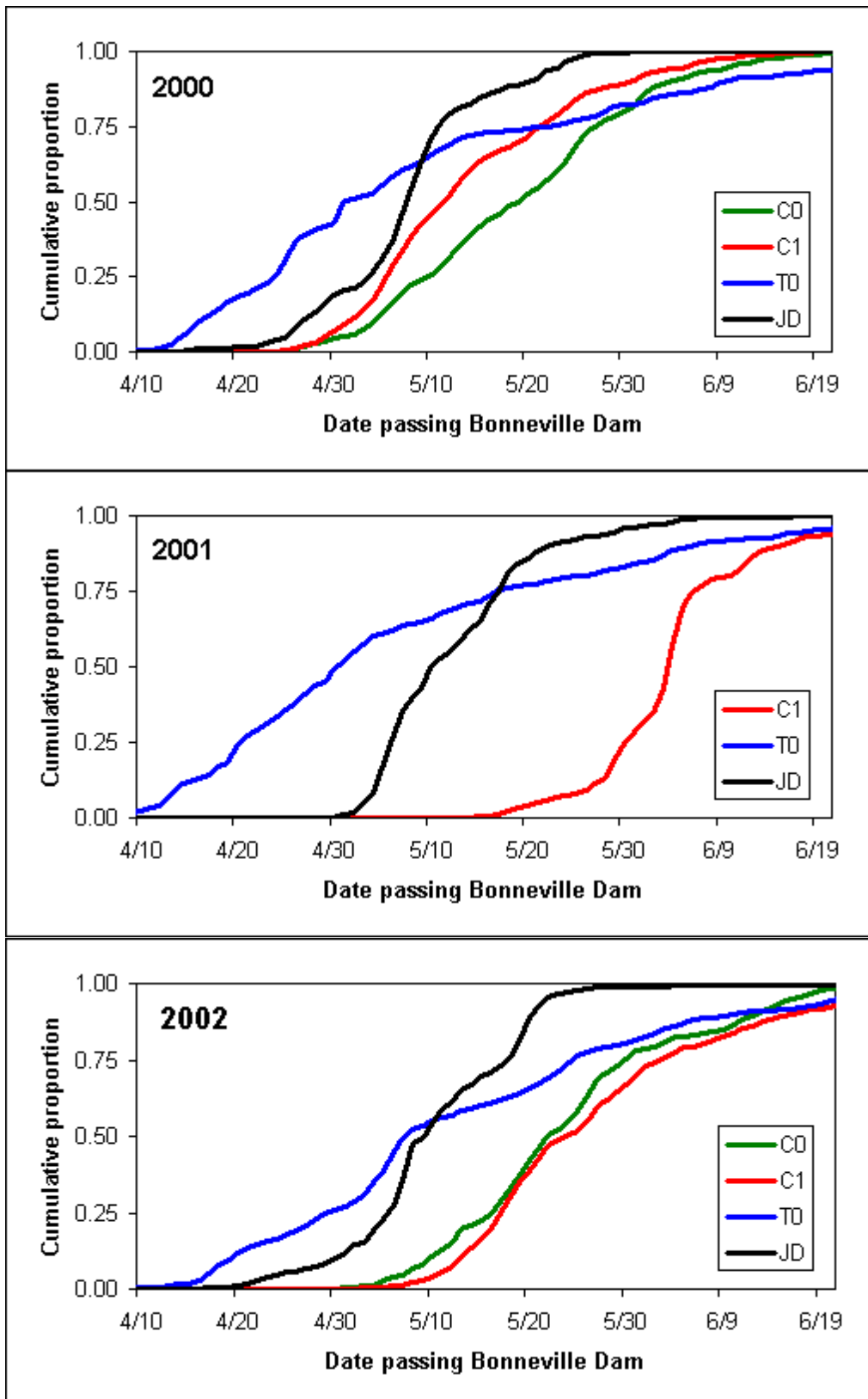


Figure F-5b. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild Chinook by CSS study group (C_0 , C_1 , and T_0), with comparison to the CSS downriver stock (JD = John Day River basin), 2000 to 2002.

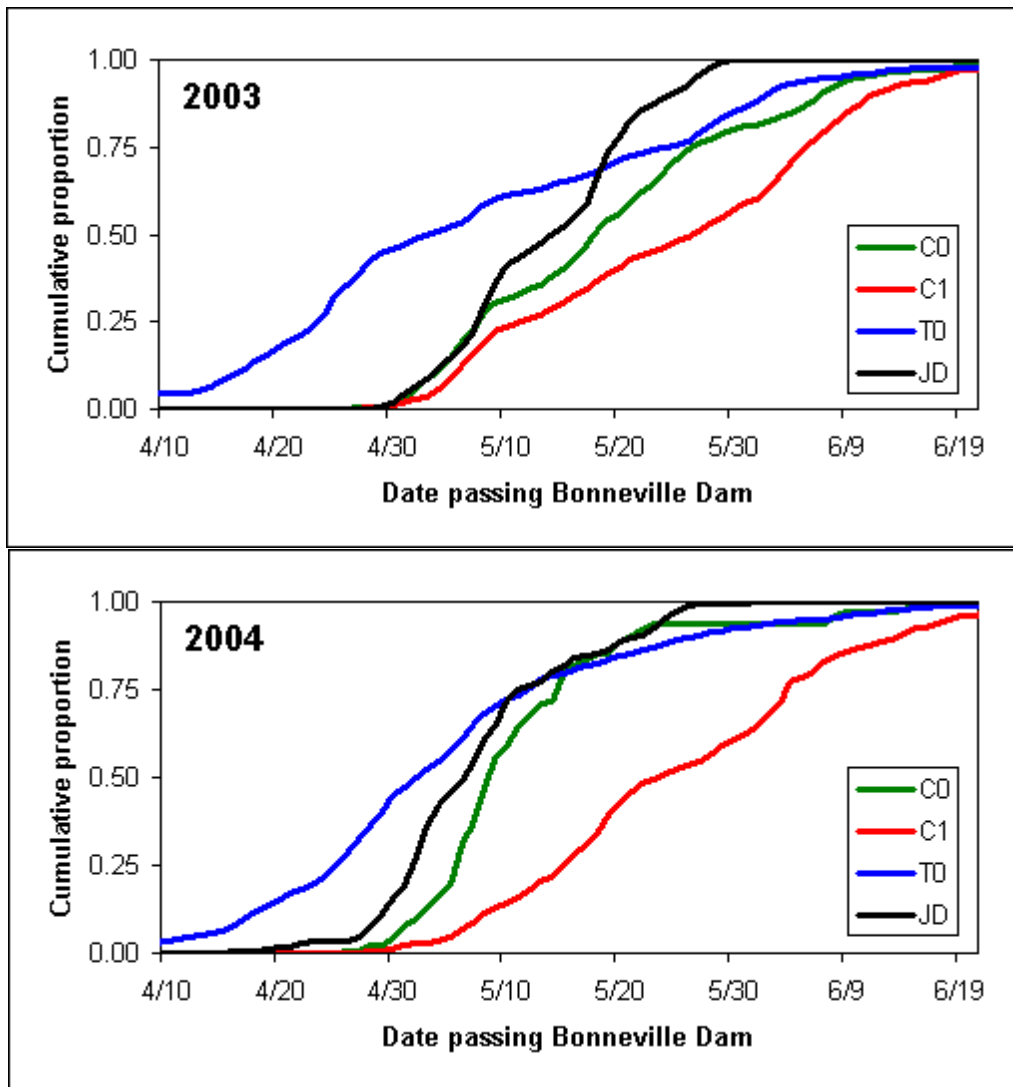


Figure F-5c. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild Chinook by CSS study group (C₀, C₁, and T₀), with comparison to the CSS downriver stock (JD = John Day River basin), 2003 to 2004.

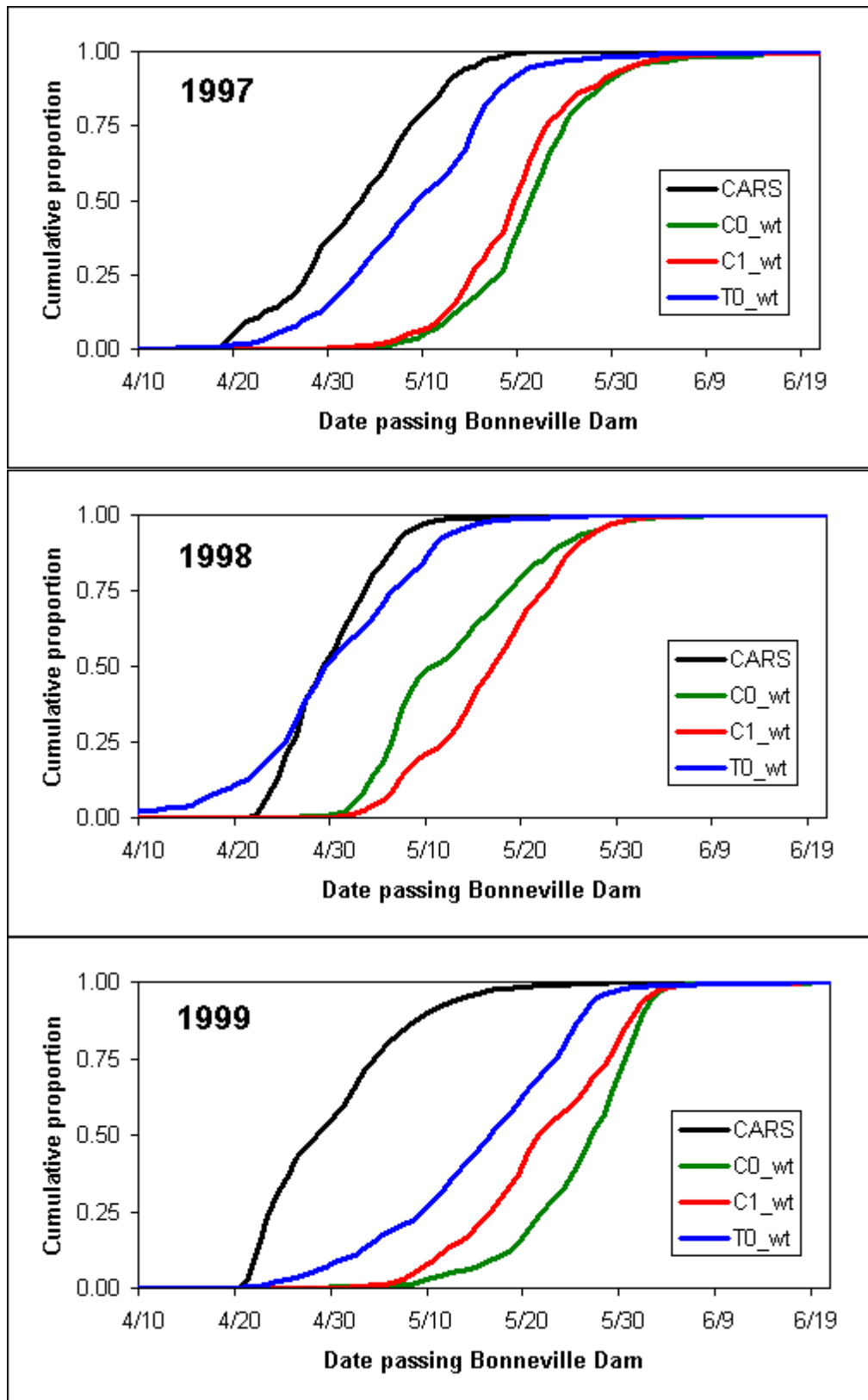


Figure F-6a. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook aggregate (detections weighted by proportion of tags in hatchery production) in each CSS study group (T_0 , C_0 , C_1), with comparison to the CSS downriver stock (CARS=Carson), 1997 to 1999.

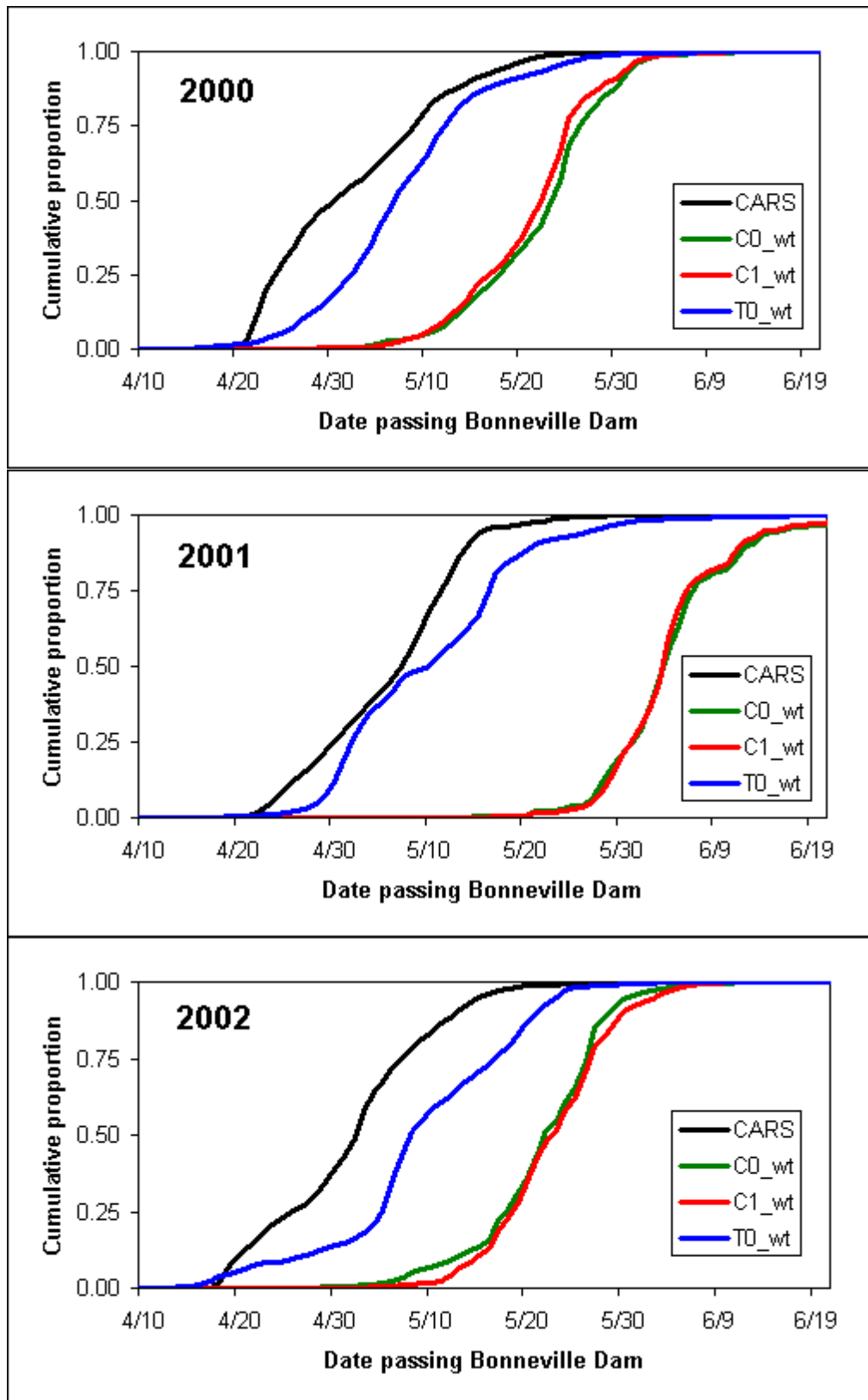


Figure F-6b. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook aggregate (detections weighted by proportion of tags in hatchery production) in each CSS study group (T_0 , C_0 , C_1), with comparison to the CSS downriver stock (CARS=Carson), 2000 to 2002.

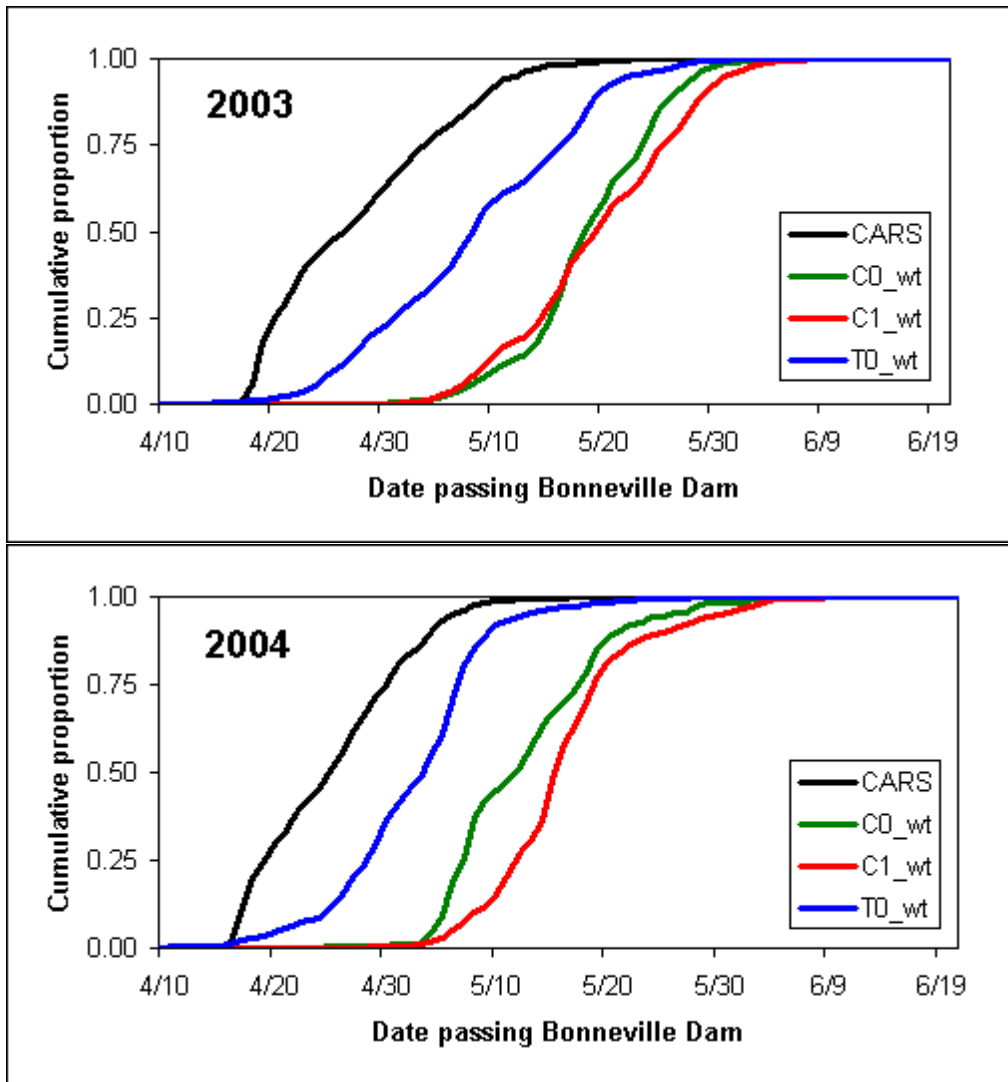


Figure F-6c. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook aggregate (detections weighted by proportion of tags in hatchery production) in each CSS study group (T_0 , C_0 , C_1), with comparison to the CSS downriver stock (CARS= Carson), 2003 to 2004.

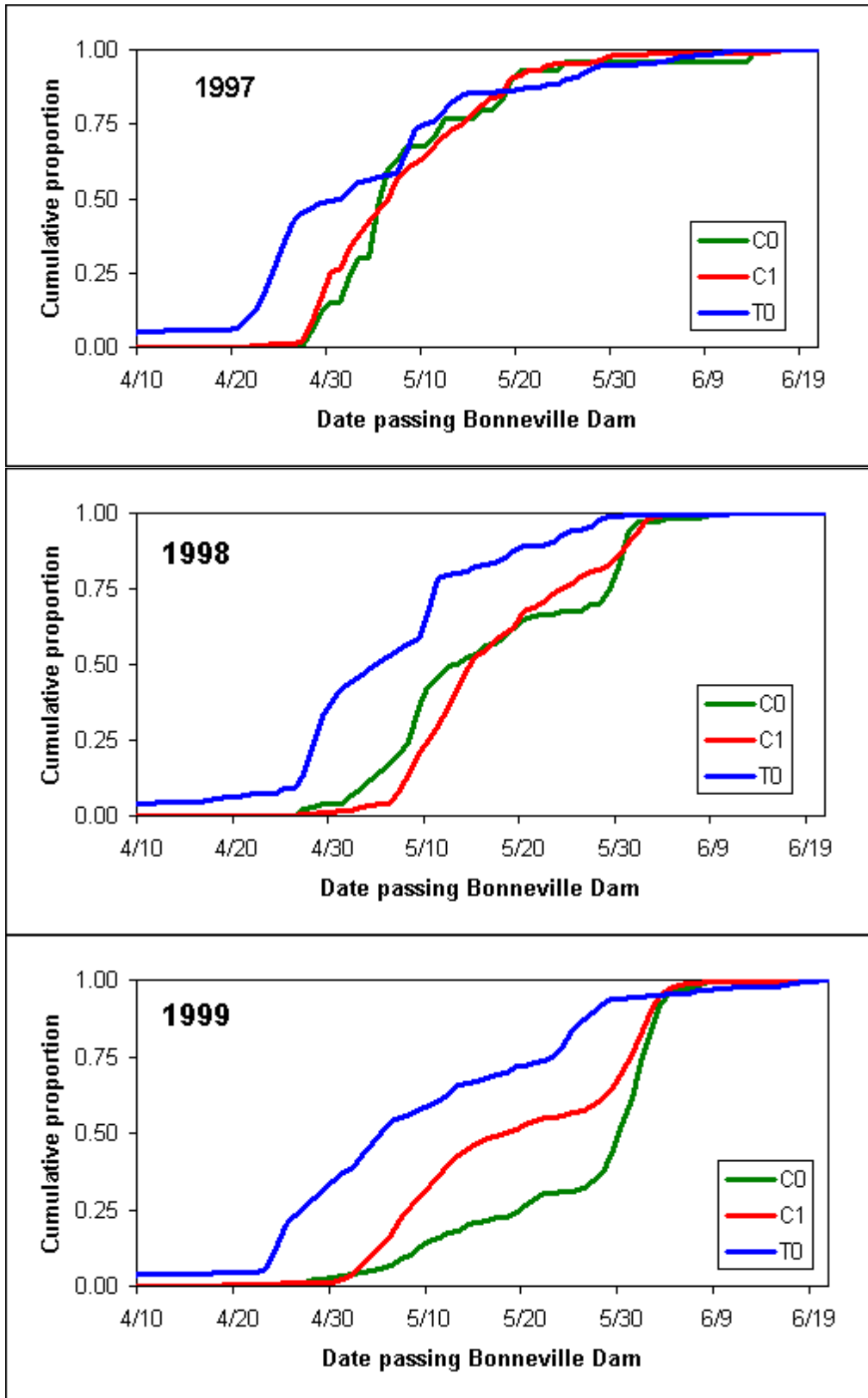


Figure F-7a. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild steelhead by CSS study group (C₀, C₁, T₀), 1997 to 1999.

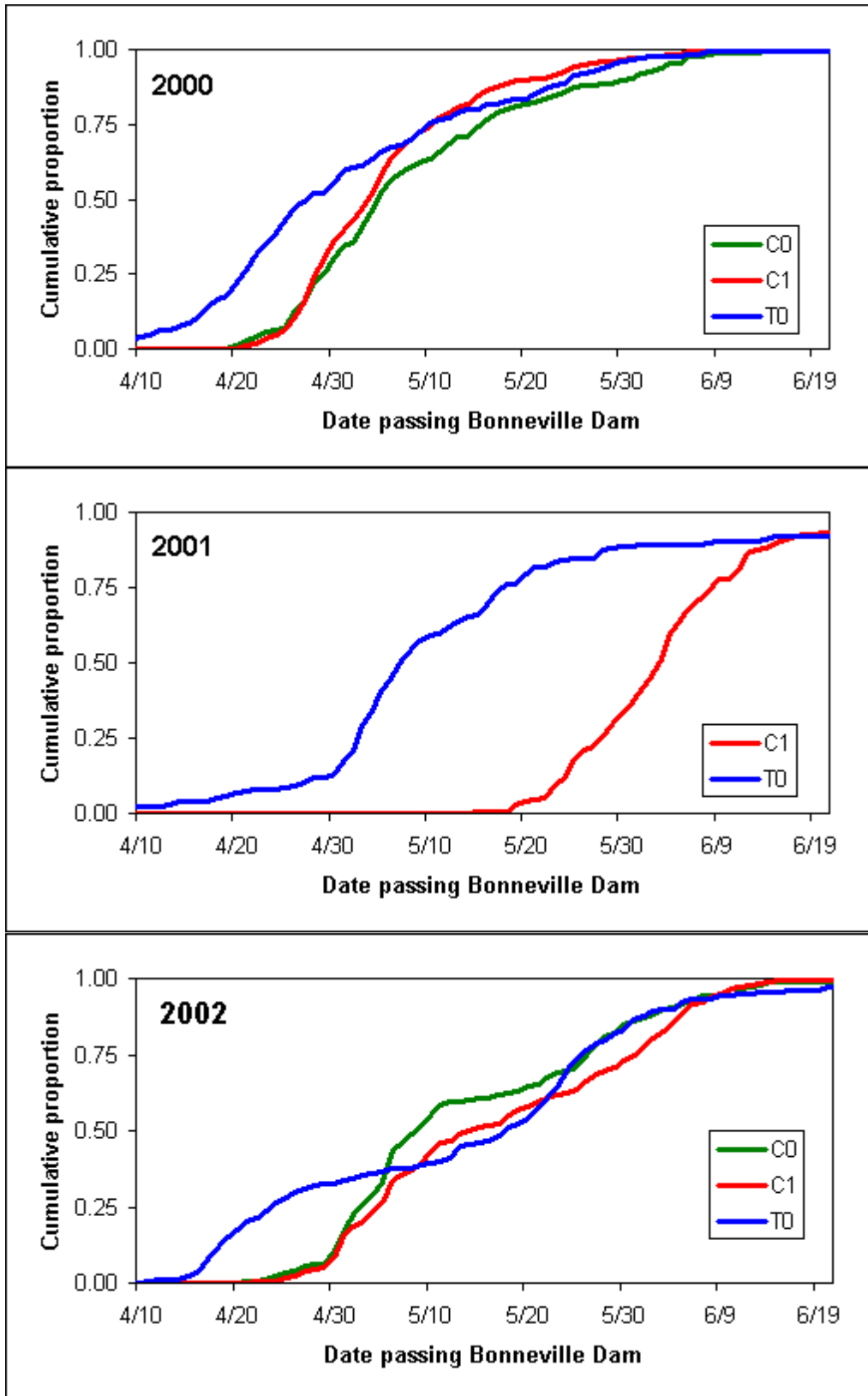


Figure F-7b. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild steelhead by CSS study group (C₀, C₁, T₀), 2000 to 2002.

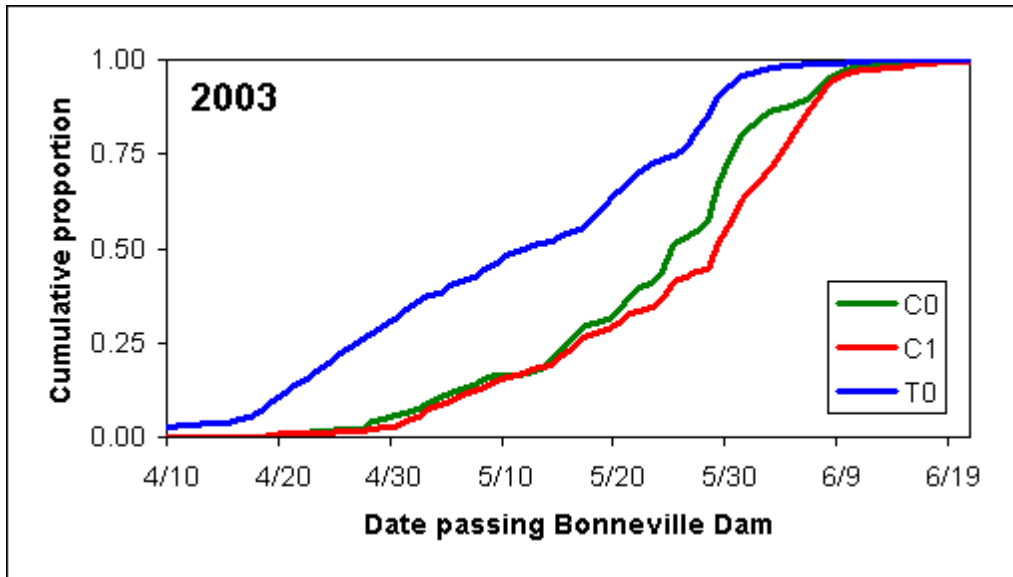


Figure F-7c. Passage timing at Bonneville Dam of Snake River basin PIT-tagged wild steelhead by CSS study group (C₀, C₁, T₀) in 2003.

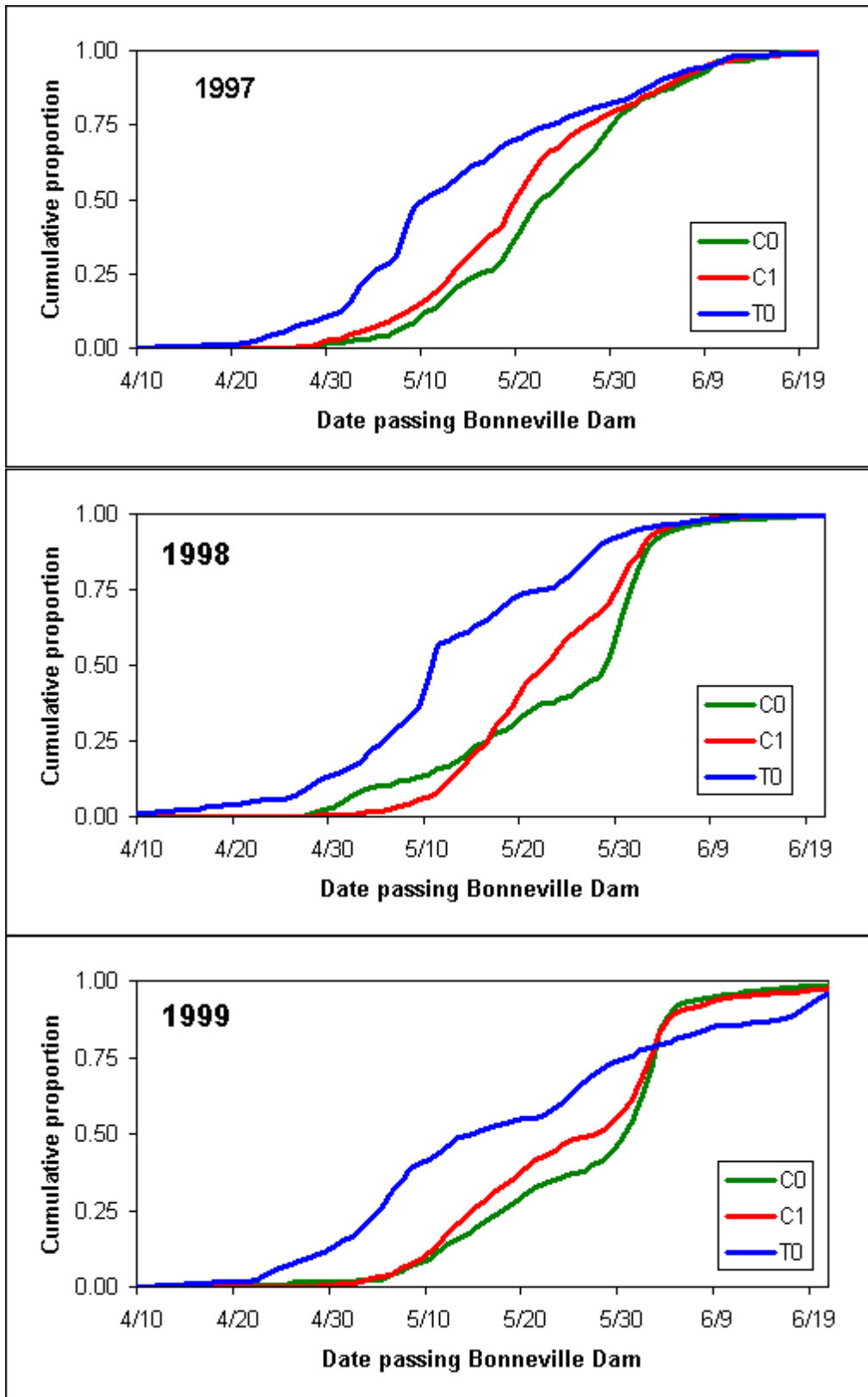


Figure F-8a. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery steelhead by CSS study group (C₀, C₁, T₀), 1997 to 1999.

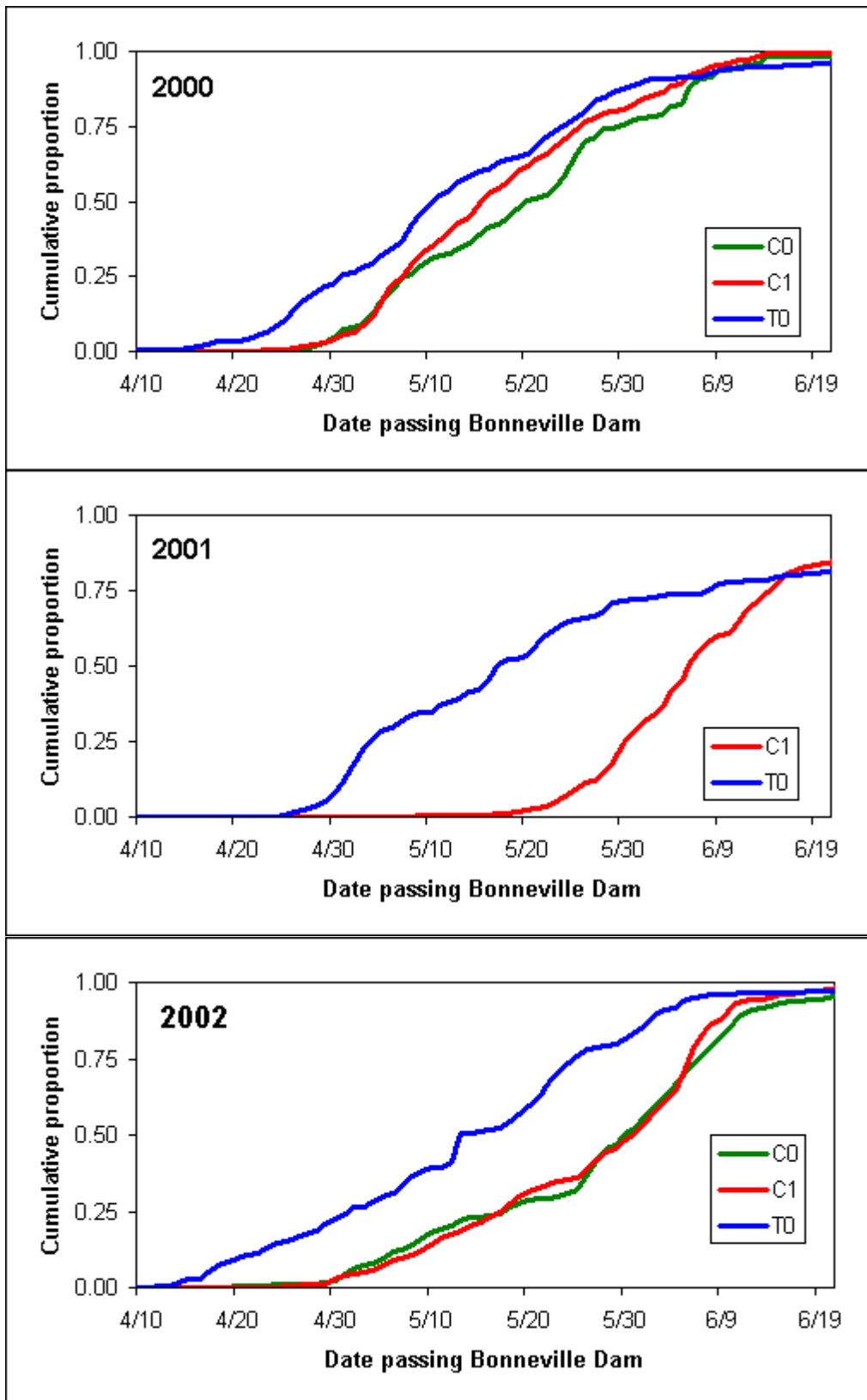


Figure F-8b. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery steelhead by CSS study group (C₀, C₁, T₀), 2000 to 2002.

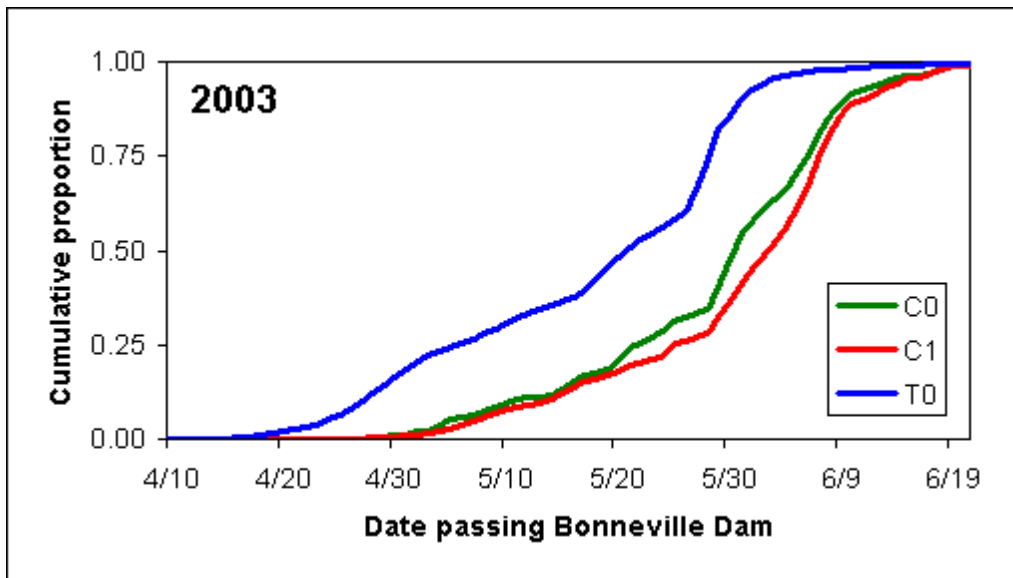


Figure F-8c. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery steelhead by CSS study group (C₀, C₁, T₀) in 2003.

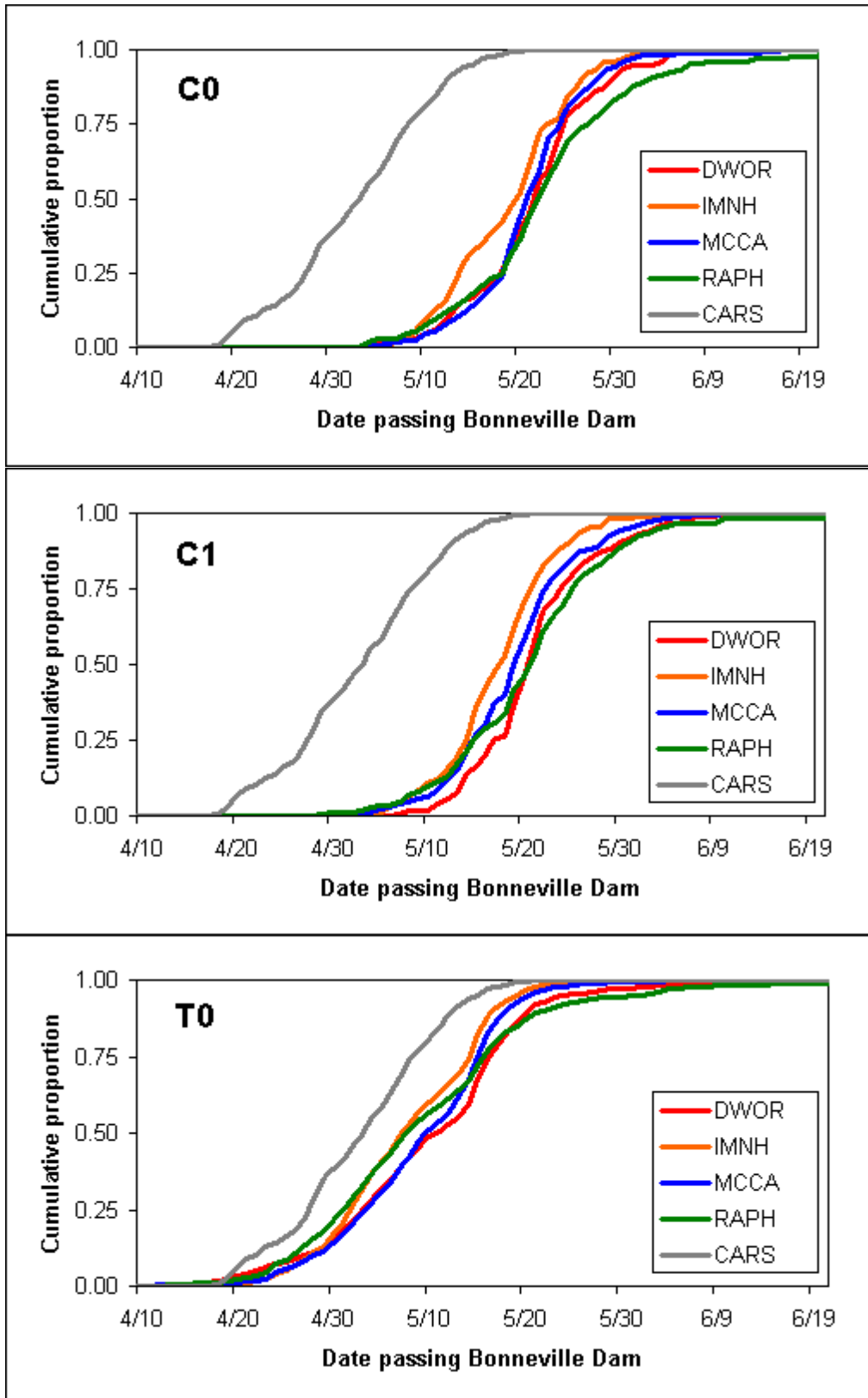


Figure F-9a. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 1997.

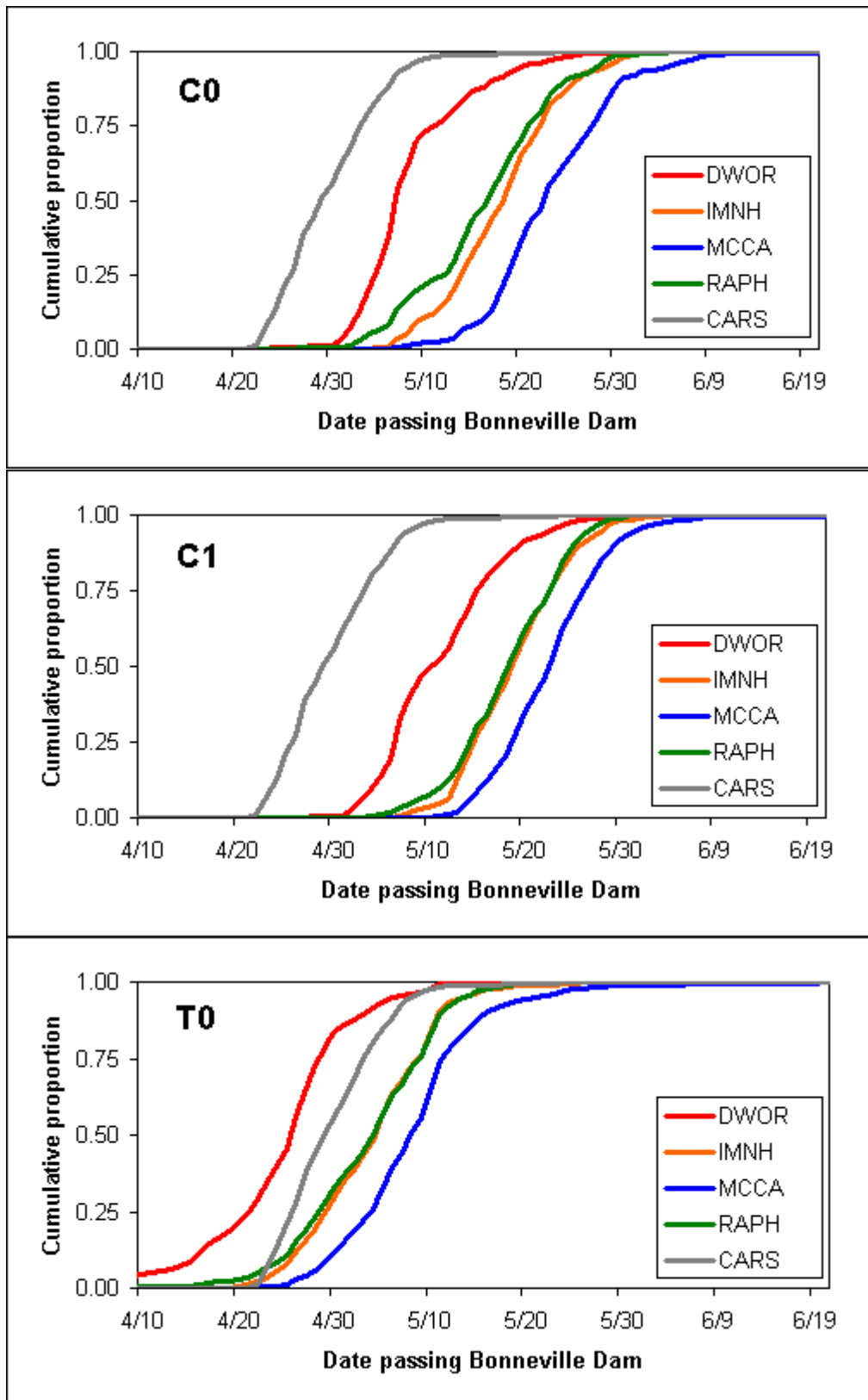


Figure F-9b. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 1998.

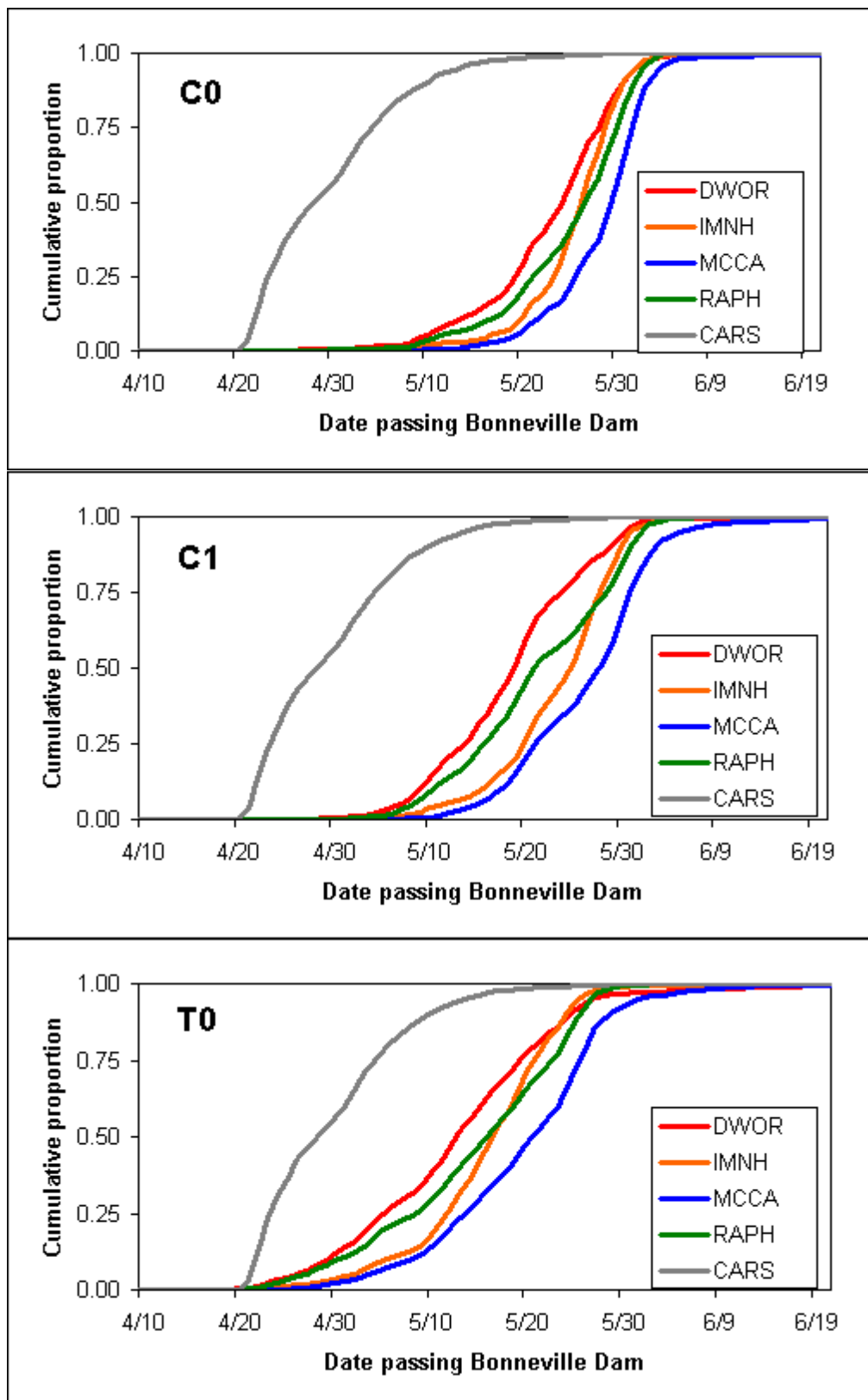


Figure F-9c. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 1999.

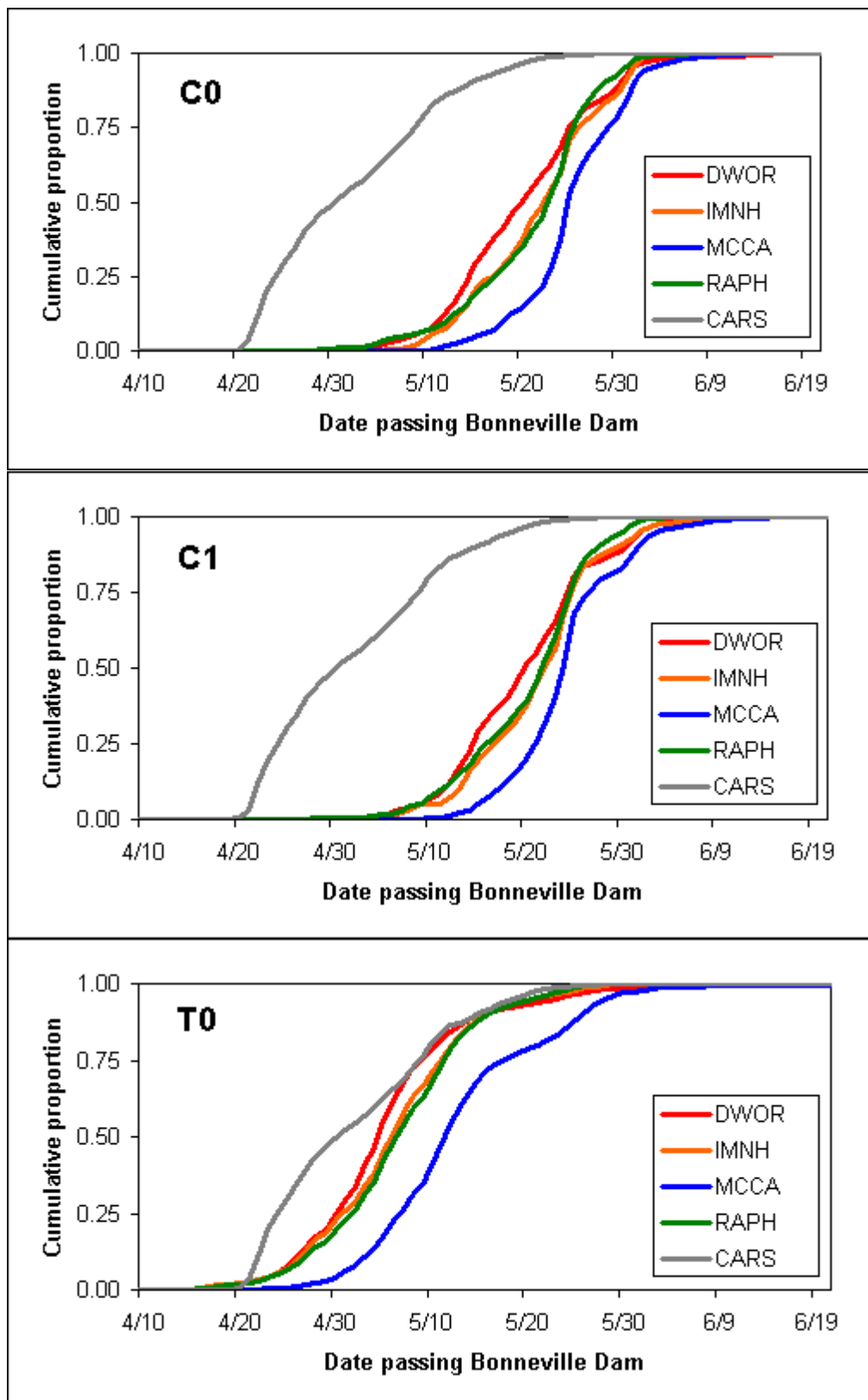


Figure F-9d. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 2000.

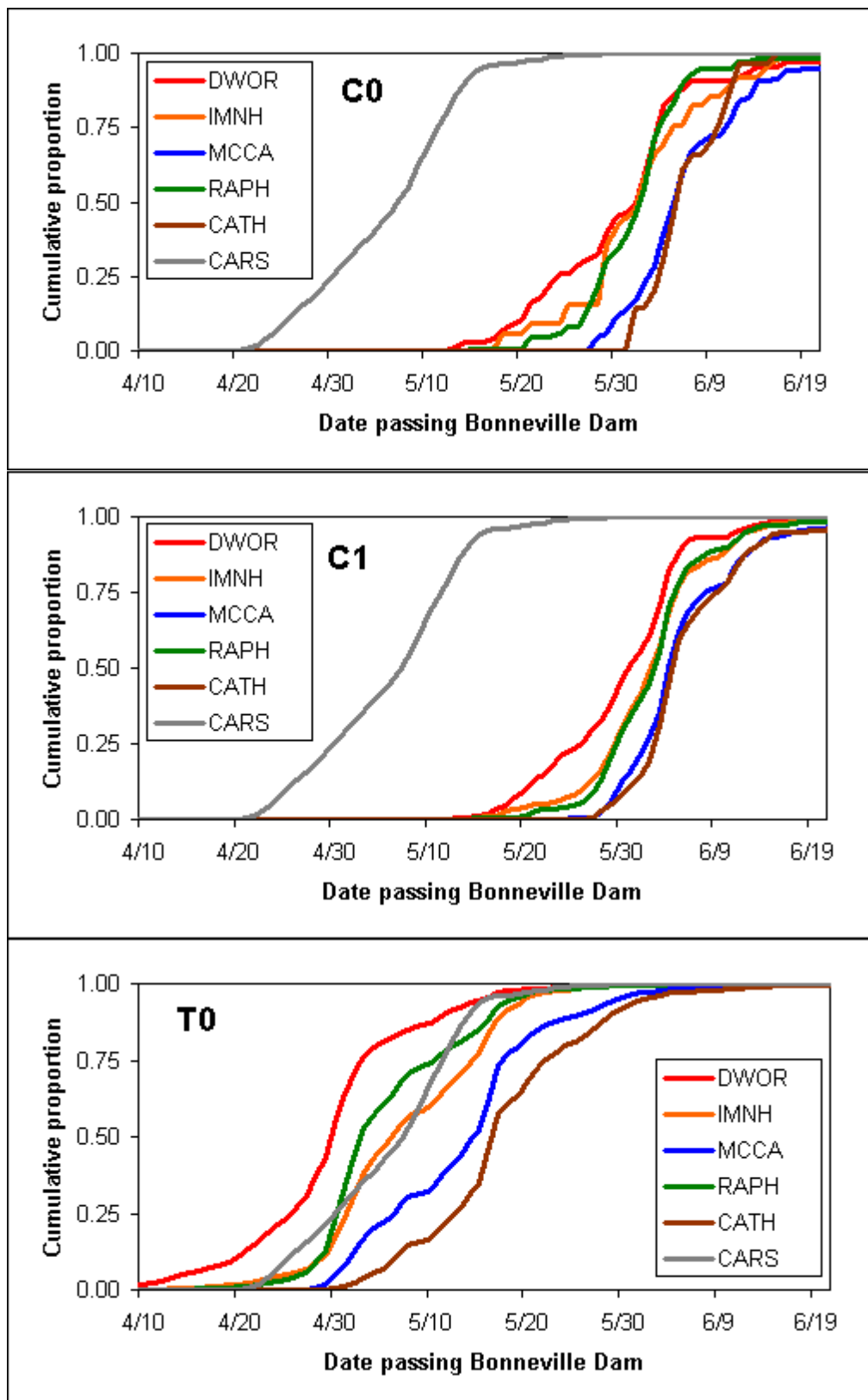


Figure F-9e. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 2001.

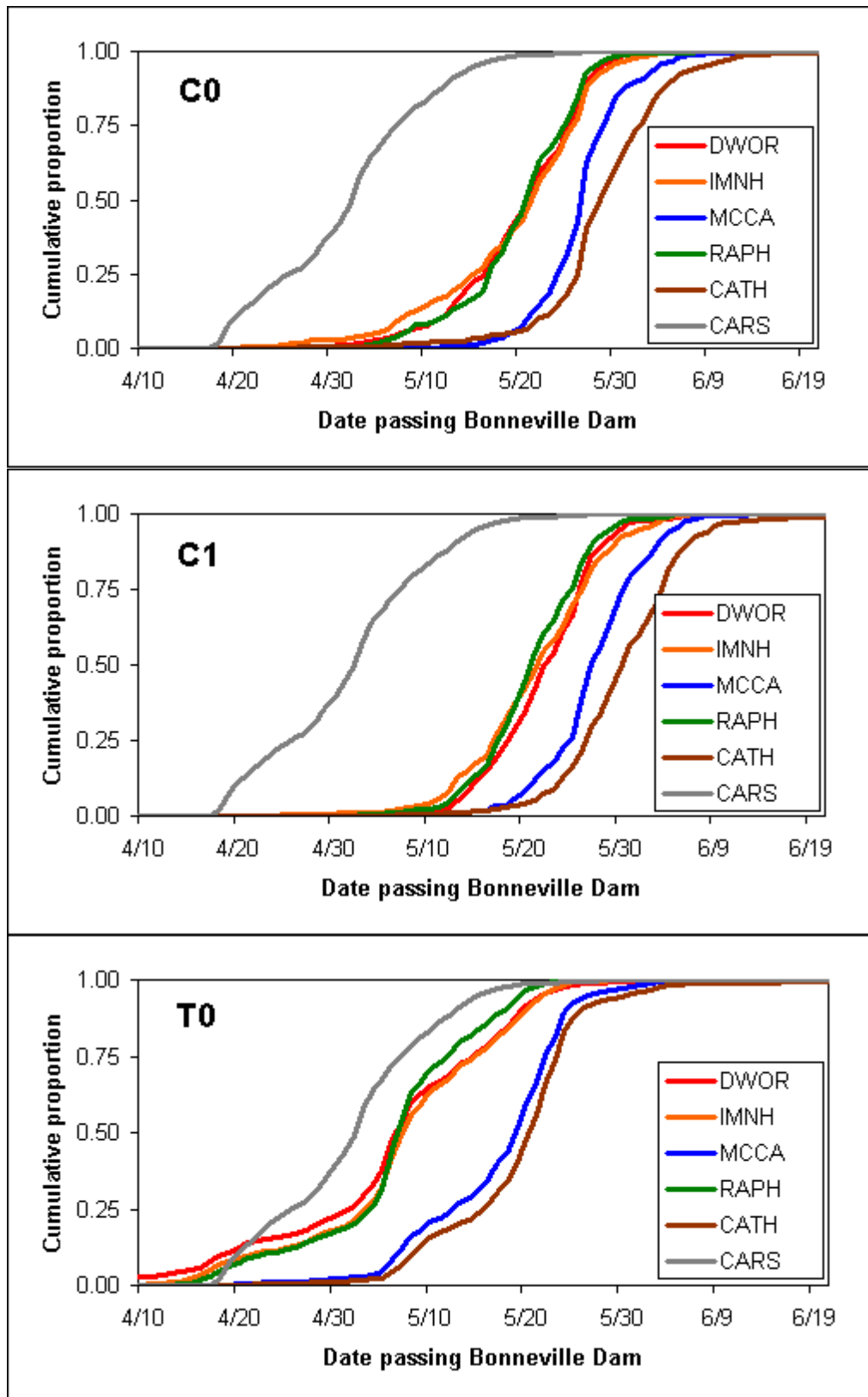


Figure F-9f. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 2002.

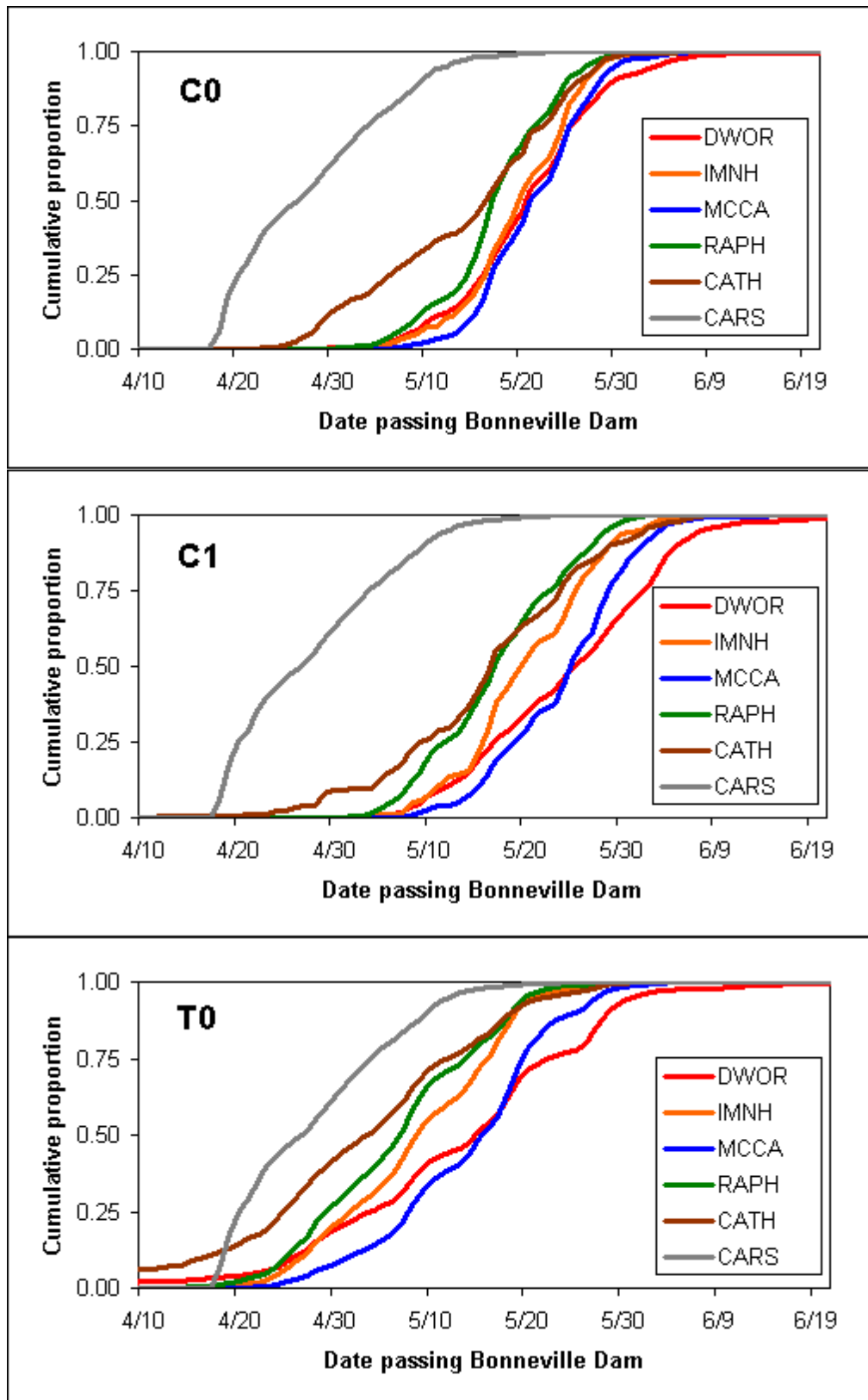


Figure F-9g. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 2003.

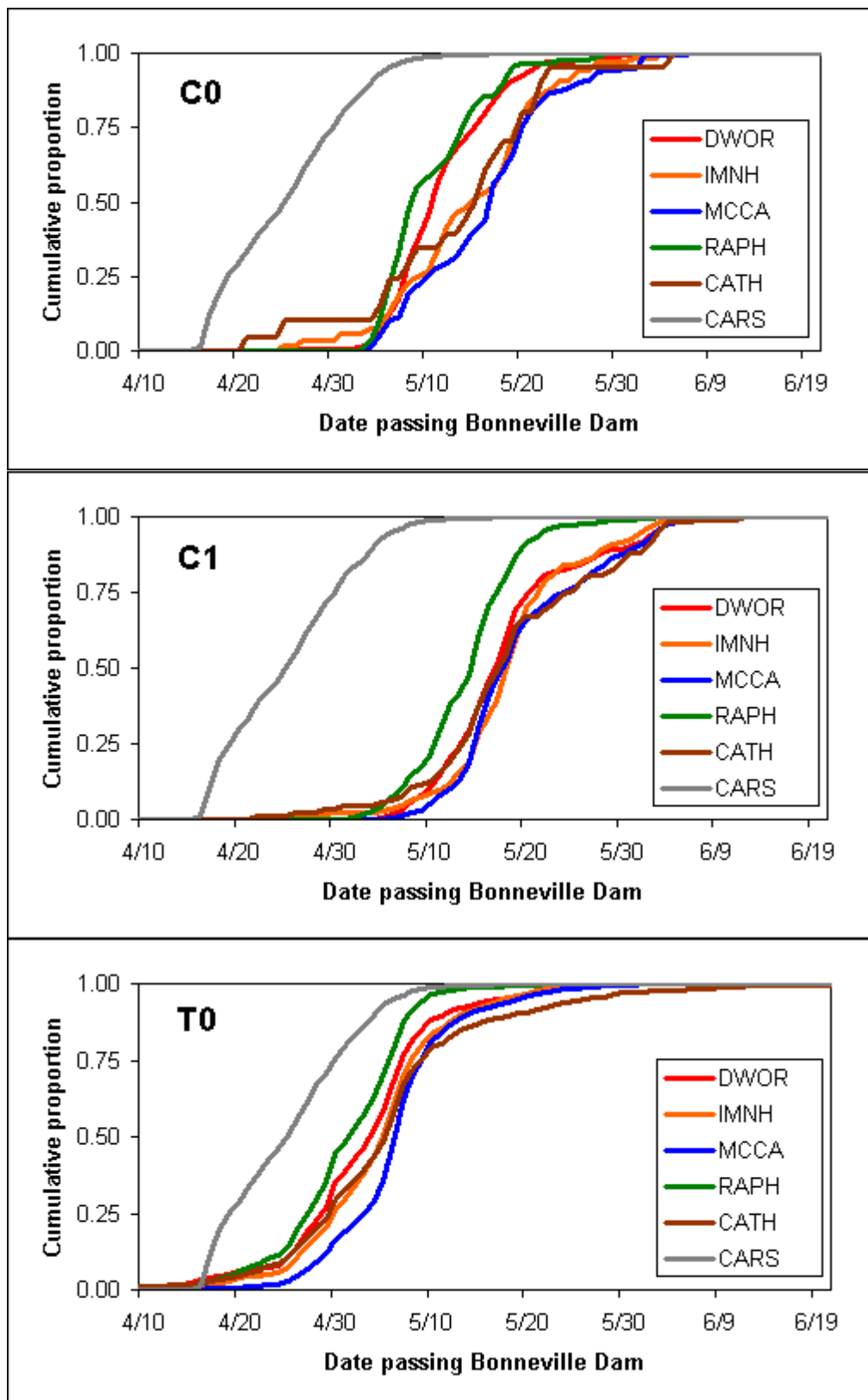


Figure F-9h. Passage timing at Bonneville Dam of Snake River basin PIT-tagged hatchery Chinook (DWOR= Dworshak; IMNH= Imnaha; MCCA= McCall; RAPH= Rapid River) by CSS study group (C₀, C₁, T₀), with comparison to the CSS downriver hatchery stock (CARS= Carson) in 2004.

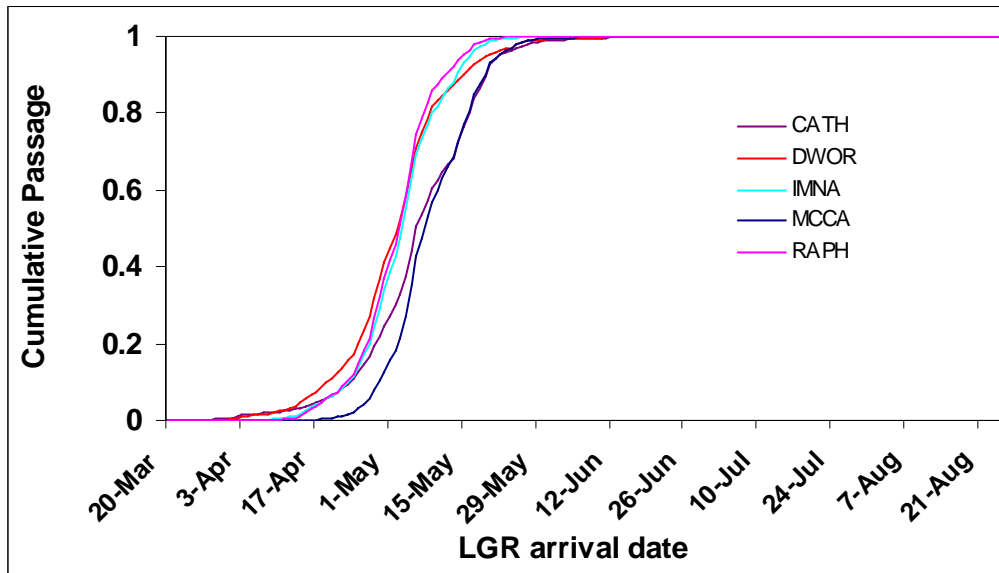


Figure F-10a. Passage timing at Lower Granite Dam of Snake River (CATH, DWOR, IMNA, MCCA, RAPH) hatchery Chinook, 2000-2005 migration years.

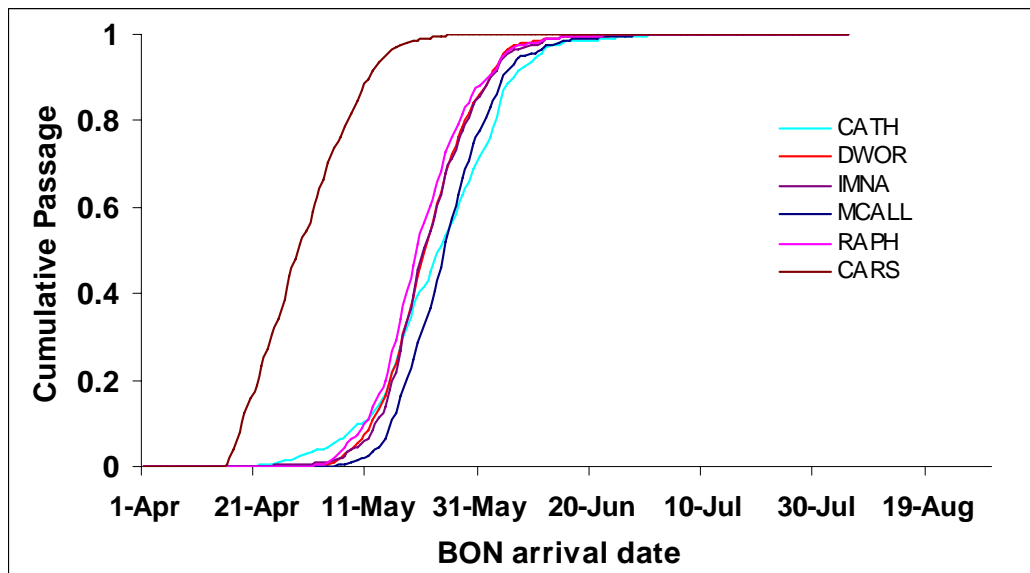


Figure F-10b. Passage timing at Bonneville Dam of Snake River (CATH, DWOR, IMNA, MCCA, RAPH) and downriver (CARS) hatchery Chinook, 2000-2005 migration years.