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COMPARATIVE SURVIVAL RATE STUDY (CSS) 2002 DESIGN AND ANALYSIS REPORT

Technical Report 2002

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COMPARATIVE SURVIVAL RATE STUDY (CSS)

2002 Design and Analysis Report

Project No. 1996-020-00

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Oversight Committee Support

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INTRODUCTION

Fisheries agencies and tribes have developed a multi-year program, the Comparative Survival Study (CSS), to obtain information to be used in monitoring and evaluating the impacts of the mitigation measures and actions (e.g., flow augmentation, spill, and transportation) under NMFS' Biological Opinion to recover listed stocks. Through 2001, the CSS has utilized PIT tagged yearling hatchery chinook that were tagged specifically for the CSS and PIT tagged wild chinook from all available marking efforts in the Snake River basin above Lower Granite Dam. We selected hatchery programs that would allow the opportunity to mark sufficient numbers of smolts to give enough returning adult fish that statistically rigorous smolt-to-adult survival rates could be computed. Since the CSS inception, hatchery fish that have consistently been used include spring/summer chinook tagged at McCall, Rapid River, Dworshak, and Lookingglass (Imnaha stock) hatcheries. The CSS has also included a group of spring chinook from Carson Hatchery in the lower Columbia River for planned upstream/downstream comparison. The wild stocks included chinook PIT tagged as parr (summer/fall tagging season) and smolts (spring tagging season) in each major tributary above Lower Granite Dam. Future years will see the CSS add wild and hatchery steelhead in the Snake River basin, hatchery steelhead in the Mid-Columbia River basin, hatchery yearling chinook in the Mid-Columbia River basin, and wild chinook in John Day River in the lower Columbia River.

Each PIT (passive integrated transponder) tag has a unique code. The tags are glass encapsulated, 11 mm in length, and implanted into the fish's underbelly by a syringe. All attempts are made to make the PIT tagged fish as representative of their untagged cohorts as possible. At trapping sites, sampling and tagging occur over the entire migration season. At hatcheries, fish to tag are obtained across as wide a set of ponds and raceways as possible to allow effective representation of production. Tag loss and mortality is monitored, and the tagging files are then uploaded to the regional PTAGIS database.

The PIT tags are read as the fish pass through the coils of the detector. For detection of smolts, there are detectors installed at six Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA), and Bonneville (BON). These site abbreviations will be used throughout this document. For detection of returning adults, there is current detection capability at LGR, and starting in migration year 2002, PIT tagged adults will be detected at both BON and MCN.

With unique PIT tags on individual fish, comparisons of survival over different life stages between fish with different experiences in the hydrosystem (e.g. different routes of dam passage, transportation vs. in-river migrants, and migration through 8 dams versus downstream stocks that migrate through at most 3 dams) can also be evaluated. CSS has taken advantage of the large hatchery releases to obtain adequate sample sizes for these different comparisons. In addition, the available wild chinook PIT tagged from other regional studies have also been used to the extent possible in the evaluation of in-river survivals, SAR's (smolt-to-adult survival rates), T/I's (ratios of transport SAR to inriver SAR) and D's (differential delayed transportation mortality). By comparing these variables for both hatchery and wild groups, it possible to determine if hatchery fish provide a reasonable surrogate for wild fish. If so, a relationship between the two groups can be developed, allowing us to use hatchery fish to track wild stocks in years where there are too few wild smolts to mark. The objectives of this study are as follows:

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

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

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

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

2. For Snake River and Mid-Columbia River basin hatcheries, develop a long-term index of survival rates from release of yearling chinook and steelhead smolts at hatcheries to return of adults to hatcheries.

Task 2(a)(1): Snake River basin fish -- Partition survival rates (*i*) from hatchery (smolts) to LGR (smolts), (*ii*) from LGR (smolts) to back to LGR (adults), and (*iii*) from LGR (adults) to the hatchery (adults). Beginning 2002, returning adults may be detected at BON and MCN, so adult survival from BON to MCN and MCN to LGR will also be generated within partition (*ii*).

Task 2(a)(2): Mid-Columbia River basin fish -- Partition survival rates (*i*) from hatchery (smolts) to MCN (smolts), (*ii*) from MCN (smolts) to back to MCN (adults), and (*iii*) from MCN (adults) to the hatchery (adults). Beginning 2002, adult survival from BON to MCN will also be generated within partition (*ii*).

Task 2(b): For the combined Snake River hatcheries, compute the annual survival rate of smolts transported at LGR to adult returns to the hatcheries.

Task 2(c): For the combined Snake River hatcheries, compute the annual survival rate of smolts migrating in-river to adult returns to the hatcheries.

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

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

Task 3(a): Compute annual survival rates (adjusted for terminal harvest rates) using both CWT and PIT tags for yearling chinook at selected upriver hatcheries (Snake River and Mid-Columbia River basins) and at the down-river Carson Hatchery. Compare estimated survival rates generated with production CWT releases and CSS PIT tag releases.

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

Task 3(c): Test if the annual ratio of down-river hatchery survival rate to upriver hatchery survival rate (all measured at the hatcheries) is greater than 2 with sufficient power to provide a high probability that the ratio is greater than 1.

Task 3(d): Test, aggregately and individually, if the annual ratio of down-river hatchery survival rate to upriver hatchery's transported smolts survival rate (all measured at the hatcheries) is greater than 2 with sufficient power to provide a high probability that the ratio is greater than 1.

Task 3(e): Explore the feasibility of developing lower river wild index stocks (*e.g.*, Warm Springs, John Day, and Klickitat rivers) to measure smolt-to-adult survival rates. This task begins with wild chinook PIT tagged in the John Day River by ODFW in migration year 2001. This task requires the ability to detect all adults passing Bonneville Dam, a capability that begins in 2002.

4. Begin a time series of smolt-to-adult survival rates for use in the regional long-term monitoring and evaluation program, which is under development, as recommended by the *Plan for Analyzing and Testing Hypothesis* process.

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

Task 5(a): Collect and catalog scales from PIT tagged adults detected at Lower Granite Dam adult trap or at the upriver hatcheries.

Task 5(b): Coordinate with the down-river hatcheries to collect and catalog scales from CWT groups that are representative of the production lots from which the PIT tagged fish were taken.

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

In this document, we report the methods used to estimate in-river survivals, SAR's (smolt-to-adult survival rates), T/I's (ratios of transport SAR to inriver SAR) and D's (differential delayed transportation mortality) for both hatchery and wild PIT-tagged Snake River spring/summer chinook and steelhead. The analytical approaches to estimating the confidence intervals around the various parameter estimates will be presented. Future hypothesis testing will stem from these analytical approaches; however, the main goal in 2002 will be in the area of parameter estimation and the representativeness of parameters based on PIT tagged smolts to the unmarked population. To date, most progress in the CSS has been made in beginning to build the long-term time series of smolt-to-adult survival rates (Objective 4). The creation of this long time series of SAR data will be useful to fishery managers regardless of the type of regional long-term monitoring and evaluation program adopted. From the conduct of this study over a series of years, in addition to obtaining estimates of smolt-to-adult survival rates, we should be able to investigate what factors may be causing differences in survival rates among yearling chinook and steelhead with different experiences in the hydrosystem.

METHODS

Program study groups of fish

One major objective of the Comparative Survival Study was to compute and compare overall smolt-to-adult survival rates for smolts transported through the hydro system versus smolts left to migrate inriver through the hydro system. In recent years, the general hydro system operation was to transport all smolts collected at LGR, LGS, and LMN throughout the spring and summer seasons, and at McNary only in the summer season. As future studies of transportation are initiated at McNary Dam, the CSS would plan to increase PIT tag release numbers to accommodate the additional transport quotas at that site. Since the tagged study groups are supposed to represent their non-tagged counterparts, how the PIT tagged fish pass through the hydro system must mimic that of the non-tagged fish. For example, only first-time detected smolts at a dam may be considered for transportation since non-tagged smolts are nearly always transported when they are first detected at a Snake River dam. We define transportation at LGR, LGS, LMN, and MCN 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 Lower Granite. Smolts "destined" for transportation at LGR, LMN, and MCN include those fish transported and those fish dying enroute to be transported (see text box below).

Therefore, an estimated survival component is needed to convert actual transport numbers at LGS, LMN, and MCN into their LGR starting number (LGR equivalent). The PIT tagged smolts that pass the Snake River dams undetected and remain inriver below LMN, the last transportation site in the spring season, are the group of interest for reflecting the inriver migration. These tagged smolts most closely mimic their non-tagged counterparts. This group's starting number is also computed in LGR equivalents, and so requires estimated survival parameters. The last group of interest is fish that are detected at one or more Snake River dams and remain inriver below LMN. These fish are important because of the need to estimate survival components. Although these fish do not mimic the general untagged population, they are of interest with regards to possible effects of passing through Snake River dam bypass systems on subsequent survival. The approach to estimating the numbers of smolts in each category will be presented later.

Smolt in-river survival estimation

Hatchery group

Survival rates for yearling chinook from CSS hatcheries in the Snake River basin are estimated to LGR tailrace and downstream between each set of dams with PIT tag detectors to the tailrace of JDA, whenever possible. Survival estimates for the complex of three reservoirs and dams to the tailrace of LMN are the primary estimates needed when estimating the number of smolts in various study categories. Survival estimates through the furthest downstream detection site are needed in the "D" computations. The CJS (Cormack 1964; Jolly 1965; and Seber 1965) methodology is used to obtain point estimates of survival with corresponding standard errors for each reach. To obtain the survival estimates, program MARK (White and Burnham 1999) is used with both the design matrix and link function set to the identity matrix These settings produce survival parameter estimates that are not constrained to the range 0 to 1, thus allowing standard errors to be calculated even when survival estimates slightly exceed 1. This may occur if the previous reach survival estimate is too low. In computing an overall reach survival across a series of "inter-dam" (1-2 dams/reach) reach survival estimates, we do not constrain ">1 estimates" to 1 unless the standard error is greater than 10% of the estimate, and we stop using reach survival estimates altogether when their standard error becomes greater than 25% of the estimate. However, in converting counts at LGS and LMN into "LGR equivalent" numbers, if one of the estimated survival components, S_2 or S_3, is greater than 1, then we will constrain that component's value to 1 and assign the unconstrained product $S_2 ? S_3$ to the other component prior to the expansions of counts to LGR equivalents.

Since the estimates of adjacent survival parameters are negatively correlated (i.e., if survival in the upstream reach is overestimated, then the survival in the downstream reach will be underestimated), the variance of the product $S_2 ? S_3$ must take into account this dependency (Meyer 1975):

$$\mathrm{var}(S_2 ? S_3) = (S_2 ? S_3)^2\{\mathrm{var}(S_2)/(S_2)^2 + \mathrm{var}(S_3)/(S_3)^2 + 2\mathrm{cov}(S_2,S_3)/(S_2 ? S_3)\} \quad \text{(eq. 1)}$$

Covariance estimates are taken directly from the MARK program output, but for presentation purposes in report appendices we show the correlation coefficients using the following identity $\mathrm{cov}(S_2,S_3) = \mathrm{se}(S_2) ? \mathrm{se}(S_3) ? \mathrm{correlation}(S_2,S_3)$.

A basic assumption of the multinomial model is that the marked fish are independently and identically distributed with a common survival probability, which we are trying to measure. When this and other model assumptions are violated the problem of "overdispersion" is encountered in which the data is more "dispersed" than is expected under the model (White, Burnham, and Anderson in press manuscript on Advanced features of program MARK). This condition causes the estimated variances to be too small. To adjust for "overdispersion," variances are multiplied by a variance inflation factor (Cox and Snell 1989), which in program MARK is estimated using the sum of the goodness-of-fit chi-squares divided by degrees-of-freedom from TEST 2 and 3 of program RELEASE.

There are no direct measures of annual survival rate of in-river smolt through the hydrosystem that exactly match the reaches around which smolts are transported. Therefore, the annual survival rate from LGR-BON (V_C) must be estimated by expanding the in-river reach survival rate estimates calculated from CJS recapture models from LGR tailrace to the lowest tailrace where an adequate survival estimate is available. The LGR tailrace to BON tailrace reach estimate of survival is calculated by taking an estimated per-mile survival rate from the CJS results and raising this rate to a power equal to number of miles in the LGR-BON reach. An alternative method is to use a per-project expansion such as used by NMFS 2000. Although we consider the per-mile expansion as more appropriate than a per-project expansion because JDA reservoir is over twice the length of the average upstream reservoirs, we plan to further investigate the effects of these two methods of expansion. We also plan to compare survival estimates made directly to BON using the trawl PIT tag detections (site TWX) as the final detection site. NMFS has estimated survival directly to BON using the trawl detections, and they found the resulting LGR-BON reach survival estimates obtained tended to be lower than that obtained by either the per project or per mile expansion approach.

Wild group

The method for estimating in-river survival for wild smolts is very similar to the method used for estimating survival for hatchery fish. One difference is that S_1 is not estimated for the wild group because wild smolts are marked at several locations above LGR reservoir. Too few smolts are released from each site to allow direct estimation of survival to LGR tailrace for each release site. Also, a pooled group from all release sites would exhibit too much overdispersion among groups to provide an accurate survival estimate. For hatchery fish, S_1 is used to estimate the number of smolts arriving at LGR, but because this was not possible for wild smolts we used a different method to estimate this number for wild PIT tagged smolts. It is based on assessing the proportion of the LGS detection that was previously detected at LGR several days prior after adjusting for any removals at LGR (see section “Arrival Numbers at LGR” below for a more detailed description).

Along with multiple release sites, wild smolts are tagged and released at multiple dates throughout the migration season in contrast to hatchery releases that generally occurs in a single release. Because we are estimating annual SAR, T/I and ‘D’ values we must calculate an annual reach survival estimate based on the reach survival estimates from several wild release cohorts. Generally we used a weekly release of cohorts to estimate survival with the minimum number of 500 released smolts detected at LGR to define the release period to minimize the variance associated with small sample sizes. However, near the end of the migration season, we may have to combine releases over several weeks to meet the minimum release size criterion. As will be seen with the weighting procedure described below, these late survival estimates tend to have little influence on the annual average survival rate because the proportion of the total outmigration represented by these late migrating smolts is very small.

To calculate annual reach survival rate estimates from the weekly PIT tag data groups, each weekly cohort survival rate estimate should be weighted to determine its appropriate contribution to the aggregate estimate. Sanford and Smith (2001) weighted the survival estimates (based on daily cohorts) by the inverse relative variance to arrive at an annual average survival rate. Weighting the individual cohort survival rate estimates by the inverse relative variance results in greater influence on the average annual survival for those cohorts with more precise survival rate estimates without biasing the weights by the survival rate estimates themselves (Sandford and Smith 2001).

Because the number of smolt PIT tagged weekly was not directly proportional to the total migration for that week (tagging of smolts was often limited due to logistical constraints) we believe that individual cohort survivals should also be weighted by the proportion of the non-tagged population migrating over that week relative to the total migration. Daily passage indices (PI) for wild yearling chinook, provided by Fish Passage Center (Portland, OR) are used to represent the population at large passing LGR dam. To create a relative passage distribution for the migration season, daily PIs are calculated at Lower Granite Dam by dividing the daily collection by the proportion of water passing through the powerhouse where sampling takes place. This adjustment accounts for the effects of spill, if present, under the conservative assumption that the proportion of fish passing through spill will be close to the proportion of water being spilled. The number of smolts (measured by the PI) for a given week is then divided by the annual cumulative PI to produce a proportion that reflects the relative contribution of that weekly cohort's estimated survival to the annual survival rate. By using this weighting procedure, cohorts that migrate during the peak migration will have a greater contribution to the average survival estimate than cohorts that migrate at either end of the migration. Weighting by both the precision of the estimate (*i.e.*, inverse relative variance) and the proportional contribution of the general population over the release period to the total migration season (PI) is used to obtain an average annual survival rate from the weekly cohort's survival estimates.

The LGR tailrace to BON tailrace reach estimate of survival (V_C) for wild chinook is also calculated by taking the estimated per-mile survival rate from the longest reach survival estimated with the CJS model and raising this rate to a power equal to number of miles in the LGR-BON reach.

Smolt allocation to transportation and in-river migration categories.

Beginning in migration year 2000, the routing scheme for hatchery chinook was set at 50 to 75% of CSS PIT tagged fish routed to transportation at all three transportation dams in the Snake River using the separation-by-code (*multimon.exe*) software. Beginning in 2001 the goal is to route 50% of the first-time detected fish at each of these three dams to transportation. Use of the separation-by-code program does not impact the timed subsample being taken at these dams because it is in effect only during non-subsampling intervals.

For migration years 1994-1999 wild PIT-tagged fish were returned to the river at all collection facilities unless a timed subsample was obtained or if a malfunction in the flipgates occurred. All subsampled fish and fish entering the raceways during flipgate malfunctions were transported. Thus, transported PIT-tagged wild smolts may not accurately represent the non-tagged population. Beginning in 2002, a portion of the wild PIT tagged chinook first-time arriving at LGR, LGS, or LMN will be routed to the raceways for transportation using the separation-by-code software. Beginning in 2001 the goal is to route 50% of the first-time detected fish at each of these three dams to transportation.

Estimating LGR-LGR SARs

Because Snake River basin smolts are tagged and released at several locations above LGR reservoir, and because smolt that enter the collection facility are counted at LGR, this dam has been used as a reference point to measure SARs. The first step to estimating SARs using PIT tag information is to estimate the total number of PIT-tagged smolt arriving at LGR. Next, a SAR from LGR back to LGR is estimated for the transported group and the in-river group. In addition, because PIT-tagged and non-PIT-tagged smolts are treated differently, SARs should be evaluated with smolt that have detection histories that are most similar to the non-PIT-tagged population. We calculate the SARs for either transported fish or in-river fish by summing the number of smolt detected at the relevant projects (in LGR equivalents) over the season and dividing this into the number of adults returning to LGR with the same detection history from that migration year. Adults are defined as ≥ 4 yr olds although we evaluated the impact of jacks on SARs for selected hatcheries. These are the general steps in estimating SARs for both wild and hatchery spring/summer chinook. Further detail is provided below.

Arrival numbers at LGR

To estimate the number of smolts arriving at LGR dam from a particular hatchery, we multiplied the number of smolts released, R_1, by the survival rate, S_1, estimated by the CJS. This method is not applicable to wild smolts because of the multiple sites from which wild smolts are released. Therefore, we used the methods described in Sandford and Smith (2001). For wild smolts, this method estimates LGR arrivals as the sum of daily passage estimates, which are calculated by dividing daily detection numbers by daily detection efficiencies. This method defined a population known to be alive at LGR (by virtue of having been detected at LGS), and then determined the proportion of smolts in the sub-population that was detected at LGR. Corrections were made for proportions of detected smolts removed (transportation or unknown disposition) using 7-day running averages.

Estimation of smolt numbers by category

<u>Transport groups</u>

As stated earlier, we only use first-time detections for transported smolts in order to mimic the non-tagged smolts. In order to report the number of smolts arriving at lower collection facilities in LGR equivalents, we must divide the number of first detected smolts that were transported by the survival to that facility. Thus, Group T_0 consists of PIT tagged CSS smolts routed to the fish barge (or truck) at LGR or first-time detected PIT tagged smolts routed to transportation at LGS, LMN, or MCN. The number of fish estimated in Group T_0 is

$$T_0 = X_{12} + X_{102}/\mathbf{S_2} + X_{1002}/\mathbf{S_2 S_3} \quad \text{with no McNary transport} \qquad \text{(eq. 2a)}$$

$$T_0 = X_{12} + X_{102}/\mathbf{S_2} + X_{1002}/\mathbf{S_2 S_3} + X_{10002}/\mathbf{S_2 S_3 S_4} \quad \text{with McNary transport} \qquad \text{(eq. 2b)}$$

Definitions of symbols:

X_{12} = number transported at Lower Granite Dam
X_{102} = number first-detected and transported at Little Goose Dam
X_{1002} = number first-detected and transported at Lower Monumental Dam
X_{10002} = number first-detected and transported at McNary Dam
R_1 = number of PIT tags released from hatchery for CSS
$\mathbf{S}_1$ = estimated survival from hatchery release site to Lower Granite Dam tailrace
$\mathbf{S}_2$ = estimated survival from Lower Granite tailrace to Little Goose Dam tailrace
$\mathbf{S}_3$ = estimated survival from Little Goose tailrace to Lower Monumental Dam tailrace
$\mathbf{S}_4$ = estimated survival from Lower Monumental tailrace to McNary Dam tailrace
m_{12} = number of fish first detected at Lower Granite Dam
m_{13} = number of fish first detected at Little Goose Dam
m_{14} = number of fish first detected at Lower Monumental Dam
m_{15} = number of fish first detected at McNary Dam
d_2 = number of fish removed at Lower Granite Dam regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_3 = number of fish removed at Little Goose Dam regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_4 = number of fish removed at Lower Monumental Dam regardless of prior capture history (includes transported fish, site-specific mortalities, unknown disposition fish, and fish accidentally removed at Lower Monumental Dam and used in NMFS survival study at Ice Harbor Dam)
$?_0$ = site-specific removals at dams below Lower Monumental Dam of fish not detected previously at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
$?_1$ = site-specific removals at dams below Lower Monumental Dam of fish previously detected at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the

UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
Note: both $?_0$ and $?_1$ are inflated by a constant factor of 2 to offset the approximate 50% survival rate to the lower Columbia River of fish starting at Lower Granite Dam

In-river groups

Because PIT-tagged smolts must go through the collection facility to be detected, and all non-tagged smolts entering the detection facility are generally transported, only PIT-tagged smolts that have not been detected should be evaluated to represent SARs for in-river fish. To estimate the number of smolts that were not detected at any of the collector projects (C_0), the number of smolts first detected (transported and non-transported) at LGR, LGS, LMN (in LGR equivalents) is subtracted from the total number of smolts estimated to arrive at LGR. Smolts detected at MCN, JDA, and BON are included in this group as fish entering the bypass facilities at these projects, both tagged and untagged, are generally returned to the river. The number of fish estimated in Group C_0 is

$$C_0 = R_1\mathbf{S_1} - (m_{12} + m_{13}/\mathbf{S_2} + m_{14}/\mathbf{S_2S_3}) - 2?_0 \qquad \text{(eq. 3)}$$

where $2\Delta_0$ is the number of smolts in LGR equivalents removed in the Congelton study (see text box for definition of symbols). C_0 was estimated in this fashion for both wild and hatchery PIT-tagged fish with one exception. In 1994, all smolts detected at MCN were transported; thus in that year all wild chinook smolts not detected at LGR, LGS, LMN, and MCN were included in C_0 category. Considerable discussion as to the definition of what constitutes a "true" in-river control has occurred in the past (Mundy et al. 1994). Often, any smolt that migrated through the hydrosystem, regardless of their detection history, has been used to represent an in-river fish. However, evidence suggests that fish entering a collection facility and returned to the river have a lower probability of returning as an adult than fish that pass a dam through either spill or through the turbines (Budy et al. 2002, Sanford and Smith 2001). Therefore, to use these fish to represent in-river control fish would be misleading as smolts that enter the collection facility are almost always transported. In this study, we evaluate the SARs of hatchery fish that were detected one or more times while migrating through the Snake River hydro system and contrast these to SARs of hatchery fish that were never detected at these sites (C_0). We refer to this group as the C_1 group, which consists of PIT tagged smolts detected at one or more of the Snake River collector dams (LGR, LGS, or LMN) that continue to migrate in-river below LMN. C_1 was not estimated for the wild PIT tagged smolts. The number of fish estimated in Group C_1 is:

$$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/\mathbf{S_2} + (m_{14} - d_4)/\mathbf{S_2S_3} - 2?_1 \qquad \text{(eq. 4)}$$

Confidence Intervals for Smolt Numbers by Category

In the 2001 CSS Status Report, we estimated confidence intervals for smolt numbers of hatchery chinook with Monte Carlo simulations. This approach was used with the SAR parameters and T/I ratios also. However, it was apparent that an alternative method needed to be developed to handle both hatchery and wild chinook, and to better incorporate all sources of variability present. A nonparametric "bootstrap" approach is currently under development to produce confidence interval around all parameters of interest including SARs, T/I ratios, and "D" values (Efron and Tibshirani 1993). The details of this approach are presented in Appendix C.

The original Monte Carlo approach will still be conducted for hatchery chinook as a check against the bootstrap method. The details of the Monte Carlo approach follow. Since all smolt numbers are expanded to LGR equivalents, the number of smolts in each category for a given hatchery and migration year is not a fixed number. In the case of categories T_0 and C_1, the known counts at certain dams must be expanded by the estimated survival to get to those dams from the LGR starting population. In the case of Category C_0, both the population at LGR must be estimated and from that estimate the known counts at certain dams expanded by the survival rates to those dams from LGR must be subtracted. In each of these cases the estimates of various reach survivals must be utilized, each with a measure of uncertainty. In order to compute the confidence intervals about the population sizes of each of these categories, a Monte Carlo approach was used in which a value was randomly selected from the distribution of the respective survival parameter and applied to each equation for T_0, C_1, and C_0 as shown below for the j^{th} iteration of 1000. The random variable (rv), for the j^{th} iteration, is $\mathbf{rv(S_2)_j} = Z_j ?\, se\mathbf{(S_2) + S_2}$ where Z_j is randomly selected from the standardized normal distribution N(0,1).

- The number of fish estimated in Group T_0 for the j^{th} iteration is
  $T_{0j} = X_{12} + X_{102}/\mathbf{rv(S_2)_j} + X_{1002}/\mathbf{rv(S_2S_3)_j}$ (eq. 5)

- The number of fish estimated in Group C_{1j} for the j^{th} iteration is
  $C_{1j} = (m_{12} - d_2) + (m_{13} - d_3)/\mathbf{rv(S_2)_j} + (m_{14} - d_4)/\mathbf{rv(S_2S_3)_j} - 2?_1$ (eq. 6)

- The number of fish estimated in Group C_{0j} for the j^{th} iteration is
  $C_{0j} = R_1?\, \mathbf{rv(S_1)_j} - (m_{12} + m_{13}/\mathbf{rv(S_2)_j} + m_{14}/\mathbf{rv(S_2S_3)_j}) - 2?_0$ (eq. 7)

The 95% confidence interval is obtained by ordering the resulting 1000 values of T_0's, C_1's, and C_0's in ascending order and selecting the values in the 25^{th} and 976^{th} rank order positions as the lower and upper limits of the confidence interval, respectively.

Recovery activities at Lower Granite Dam adult trap

LGR is a primary upriver evaluation site for many objectives of the CSS. The adult fish passage facilities at LGR incorporate an adult fish trap located just off the main fish ladder. When trapping occurs, adult fish are diverted from the main fish ladder into a pool area where two false weirs, a metal flume, coded wire detectors, and PIT detectors are in line leading to the adult holding trap. Unmarked fish or fish not required to be diverted will drop back into the fish ladder, and continue up to the main fish ladder where they can exit to the forebay of the dam. In return years through 2001, the tag identification files for CSS PIT tagged chinook were installed in the separation-by-code program that allow 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 length, sex determination, fish condition (injury), and a scale sample. Beginning in return year 2002, these data will no longer be taken at LGR. Length, sex determination, and injury data will be obtained from the hatcheries. Therefore, returning adults reaching LGR will continue upstream without any handling at that site.

Assignment of returning adults to categories

Returning adults are assigned to groups T_0 and C_1 based on which route of passage these fish took as smolts at the Snake River dams, and whether fish on a given route were actually being transported or returned-to-river during a particular period of time. Returning adults not detected as smolts at LGR, LGS, and LMN, regardless of any subsequent downstream detection, were assigned to Category C_0 (exception is when full springtime transportation occurs at MCN; then Category C_0 includes smolts that migrated in-river to the tailrace of MCN without any prior detection in an upstream bypass system). Details of the assignment process are presented in Appendix B.

Calculation of aggregate transportation SAR

Because fish transported at different transport sites appear to differ in their overall SAR (Bouwes et al. 1999), the estimate of SAR_T is affected by the collector projects selected. Smolts have been transported at LGR, LGS, and LMN throughout the migration season and at MCN only during the summer season starting 1995. To accurately portray the overall transportation operations, all collection projects where smolts are collected and transported must be included. However, because the PIT-tagged fish have often been returned to the river for survival estimation purposes, the number of PIT-tagged smolts transported at some projects is underrepresented and must be adjusted to better reflect the run-at-large. This is done using stratified sampling theory in which each dam is a stratum containing an estimated number of tagged and untagged smolts that are to be transported. Details of the theory are presented in Appendix A. A computational formula is presented below that accomplishes the goals of the stratified sampling. Adjusting the proportion of the PIT-tagged smolts that were transported by the proportion of the run-at-large that was actually transported at each project can correct this bias. Let PA_j represent the actual proportion of all spring/summer chinook smolt (tagged, non-tagged, hatchery, and wild) arriving at a collector project (j) that was transported. Let, PO_j represent the proportion of the all PIT-tagged wild or hatchery (depending on the group evaluated) spring/summer chinook arriving at a collector project that was transported. The adjustment weighs, w, applied to each $SAR_{T,j}$ is

$$w_j = \frac{PA_j / PO_j}{\sum_j \frac{PA_j}{PO_j}} \qquad \text{(eq. 8)}$$

producing a SAR_T

$$SAR_T = \frac{\sum_j w_j LGR_{A,j}}{\sum_j w_j LGR_{S,j}} \qquad \text{(eq. 9)}$$

where $LGR_{A,j}$ is the LGR returning adults and $LGR_{S,j}$ is the LGR equivalent smolts for each project *j*.

In years prior to 2000, only low numbers of first-time detected PIT tagged smolts are transported from LMN and MCN for hatchery PIT tagged fish and at all sites for wild PIT tagged fish. Routinely, a group of smolts are diverted via the flip gates into the sample room where they are anesthetized, examined, and measured. These fish are then put into the raceways to be transported and are the only PIT-tagged smolts transported at these sites. Because of the additional handling, these PIT tagged smolts may not best represent the non-tagged population. The numbers of PIT tagged smolts transported at these projects tend to be small. With small samples and associated less precise SAR estimates, the weighting procedure described will be influential on the overall estimated SAR_T. This is the reason for increasing the numbers of wild yearling chinook being PIT tagged for migration year 2002, and assuring that at least 50% of the detected PIT tagged wild and hatchery chinook at LGR, LGS, and LMN are routed to the raceways for transportation. Whether a proportion of study PIT tagged fish are routed to raceways at MCN will depend on the operation being planned for the springtime migration season each year.

Calculation of SARs with confidence intervals

In the 2001 CSS Status Report, we estimated confidence intervals for SARs and T/I ratios of hatchery chinook with Monte Carlo simulations. However, it was apparent that an alternative method needed to be developed to handle both hatchery and wild chinook, and to better incorporate all sources of variability present. A nonparametric "bootstrap" approach is currently under development to produce confidence interval around all parameters of interest including SARs, T/I ratios, and "D" values (Efron and Tibshirani 1993). The details of this approach are presented in Appendix C.

The original Monte Carlo approach will still be conducted for hatchery chinook as a check against the bootstrap method. The details of the Monte Carlo approach follows. The SAR for the life stage between smolts at LGR and adults at LGR were generated for categories T_0, C_1, and C_0 for each migration year and hatchery stock separately. The number of adults within a particular category divided by the estimated number of smolts in that category provides the initial SAR point estimate. In order to determine a 95% confidence interval for this point estimate the following Monte Carlo approach was used. The number of adults returning for a particular group of fish may be viewed as simply one of many possible outcomes from the Binomial distribution of adult returns for a particular SAR rate. In other words, by setting "n" equal to the number of smolts in a particular category and "p" equal to the SAR point estimate for that category (p=adults/n, and q=1-p), the distribution of 1000 possible adult returns was generated from the Binomial(n,p) distribution for that category. To obtain the distribution of adults needed, the normal approximation to the binomial was used where µ = np and s = sqrt(npq). For the jth iteration, rv(adult)j = Zj?sqrt(npq)+ np where Zj is randomly selected from the standardized normal distribution N(0,1). This produces the number of adults returning for the jth iteration. This number divided by the number of smolts calculated for the jth iteration produces the SAR survival rate for the jth iteration in each of the categories T_0, C_1, and C_0. At the same time during the jth iteration, the ratios of selected SAR's are being generated as SAR_{T0}/SAR_{C0} and SAR_{C1}/SAR_{C0}. The 95% confidence interval is obtained by ordering the resulting 1000 outcomes of adults, SAR's, and ratios of SAR's in ascending order and selecting the values in the 25th and 976th rank order positions as the lower and upper limits of the confidence interval, respectively.

Estimating the BON-LGR SARs

Methods to estimate LGR-LGR SARs for transported (SAR_T) and in-river (SAR_C) fish have been described above. This measurement of survival from smolts to adults includes survival rates through the hydropower system for transported (V_T) and for in-river (V_C) smolts as well as survival after smolts pass BON and return to LGR. The number of smolts passing BON dam is not observed. Therefore, to estimate BON-LGR SARs, the hydrosystem survival rate is removed from the LGR-LGR SAR values. For fish that migrate in-river the BON-LGR SAR is LGR-LGR SAR_C/V_C, where V_C is estimated through the CJS estimate expanded to the entire hydrosystem, and the BON-LGR SAR for transported fish is LGR-LGR SAR_T/V_T where V_T=0.98.

Estimating T/I ratios

Above we described the methods to estimate SARs for different detection histories of smolts that migrated in-river and smolts that were transported. These methods produce a SAR_T for the T_0 group and a SAR_C for the C_0 group. To evaluate the relative SARs for fish that were transported to fish that migrated in-river we calculate a T/I ratio = SAR_T/SAR_C. In addition, we make a comparison between the C_0 and C_1 groups, estimating the $C_1/C_0 = SAR_{C1}/SAR_{C0}$.

Estimating 'D'

'D' is the ratio of post-BON survival rate of transported fish to in-river fish. Thus,

D = BON-LGR SAR_T/BON-LGR SAR_C = LGR-LGR SAR_T/LGR-LGR $SAR_C * V_C/V_T$ (eq. 10)

where V_C is the estimated inriver survival from LGR tailrace to BON tailrace (typically averaging around 50%) and V_T is the assumed direct transportation survival of 98% (CRI and PATH model assumption). The D ratio should be around 1 if there is no differential mortality occurring between transported and inriver migrating smolts once they are both below BON and eventually entering the ocean. However, with D ratios averaging around 0.6 for hatchery and wild chinook in recent years (see the February 12, 2002 CSS Status Report for 1997-2000 migration years), there is evidence that the post BON delayed mortality of inriver fish is lower than that of transported fish.

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APPENDIX A

Weighting transportation data to create total transport aggregate

In most recent years, the overall transportation category T_0 includes fish transported from LGR, LGS, and LMN throughout the migration season, plus a few late migrating fish transported from MCN once transportation begins there each year for summertime migrants. To aggregate across the three to four dams in order to arrive at an overall annual transport SAR requires the use of stratified sampling theory where each dam is a stratum. The weighting factor across the strata is each stratum's proportion of the total tagged and untagged fish transported that occurs at that particular stratum. This weighting occurs separately for each hatchery group and for each weekly block of wild chinook.

A weighted aggregate for all four transportation sites (including MCN) is computed for both the hatchery and wild chinook. The computation formula for creating this weighted aggregate of the Snake River sites involved multiplying all returning transported adults and their corresponding smolt numbers (in LGR equivalents) by a site-specific ratio.

$$SAR(T_0) = \{W_1 A_{LGR} + W_2 A_{LGS} + W_3 A_{LMN} + W_4 A_{MCN}\} / \{W_1 n_{12} + W_2(n_{13}/S_2) + W_3(n_{14}/S_2S_3) + W_4(n_{15}/S_2S_3S_4)\}$$

where $W_{j-1} = (t_j/C_j)/(n_{1j}/m_{1j})$ for the j^{th} site (j=2 for LGR, j=3 for LGS, j=4 for LMN, and j=5 for MCN); t_j = total number of collected yearling (sp/su/fa) chinook smolts transported; C_j = total collection of yearling (sp/su/fa) chinook smolts; n_{1j} = number of first-time detected PIT tagged yearling (sp/su) chinook smolts transported; and m_{1j} = number of first-time detected PIT tagged yearling (sp/su) chinook collected.

This weight is the estimated proportion of total collected smolts transported divided by the estimated proportion of PIT tagged smolts transported in LGR equivalents. This weight adjusts for the under representation of PIT tagged smolts in transportation compared to the unmarked population of collected smolts. The estimated proportion of the total (tagged and untagged) collected smolts transported is obtained by simply taking the proportion transported of the total combined hatchery and wild chinook collection number for a given transportation facility since transportation data is collected at the combined rearing type level for chinook and steelhead. This number includes the total combination of wild spring/summer and hatchery spring/summer/fall yearling chinook of Snake River origin at all transportation facilities, plus the wild and hatchery spring/summer yearling chinook of Mid-Columbia River origin at MCN. Ideally the weight would be based on the same fish as the group being estimated, that is wild spring/summer Snake River basin chinook and the hatchery specific hatchery chinook, however, there is no way to assign the unmarked fish to their respective group. Therefore, we make the assumption that the transportation proportion for the unmarked population of each specific hatchery group and the aggregate wild group is approximately the same.

The correspondence between the computation formula given above and the stratified sampling approach will be detailed below for hatchery CSS smolts. Since the SARs for smolts transported from different dams may vary, a weighted sum of site-specific SARs (in LGR equivalents) is computed where the weighting factor is the proportion of all smolts (PIT tagged smolts and unmarked smolts) transported (in LGR equivalents) from the j^{th} dam for the h^{th} hatchery. Because we do not have a measure of the tagging proportion of wild stocks, a modified approach will be illustrated later. For the h^{th} hatchery, the tagging proportion at the hatchery is number of PIT tagged fish released (R_h) divided by hatchery production release (N_h). Under the assumption that PIT tagged and untagged smolts have the same probability of surviving to and being collected at the dams in the hydro system, the following relations are true:

Number of first-time collected h^{th} hatchery smolts at Lower Granite Dam equals

$R_h \bullet S_1 \bullet p_2 = m_{12h}$ for tagged fish
$N_h \bullet S_1 \bullet p_2 = C_{2h}$ for total tagged and untagged fish
$8_h = R_h/N_h = m_{12h}/C_{2h}$ for tagging proportion

Number of first-time collected h^{th} hatchery smolts at Little Goose Dam equals

$R_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet p_3 = m_{13h}$ for tagged fish
$N_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet p_3 = C_{3h}$ for total tagged and untagged fish
$8_h = R_h/N_h = m_{13h}/C_{3h}$ for tagging proportion

Number of first-time collected h^{th} hatchery smolts at Lower Monumental Dam equals

$R_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet (1-p_3) \bullet S_3 \bullet p_4 = m_{14h}$ for tagged fish
$N_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet (1-p_3) \bullet S_3 \bullet p_4 = C_{4h}$ for total tagged and untagged fish
$8_h = R_h/N_h = m_{14h}/C_{4h}$ for tagging proportion

Number of first-time collected h^{th} hatchery smolts at McNary Dam equals

$R_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet (1-p_3) \bullet S_3 \bullet (1-p_4) \bullet S_4 \bullet p_5 = m_{15h}$ for tagged fish
$N_h \bullet S_1 \bullet (1-p_2) \bullet S_2 \bullet (1-p_3) \bullet S_3 \bullet (1-p_4) \bullet S_4 \bullet p_5 = C_{5h}$ for total tagged and untagged fish
$8_h = R_h/N_h = m_{15h}/C_{5h}$ for tagging proportion

From the weighting factor $W_{j-1} = (t_j/C_j)/(n_{1j}/m_{1j})$ used on PIT tagged wild and hatchery chinook, we will show that the preferred approach of weighting site-specific SAR's by t_{jh} can be achieved for the individual hatchery groups. By adding a subscript h to represent an individual hatchery and rearranging terms in the relation $W_{(j-1)h} = (t_{jh}/C_{jh})/(n_{1jh}/m_{1jh})$ to solve for t_j, we obtain the following equality (j=2 for LGR, j=3 for LGS, j=4 for LMN, and j=5 for MCN):

$$t_{jh} = [(W_{(j-1)h}) › (n_{1jh}) › (C_{jh})]/(m_{1jh})$$
$$t_{jh} = [(W_{(j-1)h}) › (n_{1jh})]/8_h$$

The quantity in brackets $[(W_{(j-1)h}) › (n_{1jh})]$ adjusts the number of PIT tagged smolts for hatchery h being transported to the level expected had the PIT tag transport proportion equaled the total (tagged and untagged) transport proportion, while the factor 8_h expands the transport number to total tagged and untagged smolts for hatchery h. The weights t_{jh} are applied directly to the site-specific SAR's (in LGR equivalents) to give the following:

$$SAR(T_0) = \{t_2 \bullet SAR(T_{LGR}) + (t_3/S_2) \bullet SAR(T_{LGS|LGR\text{-}LGR}) + (t_4/S_2S_3) \bullet SAR(T_{LMN|LGR\text{-}LGR}) + (t_5/S_2S_3S_4) \bullet SAR(T_{MCN|LGR\text{-}LGR})\}/\{t_2+(t_3/S_2)+(t_4/S_2S_3)+(t_5/S_2S_3S_4)\}$$

Substituting the equality $t_{jh} = [(W_{(j-1)h}) \cdot (n_{1jh})]/\lambda_h$ into the SAR(T_0) equation, simplifying terms, and multiplying by $\{(1/\Sigma W_i)/(1/\Sigma W_i)\}$ produces the computational equation:

$$SAR(T_0) = \{[W_1 A_{LGR} + W_2 A_{LGS} + W_3 A_{LMN} + W_4 A_{MCN}]/\Sigma W_i\} / \{[W_1 n_{12} + W_2(n_{13}/S_2) + W_3(n_{14}/S_2S_3) + W_4(n_{15}/S_2S_3S_4)]/\Sigma W_i\}$$

When applying the computation equation, we are in theory weighting a linear combination of site-specific SAR's (in LGR equivalents) by the respective total proportion of tagged and untagged smolts being transported at each site (in LGR equivalents) for a given hatchery. Another way to view this is by considering the total population of h^{th} hatchery smolts (tagged and untagged) that are alive at LGR in the transportation category as being partitioned into four strata, one for each dam, with the number of smolts "destined for transportation" at a particular dam being placed into the stratum for that dam. A fish "destined for transport" could still die before arriving at a downstream transportation site or, if tagged, could still be returned to the river for survival estimation purposes. However, whether tagged or untagged, the probability of transport remains the same in the case of a fish "destined for transport."

Because both the weighting factor and site-specific SAR's in the equation for SAR(T_0) are presented in LGR equivalents, a simplification of the equation is possible. For the dams below LGR, the expansion to LGR equivalents stems from the following relations.

$$SAR(T_{LGS|LGR\text{-}LGR}) = (A_{LGS})/(n_{13}/S_2) = S_2 \cdot SAR(T_{LGS})$$
$$SAR(T_{LMN|LGR\text{-}LGR}) = (A_{LMN})/(n_{14}/S_2S_3) = S_2 S_3 \cdot SAR(T_{LMN})$$
$$SAR(T_{MCN|LGR\text{-}LGR}) = (A_{MCN})/(n_{15}/S_2S_3S_4) = S_2 S_3 S_4 \cdot SAR(T_{MCN})$$

Substituting the above relations into the equation for SAR(T_0) and simplifying terms yields the following (note that in the numerator both weights and SAR's are now not expanded to LGR equivalents – only the denominator now has the expansions):

$$SAR(T_0) = \{t_2 \bullet SAR(T_{LGR}) + t_3 \bullet SAR(T_{LGS}) + t_4 \bullet SAR(T_{LMN}) + t_5 \bullet SAR(T_{MCN})\} / \{t_2+(t_3/S_2)+(t_4/S_2S_3)+(t_5/S_2S_3S_4)\}$$

The SAR for Category T_0 fish is meant to provide an overall survival rate for yearling chinook experiencing the LGR-LGS-LMN-MCN transportation program. There is difficulty in obtaining site-specific SAR values when not enough smolts are transported at each site where an estimate is desired. Starting in migration year 2000, we have increased the numbers of study fish transported at LGS and LMN in order to improve our estimation of the Category T_0 SAR. By improving our ability to obtain site-specific SAR's, we in turn are improving the accuracy of the overall SAR for Category T_0.

APPENDIX B

Assignment of Returning Adults to the Study Categories

The following paragraphs give details on the assignment of returning adults to the various study categories. Returning adults were assigned to one of the study categories listed above by their capture disposition code. A seven digit capture disposition code was generated where the value in positions 2 (LGR), 3 (LGS), 4 (LMN), 5 (MCN), 6 (JDA), and 7 (BON) reflected what happened to an individual fish at each subsequent downstream dam. In a given position of the code, reflecting a particular dam, four possible values were available. A value of 0 indicated that the fish was not detected at that site; a value 1 indicated that the fish was detected and returned to the river at that site; a value 2 indicated that the fish was detected and "potentially" transported at that site; and a value 3 indicated that the fish had an unknown outcome (seen only on separator) at that site. Smolts that were detected as morts (most often purposely sacrificed for research purposes) at a site also received the value 3 there, but this has no effect on returning adults assignments.

In order for a returning adult to be assigned to one of the transportation categories, it had to be a first-time detected fish at the transportation site being considered, and actually transported from that site. This is because we want the PIT tag chinook to mimic their unmarked counterpart, and nearly all unmarked fish are transported when they are collected at a Snake River dam. Adults with any of the following capture disposition codes are valid Category T_0 transportation fish: "1200000"; "1020000"; "1002000"; and when full springtime transportation occurs at MCN, "1000200." An example of a transported fish that is not part of the transportation category is a fish with the code "1120000" – this fish is first detected at LGR and then collected again downstream and transported at LGS. All returning adults from smolts detected at an upstream site, and later transported from a downstream site were excluded from the transportation categories. Likewise excluded from the transportation category were those fish that based on the route (coils) detected could potentially have been transported, but were subsequently detected at a downstream dam. An example of a fish detected on the coils leading to the raceways or sample room, but not transported includes fish with a code of "1020010" indicating not transported from LGS because it was detected downstream at John Day Dam (an adult with this code would be assigned to Category C1).

In order for a returning adult to be assigned to Category C_0, it had to migrate in-river past LMN without any prior detection in a bypass system. This includes fish with the following capture disposition codes. Category C_0 contains returning adults with codes of "10001xy" where xy may take any combination of 0 or 1, "10003xy" where xy must have at least one value = to 1, "1000010", "1000011", "1000001", and "1000000." (Exception: when full springtime transportation occurs at McNary Dam, then Category C_0 includes smolts that migrated in-river to the tailrace of MCN without any prior detection in an upstream bypass system.)

In order for a returning adult to be assigned to Category C_1, it had to migrate in-river past LMN with one or more prior detections in a bypass system upstream. This latter category does not reflect what is happening to the unmarked fish, it simply occurs as the result of our returning a portion of PIT tagged fish at each dam for in-river survival estimation. Category C_1 contains fish with the widest range of codes. All that is needed is to be detected at either LGR, LGS or LMN, and not be removed at one of these sites due to transportation, unknown final disposition, or mortality. (Exception: when full springtime transportation occurs at McNary Dam, then Category C_1 includes smolts that migrated in-river to the tailrace of MCN with at least one prior detection in an upstream bypass system.) Assigning fish to this category was the most tedious because of many capture disposition codes possible.

Returning adults not assigned to any study category included those whose migration route as smolts (transportation or in-river) was unknown because they were only detected on the separator at a Snake River dam and never detected again downstream. The returning adults with unknown disposition as smolts were not used in any analyses.

Appendix C

Approach to Bootstrap
Parameter Estimates and Confidence Intervals

We propose to implement a bootstrap approach for estimating parameters and confidence intervals of river reach survivals, smolt-to-adult survival rates (SARs) for various study groups, ratios of SARs, and delayed mortality levels (Ds). In Figure 2.1 of Efron and Tibshirani (1993), the basic bootstrap process is presented. From the dataset of interest, we generate "B" samples, where each sample is obtained by sampling with replacement. For the B^{th} bootstrap sample, we compute all statistics of interest. The statistics of interest include the number of smolts arriving at LGR, river reach survivals, SARs, ratios of SARs, Ds, etc. We would plan to generate at least B=1000 bootstrap samples from each dataset of interest.

To illustrate the approach we will start with hatchery chinook, since the approach for wild chinook is more complicated and will be covered later. There are 55,000 PIT tagged chinook at McCall Hatchery in 2002. Each of these 55,000 chinook has a PIT tag code that uniquely identifies that particular fish. Associated with the unique PIT tag is the fish's individual capture history as a smolt and a designation as to whether or not that fish was detected as a returning adult. From the capture history, we will determine membership in the various study categories for each PIT tag code (see Appendix B). By sampling this population of 55,000 PIT tagged fish with replacement, there are opportunities for the same PIT tag codes to occur in any one bootstrap sample and some PIT tag codes to not show up at all, but in each bootstrap sample there will be 55,000 PIT tag codes, not all unique. If we set B=1000, this process will be repeated 1000 times to create a set of 1000 bootstrap samples, each with its associated set of PIT tag code. Our illustration of approach will start by looking at one single bootstrap sample and all the various parameters that will be estimated for that sample.

In each bootstrap sample, the process of estimating survival components using the CJS mark-recapture methods will take place. We will sum the number of smolts in each cell of the CJS input matrix directly from the capture histories, and apply the closed-form CJS equations to estimate the survival parameters N_1, N_2, N_3, N_4, and N_5. Figure 1 shows the close-form equations for the first three survival parameters (expanding by two additional columns for JDA and BON and two more rows for cohorts 5 and 6 allows the estimation of the next parameters N_4 and N_5). We will use the tallies of smolts with specific capture histories (and removal histories) to obtain the number of smolts in each cell of the CJS input matrix. Capture history codes of migrating smolts defines the detection status at a given dam's bypass/collection flumes. The full capture history code of fish originating above LGR contains seven digits, the first to signify the release and the remaining six to represent all dams with PIT tag detection capabilities. A digit of 0 or 1 is assigned to indicate whether a fish is detected or not at a given dam. For fish detected at a site, but not considered returned-to-river as the next cohort, there are special capture disposition digits created, which cover fish transported, sacrificed, or having unknown disposition.

Therefore at each site, we have fish detected and detected fish that are removed, with the difference between these two groups equaling the number of fish returned-to-river as the next cohort for survival estimation purposes. Let $X_{1AAAAAA}$ denote the number of smolts with a particular capture history, T_j denote the total removals at the j^{th} dam, R_j denote the number of detected fish returned to the river at the j^{th} dam, where A may take on values of 0 (not detected) or 1 (detected). We will sum the following capture histories to create the minimum statistics m_{ij} for the i^{th} cohort and j^{th} dam where j=2 for LGR, j=3 for LGS, j=4 for LMN, j=5 for MCN, j=6 for JDA, and j=7 for BON (each statistic m_{ij} (i>1) is conditioned on size of R_j):

Cohort 1 R_1 = initial release number

$m_{12} = G\ X_{11AAAAA}$
$m_{13} = G\ X_{101AAAA}$
$m_{14} = G\ X_{1001AAA}$
$m_{15} = G\ X_{10001AA}$
$m_{16} = G\ X_{100001A}$
$m_{17} = G\ X_{1000001}$

Cohort 2 $R_2 = (m_{12} - T_2)$ returned to river at LGR

$m_{23} = G\ X_{111AAAA|R2}$
$m_{24} = G\ X_{1101AAA|R2}$
$m_{25} = G\ X_{11001AA|R2}$
$m_{26} = G\ X_{110001A|R2}$
$m_{27} = G\ X_{1100001|R2}$

Cohort 3 $R_3 = (m_{13} + m_{23} - T_3)$ returned to river at LGS

$m_{34} = G\ X_{1A11AAA|R3}$
$m_{35} = G\ X_{1A101AA|R3}$
$m_{36} = G\ X_{1A1001A|R3}$
$m_{37} = G\ X_{1A10001|R3}$

Cohort 4 $R_4 = (m_{14} + m_{24} + m_{34} - T_4)$ returned to river at LMN

$m_{45} = G\ X_{1AA11AA|R4}$
$m_{46} = G\ X_{1AA101A|R4}$
$m_{47} = G\ X_{1AA1001|R4}$

Cohort 5 $R_5 = (m_{15} + m_{25} + m_{35} + m_{45} - T_5)$ returned to river at MCN

$m_{56} = G\ X_{1AAA11A|R5}$
$m_{57} = G\ X_{1AAA101|R5}$

Cohort 6 $R_6 = (m_{16} + m_{26} + m_{36} + m_{46} + m_{56} - T_6)$ returned to river at JDA

$m_{67} = G\ X_{1AAAA11|R6}$

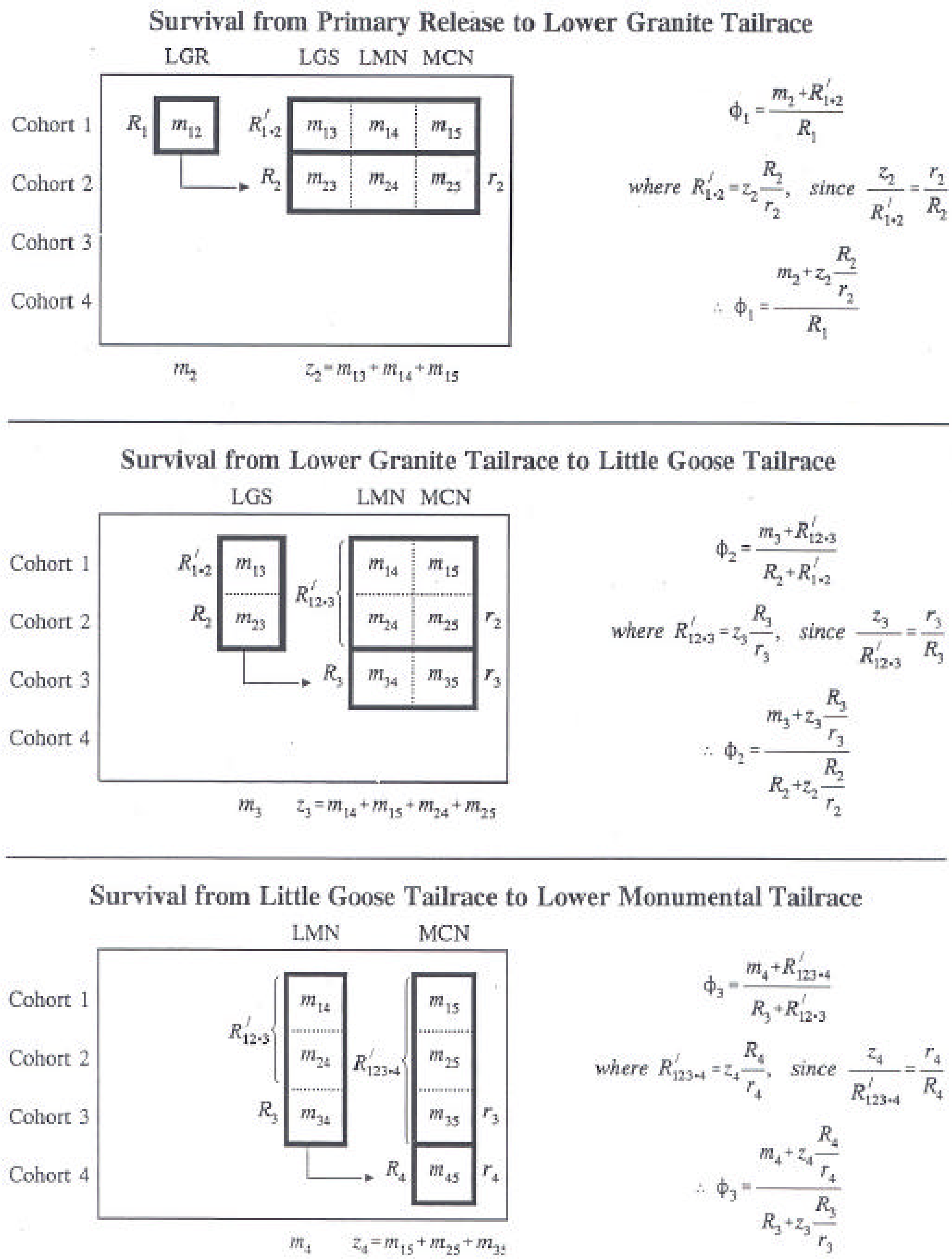

Figure 1. Schematic of CJS capture/recapture methodology showing the minimum sufficient statistics m_{ij} and R_i for the i^{th} cohort and j^{th} site used in estimating survival. (Site 2=LGR; 3=LGS; 4=LMN; and 5=MCN. Expansion to lower Columbia River would added Site 6=JDA and 7=BON with additional cohorts 5 and 6.)

Numbers of smolts in study categories

With the estimates S_i of the survival parameters N_i for i = 1, 2, and 3, we will obtain the estimates required to estimate the number of smolts arriving at LGR "destined" for transport at either LGR, LGS, LMN, or MCN (include MCN only in years with full springtime transportation), "destined" to remain in-river below LMN (or MCN), and "destined" to be detected at a Snake River dam (or MCN) and still remain in-river below LMN (or MCN). Since we are partitioning the population arriving at LGR into these classifications, the ultimate number of fish estimated at these dams or below LMN (or MCN) is expanded back to LGR equivalents to account for the survival rate to these downstream sites. For each bootstrap sample, a new set of numbers of PIT tagged smolts

Definitions of symbols:

X_{12} = number transported at Lower Granite Dam
X_{102} = number first-detected and transported at Little Goose Dam
X_{1002} = number first-detected and transported at Lower Monumental Dam
X_{10002} = number first-detected and transported at McNary Dam
R_1 = number of PIT tags released from hatchery for CSS
$\mathbf{S}_1$ = estimated survival from hatchery release site to Lower Granite Dam tailrace
$\mathbf{S}_2$ = estimated survival from Lower Granite tailrace to Little Goose Dam tailrace
$\mathbf{S}_3$ = estimated survival from Little Goose tailrace to Lower Monumental Dam tailrace
$\mathbf{S}_4$ = estimated survival from Lower Monumental tailrace to McNary Dam tailrace
m_{12} = number of fish first detected at Lower Granite Dam
m_{13} = number of fish first detected at Little Goose Dam
m_{14} = number of fish first detected at Lower Monumental Dam
m_{15} = number of fish first detected at McNary Dam
d_2 = number of fish removed at Lower Granite Dam regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_3 = number of fish removed at Little Goose Dam regardless of prior capture history (includes transported fish, site-specific mortalities, and unknown disposition fish)
d_4 = number of fish removed at Lower Monumental Dam regardless of prior capture history (includes transported fish, site-specific mortalities, unknown disposition fish, and fish accidentally removed at Lower Monumental Dam and used in NMFS survival study at Ice Harbor Dam)
$?_0$ = site-specific removals at dams below Lower Monumental Dam of fish not detected previously at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
$?_1$ = site-specific removals at dams below Lower Monumental Dam of fish previously detected at a Snake River Dam (includes incidental fish transported at McNary Dam, fish purposefully removed and sacrificed at downstream dams for the UICFWRU study, and fish accidentally removed at John Day Dam and used in NMFS survival study at The Dalles Dam)
Note: both $?_0$ and $?_1$ are inflated by a constant factor of 2 to offset the approximate 50% survival rate to the lower Columbia River of fish starting at Lower Granite Dam

in each study category (Categories T_0, C_0, and C_1) is computed based on that bootstrap sample's set of survival estimates using the following formulas.

In years without springtime transportation at McNary Dam, we will consider Category T_0 to include only fish transported at LGR, LGS, and LMN, even though low numbers of wild and hatchery spring/summer chinook and steelhead production fish will be transported later in the summer when MCN transportation operations resume.

$$T_0 = X_{12} + X_{102}/\mathbf{S_2} + X_{1002}/\mathbf{S_2 S_3}$$

In years when springtime transportation of both marked and unmarked production smolts occurs at McNary Dam, we will include all four transportation sites.

$$T_0 = X_{12} + X_{102}/\mathbf{S_2} + X_{1002}/\mathbf{S_2 S_3} + X_{10002}/\ \mathbf{S_2 S_3 S_4}$$

(Note: the above is total number of PIT tagged smolts transported in LGR equivalents; the computation of SAR_{T0} will use weighting as described below and Appendix A]).

In years without springtime transportation at MCN, Category C_0 will encompass the "unseen" population (no prior passage through bypass systems at upstream dams) surviving to the tailrace of LMN and convert to LGR equivalents.

$$C_0 = R_1\mathbf{S_1} - (m_{12} + m_{13}/\mathbf{S_2} + m_{14}/\mathbf{S_2 S_3}) - 2?_0$$

In years with regular transportation throughout the springtime at MCN, we will estimate the "unseen" population further downstream to the tailrace of MCN and convert to LGR equivalents.

$$C_0 = R_1\mathbf{S_1} - (m_{12} + m_{13}/\mathbf{S_2} + m_{14}/\mathbf{S_2 S_3} + m_{15}/\mathbf{S_2 S_3 S_4}) - 2?_0$$

In years without springtime transportation at MCN, Category C_1 will encompass the "detected" population (detected in one or more bypasses) surviving to the tailrace of LMN and converted to LGR equivalents.

$$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/\mathbf{S_2} + (m_{14} - d_4)/\mathbf{S_2 S_3} - 2?_1$$

In years with regular transportation throughout the springtime at MCN, Category C_1 will encompass the "detected" population (detected in one or more bypasses) surviving to the tailrace of MCN and converted to LGR equivalents.

$$C_1 = (m_{12} - d_2) + (m_{13} - d_3)/\mathbf{S_2} + (m_{14} - d_4)/\mathbf{S_2 S_3} + (m_{15} - d_5)/\mathbf{S_2 S_3 S_4} - 2?_1$$

<u>"D" estimate.</u>

In addition to the estimated survivals used to expand smolt numbers to LGR equivalents, there is the need to generate, in each bootstrap sample, a reach survival estimate from

LGR tailrace to Bonneville Dam tailrace, V_C . Since in-river survival is only estimated to the tailrace of John Day Dam, the further expansion to Bonneville Dam is based on using a LGR-JDA "per mile" survival rate for the extra 69.5 miles from JDA to BON. When reliable estimates of survival to JDA are unattainable, then a LGR-MCN "per mile" survival rate will be used on the extra 146 miles from MCN to BON. This survival component is used with the inriver migrating Category C_0 fish, while a fixed survival rate of $V_T = 0.98$ is used for transportion Category T_0 fish. These reach survival rates are divided into their respective 'LGR-LGR' SAR to create a 'BON-LGR' SAR for each study category as follows:

$$D = (\text{LGR-LGR } SAR_{T0}/V_T)/(\text{LGR-LGR } SAR_{C0}/V_C) = (\text{BON-LGR } SAR_{T0})/(\text{BON-LGR } SAR_{C0})$$

The adult counts that go into the SARs in each bootstrap sample will come directly from the set of PIT tags in the bootstrap sample, where tags with returning adults have code 1 and tags with no returning adults have code 0. The same capture history and disposition codes that were used to assign PIT tagged smolts to the various study categories will be used to assign the adults (see Appendix B for details).

Total transportation SAR

In addition to estimates of site-specific SAR's for each transportation dam, we will compute an overall aggregate transportation SAR across the dams operating in the transportation mode during the springtime season.

In years without springtime transportation at McNary Dam, we will consider Category T_0 to include only fish transported at LGR, LGS, and LMN, even though low numbers of wild and hatchery spring/summer chinook and steelhead production fish will be transported later in the summer when MCN transportation operations resume.

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

In years when springtime transportation of both marked and unmarked production smolts occurs at McNary Dam, we will include all four transportation sites.

$$SAR(T_0) = \{t_2 \bullet SAR(T_{LGR}) + t_3 \bullet SAR(T_{LGS}) + t_4 \bullet SAR(T_{LMN}) + t_5 \bullet SAR(T_{MCN})\} \\ /\{t_2+(t_3/S_2)+(t_4/S_2S_3)+(t_5/S_2S_3S_4)\}$$

Note that in each $SAR(T_0)$ equations above, both the t_j weights and SAR's in the numerator are not expanded to LGR equivalents; only the t_j weights in the denominator are expanded (see Appendix A for rationale). Using the computation weighting factor W_{j-1} from Appendix A, the individual weights t_j arise from the relation $W_{j-1} = (t_j/C_j)/(n_{1j}/m_{1j})$, where j=2 for LGR, j=3 for LGS, j=4 for LMN, and j=5 for MCN). Rearranging terms of the weight gives

$$t_j = [(W_{(j-1)}) \rangle (n_{1j}) \rangle (C_j)]/(m_{1j})$$
$$t_j = [(W_{(j-1)}) \rangle (n_{1j})]/8$$

The quantity in brackets [($W_{(j-1)}$)›(n_{1j})] adjusts the number of PIT tagged smolts being transported to the level expected had the PIT tag transport proportion equaled the total (tagged and untagged) transport proportion, while the factor 8 expands the transport number to total tagged and untagged smolts for a given hatchery. When working with wild chinook groups, the factor 8 is not available (it is omitted by being set to 1).

In-river SAR (Category C_0 and C_1)

SAR(C_0) = returning adults in C_0/estimated number of smolts in C_0 in LGR equivalents.

SAR(C_1) = returning adults in C_1/estimated number of smolts in C_1 in LGR equivalents.

Ratio of key SARs

The two ratios of key SAR to be computed include the following:

SAR(T_0)/SAR(C_0) and SAR(C_1)/SAR(C_0)

Confidence intervals for the parameter estimates:

All of the above parameters of interest, survival estimates, D values, SARs, and ratios of SARs will be computed for each individual bootstrap sample. From the 1000 bootstrap samples, we will compute the averages and variances for each parameter of interest. We will compute a test for skewness (Snedecor and Cochran, 1989, 8th Ed. of Statistical Methods) on each parameter of interest to see if normality is achieved over the 1000 bootstrap samples. If normality is achieved, we will compute a 95% percent confidence interval using the conventional ±1.96*Standard Error of the Mean to define bounds. Since the distribution of the ratios of binominal SARs is expected to be lognormal, as well as that of the D's, we would take logarithms on these values before testing for normality. Confidence intervals computed on the transformed data would be transformed back to the original scale by taking the anti-logarithm on the transformed confidence interval points. In all cases, a nonparametric 95% confidence interval will also be computed. The 95% confidence interval is obtained by first ordering the resulting 1000 values of each parameter of interest in ascending order and then selecting the values in the 25th and 976th rank order positions as the lower and upper limits of the confidence interval, respectively, for that parameter.

Estimates for aggregates of hatcheries:

The above description illustrates the approach used on a single hatchery population. We also will be summarizing the hatchery data at the level of aggregates across the study hatcheries in a given year for the purpose of making comparisons with the annual aggregate wild chinook results. Since hatchery production varies greatly among the CSS hatcheries, it is important to properly weight the hatchery specific SAR data in order to obtain an annual SAR estimate that is comparable to what is computed for wild chinook. For the same reasons that weighting was needed in the estimation of the Category T_0 to reflected the magnitude of transportation occurring at each dam, there is the need for weighting to reflect the magnitude of each hatchery in the final aggregated group. For the CSS hatchery chinook groups, the sum of the estimated number of tagged and untagged smolts "destined for transportation" at each dam provides the preferred weighting factor for Category T_0 fish. For Categories C_0 and C_1 fish, the estimated number of tagged and untagged smolts "destined to be migrate in-river to LMN tailrace, undetected and detected, respectively, are divided by the hatchery-specific factor λ_h to produce the preferred weighting factor. The concept of "destined to …" is taken into account through the expansion of smolt numbers into LGR equivalents.

We will also compute the ratios of weighted SARs for the hatchery chinook aggregate. The use of weighted SARs of the hatcheries in the aggregate will make the results more comparable to the already aggregated wild chinook. In the summarization of SARs and ratios of SARs across years, geomeans (unweighted natural logarithmically transformed data) will be used based on general findings of Peterman (1981) when working with SAR data.

Special considerations for wild smolts

At the start of this appendix, we stated that we would first illustrate our bootstrap approach with hatchery chinook, since the approach for wild chinook is more complicated and will be covered later. Now we will cover those differences that require special handling in our bootstrap approach for wild chinook.

First, the method of obtaining the starting population of PIT tagged fish at LGR differs between the hatchery and wild chinook. The starting number of hatchery chinook at LGR ($m_{12}=R_1S_1$) is obtained directly from the CSJ model, but not that of wild chinook. The starting population for wild chinook requires the estimation of collection efficiency at LGR, and this collection efficiency in turn is used to expand PIT tagged numbers detected at LGR into an estimate of total PIT tag numbers of undetected and detected smolts. The same method as used by NMFS (Sanford and Smith 2001) is used for the wild chinook in the CSS study. From daily PIT tag detections at LGS, the proportion of previously detected PIT tagged wild chinook (adjusted for site-specific removals) is estimated as this collection efficiency. For smolts in Category C_0, the estimated starting population of PIT tagged smolts at LGR is the critical component in the estimation process. Category C_0 smolt numbers are estimated by:

$$\text{Hatchery chinook } (C_0) = m_{12}/p_2 - (m_{12}+m_{13}/S_2+m_{14}/S_2S_3)$$
$$\text{Wild chinook } (C_0) = \Sigma(m_{12k}/p_{2k}) - (m_{12}+m_{13}/S_2+m_{14}/S_2S_3)$$

where m_{1j}=first-time detected PIT tagged fish collected at j^{th} site (j=2 for LGR, j=3 for LGS, j=4 for LMN, and j=1 used to reference release site); $m_{1jk}= m_{1j}$ on k^{th} day; p_2= collection efficiency at lgr; $p_{2k}= p_2$ on k^{th} day; S_j=survival from j^{th} site tailrace to $(j+1)^{th}$ site tailrace (S_1=release site to LGR tailrace, S_2=LGR tailrace to LGS tailrace, and S_3=LGS tailrace to LMN tailrace).

For hatchery chinook, the formula $R_1S_1 = m_{12}/p_2$ gives equivalent formula for estimating the LGR starting population. The LGR starting population for wild chinook is estimated by $G(m_{12k}/p_{2k})$, where summation is over the days of the migration period. These two estimators m_{12}/p_2 from the C-S-J model and $G(m_{12k}/p_{2k})$ from the daily estimation method are simply two different estimators trying to arrive at the same starting population size at LGR. To verify that these two estimators are producing similar population estimates, we will apply each estimator to the hatchery chinook in the bootstrap samples.

The formula for estimating the numbers of PIT tagged wild chinook in Categories C_1 and T_0 are the same as shown earlier for hatchery chinook, however, the estimates are for a particular weekly cohort of wild chinook as opposed to a particular hatchery. The aggregation of the set of weekly cohorts to the total wild PIT tagged population requires some additional steps, which will be discussed next.

Typically, the set of weekly cohorts of wild PIT tagged chinook must be aggregated first to a seasonal total before estimation of SARs are possible. This is due to the lower number of PIT tagged chinook smolts available and corresponding smaller number of returning adults compared to the hatchery fish being used. In the past, we obtained annual survival components by weighting estimated survivals across the cohorts, using the proportion of relative variance and weekly passage indices as the weighting factor. Then the number of smolts in each study category was estimated at the aggregate level and a single aggregate wild chinook SAR estimated for each study category C_0, C_1, and T_0 directly at the aggregate level. In the bootstrap approach we will compare the results of estimating all parameters for each cohort separately and then aggregating these results by weighting by the proportion of PIT tagged smolts in each cohort (stratified sampling approach) with the results of obtaining all parameter estimates directly on the annual aggregate of cohorts. The relative variances used to obtain the weighted average survival components will come from each cohort's bootstrapped estimate of variance.