An Alternative Technique to Quantify the Incidental Take of Listed Anadromous Fishes at the Federal and State Water Export Facilities in the San Francisco Bay-Delta Estuary

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EXECUTIVE SUMMARY

In the National Marine Fisheries Service's (NMFS) final biological opinion and conference opinion based on their review of the proposed long-term operations of the Central Valley Project (CVP) and State Water Project (SWP) water pumping facilities in the San Francisco Bay- Delta estuary, NMFS called for point and interval estimates of the loss of Endangered Species Act-listed anadromous fishes to project operations. This report addresses these estimates.

Fish enter the CVP and SWP fish collection facilities guided by arrays of louvers that concentrate the fish into holding areas from which they are transported by trucks to the western edge of the estuary for release. At both CVP and SWP facilities, a large (≅25%) fraction of the daily fish salvage is identified, counted, and measured from samples taken approximately every two hours. These counts are then expanded by the inverse of the fraction of export-pumping time that each represents. Using salvage data from water year 2009, a general method is provided here for estimating the standard error of the expanded salvage. Standard errors were roughly 7-15% of the salvage, giving 95% confidence limits <± 30%.

To estimate fish loss from the expanded salvage, it is first necessary to estimate the efficiency with which the fish are salvaged. As part of this effort, the available literature on field estimates of survival (1-loss) rates of salmonid fishes at both facilities was reviewed. Estimates of overall survival rates of fish within the influence of the projects were more useful than estimates of louver efficiency within the facilities themselves. Disappearance of experimentally released fish (presumed due to predation) within and in front of the facilities has been found to be a major source of mortality of out-migrating salmonids as well as a source of error in both general types of survival estimate. The author found or calculated the precision of survival estimates or of louver efficiency estimates when necessary. The precision of these estimates was as good as, or nearly as good as those for the expanded salvage. However, questions about experimental accuracy, including doubts about the applicability of experiments using hatchery fish, as well as unknowns as to the intensity and spatial extent of prescreen predation place a greater amount of uncertainty on the loss estimates than those that derive from expanding salvage or from variability in experimental results.

Also reviewed was the literature on the currently used method of chinook salmon (hereafter, chinook) run assignment. Essentially, the method uses the size of a fish to estimate its date of emergence, from which the spawning run can in principle be inferred. This method relies on a table of length-at-date for four runs of Central Valley chinook within the Delta, based on a poorly documented growth curve (the "Delta Model"). Genetic studies have shown the method to be inaccurate in the Delta, particularly when applied to winter-run chinook. Moreover, the author finds that the original purpose of the general technique was to identify broad groups of fish by graphing their length-frequency distributions by date, not to assign individual fish to runs. The method was nonetheless applied, as there is no alternative available for separating out winter- and spring-run chinook counts from the database. Without independent information on the identity of the fish, a statistical evaluation of the accuracy of the Delta Model is not possible.

Finally, while the methods recommended here can in principle be applied to green sturgeon, lack of parameter estimates prevent a precise application at present. Small numbers of green sturgeon have been salvaged at the projects in most years (none in 2009) since species identification of young green sturgeon became standardized (1993). An approximate estimate, without confidence limits, puts the median annual green sturgeon loss at <300 fish. The loss of green sturgeon to the projects is probably not zero, because some fish are salvaged in most years. Moreover, a small fishery exists for the rather similar, but more abundant, white sturgeon in San Luis Reservoir and its forebay, the apparent result of juvenile white sturgeon passing through the louvers due to water exports by the projects.

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Table of Acronyms and Abbreviations

BR	Bypass ratio (bypass velocity/approach velocity)
CCF	Clifton Court Forebay
CVP	Central Valley Project (Federal)
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
ESA	Federal Endangered Species Act
NMFS	National Marine Fisheries Service
OCAP	Operations Criteria and Plan for CVP and SWP
PIT	Passive integrated transponder
RPA	Reasonable and Prudent Alternative
SFPF	J. E. Skinner Delta Fish Protective Facility (SWP, DWR)
SWP	State Water Project (California)
TFCF	Tracy Fish Collection Facility (CVP, USBR)
USBR	U. S. Bureau of Reclamation
cfs	cubic feet per second
df	degrees of freedom
lcl	lower confidence limit
ucl	upper confidence limit

1 INTRODUCTION

1.1 Origin of this study

Under Section 7 of the federal Endangered Species Act, (ESA, 7 U.S.C. § 136, 16 U.S.C. § 1531 et seq), Federal agencies (and their designated partners) which authorize, fund, or carry out actions are required to consult with the National Marine Fisheries Service (NMFS) to ensure that their actions are not likely to jeopardize the continued existence of ESA-listed species or result in the destruction or adverse modification of designated critical habitats.

The U.S. Bureau of Reclamation consulted with NMFS on its proposed long-term 'Operations Criteria and Plan' for the U.S Bureau of Reclamation's federal Central Valley Project and the California Department of Water Resources' (DWR's) State Water Project (' CVP/SWP operations'[1] – the 'proposed action') in California's Trinity River, Central Valley and the San Francisco Bay-Delta estuary ecosystem.

Among many actions, both of these water projects pump water from the San Francisco Bay-Delta estuary for use south and west of the Delta, mainly in the San Joaquin Valley and southern California.

NMFS found that the 'proposed action' was, in fact, likely to jeopardize ESA-listed species under NMFS' jurisdiction, which included the endangered Sacramento River winter-run Chinook salmon, threatened Central Valley soring-run Chinook salmon, threatened Central Valley steelhead, and the Southern Distinct Population Segment of North American green sturgeon. NMFS developed a 'Reasonable and Prudent Alternative' (RPA) to the proposed action, which included 72 specific measures designed to reduce the impacts of CVP/SWP operations on the ESA-listed species and their designated critical habitats to levels which will not contribute to the species' further jeopardy – or, in the case of this study, to more clearly define the impact of such operations on the ESA-listed species

Implementation of these measures is non-discretionary and must be implemented by Reclamation and DWR in order (among other things) for the continuance of NMFS'

[1] CVP/SWP operations are integrated, for the principal purpose of meeting the water quality standards laid down in California State Water Resources Control Board's 1978 Water Right Decision 1485, pursuant to the 1985 'Agreement Between the United States of America and the Department of Water Resources of the State of California for Coordinated Operation of the Central Valley Project and the State Water Project'. The Agreement produced the joint CVP/SWP 'Operations Criteria and Plan' ('OCAP') which was the basis of NMFS' review and the final biological opinion and conference opinion (NMFS 2009) discussed here. While technically the U.S Bureau of Reclamation is the 'action agency' and the Department of Water Resources the 'applicant', the operations of the two agencies are effectively joined, and the requirements laid down in NMFS' OCAP opinion apply to both agencies and their water diversion projects.

permission for the projects' 'incidental take' of the ESA-listed species under ESA Section 7(o)(2).

NMFS' 2009 final OCAP biological opinion explicitly states, under its 'Terms and Conditions' (T&C), at page 783 that:

> '2. Reclamation shall seek to develop an alternative technique to quantify incidental take of listed anadromous salmonid species at the Federal and State export facilities.
>
> a. In coordination with NMFS, Reclamation shall select and fund an independent contractor to determine the best technique to quantify incidental take of winter-run, spring-run, CV steelhead, and the Southern DPS of green sturgeon at the Federal and State export facilities. Reclamation shall submit a final report to NMFS by December 31, 2010, summarizing the recommendations for quantifying incidental take, with the selection of a proposed technique. The technique for quantifying take shall be implemented immediately upon NMFS' concurrence. In the event that this measure is not implemented immediately and reflected in the annual report per term and condition 3.a. below, <u>take authorization for CV steelhead shall cease on December 31, 2011</u>.' [emphasis added]

Despite the clear and compelling language in term and condition 2.a, Reclamation did not initiate development of an alternative technique to quantify the incidental take of the ESA-listed anadromous salmonid species and green sturgeon at the Federal and State water export facilities. Instead, NMFS identified funds of its own to assist Reclamation in meeting the requirements of the T&C, and contracted for it to be performed by Ocean Associates, Inc. of Arlington, VA. Ocean Associates, in turn, subcontracted with Kier Associates to perform the task.

1.2 Task List

Ocean Associates included the following items in Task Order (TO) 3062:

1 Review the Delta Division section of the NMFS Opinion that pertains to the direct and indirect effects of the export facilities (pages 314-385), and the literature cited in that section.

2 Coordinate with Reclamation and the California Department of Water Resources (DWR) to obtain the calculations, and rationale, currently used to determine expanded salvage and calculated loss (loss is what is currently considered incidental take at the Federal and State Facilities) of the listed anadromous fish species at the Federal and State facilities.

3 Using the best commercial and scientific information available, develop a statistically robust technique to quantify incidental take of the listed anadromous fish species at the Federal and State fish facilities, while taking into consideration the direct and indirect effects identified in the Delta Division section of the NMFS Opinion.

4 In developing the method(s) used to quantify incidental take at the pumps, the subcontractor shall assess the degree of uncertainty contributed by the following factors (and others as appropriate):

a. Predation in Clifton Court Forebay (for the SWP facilities) and in channels within the SWP and CVP fish facilities.

b. Louver efficiency.

c. Expansion of counts of salvaged fish.

5 Run identification using length-at-date criteria (applicable to Chinook salmon only).

6 The technique(s) developed to quantify take should be able to provide a point estimate and confidence interval (or some appropriate measure of “center” and “spread”) of take for the listed species taken at the fish facilities. The subcontractor may recommend different quantification techniques for different species, or perhaps different techniques for different times of year (either between or within species).

7 If multiple techniques are developed [Note: they were not, one general technique with parameters specific to each species and facility is presented; the parameters can and should be changed as new conditions arise and/or new information becomes available], the subcontractor shall describe the advantages and disadvantages of each technique, and recommend one technique (per species) for implementation. The documentation for each technique shall include assumptions, data sources, and key areas of uncertainty. Any limitations or potential errors that may reduce the accuracy, certainty, and reliability of the incidental take estimates shall be clearly identified.

8 To the extent possible, each factor used to quantify take (predation, louver efficiency, *etc*.) should itself be quantified with a point estimate and confidence interval. The subcontractor shall provide an estimate of how uncertainty in the final point estimate may be attributed to the factors that affect take (*e.g*., W% of the uncertainty in the final take estimate comes from uncertainty in the expansion term, X% comes from uncertainty in louver efficiency, Y% comes from uncertainty in run identification, and Z% comes from uncertainty in predation rates).

1.3 Approach

The author reviewed the available literature (Task 1) and had conversations with Brent Bridges and Cathy Karp of the Bureau of Reclamation (USBR), Dan Odenweller [retired, California Department of Fish and Game (DFG) and NMFS), Jerry Morinaka and Geir Aasen (DFG), and Kevin Clark, Javier Miranda, Teresa Geimer and others at DWR. Brent Bridges gave the author a thorough tour of the fish salvage facility at Tracy and answered several follow-up questions about louver system operations and on-going research, as did Kevin Clark and Javier Miranda at the State facility. Dan Odenweller kindly shared his library and described the evolution of the currently used loss calculator for chinook salmon. Geir Aasen helped the author obtain access to the joint CVP/SWP fish salvage data, and David Swank of NMFS extracted complete sampling effort data from the salvage database. Bill Kier researched and described the project background and edited the report. Two drafts of this report were reviewed by personnel from NMFS, USBR, and DWR.

This report presents the author's attempt to estimate the quantity and confidence limits of the loss of wild Central Valley steelhead and wild, tentatively-identified winter- and spring-run chinook salmon through a simple statement of the problem, a formal equation of this statement, and an analysis of available literature to obtain point estimates and uncertainties of the parameters necessary to apply the loss equations to data. The equation is then applied to salvage data from the State and Federal projects for water year 2009 as an example. This year was chosen because it is the most recent for which final data were available, and that therefore was most likely to represent current methods of facility operations and data acquisition. This report is explicitly not a model of population effects, nor is it an exhaustive treatment of possible indirect mortality in the south Delta. Green sturgeon loss can in principle be estimated by the same methods described in detail here for the salmonids, but absence of parameter estimates hamper the calculation at present. Recommendations, general as to methods and specific as to desired results, are made for future studies to fill the knowledge gaps identified here.

1.4 Setting

The Sacramento River, the San Joaquin River, and streams draining the western slope of the Sierra Nevada in between these major rivers all meet in California's Central Valley in a network of channels and islands popularly referred to as ‘the Delta’ (Figure 1). Anadromous fishes use the Delta as a migratory pathway between their home streams and the Pacific Ocean and as rearing habitat (Moyle 2002, NMFS 2009, Williams 2006). The species of concern here are Central Valley steelhead (*Oncorhynchus mykiss*) winter-run and spring-run chinook salmon (*O. tshawytscha*), and green sturgeon (*Acipenser medirostris*), all of which are protected under the federal Endangered Species Act (ESA). The immediate concern for these species in the context of this report arises from CVP/SWP operations in the southwest Delta near an elbow-like bend in Old River, between what Brandes and McLain (2001) refer to as (the north-south trending) Lower Old River and (the more-or-less east-west trending) Upper Old River. Old River is a highly modified, riprapped channel in the south Delta that connects to the San Joaquin River at either end, although the connection is modified and managed at its east end (Brandes and McLain 2001). The SWP and CVP pump large volumes of water from the Delta into canals to be delivered to municipal, agricultural, and wildlife refuge end users south and west of the Delta. To save fish from following the water, fish salvage facilities were built for both projects.

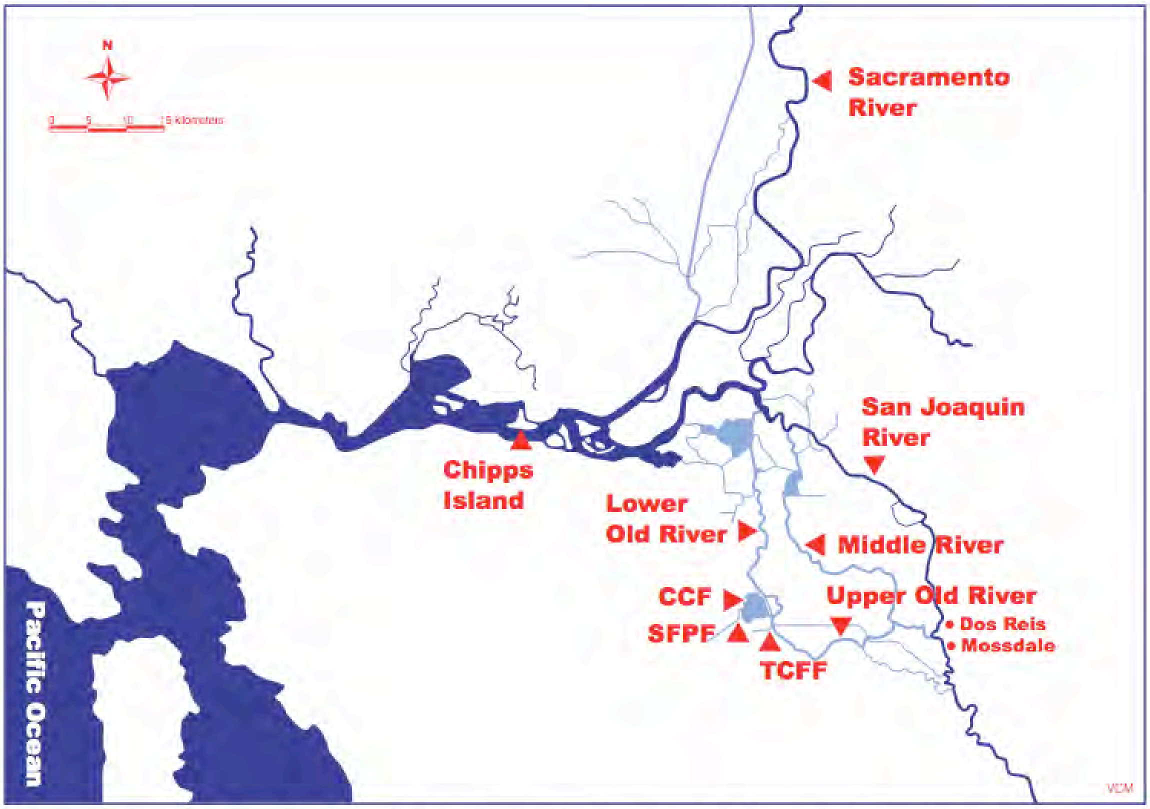

Figure 1. Map of the San Francisco Estuary showing locations of places and facilities mentioned in the text. SFPF and TCFF are, respectively, the State and Federal fish facilities.

1.5 Statement of Problem

1.5.1 Direct loss

The fish salvage facility at the CVP pumping plant is based on a behavioral barriers approach developed through intensive studies of fish reaction to louvers (Bates 1960, Skinner 1974). Hallock et al. (1968), writing about the CVP fish facility, described the fish salvage system, and system-related direct loss factors, as follows:

> The screen system includes a primary louver system designed to divert fish into any of four bypasses. The bypasses, of necessity, carry so much water that a secondary louver system is used to get most of this water back into the canal and divert the fish into a collection chamber from which they are transferred to tank trucks and transported to a place where water currents will not take them back to the screen.
>
> To be successfully screened and returned to live in the Delta or to migrate out of it, a fish must:
>
> 1. Be diverted by the primary louver system into one of the bypasses.
> 2. Be diverted by the secondary louver system into the collection system.

3. Survive crowded conditions in the collector – often with large quantities of trash which also get bypassed.

4. Survive the truck ride.

5. Be released uninjured in a place where it has a good chance to escape predators and find an ecology suited to its needs.

The proportion surviving the entire experience is the product of the proportions surviving each of the individual experiences.

In the sections to follow, some of these factors are combined as necessitated by availability of appropriate estimates of their magnitude and uncertainty. The SWP fish facility was built to a similar, but not identical, design based on the same studies of louver efficiency (DWR/DFG 1973). A key difference between the two facilities is the presence of the large (≈9 km^2) Clifton Court Forebay (CCF) at the SWP, with closeable gates that allow export pumping to be less restricted by the tidally changing elevation of the surface of Old River. As described below, studies at the CCF have demonstrated and estimated a further loss factor – mortality due to predation by piscivorous fish and birds in the forebay, before the fish encounter the salvage facility. This factor has been termed "pre-screen loss." Pre-screen loss undoubtedly occurs to some unknown extent at the CVP as well. There are other differences between the two facilities, including multiple primary louver bays with closeable gates at the newer SWP. Survival parameters should not be assumed to be identical at the two facilities, even though in some cases SWP values are substituted for missing CVP values, which amounts to a mathematical assumption pending proper, site-specific parameter estimates.

In section 3, adjustments will be made where appropriate to survival rates at CVP for losses expected as a result of the cleaning operations. These operations were described in an unpublished communication to NMFS (Bridges 2008) as follows:

> The primary louver system is 320 ft long and consists of 1-inch wide louver panels arranged at a 15^o angle to flow across the intake channel. There are 4 bypasses spaced every 73 ft. Each bay contains one bypass and the nine louver panels directly upstream of it. To clean the primary louvers (composed of 36 panels 8 ft wide and 23 ft tall) one panel at a time must be lifted, spray washed clean, and then lowered back into the water. Cleaning of one panel takes on average 129.3 seconds to accomplish [based on data compiled from November through June, 2003 through 2005] While a louver panel is out of the water, there is less hydraulic resistance to flow through the bay being cleaned, with the result that surface elevation in the bay is reduced and average water velocities at the entrance to the bay are increased. The large hole in the primary louver system allows fish the opportunity to swim through and travel downstream to the Tracy Pumping plant. In addition, each one of the four bypasses is closed when one of the nine louver panels immediately upstream are being lifted. This prevents plant debris that sloughs off the lifted panels from traveling downstream into the bypass. Consequently, weak swimming fish that would have normally been salvaged by the ... bypass could potentially be swept through the louvers if they cannot hold their position in the current. During salmonid season, defined by

> [Bridges] as Nov 1 to June 30 for this model only, the primary louvers are cleaned approximately once daily and each cleaning cycle takes on average 129.7 minutes to complete...
> The secondary louvers are cleaned with a different technique than the primary louvers because of their smaller size. The secondary channel is shallow, usually less than 7 ft deep, is only 8 ft wide, and can be completely dewatered easily by turning off the primary bypass tubes 1, 2, 3, and 4. During the dewatering process, the debris rolls down the louver panels and is condensed into a pile at the base of the louvers as water levels recede. Diversion workers must then enter the secondary channel to remove the debris by hand. Consequently, the secondary channel is dewatered daily at approximately 10 AM to dig off the debris at the base of the louvers. The secondary cleaning process is performed once daily and requires approximately 49.3 minutes to complete.

1.5.2 Indirect loss

Among the "action elements" analyzed by NMFS (2009), the one pertinent to the present effort is "Exports from the CVP and SWP water diversions facilities which include changes in delta hydrodynamics, direct entrainment of listed fish at the project facilities, and indirect mortality within the delta related to exports and non-export factors." Non-export factors are not within the scope of this report. However, as the foregoing mention of pre-screen loss indicates, there is no logical bright line between direct effects within the fish screening facilities and predation effects within and near them. As demonstrated by Kimmerer (2008), uncertainties and unknowns concerning these near-field predation effects rank among the leading impediments to accurate and precise fish loss estimates attributable to CVP/SWP operations. There are two main reasons given in NMFS (2009) to question the accuracy of pre-screen loss estimates: naivety of tagged hatchery experimental subjects, and potential exit of tagged fish from the study area (sometimes called "non-participation"). The fate of experimental subjects that do not end up in the salvage is unknown but generally assumed to represent loss in the experimental results. Especially under low-flow conditions, fish can leave the area in which they are introduced and swim into Old River, or even into the other project (CVP to SWP and vice versa). Clark et al. (2009) and USBR (in comments on earlier drafts of this report) have suggested that such non-participating fish be excluded from the loss side of the survival estimate, resulting in higher estimated survival and smaller loss estimates. However, the lack of a reasonable definition of the near-field entrainment zone, and the near absence of predation studies outside the physical boundaries of the CVP/SWP facilities, give rise to the possibility that all existing loss estimates are biased low. In acknowledgement of such uncertainties, a range of survival parameter estimates incorporating plausible values derived from experiments were used for the loss estimates presented here; no choice of "best" estimate is implied for any of these. Better experiments, in which the fate of telemetrically tagged fish is more completely known, are clearly in order.

2 Methods

2.1 Fish Salvage Data

As described in the introduction, the screening systems at both the CVP and SWP fish facilities are designed essentially to "strain"[2] fish out of the flow of water on its way to the export pumps and to truck them to the western Delta, beyond the pull of the pumps. The counting system originated as an effort to gauge the oxygen demand of the catch to insure safe conditions during transport (Dan Odenweller, personal communication). The counting effort has evolved through the years such that in 2009, 10- to- 30- minute counts were generally taken every two hours (sometimes more often, especially at SWP; at SWP, a few counts were of 5-minutes duration, but these were on an hourly basis over short periods, such that the fraction of pumping time represented by any given sampling unit was always $\geq 1/12$). Under normal conditions, every fish in the sample is identified and counted, and a fraction including all salmonids are measured. (Under high debris loads or very high fish entrainment rates, some fish may be missed, but there do not appear to be estimates of the severity or frequency of such conditions). The count data are stored along with flow, temperature, and other operational data, including the sampling duration and the duration of pumping associated with each sample. Another table in the database contains the length data along with the presence/absence of a dorsal adipose fin-clip indicative of hatchery-reared salmonids. An electronic supplement to this report contains the data used – both in the form received and in its final format.

During data processing, the ratio of the pumping duration to the sampling duration is used to expand the count data to an estimate of the number of fish salvaged in each two-hour time period. Karp et al. (2008) used rank-correlation of 210 pairs of ten-minute samples and 110-minute samples to test for a bias in the expansion procedure and concluded that it was unbiased. That these authors resorted to a non-parametric method is indicative of the variance in their two data sets. Estimating the uncertainty involved in the count expansion is one of the tasks addressed in the present report. In addition to the regular samples there are occasional predator removal events during which all fish are counted. The counts from predator removal events do not need expansion and thus, though part of the salvage totals, have no sampling error and play no part in the uncertainty of the estimated salvage.

After extraction into flat files, the data were worked up in the spreadsheet program Microsoft Excel[3] to expand the salmonid counts for each sample and to sort the fish into categories by size and fin clip as appropriate. The database stores only catches, so to calculate the sample variance of the regular sampling data, zeros were inserted (as described below) for sampling times for which the species category of interest was not recorded. Fish numbers vary seasonally and even within seasons, so initially a stratification scheme (Cochran 1977) based on month was used in an effort to derive an

[2] The barriers at these projects are behavioral, not physical. Except for very large fish, words line "strain" and "screen" are simply convenient short-hand.
[3] Any and all references to particular software used in the preparation of this report are facts, not recommendations.

efficient estimate of the standard error of the expanded salvage. The stratification scheme proved ineffective for this purpose and was abandoned in favor of a simpler approach in which the variance was calculated in the usual way, and then adjusted by the sampling fraction and, where appropriate, an estimate of first-order autocorrelation, as described below.

While summing the expanded salvage for a species over any time period is straightforward, calculating a variance is not so simple. This is because we want to know the variance of the counts during all the times when the fish species is available to be captured. To do this, the data base was queried for all unique sampling times. These were matched with the capture data for a species, and zeros were inserted wherever a count was missing. At this point, a rule was applied to remove some of the zeros. If the fish is around and simply not captured during a sampling event, that is one kind of zero, and it means simply that the fish is in low abundance at the time of the sample. But if a species is nowhere around it will not be taken in any samples. That is a second kind of zero. In proposing a method to estimate uncertainty, a simple rule is required to eliminate the second kind of zero from the sampling domain and so to avoid distorting the variance while retaining some overall objectivity in the method. The situation is analogous to the spatial patterns of zero catches in grid sampling at sea (e.g., Smith and Hewitt 1987), and there are no hard-and-fast solutions to the problem. An earlier version of this report put forward the unverified but seemingly harmless assumption that both facilities draw from the same population of fish. In months when the species occurred <15 days, the sample was deemed to include only those days when the fish was recorded (either in a regular salvage count or during a predator removal), regardless of presence or absence at the other facility. In months when the fish was captured on 15 days or more, the domain included all days when the fish was taken at either facility. Whatever assumption is made about including or excluding zero counts, the effect is not to change the point estimate of loss – only its variance.

The last sentence has been viewed with skepticism by some reviewers, and so to explain, an example: Let us suppose that in a given time period, say one day, three steelhead are counted, one in a count of ten minutes duration, and the other two each in counts of 30 minutes duration, and each count representing 120 minutes of export pumping. Further, in the example, there were nine other sampling units, each with zero steelhead. The current method (Appendix A) expands all three positive counts by the inverse of their sampling fractions, giving 12 + 4 +4 = 20 fish total for the time period. The variance of these positive counts is just over 21, but this is not the true variance of the count per sampling unit, because it omits the other nine sampling units in which the count was zero. The proposed method, in effect, expands all 12 counts, including the nine zeros that were not stored in the count data but can be inferred by the fact that there are data (duration of pumping and of counting) for all twelve sampling units elsewhere in the data base. The true variance of the 12-count sample is thus about 13. In obtaining this variance, we also obtain a mean, which is 20/12, or about 1.67 fish per sampling unit. Clearly, this mean is affected by the number of zeros included in the sample. However, the point estimate of interest is the total expanded salvage in time period d (H_d), which is given by

$$H_d = \sum C_p + N_d * m_d = \sum C_p + \sum_{t=1}^{N_d} \frac{C_t}{F_t} \qquad (1)$$

where C_p are the fish counts from predator removal events (zero in the example) and all symbols are as defined in Table 1. In this case, H=0+12 x 1.67 = 20 fish. Thus, inserting empty sampling units in the sample affects the variance but does not affect the point estimate of interest.

Reviewers appeared to agree with the insertion of zeros within days, but found fault with the assumption of a common pool of fish available to both facilities. The objections apparently involved observations that, at least under certain circumstances, fish enter the "elbow" of Old River from either the north or the east such that they become available to one project before the other. [At least one counter-example exists in the work of Nobriga and Cadrett (2001), who showed that SWP salvage was a necessary addition to CVP exports in a linear model predicting CVP salvage of steelhead.] Another comment suggested that the delay in crossing CCF can be of several days duration. This is a valid point, although no particular remedy was suggested. There may be many alternative, simple rules for parsing the zeros in the database. However, absent data in the salvage database by which to divide the sampling domain into times when fish approach from the east or from the north, or to calculate the mean time to cross CCF, it seems that only two truly simple options are amenable to an objective analysis. The first (option 1), is to assume that there is a common pool of fish withdrawn by both facilities (as applied, the rule is actually a hybrid, because of the 15-day criterion). The second (option 2) is to assume that each facility draws independently and simply to eliminate any day that did not produce a count of the species at a given facility. The abundance tables presented below provide some suggestion that either rule can be realistic for certain species at certain times. The consequence may seem surprising, if not anti-climactic. As it happens, in these data zero is the median count value even with the all-zero days removed; inasmuch as the variance is a kind of average (average squared deviation from the mean), the effect of eliminating supernumerary zeros is to increase the variance somewhat in the mean catch per sampling unit, although there is a small decrease in the standard error of the expanded count owing to the reduced number of sampling units (Equation 6). Results for both options are shown for spring-run chinook at the SWP, a species that showed a large discrepancy in days of occurrence between the two facilities.

2.2 Loss Calculation

2.2.1 Concept and definitions

Conceptually, fish loss begins somewhere in front of the trash racks where unnaturally intense predation begins to reduce the numbers of fish approaching the facilities. Computationally, though, we work backwards from the salvage data, because that is the only biological variable that is routinely measured. The fish count is expanded first by the sampling fraction, then by an experimentally derived louver efficiency term, and then by an estimate (estimated at SWP, guessed at CVP) of prescreen loss. Finally, the number of salvaged fish estimated to survive the trip to the western Delta is subtracted (Equation 1) to estimate the number of fish lost during a given time period:

$$K_{id} = \frac{H_{id}}{E_{id} * P_i} - H_{id} * T_{id} \qquad (2)$$

Here H refers to the sum of the expanded count from the regular samples plus those fish counted during predator removals (Equation 1), **d** is time period, and **i** refers to fish salvage facility (see Table 1 for all variable definitions).

Table 1. Definitions of symbols

Symbol	Description (units if applicable)
i	Facility index
d	Time period index
t	Sampling time (sampling unit) index
C, C_t	Actual fish count, normal sampling event (fish)
C_p	Fish count from predator removal event (fish)
E	Louver efficiency, as survival rate of fish between trash rack and holding tank
F	Fraction of time represented by actual fish count
H	Estimated number of fish in holding tanks (fish)
K	Loss to export facilities (fish/time period (e.g., year))
k	Correction term for first-order autocorrelation
m	Sample mean (fish per sampling unit)
N	total number of sampling units
P	Survival rate of fish in area of increased predation in front of trash racks
R	Survival rate immediately upon release in western Delta
r_i	Autocorrelation at time lag j
S	Total pre-transport survival rate under direct influence of operations (product of E x P if estimated separately)
SE	standard error (same units as point estimate)
T	Survival rate during holding and transport
V	Sample variance

2.2.2 Current method

Task 2 was addressed by examining the only currently used official method of estimating loss, that for chinook described in an anonymous document cited by Aasen (2010) as DFG 2006 (Appendix A). Therein, separate linear adjustments are made to louver efficiency (**E**) for two size classes of chinook based on primary channel velocity (slope and intercept assumed the same at both SWP and CVP facilities). Although the method is undocumented, it appears to derive from Appendix A of the Four Pumps Agreement[4], where identical equations having the same coefficients can be found. The origin of these linear adjustments is said (Collins 1991) to derive from "a field testing program at the facility in 1970-71", presumably that described in DWR/DFG (1973). Here is what the latter document had to say about the effect of primary velocity on louver efficiency:

> The efficiency of 50 to 100 mm salmon in relation to approach velocity was variable in 1970 but there appeared to be a direct relationship in primary Bay A and the secondary channel. The efficiency of 100 to 125 mm salmon was not as closely related to approach velocity although efficiency was generally highest at

[4] The 1986 Delta Fish Agreement between DWR and the California Department of Fish and Game sought to offset the adverse impacts to chinook salmon, steelhead, and striped bass caused by adding four new pumps to DWR's Delta Pumping Plant.

the highest velocities. In 1971 there was a slight inverse relationship between approach velocities and efficiency, although differences were not significant.

DWR/DFG (1973) then cites a small increase in secondary louver efficiency with secondary velocity reported by Bates (1960) as well as later results of DWR in which no relationship between efficiency and velocity was found.

In fact, the only apparent linear relationship between approach velocity and efficiency was that for 50-100 mm chinook in Table 2 of DWR/DFG (1973), where a significant relationship is indicated for this size group but not for larger fish. (Exactly how the values of the regression coefficients in Appendix A were derived remains a mystery since the data from the study no longer exist (Dan Odenweller, personal communication.) In the theory of louver effectiveness (e.g., Bates 1960, Skinner 1974), there is expected to be a steep rise in louver effectiveness as approach velocity nears the burst swimming speed of the fish. One might then expect a sort of dose-response curve with moderate increase of effectiveness at low velocity, a steep and nearly linear rise as burst swimming speed is approached, and then a plateau of high effectiveness with increasing velocity until the fish is no longer able to avoid the louvers[5]. For these and other reasons, it is reasonable to expect different survival rates for different-sized fish. However, the studies cited above do not meet the needs of the present effort because of inadequate documentation and absence of error estimates.

The CVP and SWP systems were designed so that typical velocities past the louvers would be optimized for out-migrating chinook and young-of-the-year striped bass >25 mm. However, a system optimized for 25-mm striped bass is not optimized for juvenile salmon. Under the reduced pumping rates called for in the Vernalis Adaptive Management Plan (VAMP), and during late May when the SWP switches to a striped bass-protection priority, velocities through the fish facilities can be less than design criteria for salmonids, lowering louver efficiency. DWR, in their comments on the first draft of this report, claim the more flexible design of their facilities allows them to remain "within criteria" – but the criteria themselves may not be protective. A report by Sutphin and Bridges (2008) makes the case that the so-called bypass ratio (BR, the ratio of approach velocity to the velocity at the entrance to a bypass) is an insufficient criterion for louver efficiency. Instead, the authors present results supportive of the hypothesis that the actual velocity in the bypass itself must exceed the burst swimming speed of the fish or else the fish can swim out of the bypass and be once again exposed to the louvers and potential predators. Under low-flow conditions this calls for very much higher BR (e.g., 7 or so) than those typical of earlier studies (generally in the range 1.2 to 1.6). The existing database has fields for primary and secondary channel flow from which primary bypass velocity could be calculated for either facility. However, there is no way to calculate secondary bypass velocity from the existing database. Moreover, Sutphin and

[5] Although Skinner (1974) worked with a range of velocities, he did not present scatter plots of efficiency vs. velocity, probably because his "laboratory" was the SWP fish facility, where velocity is not minutely controllable. However, a reasonable surrogate for velocity, and one that is perhaps more directly applicable in the present context, is to work with a precisely measured range of fish lengths, of varying swimming capacities; Skinner's graphs of efficiency vs. fish length do tend to show the expected S-curve, e.g. his figures 17, 19 and 20.

Bridges (2008) injected fish directly into a bypass so that the information to estimate overall louver efficiency under these altered flow conditions does not exist.

As discussed in a later section, acceptable estimates of overall louver efficiency at the CVP do exist for chinook. However, what are really needed are overall survival estimates for the species of interest entrained into both facilities under foreseeable conditions. A good start has been made at such estimates for the SWP. A simplifying modification of Equation 2 is, therefore, recommended below.

2.2.3 Proposed method

The existing method of loss calculation (appendix A) is basically a 3-part calculation consisting of (1) a straight-forward expansion of the salvage numbers based on sampling fraction, (2) some further expansion of the expanded salvage to account for louver efficiency and pre-screen predation loss, and (3) a final adjustment to allow for the estimated survival of the salvaged fish that are transported to the western Delta. The most serious fault with the present method is that none of the parameters are furnished with error terms that would allow calculation of the precision of the loss estimate. Other short-comings of the present method include its specificity to chinook and inadequate documentation of parameter estimates. The proposed method is conceptually identical to the existing method, and in other ways completely compatible with it. The important difference is that each parameter used in the expansion has a standard error, such that confidence limits on the loss estimate can be calculated. The proposed method uses an algebraically equivalent salvage expansion, but then simplifies the calculation by using fewer parameters that require independent experimental estimation.

It has been the practice of DWR and USBR to report fish survival through their facilities in terms of louver efficiency, generally as a percentage of fish introduced in front of a louver set that is successfully "louvered" to the next section of the facility (from primary to secondary or from secondary to holding tanks). On reviewing the agency reports concerning louver efficiency it became apparent that most estimates of primary louver efficiency were made by first estimating overall efficiency and then adjusting it by an estimate of secondary louver efficiency (one of the exceptions is Bates 1960). This is because it is logistically very difficult to estimate primary efficiency independently (doing so requires catching the experimental subjects as they exit the primary bypass – possible, at least at CVP, but there the procedure risks drowning the investigator). Similarly, estimates of prescreen survival (actually expressed in terms of loss, i.e. 1-survival; Gingras 1997, Clark et al. 2009) were made by measuring overall loss rates between the entrance to CCF and the SWP holding tanks and then adjusting this by measurements or other estimates of total louver/facility efficiency. As such, prescreen survival (or loss) estimates are not independent of louver efficiency estimates, and more to the point, their errors are confounded. Because overall survival estimates exist for SWP, and to emphasize that such estimates are all that is really needed in the divisor, we use here a simplified version of Equation 2 (Equation 3)

$$K_{id} = H_{id} / S_i - H_{id} * T_{id} \qquad (3)$$

where S_i is the estimated survival of the species category of interest under the influence of facility i. In theory, S could be double-subscripted as S_{id}, if and when studies show S to vary in time in a manner that can be calculated from the salvage database. In the treatment here, time period d is water year 2009 (1 October 2008 to 30 September 2009), so hereafter the subscript d is not used. The survival rate in transport (T) is so close to 100% for the species considered here that it gets lost in the uncertainties associated with H and S. Therefore, T is dispensed with as well (i.e., set = 1), at least for the time being. (It is possible that future studies may quantify the survival rate upon immediate release, which might be expressed either as a separate multiplier R (i.e., T*R) or simply as a further conditioning of T. Because estimates of S are generally in the range 0.1-0.5, the effect of reduced T (or T*R) will be little noticed unless it, too, becomes quite small.)

With the expanded 2-hourly counts, and zero counts inserted as described above, the mean count per sampling unit (m) is (from Equation 1) simply the sum of the expanded counts divided by the number of sampling units (N), and the variance (V) is, as usual, the sum of squared deviations from the mean divided by (N-1). The mean is of no real interest, because it is simply a scaling of the expanded count total, which we already had. What we are really after here is the standard error of the mean, which will allow calculation of a confidence limit. The standard error, SE(m), also as usual, is the square root of the ratio of the variance to the sample size (i.e., $SE(m) = \sqrt{V/N}$), except here we make an adjustment for the unusually large sampling fraction in the salvage data set. From Cochran (1977, Equation 2.50), we have

$$SE(m_a) = SE(m)\sqrt{1-F} \qquad (4)$$

where $SE(m_a)$ is the adjusted standard error and F is the cumulative sampling fraction, i.e., the ratio of the sum of minutes sampled to the sum of minutes of pumping. The reader can appreciate that if we had a complete census of the salvage (sampling minutes = pumping minutes), this error term would vanish. As it is, with F ≅.25, the adjustment is substantial. One feature that became apparent in some of the salvage tables is serial autocorrelation, in which the daily salvage was somewhat predictable from the previous day's salvage. Autocorrelation can lead to underestimation of standard errors, because there are fewer degrees of freedom than assumed for random sampling (Cochran 1977, Bence 1995). A simple correction term for first-order autocorrelation suggested by Bence (1995) is

$$k = \left[(1+r)/(1-r)\right]^{1/2} \qquad (5)$$

where r (designated r_1 in the tables) is the correlation at a time lag of one sampling period. Calculation of r_1 (using an AR(1) model in SYSTAT 11) and k was based on the vector of approximately 2-hourly samples (not the daily totals shown in the tables) for time periods in which a species was captured on a daily basis. The corrected standard error is then simply k times the result of Equation (4), and the standard error of the expanded count is thus

$$SE(H) = N * k * SE(m_a) \qquad (6)$$

This procedure is conservative, because, strictly speaking, the factor k only applies to the time period over which it was calculated (i.e., omitting the few sporadic counts at beginning and end of the season).

Next, having obtained from studies at the projects estimates of S_i and their standard errors $SE(S_i)$, we expand the salvage to total entrainment as in (3) as G=H/S. An estimate of the standard error of G is got through propagation of errors from H and S (e.g., from Bevington and Robinson 1992, equations 3.20 and 3.26; setting the covariance term to zero and taking square roots)

$$SE(G_i) = G_i * \sqrt{\left(\left(\frac{SE(H_i)}{H_i}\right)^2 + \left(\frac{SE(S_i)}{S_i}\right)^2 - ...\right)} \tag{7}$$

The "-..." in equation 7 is a reminder that, while we have no estimate for it, the covariance between survival rate and salvage may not actually be zero. There is thus a chance that Equation 7 overestimates the standard error of the estimated entrainment. The covariance can, at least in principle, be estimated through careful study and reporting of S_{id} and H_{id}. The standard error of the loss estimate is then (with T_i set =1)

$$SE(K_i) = SE(G_i) - SE(H_i) \tag{8}$$

Further adjustment of (8) may be warranted if T (or T*R) is found to be substantially <1.

Examination of equation 7 shows the path to addressing task 8, the apportioning of uncertainty components. Assuming they are well known (i.e., accurate), the two components contribute according to the ratios of each standard error to its point estimate; for example, if the salvage is 1000 fish with standard error = 500, and our estimate of S is 0.2 with standard error 0.02, we obtain:

$$K = \frac{1000}{.2} - 1000 = 4000 \text{ and } SE(K) = 4000 * \sqrt{\left(\left(\frac{500}{1000}\right)^2 + \left(\frac{.02}{.2}\right)^2\right)} - 500 = 1539.$$

In the example, the ratio of SE(K) to K is about 0.38, which is closer to the larger ratio, SE(H) : H (0.5), than to the smaller ratio, SE(S) : S (0.1). Following the example, if H were known without error, then SE(K) would reduce to $4000 * .1 = 400$, and *vice versa*, if SE(H) remains as given, but SE(S) were known without error (i.e., SE(S)=0), we would obtain $SE(K) = 4000 * .5 - 500 = 1500$. If none of these examples seem to answer the questions posed in task 8, it is because the square root of the sum of squared ratios has no easily reducible translation. As the following sections demonstrate, another component of uncertainty is our doubts about the accuracy of existing estimates of S. These uncertainties are explored by using a range of parameter estimates and tabulating the results.

Finally, the total estimated loss is the sum of the estimates of K_i for CVP and SWP, with standard error as follows:

$$SE(K) = SE(K_1) + SE(K_2) \tag{9}$$

and the 95 % confidence limit of the loss estimate is, as usual,

$$CL = K \pm t_{.05,df} * SE(K) \qquad (10)$$

The nominal (not adjusted for autocorrelation) degrees of freedom (*df*) in the estimate of K are (N-1)**df*(S)-1 (Walker 1940). In the present application, this is always a number in the hundreds or thousands, and so $t_{.05}$ is very close to its asymptotic value 1.96.

2.2.4 Calculation summary

Because the data base does not store zero counts, a number of steps are required to produce a vector of expanded counts from which to calculate the standard error of the expanded salvage. These are:

1. Identify the species, category, etc. of fish and the time period and project of interest and make a list, by date, of the positive (non-zero) records. For chinook, this involves separating the fish into runs by length at date and then summing the fish by sampling time (sampling unit).

2. Expand each count (C_t) by the sampling fraction (F_t) for its sampling unit.

3. Sum the expanded counts and add in the counts from predator removal events to estimate the salvage (H) for the time period.

4. Having performed steps 1 through 3 for both projects, get the first and last dates of occurrence of the species during the time period.

5. Obtain a list of all sampling times and sampling efforts (duration of pumping and duration of counting) for the time interval from step 4.

6. Make a vector containing either a zero or, when present, an expanded count for each sampling time.

7. Define the sampling domain by removing unwanted zero-count days by option 1(recommended) or option 2.

The table resulting from step 7 will contain a vector of expanded counts, including zero counts, from which to calculate the statistics of interest.

8. Calculate mean, variance, N, and cumulative F from the file resulting from step 7.

    8a. N is simply the length of the vector of expanded counts (including the zeros): as long as the count schedule is about 12 times per day, N should be close to 12 x the number of dates in the sampling domain, but it will vary due to occasional hourly samples and periodic or emergency down time.

    8b. The mean (m) is the sample mean of the vector of expanded counts, and V is the variance of the same vector. The product of N and m should equal the sum of the expanded counts in step 3.

    8c. Calculate cumulative F as the sum of sampling duration divided by the sum of pumping duration.

    8d. Use equation (4) to calculate the adjusted standard error of the expanded salvage.

9. Check and correct for serial autocorrelation.

9a. Find N_{dr}, the longest set of contiguous dates in the sampling domain (the lists from step 7 are the best for this, unless option 2 is used for trimming the domain in step 7, in which case the lists from step 2 may be more convenient). If the fish was taken over several months and $N_{dr} < 20$, the data set probably does not meet the definition of a times series, and no correction is needed; set k=1 and go to step 10.

9b. ($N_{dr} > 20$). Using the vector of expanded counts from the longest set of contiguous dates (this will be of length N_r , which should be approximately of length 12 x N_{dr}), compute r_1, the Pearson product-moment correlation coefficient at a lag of one sampling period (nominally, 2 hours)

9c. Use equation (5) to compute the correction factor k

10. Use equation (6) to compute the standard error of the salvage, and then, with the appropriate point and error estimates of survival, proceed to estimate the loss beginning at equation (7).

2.2.5 Adjustment for louver cleaning at CVP

As introduced in Section 1, the design of the fish facility at CVP is such that under louver-cleaning operations, some or all of the water approaching the facility must be shunted past the fish salvage structures and pass directly into the canal leading to the export pumps. The cleaning operations were described as occurring approximately once per day during the salmonid season (Bridges 2008). When the secondary louvers are cleaned, which took an average of 49 seconds in three seasons of test data, all four bypasses are closed, so that fish must either remain in front of the louvers or else pass through them toward the export pumps. When the primary louvers are cleaned, a section of louvers is raised into the air, creating a gap with no fish guidance, and the bypass for that section of the louver structure is closed. There are four bypasses, and the data gave the average cleaning time for the louver sections pertaining to each as 32.4 minutes. Bridges (2008) presented a rather complex, mechanistic model (albeit one with several difficult-to-test assumptions) of increased fish loss resulting from these operations, while also suggesting that the actual effects could be measured by experiment. For this purpose, the present author much prefers estimation by experiment to modeling. However, if tested as suggested by Bridges, application of the results would require the salvage database to be modified to contain the times and durations of cleaning operations, and the loss calculation would become correspondingly more complex.

The apparent advantage of a direct estimate of loss rate due to cleaning operations is greater specificity, i.e., cleaning loss could be quantified individually for each species, size class, and approach velocity and applied only to the actual time intervals of cleaning events by expansion of the adjacent (in time) salvage numbers. Cost factors aside, it is questionable whether the resulting increase in specificity would result in greater precision after the errors of the separate parameters are propagated into a single estimate of loss. In keeping with the present theme of combining all (pre-transport) loss factors in a single parameter, the author suggests the alternative of simply quantifying survival at CVP in such a manner that the cleaning operations are integrated as part of the overall experimental design. Because this has not been the case, all existing (or in what follows, borrowed) survival estimates at CVP must be adjusted for the possible effects of louver cleaning. With no estimate of real effects, we make a place-holder adjustment factor by assuming all fish are lost during cleaning operations, which are assumed to be performed once per day. Thus we have (4 x 32.4 + 49) = 179 minutes of daily cleaning divided by 1440 minutes per day for a place-holder loss factor of 12%.

2.2.6 Precision

The term "precision" is used here in two ways. Mainly, it is used in a comparative sense when applied to an estimate, i.e., the size of a standard error (or similarly, the width of a confidence limit) with respect to the point estimate. Precision thus has two components – the variability among repeated, independent determinations and the number of such replications. Rather than introducing a formal measure of precision, estimate A will simply be considered more precise than estimate B when [SE(A)/A] < [SE(B)/B)].

A related concept is the limiting precision of an overall estimate as determined by the number of significant digits in its component parts. In this sense, while the expanded counts and their associated standard errors generally have high (three-to-five digit) precision, the other components in the loss equations have less than this, some only two. Technically, this limits the precision of the estimates to two significant digits, and they should be reported as such. In the present report, results are rounded to the nearest whole fish, but otherwise reported as calculated, so that one wishing to follow the loss calculations can do so with confidence.

3 Results and Discussion

3.1 Predation

This section addresses tasks 2, 3,4, and 6. The decision to use an overall survival term instead of separate prescreen and louver estimates was made for two reasons. As discussed above, the errors in existing assessments of louver efficiency and prescreen loss are not independent. This is partly operational in that the methods of estimating these conceptually separate parameters have been linked. However, variability in estimates of louver efficiency are not strictly due to reactions by the fish to changes in flow variables in the salvage facilities. Bates (1960) noted the need for predation studies at CVP (and by implication, SWP), because predators in other studies had concentrated in front of bypasses, causing both direct predation and fright responses leading to loss of fish through the louvers. Studies at the Tracy facility (CVP) have shown that striped bass large enough to consume the salmonids of interest here can be present throughout the system, including the secondary channel, and even moving into and back out of the export canal (USBR 1994). The periodic predator removal events at both facilities are an effort to control this problem, even though predator build-up within SWP louver areas has not been documented (K. Clark, comments to first draft).

The louvers work by effectively concentrating small ("louverable") fish at each step. This saves most of them from the export pumps but makes an attractive foraging ground for piscivores. Because it is very unlikely that the density of predators reduces to background levels immediately outside the trash racks, it makes sense for the present purpose to use the overall loss rate between the radial gates (at SWP) and the salvage holding tanks. This was estimated for steelhead, as the mean of 58 trials (10-20 fish each, 922 total fish from January to mid-April), at 87% ±2.5% (Clark et al. 2009). A second reason to prefer this estimate for steelhead is that it is the more precise loss estimate of the two that exist for this species. An overall loss estimate, though not so precise, is also available for chinook at SWP from the studies reported in Gingras (1997). Application of these loss rates to CVP facilities is discussed under the separate species accounts. Finally, while it makes sense to discuss predation in terms of loss rates, it will be convenient to calculate fish loss in terms of survival rates (as per Equation 3), one being the complement of the other (survival rate = 1-loss rate). Thus the remainder of the discussion will be presented in terms of survival or in some cases the essentially equivalent term louver efficiency. Like estimates of S, field measures of E generally incorporate some unknown degree of predator effects, as well as possible non-participation errors.

3.2 Central Valley Steelhead

3.2.1 Steelhead survival at export facilities

One estimate was found of louver efficiency for steelhead, this at SWP from 47 PIT-tagged release groups (Clark et al. 2009) with point estimate of 74% and standard error (again, from their Table 12) of 3.5%. However, for reasons discussed above, there is no independent estimate of prescreen survival, which would be needed to accompany this estimate of louver efficiency in an overall survival estimate. Moreover, their one-piece estimate of total survival of steelhead at the SWP, which is actually what is needed for the present purpose, is even more precise. From early January to mid-April, 2007, Clark et al. (2009) released 58 separate groups of 10 or 20 PIT-tagged steelhead at the radial gates that open into to the forebay. The fish ranged in length from 111 to 310 mm with a mean of about 217 mm. Clark et al. calculated a total loss rate of 87% with a 95% confidence limit of ±2.5%. This gives a survival rate of 0.13 with standard error (to two significant digits, from statistics in their Table 12) of .013.

As precise as this estimate was, the authors had some reservations as to its accuracy. Based on the observation that 18 of 64 acoustic-tagged steelhead (28%) swam out of the forebay and were last detected in Old River, Clark et al. offered a revision of their loss estimate (to 82%±3%) in which the number of released PIT-tagged fish was adjusted for this bias (emigration rate), giving a revised survival estimate of 0.18 with standard error of 0.017. Their revised estimate is not ideal, because it is based on an unreplicated observation. Moreover, Clark et al. (2009) note that some of the fish that emigrated from the forebay appeared to have been predated, raising questions as to the meaning of "emigration" from the study area (predated fish should be counted as lost and not used in the adjustment). Technical issues regarding such experiments will be discussed in a later section.

Even in its unadjusted form, there is another reason to question the accuracy of applying a steelhead survival rate based on hatchery fish introduced into a novel environment. In her testimony regarding pre-screen loss of chinook salmon at SWP (discussed in a later section), Greene (2008) opined that a loss rate of 85% based on hatchery fish should be adjusted downward to 75% to reflect the difference in fitness between hatchery fish placed somewhat abruptly in a novel environment and wild fish that enter more gradually. In this author's opinion, the adjustment should not simply be a matter of opinion. As difficult as this might be to measure directly, attempts should be made at least to tie the adjustment to some kind of relevant measure of performance of wild and hatchery fish, such as predator avoidance. For the present, let us use the revised estimate from Clark et al. (2009) as an acknowledgement of the combined uncertainties attending their experiment [i.e., emigration (or non-participation) plus possibly unrepresentative fitness of naive hatchery fish], and use as our medium estimate of steelhead survival rate in the SWP fish facility S_1= 0.18, with a standard error of .017. For symmetry in the presentation, we take a high-survival estimate (again from Clark et al. 2009, Table 12) based on the mean loss minus two standard deviations, giving S_1=1-(.87-.2)= 0.33, with standard error of .013. Better estimates of bias in these experiments should be of interest to managers. In their absence, this element of uncertainty is addressed by employing this range of low, medium, and high survival rates in the following section.

Finally, there are no estimates whatever of pre-screen loss at the CVP facilities, nor do there appear to be appropriate studies there of steelhead. In the Four Pumps Agreement, prescreen loss of chinook salmon is stipulated at 15% (Appendix A). This number was agreed to as a "place holder" pending actual studies (Dan Odenweller, personal communication, 18 March 2011). More than 20 years later, the studies have not been performed for any species, although there are some data for chinook in Old River (Vogel 2002) that pertain to this question, as discussed below (see Chinook survival at export facilities). If one were to accept a stipulated prescreen loss (without error) of 15% for steelhead at CVP, and further assume that the louver efficiency reported by Clark et al. (2009) for steelhead at SWP is applicable to steelhead at CVP adjusted for the louver-cleaning factor presented in Section 2, then we have S_2=.74*(1-.15)*(1-.12) = 0.55 with standard error =.035. These values appear in the loss tables as the medium point and error estimates for steelhead survival rate at CVP. The louver efficiency with cleaning adjustment but without the prescreen loss adjustment will similarly serve as the interim maximum-S_2 estimate (S_2=.74*(1-.12) = 0.65), and we will use the medium-survival estimate from SWP for the low-survival estimate of S_2 at CVP, in recognition of the possibility that prescreen loss may be very much higher than that stipulated for chinook in the four pumps agreement, while allowing some credit for the lack of a forebay at CVP. All these values of S_2 should be replaced when appropriate studies at CVP become available.

3.2.2 Steelhead salvage and loss estimates

Wild salmonids in the Central Valley are distinguished from hatchery fish by the presence of an adipose fin (which in recent years has been removed from all hatchery steelhead before release from hatcheries; Williams 2006). Steelhead were salvaged from January through July in 2009, with most fish taken in March, when salvage numbers were nearly 70% higher at CVP (Tables 2 and 3). The rows at the bottom of the tables show the number of approximately 2-hr sampling periods, which are the sampling units, as well as the mean and variance of the expanded count per sampling unit, and the cumulative sampling fraction and other statistics that feed into the loss calculation. The zeros for expanded counts in Tables 2 and 3 represent usually 12 (sometimes more, especially at SWP) zeros in the stratum for that day. Blank cells in these and similar tables represent days that are considered outside the sampling domain (i.e., days of no catch at a facility in a month when the species was captured < 15 days, or days in other months when the species was not taken at either project). In these and all following salvage tables, the arrangement in columns by month is simply for display. The expanded salvage calculations are based on a single vector of length N (the number of sampling units). Also given in the salvage tables are the mean per sampling unit, sampling fraction (minutes sampled/minutes of pumping), first-order autocorrelation coefficient (not applicable to steelhead), the adjusted and corrected standard error estimates (these being the same for this species), and the expanded standard error to be used in the loss calculations. It can be seen that the half-width of the 95% confidence limit of the expanded salvage numbers (roughly, twice the standard error) is in the range 20-24% of the point estimate for steelhead.

Table 2. Expanded regular salvage of wild steelhead, SWP in water year 2009, with (counts) from predator removals.

Day	January	February	March	April	May	July
1			2	4		
2			2			
3			0	4		
4			10			
5			0			
6						
7			4			4
8			2		4	
9		3	4		4	
10			4			
11		3			4	
12				4		
13			2			
14			0			
15			0	4		
16			12			
17						
18						
19			0	4		
20		9	14	4		
21			0			
22			12			
23			8			
24				4		
25	6					
26	9	2	0			
27		18				
28				0(1)		
29						
30			0			
31			0			
Total Expanded Count	15	35	76	28 (1)	12	4
Number of sampling units	487					
Mean estimated salvage/2						
hr period	0.349		Expanded Salvage		170	
Sampling fraction	0.274		from predator removal		1	
SE(m_a)	0.042		Total fish		171	
r_1	n/a					
corrected SE	0.042		Expanded SE		20.3	

Table 3. Expanded regular salvage of wild steelhead, CVP in water year 2009, with (counts) from predator removals.

Day	January	February	March	April	May	June
1			8			
2			4			
3			12	5.17 (1)		
4			8			
5			4		0 (1)	4
6					4	
7			12			
8			12			
9			0			
10			4	4		
11		4		4		
12		4				
13			0			
14			4			
15			4			
16			20	0 (1)		
17						
18		4				
19			8			
20			0		4	
21			4			4
22			0	4		
23		12	4			
24		8				
25						
26			12			
27						
28						
29				4		
30			4			
31			4 (1)			
Total Expanded Count		32	128 (1)	21.17 (2)	8 (1)	8
Number of sampling units	444					
Mean estimated salvage/2						
hr period	0.444		Expanded Salvage		197	
Sampling fraction	0.258		from predator removal		4	
SE(m_a)	0.054		Total fish		201	
r_1	n/a					
corrected SE	0.054		Expanded SE		23.8	

The statistics at the bottom of Tables 2 and 3 are the inputs to the loss calculation. Because there were so many gaps between the times when steelhead were salvaged, the steelhead data do not meet the definition of a time series, and so serial autocorrelation was not a factor in the 2009 data for this species. The range of loss estimates for steelhead in both projects is given in Table 4 with three values for S at each project, as described in the previous section.

Table 4. Water year 2009 loss estimates with 95% confidence limits for steelhead under a range of loss parameter (S) estimates

Name of Parameter or Result	SWP			CVP		
S	0.13	0.18	0.33	0.18	0.55	0.65
SE(S)	0.013	0.017	0.013	0.017	0.035	0.035
Loss	1144	779	347	916	164	108
lcl	749	512	247	630	114	76
ucl	1539	1046	447	1202	214	140

The half-width of the 95% confidence limits of the loss estimates is about in the range ±35% of the point estimates, i.e., moderately greater than that for the salvage, owing to the added contribution of error from the survival estimates. However, it can be appreciated from Table 4 that the 95% confidence limit on the loss estimate based on the medium estimate of S (i.e., sums of CLs: 626 to 1260) is exceeded by the range of estimates produced by plausible alternatives for S (sums of loss estimates: 455 to 2060). The alternative values differ in their assumptions about prescreen loss and, to a lesser extent, details of the estimating experiments. Reviewers of earlier drafts of this report expressed dissatisfaction and/or puzzlement over the range of survival rates in Table 4, especially over the application of the SWP experiments to CVP. However, no specific alternatives were suggested, other than adjusting somehow for cleaning operations at CVP (done here) and a plea from USBR to retain the old method, which has no estimate of error and therefore does not meet the assignment. The general dissatisfaction, coupled with the absence of workable alternatives for the place-holder S values at CVP, points out the need for more studies. It is obvious that the variance in the salvage sampling procedure (which gave confidence limits in the range 20-24% of the estimated salvage) is the lesser component of the uncertainty in the loss estimate, which varies more than 10-fold. The sum of the medium loss estimates is 943 wild steelhead, about 2.5 times the estimated salvage in 2009. The sum of the two highest upper confidence bounds (2741) is just less than the current combined project take limit of 3,000 for Central Valley steelhead. It is thus possible that the take limit was exceeded in 2009 if the low-survival values of S apply and predation mortality at the release sites (a difficult thing to measure – see Miranda et al. 2010) was ≥ 70%.

3.3 Wild Chinook Salmon

3.3.1 Run separation

The author interprets task 5 as an invitation to review reports on the efficacy of the existing run separation method, shown here as length-at-age tables from the "Delta Model" in Appendix B.

Williams (2006, p 83) wrote:

> Most fall-run juveniles in the Central Valley begin migrating toward the lower rivers or the Estuary in January, February or March, shortly after they emerge from the gravel, when they are still less than 50 mm long; however, a considerable number rear near the spawning areas for one to three months before migrating, typically in April and May and at more than 60 mm. A few emigrate in the fall or winter, or in spring as yearlings. Most spring-run in the Central Valley follow a juvenile life-history pattern similar to that of fall- run, although some follow the typical stream-type life history pattern. The timing of migration among winter-run, late fall-run, and yearling spring-run is less clear, because the size-at-date method for distinguishing the runs is unreliable in the Delta.

Using microsatellite DNA data, Hedgecock et al (2001) developed an accurate method to identify winter-run chinook. They showed that the length-at-age method

> " clearly overestimate the losses of winter- run in the Delta. These results further suggest the hypothesis that the winter run does not use the lower Delta as rearing habitat....
>
> Extension of the methods developed for winter-run identification to threatened spring-run populations should now be straightforward. "

Fisher (1992, p 31) might have taken issue with the above quote from Hedgecock concerning winter chinook rearing in the Delta. At least in the years leading up to his study, chinook in the size range predicted for winter-run fish were common in the Delta, appeared to grow faster there, and were taken in significant numbers at the SWP and CVP fish facilities (Fisher 1992, Figure 2).

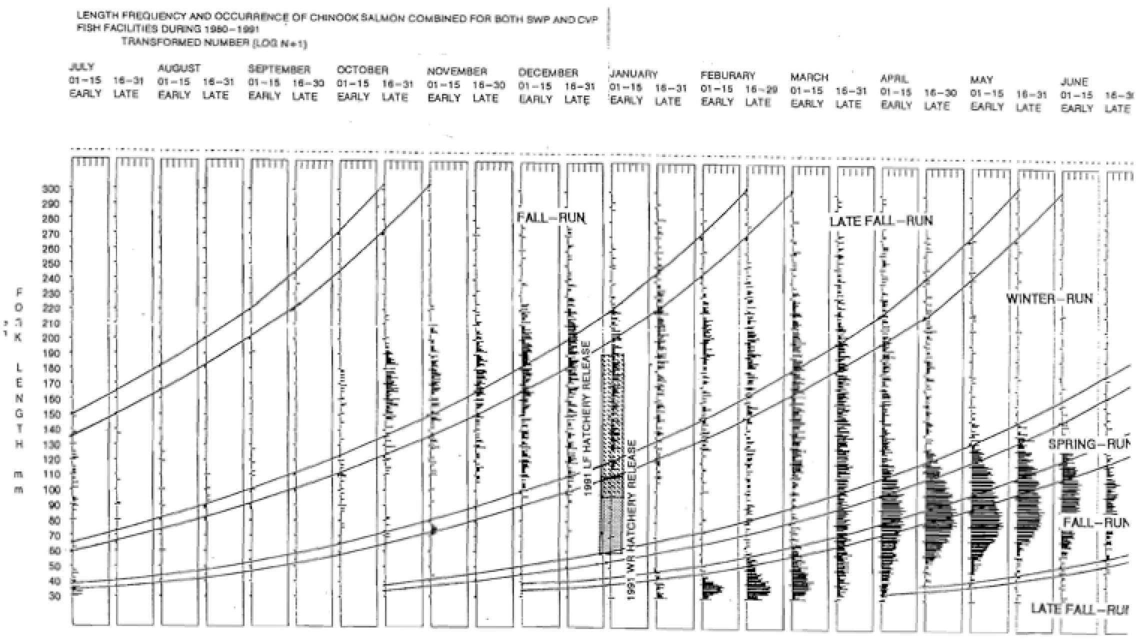

Figure 2. Interpretation of length frequency data of salvaged chinook at SWP and CVP from Fisher 1992, Figure 11. See Appendix C for explanation of curves.

The Delta Model bears some resemblance to the work of Fisher (1992), as examined briefly in Appendix C. Fisher calculated a generalized chinook growth curve (exponential) from production data for an outdoor, naturalistic hatchery facility. Rather than calculate statistical error for his predictions, he accounted for variation in length at date by using a range of emergence dates for each run. He then used the derived relationships of length at age to identify runs from length frequency plots arranged by date.

Fisher knew that growth rates varied in time and place, noting that chinook appeared to grow faster in the Delta. Growth curves are simple mathematical models that are generally fit to data from populations, the exponential curve being a good approximation to growth in the first year or so for many species (Ricker 1975). It is not clear what Fisher might have done if faced with the problem of identifying individual fish to run, but it is quite clear that this was not his purpose. When faced with an individual fish, the investigator must admit that the growth rate is not known with certainty, and in fact may not have been constant (in the logarithmic sense). The difference between describing a population growth rate and hind-casting the emergence date of an individual fish is akin to the difference between a confidence interval and a prediction interval. Prediction intervals are always wider (see, e.g., Hahn and Meeker 1991).

It would appear possible, and might be interesting, to construct prediction intervals from Fisher's data for ages based on length and his expected emergence times, but this exercise is left for future work. At any rate, what is needed at present is elucidation of the underpinnings of the Delta Model, which does not use Fisher's growth curve; either the emergence dates or the growth rates, or both, are not the same (Appendix B and Appendix C).

Williams (2006) attempted to find documentation and attributions for the Delta Model of length-at-age and reported these to be incomplete. However, lacking an alternative at this time, assignment of chinook to runs was done here using the Delta Model. The salvage and loss estimates of ESA-listed winter- and spring-run races should therefore be considered tentative, because the uncertainty attending run assignment affects the raw counts of winter- and spring-run chinook in the salvage. At this writing there is no quantitative estimate of the errors involved in the run assignments.

3.3.2 Chinook survival at export facilities

Gingras (1997) summarized a series of experiments from various agency reports on chinook at SWP with an emphasis on prescreen loss. The number of tagged fish released near the opening to the forebay is given for each experiment, and in the text there are salvage numbers for seven of the eight experiments. From these numbers, the total survival parameter can be calculated, as in Table 5. For the fall 1978 experiment the author calculated recoveries from the prescreen loss in the table and the louver efficiency stated in the text; applying the same procedure to the other seven experiments gave an average percent disagreement of 28%.

Table 5. Re-analysis of chinook survival data at SWP from Gingras (1997)

Experiment	released	recovered	S
Fall 76	6825	191	0.028
Fall 78	10510	1021*	0.097
Spring 84	13493	3310	0.245
Spring 85	11606	1058	0.091
Spring 92	21894	58	0.003
Winter 92	10729	1677	0.156
Spring 93	10332	121	0.012
Fall 93	10015	45	0.004
	mean survival, radial gates to holding tank		0.080
		std err.	0.03

* calculated value

The mean total survival estimate for chinook at SWP based on the Gingras report is 0.080 ± 0.03 (standard error). Only one significant digit seems appropriate for the error estimate because of the inconsistencies in the reported values noted above. The standard error of this estimate is three times as large as that for steelhead, mainly because so few experimental determinations were made ($\sqrt{58/8} = 2.7$). Williams (2006) commented on the Gingras report as follows:

> Fish not recovered were assumed to have died. Estimated mortality for salmon in the forebay has ranged from 63 to 99%, with no obvious patterns in the data ... The estimated forebay mortality is large and plays an important role in the calculation of the take of winter-run Chinook, so it seems that more effort should be made to characterize it well, as urged by the 2002 EWA Review Panel (2002).

Some indication that the effects of both projects may extend beyond the physical boundaries of the facilities is seen in the work of Vogel (2002), who did repeated experiments with groups of radio-tagged chinook released in Old River approximately 12 km north of the projects. In his words:

> It became evident during the four experiments that radio-tagged salmon reaching the southern Delta channels in close proximity to the export facilities exhibited pronounced net southerly movements (sometimes very rapid) when encountering that region. For example, if a radio- tagged salmon consistently displayed a strong net southerly migration, despite some seiching movements north and south with the ebb and flood tides, respectively, that fish was assumed to have been ultimately entrained into either the SWP or CVP. If a radio-tagged fish seiched north and south (or east and west in side channels such as Indian Slough) with the ebb and flood tides but did not exhibit a strong net southerly migration pattern, that fish was assumed to have remained in the Delta channels north of the export facilities for the duration of the monitoring period (i.e., three to four days) or was categorized as “unknown” if the radio tag could not be located; fish in this category were not assumed to have been entrained into either the SWP or CVP.

Vogel's Table 1 shows estimated combined SWP/CVP entrainment of 23% and 33% under low export conditions (Old River flow -500 to -2500 cfs) and 62% and 67% under medium export conditions (OR flow -4000 to -6000 cfs, Vogel 2002 Figure 54). Vogel discussed these observations as follows:

> The single most evident difference in results between the two medium export experiments and the two low export experiments was the behavior of radio-tagged fish during the first day after release. Radio-tagged salmon in releases 1 and 2 (medium export) experienced minimal or no positive (downstream) flow on the first day whereas fish in releases 3 and 4 (low export) experienced long periods of high positive flow. The medium export levels dampened out or nearly eliminated any positive or north flows in Old River. Most fish in releases 1 and 2 exhibited a rapid, southerly migration responding to the high negative flow conditions. In contrast, most fish in releases 3 and 4 moved back and forth (i.e., north and south in Old River in response to the ebb (positive) and flood (negative) flow conditions and remained detectable in Old River for a longer duration than those fish in releases 1 and 2.

The draw toward both projects clearly extends far beyond their physical boundaries. This does not in itself mean that predation is increased throughout the entire reach observed by Vogel. In fact, Vogel's report could be used in an argument that prey fish concentration does not increase until the projects are encountered. In fact, reviewers from both DWR and USBR made this claim in their reviews of the first draft of this report. The way to win this argument would be to do a study. However, it is a good assumption that predator fish are concentrated near the fish facilities, at least at times, and how far this above-background concentration extends is an important thing to know. An effort should be made to investigate the density of predators and the rate of predation on both chinook and steelhead within a few km of the projects. Brandes and McLain (2001) reported survival of marked chinook from upper Old River to Chipps Island in the western Delta ranging from .01 to .62 (from 1985 to 1990, before installation of the barrier at the head of Old River) and a mean of .16. Time-paired releases at Dos Reis, a similar distance from Chipps but probably excluding Old River as the migratory pathway, ranged from .04 to .83 with a mean of .30. The authors concluded the difference (about 46%) was not statistically significant but seemed to believe it was nonetheless real[6]. Inconveniently for the present purpose, releases into Old River were discontinued after 1990 in the studies reported by Brandes and McLain. In recent years, survival in Old River appears to be very much less than 16%, but the studies are confounded by technical problems involving acoustic tag detections of predated subjects (D. Vogel, personal communications, 19 and 24 May 2011). A recent analysis of the VAMP experiments (Newman 2008) does show lower survival of outmigrant chinook using the Old River vs. the San Joaquin River, but those experiments still confound direct loss to water exports with enhanced predation in Old River. To fully expand salvage data to an estimate of loss of out-migrating salmonids, it is imperative that a reasonable estimate of the distance (north and east) along Old River over which above-background predation occurs (or does not occur) be made and that the average survival rate within the area so defined be determined. Without such information, there exists a real possibility that estimates of prescreen loss at SWP are biased low. It is not possible to estimate how great this bias might be, but one can guess it is substantial based on the predation rate in CCF and the mobility of the main predator, striped bass.

Without data, it is not possible to estimate a range of point estimates for S_1 for chinook. However, proceeding as in section 3.2.1, we can upgrade the survival estimate from Table 5 for possible non-participation and hatchery fish effects by adding (with no adjustment to the error term) 5 percentage points, giving $S_1 = .05+.08= 0.13$, still with a standard error of 0.03. This guess appears in the loss tables as the medium-survival estimate in the second column for SWP. The high-survival estimate of S_1 is .25 from the spring 1984 experiment (Table 5) with no standard error, and the low-survival value is simply the mean S from Table 5, $S_1= .08$, all with standard error = .03.

Lacking a direct estimate of prescreen loss at CVP, we obtain an upper bound on the survival parameter as the complement of the overall louver efficiency, adjusted for louver-cleaning (Section 2.2.5). Karp et al. (1995) reported a series of experiments in which groups of marked chinook were released in two sites, one in front of the trash boom (immediately ahead of the primary channel) and one in the primary channel. Four trials each at design velocities produced eight independent sets of ratios (number recovered in holding tank/ number released). They also performed two tests under low-velocity conditions. Their results are summarized in Table 6. In casting Table 6 the author made corrections as needed to some of the salvage numbers, to wit: a salmon that was recovered from the gut of a striped bass in the salvage was subtracted from the salvage , and the number of fish that were recovered for each trial after the pre-set observation period was over were added to the salvage.

[6] It is not clear to this author how Brandes and McLain analyzed their data, but a paired t-test on arcsin-square root-transformed survival indices from their Table 9 has power of only 52%. Five more replications of the experiment would have boosted the power to the often-recommended level of 80%.

Table 6. Revised chinook survival data through CVP louvers from Karp et al. (1995)

Date	Primary Velocity (cm/s)	Number Released	Relase site*	Number Salvaged	Survival
13-Apr-1993	70	249	T	118	0.474
13-Apr-1993	70	250	P	148	0.592
15-Apr-1993	79	193	T	97	0.503
15-Apr-1993	79	197	P	92	0.467
12-May-1993	9	249	T	19	0.076
12-May-1993	9	250	P	55	0.220
13-May-1993	9	250	T	20	0.080
13-May-1993	9	250	P	65	0.260
25-May-1993	58	254	T	189	0.744
25-May-1993	58	250	P	166	0.664
26-May-1993	55	252	T	190	0.754
26-May-1993	55	252	P	181	0.718

* T=trash racks, P = primary channel

From Table 6 we obtain a survival rate under high flow of .61*(1-.12) = .54 with standard error .043 as the upper bound on chinook survival at CVP. The medium-survival estimate for CVP is then this upper bound adjusted by the place-holder prescreen survival (1- stipulated prescreen loss estimate from Appendix A), giving S_2=0.85*.88* .61 = .46. Under low flow (corresponding to approximately 1.2 body lengths per second), four ratios gave a mean survival of .16 with a standard error of .047. This low-flow estimate may or may not apply under the much higher bypass ratios proposed by Sutphin and Bridges (2008) for low-flow conditions. If the facilities are to be operated constantly at low flow during the peak salmonid season, then all existing loss rates, for both species at both facilities, need to be re-estimated. Calculating as above for low flow, the minimum-survival estimate for S_2=.16*.88*.85=.12. As there seems little point in adding a guess to a guess, no further adjustment is made to this low-survival value for the unknown effects of experimental bias and far-field predation in old River.

3.3.3 Chinook salvage and loss

Chinook salmon meeting the length-at –date criteria (Appendix B) for winter-run first appeared in late December at CVP with sporadic captures in January and (at both projects) February (Tables 7 and 8). From 28 February to 18 March, winter chinook were salvaged at both projects, with absences only on the 6th at CVP and at both projects on the 14th. Thereafter, sporadic captures were made in late March and in April. The 14 days from 28 February to 13 March are the longest run of contiguous days of capture of winter chinook at SWP, and so by rule there is no correction for first-order autocorrelation at this location. Similarly at CVP, the catch data did not meet our definition of a time series and so no correction for autocorrelation was made for this species (Table 8). As for steelhead, the statistics at the bottom of Tables 7 and 8 were inputs to the loss calculations presented below.

Table 7. Expanded salvage of winter-size chinook at SWP in water year 2009 with (counts) from predator removals.

Day		February	March	April
1			4	
2			6	
3			18	
4			12	
5			24	
6			16	
7			16	
8			46	
9			44	
10			12	
11			12	
12			10	
13			6	
14				
15			28	
16			8	
17			2	4
18			8	
19				
20				
21				
22				
23				
24		0(1)		
25				
26		2		
27				
28		8		
29				
30				
31				
Total Expanded Count		10(1)	272	4
Number of sampling units	276			
Mean estimated salvage/2-hr period	1.036	Expanded Salvage		286
Sampling fraction	0.292	from predator removal		1
$SE(m_a)$	0.156	Total fish		287
r_1	n/a			
corrected SE	0.156	Expanded SE		43.1

Table 8. Expanded salvage of winter-size chinook at CVP in water year 2009.

Day	December	January	February	March	April
1				12	
2				12	
3				20	
4				8	
5				8	
6				0	
7				12	
8		12		12	
9		12		16	
10				3	
11				12	4
12				8	
13				4	
14					
15				11	
16				44	
17				16	
18				16	
19					
20			4		
21					
22			8		
23			4		
24					
25			4		
26			8		
27					
28			12	4	
29					
30	9				
31					
Total Expanded Count	9	24	40	218	4
Number of sampling	336				
Mean estimated	0.878		Expanded Salvage		295
Sampling fraction	0.238		from predator removal		0
$SE(m_a)$	0.113		Total fish		295
r_1	n/a				
corrected SE	0.113		Expanded SE		38.0

Salmon meeting the length criteria for spring chinook appeared in mid-March and were abundant in April and May (Tables 9 and 10). Spring chinook were captured at CVP every day from 21 March through 22 May, whereas they did not appear reliably at SWP until 14 April. This may be an example of fish approaching from the east (presumably via Middle River to upper Old River, as this run no longer spawns in the San Joaquin), as suggested in comments on the first draft, or else it may signal intense predation in CCF in March and early April. First-order autocorrelation was calculated for the 21 March – 22 May time period at CVP, and from 14 April to 11 May at SWP (SWP was not in operation from 12-14 May.) Corrections for autocorrelation were substantial for both projects. However, the in-fill of zeros at SWP on days when spring chinook were captured at CVP but not SWP made very little difference (removal caused about a 4% reduction in the expanded standard error; see separate analysis at bottom of Table 9). It may be instructive to note that, even with the 183 "extra" zeros removed, the median value in the vector of salvage numbers (not the daily totals shown in the tables) was still zero.

Table 9. Expanded salvage of spring-size chinook at SWP in water year 2009 with (counts) from predator removals. * denotes a day of zeros removed from the second analysis at bottom of table. nd = no data.

Day	March	April	May
1		*	36
2		*	32
3		*	48
4		*	68
5		*	36(2)
6		*	24
7		*	16
8		*	12
9		*	8
10		*	28
11		*	56(22)
12		*	nd
13		*	nd
14		8	nd
15	8	20	16
16		92	16
17		20	4
18		12	*
19		28	0(2)
20		28	4
21		24 (5)	*
22		140	*
23		152	
24	8	148	5
25		54	
26		16	6
27		6	4
28		106(1)	
29		50	
30		88	
31			
Total Expanded Count	16	992(6)	419(26)

Number of sampling units	593		
Mean estimated salvage/2-hr period	2.406	Expanded Salvage	1427
Sampling fraction	0.262	from predator removal	32
$SE(m_a)$	0.207	Total fish	1459
r_1	0.347		
corrected SE	0.297	Expanded SE	176.3
Number of sampling units	410 (* zeros removed)		
Mean estimated salvage/2-hr period	3.480	Expanded Salvage	1427
Sampling fraction	0.263	from predator removal	32
$SE(m_a)$	0.288	Total fish	1459
r_1	0.347		
corrected SE	0.413	Expanded SE	169.5

Table 10. Expanded salvage of spring-size chinook at CVP in water year 2009 with (counts) from predator removals.

Day	March	April	May	June
1		68	48	
2		84	44	
3		52(2)	112	
4		24	68	
5		64	40(1)	
6		31	28	
7		32	40	
8		100	28	
9		130	28	
10		80	24	
11		149	40	
12		64	28	
13		128	56	
14		48	41	
15	4	50	40	4
16		32	20	
17	16	66	18	
18	8	28	16	
19		92	8	
20		88	4	
21	4	68	8	
22	4	112	8	
23	4	130.8		
24	4	106	4	
25	2.3	52		
26	1	24		
27	28	79		
28	64	63.3		
29	56	68		
30	76	32		
31	96			
Total Expanded Count	367	2145(2)	751(1)	4
Number of sampling units	831			
Mean estimated salvage/2-hr period	3.931		Expanded Salvage	3267
Sampling fraction	0.256		from predator removal	3
SE(m_a)	0.209		Total fish	3270
r_1	0.303			
corrected SE	0.286		Expanded SE	237.3

While twice the standard of the expanded salvage gives ratios of the half-width of the 95% confidence limit in the approximate range 15%-30%, loss tables for chinook (Tables 11 and 12) show half-widths of confidence intervals in the approximate range 30%-80% (the high-survival estimate for spring chinook at SWP, without error in the S parameter, is the trivial exception to this). Moreover, as with steelhead, the range of point estimates of loss exceeds the total width of the confidence interval for the medium-survival estimates, implying that uncertainty in the survival parameter (due to missing data and some doubts about existing data), not that from expanding the counts, dominates the error attending these estimates of loss. In the case of chinook, this conclusion is tentative, because of the uncertainty in assigning the fish to their respective runs; this last error source is yet to be fully evaluated.

Table 11. Water year 2009 loss estimates with 95% confidence limits for winter chinook under a range of loss parameter (S) estimates

Name of Parameter or Result	SWP			CVP		
S	0.08	0.13	0.25	0.14	0.46	0.54
SE(S)	0.03	0.03	0	0.047	0.043	0.043
Loss	3301	1921	861	1812	641	251
lcl	533	810	607	396	220	163
ucl	6069	3032	1115	3228	472	339

Table 12. Water year 2009 loss estimates with 95% confidence limits for spring chinook under a range of loss parameter (S) estimates

Name of Parameter or Result	SWP			CVP		
S	0.08	0.13	0.25	0.14	0.46	0.54
SE(S)	0.03	0.03	0	0.047	0.043	0.043
Loss	16779	9764	4377	20087	3839	2786
lcl	3013	4369	3338	4806	2653	1971
ucl	30545	15159	5416	35368	5025	3601

	SWP with reduced zeros		
S	0.08	0.13	0.25
SE(S)	0.03	0.03	0
Loss	16779	9764	4377
lcl	3037	4397	3377
ucl	30521	15131	5377

3.4 Green Sturgeon

There is no estimate of louver efficiency for green sturgeon. Kynard and Horgan (2001) tested yearlings of the congeneric short-nose sturgeon (*A. brevirostris*, 238-315 mm) and 3-month-old pallid sturgeon (*Scaphirhynchus albus*, 174-273 mm) in a laboratory setting with louver spacings of 3.9 and 9.0 cm, approach velocities of 30-33 cm/s and bypass ratios in the range .7 to .9. Only half of the shortnose sturgeon tested under these conditions passed downstream into the louvered section of the test facility, but all of these (9 at each louver spacing) were guided into the bypass (100%). Pallid sturgeon had higher participation in the experiment (92%) and of those that entered the louver section, there was 100% guidance by the narrower-spaced louvers and 96% (22 of 23) guidance at the greater louver spacing. Application of these findings to green sturgeon under the distinctly different conditions at SWP and CVP is straight-forward, because field measures of survival or louver efficiency are expected to be reduced by some level of predator interference. Also, prescreen mortality due to predator concentrations around the projects is probably not negligible. That said, there is no reason in principle why the general formulation for loss applied here to the salmonids could not be used for green sturgeon. We simply are not ready to do so, because the parameters have not been estimated.

No green sturgeon were salvaged in 2009. The most recent previous[7] specimens salvaged by either project were a 354-mm individual on 25 January 2008 and an unmeasured individual on 5 April 2008, both at CVP (expanded salvage of green sturgeon was 8 fish in 2008 and 12 fish in 2007; Aasen 2009). Between 1993, when identification of juvenile green sturgeon became standardized, and 2006, NMFS (2011) reported unexpanded salvage of green sturgeon at SWP and CVP combined ranged from 0-363 with a median of 50 and was <200 fish in all years except 2006. Sampling fractions calculated for salmonids here may not be applicable to green sturgeon in the years before 2008 and were probably about 1/12 in 2003 (based on Bridges 2008) and before. Expansion of the known salvage reported by NMFS (2011) with standard error calculable by the methods in section 2 might well produce a median salvage of some 600 green sturgeon per year. According to McLain (2006), green sturgeon in the Delta are generally larger than 300 mm, and judging from the work of Kynard and Horgan (2001), sturgeon > 170 mm would be expected to be louvered efficiently. Thus, recent salvage data suggest (assuming >50% cleaning-adjusted louver efficiency[8] and a low rate of predation – both unknowns) that project take of these fish is probably < 300 fish in most years at current population levels. Their low abundance in the salvage is likely an indication of either small numbers in Old River or low availability to entrainment.

Occasional catches of white sturgeon (*A. transmontanus*) in San Luis Reservoir and the associated O'Neill Forebay (http://www.fishsniffer.com/maps/sanluis.html) are a strong indication that young sturgeon are transported out of the Delta by the projects. At any rate, even in years when 10's to 100's of green sturgeon are salvaged (e.g., 1994 to 1999, 2006; NMFS 2011, Table 7), there is insufficient information to estimate loss for this species with much confidence.

3.5 Comments on existing studies

Much of the research at both facilities has historically focused on the "efficiency" with which fish are guided past louvers and into holding tanks. This was necessary at first in order to establish operations procedures for optimizing fish salvage (e.g., Mecum 1977). Some of these studies (e.g. Bowen et al. 1998) focused on secondary louver efficiency or even a component of it (e.g., Sutphin and Bridges 2008). While these may give insight for operations (the omission of data points in Sutphin and Bridges compromises even this application), such studies are of no value to loss estimation without independent estimates of primary louver efficiency, and louver efficiency does not lead to a loss estimate without independent measures of prescreen loss.

Some early reports, e.g. DWR/DFG 1973, give evidence of massive amounts of work with little to show in terms of statistically applicable parameters. As appreciation for the Central Limit Theorem has grown over the last 40 years, biologists have in general

[7] Several green sturgeon, some < 100 mm, were salvaged in 2011, while this report was being written.
[8] USBR (1994) reported striped bass as large as 600 mm emigrating from the Delta-Mendota Canal back into Old River through both primary louvers and trash racks. If that is possible, then there is no reason to believe the louvers would be 100% efficient for sturgeon even without cleaning losses.

become much better at reporting the precision of their estimates, or at least the information needed for doing so (e.g., Clark et al. 2009, Karp et al. 1995). The focus of Clark et al. (2009) on prescreen loss of steelhead, as well as their thorough reporting of results, is a long step toward obtaining the information necessary to estimate total loss to these facilities. Similar studies for chinook reported by Gingras (1997) seem to have mistaken the importance of number of experimental subjects for the need for replicated experimental trials, and the reporting of the results is inconsistent. In the context of loss calculation, studies in and near CVP facililties are insufficient for both species.

3.6 General guidelines for future studies

Past studies of louver efficiency and whole-facility survival rate were done over a range of conditions that were expected to apply at the time of the experiments. As the changing environment and changing regulations impose new target export rates and concomitant changes in operations, new conditions will apply. For the loss calculations to give realistic estimates, it will be necessary to inform the procedures with parameter estimates relevant to the new conditions. At present, regulations and prior agreements (e.g., the Four Pumps) appear to limit operations as regards approach velocities and bypass ratios to an extent that probably makes the facilities less efficient for salmonid salvage than they might otherwise be. Even if such restrictions were to be discontinued, it would be worthwhile to extend the envelope of experimental conditions beyond the present operations criteria (in particular, bypass ratios) in order to demonstrate possible improvements in screening efficiency.

The loss estimate proposed here is patterned after the best available studies as defined by the necessity for both a point estimate and confidence intervals. As it stands, the proposed calculation assumes that the covariance between salvage and loss is zero, an assumption that could and perhaps should be tested with a properly designed experiment (or possibly from Clark's existing data?). What is more, the proposed calculation omits covariates that might be expected to improve the precision and specificity of the loss estimates. One obvious potentially helpful factor is fish size, because both theory and practice have shown size-related swimming performance to be a factor in louver efficiency (a fact that is recognized, if not handled well, in Appendix A). If estimates with standard errors were available for the relationship of fish size to overall facility efficiency, the author would have used them. Similarly, if operations criteria such as approach velocity and bypass ratio could be quantitatively related to overall survival, it would make sense to improve the estimate by incorporating these relationships. Just as is the case for substituting, e.g., actual CVP steelhead experimental results for the place-holder parameters used above, all such improvements can fit with relative ease into the basic scheme proposed. However, easy though the application of such modifications may be, obtaining the experimental evidence to support them will be a substantial effort.

The series of experimental trials reported by Clark et al. (2009) provide the best example to date of a whole-facility survival estimate. In principle, similar studies could be expanded to include information on size-specific survival and effects of various options in facility operations (e.g., bypass velocity). Devoting replications to such variables would add significantly to costs of the experiments, but should be considered on the basis of the potential benefits of greater specificity of experimental outcomes. What those benefits might be is not a subject to be covered here, but rather should become obvious to DWR and USBR as time passes and experience with ESA take issues grows.

It is apparent that use of telemetric tags in predation studies is bedeviled by detections of dead (predated) fish. On the other hand, use of PIT tags is limited by the inability to detect tagged fish that leave the study area. In principle, one method can be used to constrain the results of the other, as Clark et al. (2009) attempted to do. Further method development for detecting predation, coupled with careful data processing, may be the answer to culling dead-fish detections from true escapees in acoustic data. Care must be taken to devote replications to both techniques, such that adjustments can be made with confidence.

Finally, it is recognized that a multi-step calculation, such as that in Equation 2 (applied here, albeit without an error estimate for P, to chinook at CVP), may be necessary for species as difficult to obtain as green sturgeon. Investigators are reminded of the desirability of designing such studies in a way that not only estimates the variance of each step, but also the covariances among them. This is not necessarily an addition to the uncertainty; variables can potentially co-vary in a way that actually reduces overall variance.

The following is a short list of studies, in order of importance as judged by the author, that would strengthen the basis for the loss calculations of the species treated here.

1. Joint studies to determine the spatial extent of above-background predation of chinook and steelhead in Old River with respect to distance from the export facilities

2. Survival of steelhead under the influence of CVP pumping (controlled for non-participation and entrainment at SWP) within the area defined in #1 and with normal louver cleaning schedules

3. Joint studies to determine survival of chinook under the influence of both facilities (conditioned as in #2) under the range of flows and export intensity anticipated in the near future.

4. Determination of predation intensity on salmonids at the release sites in the western Delta

5. Louver efficiency studies using white sturgeon as a surrogate species for green sturgeon (and with louver cleaning at CVP).

6. Estimation of relevant differences in performance between experimental subjects and the wild fish of interest.

7. Detailed examination of the Delta Model of chinook run assignment, along with compilation of better statistics on emergence dates.

8. Periodic reevaluation of the survival estimates as conditions change.

9. At some future time when all parameters are estimated with three-digit precision, it would be advisable to re-visit the correction for autocorrelation in the standard error of the salvage, which uses a somewhat arbitrary criterion for its application and an approximation to calculate the correction factor.

4 Summary

Expanded salvage numbers at SWP and CVP for steelhead and chinook were analyzed using the 2009 water year in the examples. Salmonid loss estimates were performed by dividing the expanded salvage by the survival rates estimated for fish under the direct influence of the projects and propagating the errors involved in estimating both quantities. For these species, adjusting the loss for the survival rate during transport is probably not important, although the unknown intensity of predation immediately upon release could potentially make a difference in whether steelhead take exceeds current limits. No green sturgeon were taken in 2009, but in any case, this species is too rarely salvaged at the projects, and too little-studied in terms of louver efficiency and predation vulnerability, to produce a loss estimate based on salvage data.

As sampling programs go, the fish salvage programs at the SWP and CVP sample large fractions (≥25%) of the populations passing through the fish facilities. Nevertheless, there is sampling error attending the expansion of these samples to the total estimate of salvaged fish. For steelhead, the standard errors of the salvage were <25% of the estimates, whereas for chinook they were roughly 15-30%. An estimate of total survival of steelhead at SWP has ±10% precision, whereas a comparable estimate for chinook at SWP is about three times less precise. An upper bound on the survival rate of chinook at CVP was derived from studies there of louver efficiency, and this estimate has precision comparable to the estimate of chinook survival at SWP. Uncertainties regarding the accuracy of the survival rates lead to very large differences in calculated losses for both species for the 2009 water year.

A further source of uncertainty for chinook, possibly as great as that attending the survival rate, is that concerning the run identity of individuals. Information necessary for a valid statistical estimate of this uncertainty is within the reach of modern methods but does not yet exist.

5 Conclusions and Recommendations

A massive sampling effort at both the SWP and the CVP produces precise (95% confidence limits < ± 30%) estimates of the salvage. Survival rates also have been estimated with good precision, such that 95% confidence intervals on the loss estimates are < ± 85% of point estimates. However, uncertainties regarding the accuracy of the survival rates lead to adjustments, some arbitrary, and consequently very large differences (>> 100%) in calculated losses for wild salmonids. This was demonstrated for the 2009 water year, but similar ranges would obtain for any other year, because the knowledge gaps have nothing to do with the raw count data. Great uncertainty also exists in regard to chinook run identification. Most of the uncertainty in survival and run identity can be alleviated through application of modern research methods.

The historical focus on louver efficiency within the fish facilities, though necessary for optimizing the operations, is insufficient for estimating overall survival rates of species within the area presumed to be directly affected by the projects. The currently applied loss calculator for chinook relies on a poorly documented relationship of louver efficiency with primary velocity data. Current export volumes at times can lead to louver-approach velocities that are below design criteria for chinook. If research shows that these can be managed effectively through alterations in secondary pumping rates or other modification in operation, and if anything like the present loss calculator is desired, then the data base will need to be updated to contain the necessary fields so that new operations parameters can be included the calculations. Even with improved louver efficiency estimates, accurate loss estimates would still require accurate prescreen survival rates, louver-cleaning effects estimates, etc.

A more direct approach, with fewer loss terms and associated errors, is to measure overall survival between the outer limits of project-influenced mortality and the salvage. Studies such as those described by Clark et al. (2009) using PIT and acoustic tags are necessary to define the range and levels of predation as fish approach the facilities under reverse flow in Old River. These studies must be carried out under the flow conditions that prevail, and are likely to prevail, during the season of maximum entrainment for the species and size ranges of interest, generally from March to May for the salmonids. Emphasis should be on maximizing the number of repeated, independent trials. The first priority would seem to be steelhead survival estimation at CVP. However, because of the tendency for experimental subjects to leave the study area, all studies should be cooperative between the two projects and cover some distance east and north in Old River to learn the fate of as many acoustic-tagged fish as possible. For this reason, it is suggested that the range-finding studies be conducted first.

The length-at-date method of guessing the run identity of chinook is poorly documented and in any case uses 18th century technology. Modern genetic methods can identify these fish with high accuracy. Even if these methods are too costly or time-consuming for regular application, they should be used for a few years on salvage samples from a range of dates and fish lengths. The results might then be used to establish a more reliable statistical technique for run assignment based on size and date using Bayesian priors. Alternatively, the actual data upon which the Delta Model is based might be analyzed so as to produce prediction intervals for age-at-length, from which it should be possible to assess the error rates involved in the run assignments.

Finally, rather crude calculations suggest loss of green sturgeon to the projects is usually < 300 fish per year. Whether or not such loss is negligible for a listed species is not a subject of this report. Some green sturgeon do occasionally wind up in the salvage, proving that loss is a possibility. Studies with a surrogate species (white sturgeon) to quantify louver efficiency (at least) should be considered.

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Appendix A. Currently Used Chinook Salmon Loss Calculator

Chinook Salmon Loss Estimation
for
Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility

I. Introduction

Estimates of salmon loss are based on fish salvage and operational data collected at the John E. Skinner Delta Fish Protective Facility (Skinner) and the Tracy Fish Collection Facility (Tracy). Loss calculations utilize estimates based on DFG studies of screening efficiency, handling and trucking mortality due to operation of the Skinner facility, and pre-screening losses occurring in Clifton Court Forebay (CCF) and the intake channel.

II. Loss Estimation

There are 4 essential components of loss estimation: salvage, pre-screen loss (predation), screen (louver) efficiency, and handling and trucking loss. Losses are estimated from the time salmon enter Clifton Court Forebay (at Skinner) or across the trash racks (at Tracy) to the time they are released back into the Delta. Salmon are lost in two ways before they are collected in the facility: 1) they might be eaten by predatory fish, or 2) they might pass through the louvers and then exported along with Delta water. Once collected, fish loss occurs when some fish die in the process of being handled or trucked.

A. Salvage Estimation

The first step in estimating loss is to estimate fish salvage. Salvage is estimated from samples (counts) of fish collected at least every two hours while water is being pumped.

SALVAGE = Observed number of fish x (Total minutes pumping ÷ Count length)

Exceptions: If the fish is observed in a predator removal, then SALVAGE = Observed number of fish x 1.
If the fish is observed during a special study, then SALVAGE = 0.

Example: 1 salmon in count * (120 min. pumping / 10 min. count length) → SALVAGE = 12

B. Entrainment Estimation

The number of fish that are entrained into the facilities is estimated in two steps. First we estimate how many fish encountered the screens, the second step is to estimate how many fish entered the facility.

1. Encounter Estimation

A1

We have already estimated how many salmon were collected (salvage), but since the screens are not 100% efficient, we know some fish passed through and were lost. Estimating the number of fish encountering the screens depends on fish size. Efficiency is generally higher for fish < 100 mm than for fish > 100 mm. The fish's ability to avoid the louvers and enter the bypass also depends on the water velocity through the louvers. For small fish, higher velocities will make it more difficult for them to avoid the louvers and will increase the likelihood that they will pass through the louvers and will be lost. The number of fish encountering the screens (ENCOUNT) is calculated by dividing the salvage (SALVAGE) by the screen efficiency (EFF).

If Length < 101 mm → ENCOUNT = SALVAGE/EFF1;
If Length > 100 mm → ENCOUNT = SALVAGE/EFF2;

EFF1 = 0.630 + (0.0494 * (Primary Channel Flow /(Primary Channel Depth * Width)))
EFF2 = 0.568 + (0.0579 * (Primary Channel Flow /(Primary Channel Depth * Width)))

<u>Note</u>: Channel width at Skinner depends on the number of bays open. As the pumping rate changes, bays are opened and closed to maintain primary channel approach velocities and bypass ratios within established criteria. Channel width at Tracy is fixed (84 ft).

2. Entrainment Estimation

The number of fish entrained (ENTRAIN) is calculated by dividing the number of fish encountering the screens (ENCOUNT) by the proportion of fish assumed to survive the journey to the louvers (1 – P). The pre-screen loss rate (P) is the rate of loss to entrained salmon during movement from the radial gates (Skinner) or trash racks (Tracy) to the louvers. The pre-screen loss at Skinner is based on an average of measured pre-screen loss rates in CCF for chinook salmon (75%). The pre-screen loss rate at Tracy is an agreed-upon value (15%).

ENTRAIN = ENCOUNT / (1 – P)

For Skinner: P = 0.75
For Tracy: P = 0.15

C. Live Release Estimation

We then estimate the number of salvaged fish that will survive the process of being transferred from the holding tanks to the truck and transported back to the Delta. This estimate is based on studies with salmon at the Skinner facility and depends on

A2

salmon length. Mortality during the transport process has been referred to as handling and trucking loss. For salmon less than or equal to 100 mm, mortality is assumed to be 2% and for salmon larger than 100 mm, mortality is assumed to be 0.

If length < 101 mm → RELEASE = SALVAGE x (1 – 0.02)
If length > 100 mm → RELEASE = SALVAGE

Note: Trucking and handling loss is combined into a single rate (2% for smaller fish).

D. System Loss Estimation

The final step in loss estimation is to subtract the estimated number of fish released alive from the estimated number of fish entrained.

LOSS = ENTRAIN – RELEASE

Exceptions:
If the fish is observed in a Skinner predator removal, then LOSS = SALVAGE x 4.33
If the fish is observed in a Tracy predator removal, then LOSS = SALVAGE x 0.569
If the fish is observed in a special study, then LOSS = 0

III. Loss Calculation Examples:

A. Skinner:

1 salmon observed in count * (120 min. pumping / 10 count length) → Salvage = 12, but some fish went through louvers and were not salvaged, so...

If < 101 mm, # fish encountering screens = 12 / (0.63 + (0.0494 * (2260 cfs / 20 ft.* 106 ft))) = 17.6

But, most of the salmon were eaten before they got to the louvers, so... # fish entrained = 17.6 / (1-.75) = 70.4

But, we were able to release some of these fish back into the delta alive, so if fish < 100 mm... # fish released = 12 * (1 – .02) = 11.8

So, loss is the number of fish entrained minus the number of fish released alive... # fish lost = 70.4 - 11.8 = 58.6

B. Tracy:

1 salmon observed in count * (120 min. pumping / 10 count length) → Salvage = 12, but some fish went through louvers and were not salvaged, so...

If < 101 mm, # fish encountering screens = 12 / (0.63 + (0.0494 * 2806 cfs /

A3

(16.7 ft.* 84 ft))) = 16.4

But, most of the salmon were eaten before they got to the louvers, so... # fish entrained = 16.4 / (1-.15) = 19.3

But, we were able to release some of these fish back into the delta alive, so if fish < 100 mm... # fish released = 12 * (1 – .02) = 11.8

So, loss is the number of fish entrained minus the number of fish released alive... # fish lost = 19.3 - 11.8 = 7.5

A4

Appendix B. The Delta Model for separation of chinook runs

The following table gives minimum and maximum lengths for assigning chinook to the winter- and spring-run "races" on the dates indicated. Supplied by Geir Aasen of CDFG and modified by the author for presentation purposes.

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race
01/01	58	155	Winter
01/02	59	156	Winter
01/03	59	157	Winter
01/04	60	158	Winter
01/05	60	160	Winter
01/06	61	161	Winter
01/07	61	162	Winter
01/08	62	164	Winter
01/09	62	165	Winter
01/10	63	166	Winter
01/11	63	168	Winter
01/12	64	169	Winter
01/13	64	171	Winter
01/14	65	172	Winter
01/15	65	173	Winter
01/16	66	175	Winter
01/17	66	176	Winter
01/18	67	178	Winter
01/19	68	179	Winter
01/20	68	181	Winter
01/21	69	182	Winter
01/22	69	184	Winter
01/23	70	185	Winter
01/24	70	187	Winter
01/25	71	188	Winter
01/26	71	190	Winter
01/27	72	191	Winter
01/28	73	193	Winter
01/29	73	194	Winter
01/30	74	196	Winter
01/31	74	198	Winter
02/01	75	199	Winter
02/02	76	201	Winter
02/03	76	202	Winter
02/04	77	204	Winter
02/05	78	206	Winter
02/06	78	207	Winter
02/07	79	209	Winter
02/08	79	211	Winter
02/09	80	213	Winter
02/10	81	214	Winter
02/11	81	216	Winter
02/12	82	218	Winter
02/13	83	220	Winter

Date	Min	Max	Race
01/01	41	57	Spring
01/02	41	58	Spring
01/03	41	58	Spring
01/04	41	59	Spring
01/05	42	59	Spring
01/06	42	60	Spring
01/07	42	60	Spring
01/08	43	61	Spring
01/09	43	61	Spring
01/10	43	62	Spring
01/11	43	62	Spring
01/12	44	63	Spring
01/13	44	63	Spring
01/14	44	64	Spring
01/15	45	64	Spring
01/16	45	65	Spring
01/17	45	65	Spring
01/18	45	66	Spring
01/19	46	67	Spring
01/20	46	67	Spring
01/21	46	68	Spring
01/22	47	68	Spring
01/23	47	69	Spring
01/24	47	69	Spring
01/25	48	70	Spring
01/26	48	70	Spring
01/27	48	71	Spring
01/28	49	72	Spring
01/29	49	72	Spring
01/30	49	73	Spring
01/31	50	73	Spring
02/01	50	74	Spring
02/02	50	75	Spring
02/03	50	75	Spring
02/04	51	76	Spring
02/05	51	77	Spring
02/06	51	77	Spring
02/07	52	78	Spring
02/08	52	78	Spring
02/09	53	79	Spring
02/10	53	80	Spring
02/11	53	80	Spring
02/12	54	81	Spring
02/13	54	82	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
02/14	83	221	Winter	02/14	54	82	Spring
02/15	84	223	Winter	02/15	55	83	Spring
02/16	85	225	Winter	02/16	55	84	Spring
02/17	86	227	Winter	02/17	55	85	Spring
02/18	86	229	Winter	02/18	56	85	Spring
02/19	87	231	Winter	02/19	56	86	Spring
02/20	88	233	Winter	02/20	56	87	Spring
02/21	88	234	Winter	02/21	57	87	Spring
02/22	89	236	Winter	02/22	57	88	Spring
02/23	90	238	Winter	02/23	58	89	Spring
02/24	91	240	Winter	02/24	58	90	Spring
02/25	91	242	Winter	02/25	58	90	Spring
02/26	92	244	Winter	02/26	59	91	Spring
02/27	93	246	Winter	02/27	59	92	Spring
02/28	94	248	Winter	02/28	59	93	Spring
02/29	94	248	Winter	02/29	59	93	Spring
03/01	94	250	Winter	03/01	60	93	Spring
03/02	95	252	Winter	03/02	60	94	Spring
03/03	96	254	Winter	03/03	61	95	Spring
03/04	97	256	Winter	03/04	61	96	Spring
03/05	97	259	Winter	03/05	61	96	Spring
03/06	98	261	Winter	03/06	62	97	Spring
03/07	99	263	Winter	03/07	62	98	Spring
03/08	100	265	Winter	03/08	63	99	Spring
03/09	101	267	Winter	03/09	63	100	Spring
03/10	101	269	Winter	03/10	64	100	Spring
03/11	102	272	Winter	03/11	64	101	Spring
03/12	103	274	Winter	03/12	64	102	Spring
03/13	104	276	Winter	03/13	65	103	Spring
03/14	105	278	Winter	03/14	65	104	Spring
03/15	106	281	Winter	03/15	66	105	Spring
03/16	107	283	Winter	03/16	66	106	Spring
03/17	107	285	Winter	03/17	67	106	Spring
03/18	108	287	Winter	03/18	67	107	Spring
03/19	109	290	Winter	03/19	67	108	Spring
03/20	110	292	Winter	03/20	68	109	Spring
03/21	111	295	Winter	03/21	68	110	Spring
03/22	112	297	Winter	03/22	69	111	Spring
03/23	113	299	Winter	03/23	69	112	Spring
03/24	114	300	Winter	03/24	70	113	Spring
03/25	115	300	Winter	03/25	70	114	Spring
03/26	116	300	Winter	03/26	71	115	Spring
03/27	117	300	Winter	03/27	71	116	Spring
03/28	118	300	Winter	03/28	72	117	Spring
03/29	118	300	Winter	03/29	72	117	Spring
03/30	119	300	Winter	03/30	72	118	Spring
03/31	120	300	Winter	03/31	73	119	Spring
07/01	0	35	Winter	.	.	.	.
07/02	0	35	Winter	.	.	.	.
07/03	0	35	Winter	.	.	.	.
07/04	0	35	Winter	.	.	.	.
07/05	0	36	Winter	.	.	.	.

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
07/06	0	36	Winter	.	.	.	.
07/07	0	36	Winter	.	.	.	.
07/08	0	37	Winter	.	.	.	.
07/09	0	37	Winter	.	.	.	.
07/10	0	37	Winter	.	.	.	.
07/11	0	37	Winter	.	.	.	.
07/12	0	38	Winter	.	.	.	.
07/13	0	38	Winter	.	.	.	.
07/14	0	38	Winter	.	.	.	.
07/15	0	39	Winter	.	.	.	.
07/16	0	39	Winter	.	.	.	.
07/17	0	39	Winter	.	.	.	.
07/18	0	40	Winter	.	.	.	.
07/19	0	40	Winter	.	.	.	.
07/20	0	40	Winter	.	.	.	.
07/21	0	41	Winter	.	.	.	.
07/22	0	41	Winter	.	.	.	.
07/23	0	41	Winter	.	.	.	.
07/24	0	42	Winter	.	.	.	.
07/25	0	42	Winter	.	.	.	.
07/26	0	42	Winter	.	.	.	.
07/27	0	43	Winter	.	.	.	.
07/28	0	43	Winter	.	.	.	.
07/29	0	43	Winter	.	.	.	.
07/30	0	44	Winter	.	.	.	.
07/31	0	44	Winter	.	.	.	.
08/01	0	44	Winter	.	.	.	.
08/02	0	45	Winter	.	.	.	.
08/03	0	45	Winter	.	.	.	.
08/04	0	46	Winter	.	.	.	.
08/05	0	46	Winter	.	.	.	.
08/06	0	46	Winter	.	.	.	.
08/07	0	47	Winter	.	.	.	.
08/08	0	47	Winter	.	.	.	.
08/09	0	47	Winter	.	.	.	.
08/10	0	48	Winter	.	.	.	.
08/11	0	48	Winter	.	.	.	.
08/12	0	49	Winter	.	.	.	.
08/13	0	49	Winter	.	.	.	.
08/14	0	49	Winter	.	.	.	.
08/15	0	50	Winter	.	.	.	.
08/16	0	50	Winter	.	.	.	.
08/17	0	51	Winter	.	.	.	.
08/18	0	51	Winter	.	.	.	.
08/19	0	51	Winter	.	.	.	.
08/20	0	52	Winter	.	.	.	.
08/21	0	52	Winter	.	.	.	.
08/22	0	53	Winter	.	.	.	.
08/23	0	53	Winter	.	.	.	.
08/24	0	54	Winter	.	.	.	.
08/25	0	54	Winter	.	.	.	.
08/26	0	54	Winter	.	.	.	.

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
08/27	0	55	Winter	.	.	.	.
08/28	0	55	Winter	.	.	.	.
08/29	0	56	Winter	.	.	.	.
08/30	0	56	Winter	.	.	.	.
08/31	0	57	Winter	.	.	.	.
09/01	0	57	Winter	.	.	.	.
09/02	0	58	Winter	.	.	.	.
09/03	0	58	Winter	.	.	.	.
09/04	0	59	Winter	.	.	.	.
09/05	0	59	Winter	.	.	.	.
09/06	0	60	Winter	.	.	.	.
09/07	0	60	Winter	.	.	.	.
09/08	0	61	Winter	.	.	.	.
09/09	0	61	Winter	.	.	.	.
09/10	0	62	Winter	.	.	.	.
09/11	0	62	Winter	.	.	.	.
09/12	0	63	Winter	.	.	.	.
09/13	0	63	Winter	.	.	.	.
09/14	0	64	Winter	.	.	.	.
09/15	0	64	Winter	.	.	.	.
09/16	0	65	Winter	.	.	.	.
09/17	0	65	Winter	.	.	.	.
09/18	0	66	Winter	.	.	.	.
09/19	0	66	Winter	.	.	.	.
09/20	0	67	Winter	.	.	.	.
09/21	0	67	Winter	.	.	.	.
09/22	0	68	Winter	.	.	.	.
09/23	0	68	Winter	.	.	.	.
09/24	0	69	Winter	.	.	.	.
09/25	0	70	Winter	.	.	.	.
09/26	0	70	Winter	.	.	.	.
09/27	0	71	Winter	.	.	.	.
09/28	0	71	Winter	.	.	.	.
09/29	0	72	Winter	.	.	.	.
09/30	0	72	Winter	.	.	.	.
10/01	0	73	Winter	.	.	.	.
10/02	0	74	Winter	.	.	.	.
10/03	0	74	Winter	.	.	.	.
10/04	0	75	Winter	.	.	.	.
10/05	0	75	Winter	.	.	.	.
10/06	0	76	Winter	.	.	.	.
10/07	0	77	Winter	.	.	.	.
10/08	0	77	Winter	.	.	.	.
10/09	0	78	Winter	.	.	.	.
10/10	0	79	Winter	.	.	.	.
10/11	0	79	Winter	.	.	.	.
10/12	30	80	Winter	10/12	0	29	Spring
10/13	30	81	Winter	10/13	0	29	Spring
10/14	31	81	Winter	10/14	0	30	Spring
10/15	31	82	Winter	10/15	0	30	Spring
10/16	31	83	Winter	10/16	0	30	Spring
10/17	31	83	Winter	10/17	0	30	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
10/18	32	84	Winter	10/18	0	31	Spring
10/19	32	85	Winter	10/19	0	31	Spring
10/20	32	85	Winter	10/20	0	31	Spring
10/21	32	86	Winter	10/21	0	31	Spring
10/22	33	87	Winter	10/22	0	32	Spring
10/23	33	87	Winter	10/23	0	32	Spring
10/24	33	88	Winter	10/24	0	32	Spring
10/25	33	89	Winter	10/25	0	32	Spring
10/26	34	90	Winter	10/26	0	33	Spring
10/27	34	90	Winter	10/27	0	33	Spring
10/28	34	91	Winter	10/28	0	33	Spring
10/29	35	92	Winter	10/29	0	34	Spring
10/30	35	93	Winter	10/30	0	34	Spring
10/31	35	93	Winter	10/31	0	34	Spring
11/01	35	94	Winter	11/01	0	34	Spring
11/02	36	95	Winter	11/02	0	35	Spring
11/03	36	96	Winter	11/03	0	35	Spring
11/04	36	96	Winter	11/04	0	35	Spring
11/05	37	97	Winter	11/05	0	36	Spring
11/06	37	98	Winter	11/06	0	36	Spring
11/07	37	99	Winter	11/07	0	36	Spring
11/08	38	100	Winter	11/08	0	37	Spring
11/09	38	100	Winter	11/09	0	37	Spring
11/10	38	101	Winter	11/10	0	37	Spring
11/11	38	102	Winter	11/11	0	37	Spring
11/12	39	103	Winter	11/12	0	38	Spring
11/13	39	104	Winter	11/13	0	38	Spring
11/14	39	105	Winter	11/14	0	38	Spring
11/15	40	105	Winter	11/15	0	39	Spring
11/16	40	106	Winter	11/16	0	39	Spring
11/17	40	107	Winter	11/17	0	39	Spring
11/18	41	108	Winter	11/18	0	40	Spring
11/19	41	109	Winter	11/19	0	40	Spring
11/20	41	110	Winter	11/20	0	40	Spring
11/21	42	111	Winter	11/21	0	41	Spring
11/22	42	112	Winter	11/22	0	41	Spring
11/23	42	113	Winter	11/23	0	41	Spring
11/24	43	113	Winter	11/24	0	42	Spring
11/25	43	114	Winter	11/25	0	42	Spring
11/26	43	115	Winter	11/26	0	42	Spring
11/27	44	116	Winter	11/27	0	43	Spring
11/28	44	117	Winter	11/28	0	43	Spring
11/29	45	118	Winter	11/29	0	44	Spring
11/30	45	119	Winter	11/30	0	44	Spring
12/01	45	120	Winter	12/01	33	44	Spring
12/02	46	121	Winter	12/02	33	45	Spring
12/03	46	122	Winter	12/03	34	45	Spring
12/04	46	123	Winter	12/04	34	45	Spring
12/05	47	124	Winter	12/05	34	46	Spring
12/06	47	125	Winter	12/06	34	46	Spring
12/07	48	126	Winter	12/07	34	47	Spring
12/08	48	127	Winter	12/08	35	47	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race
12/09	48	128	Winter
12/10	49	129	Winter
12/11	49	130	Winter
12/12	50	131	Winter
12/13	50	132	Winter
12/14	50	134	Winter
12/15	51	135	Winter
12/16	51	136	Winter
12/17	52	137	Winter
12/18	52	138	Winter
12/19	52	139	Winter
12/20	53	140	Winter
12/21	53	141	Winter
12/22	54	143	Winter
12/23	54	144	Winter
12/24	55	145	Winter
12/25	55	146	Winter
12/26	56	147	Winter
12/27	56	148	Winter
12/28	56	150	Winter
12/29	57	151	Winter
12/30	57	152	Winter
12/31	58	153	Winter
04/01	121	300	Winter
04/02	122	300	Winter
04/03	123	300	Winter
04/04	124	300	Winter
04/05	125	300	Winter
04/06	126	300	Winter
04/07	128	300	Winter
04/08	129	300	Winter
04/09	130	300	Winter
04/10	131	300	Winter
04/11	132	300	Winter
04/12	133	300	Winter
04/13	134	300	Winter
04/14	135	300	Winter
04/15	136	300	Winter
04/16	137	300	Winter
04/17	138	300	Winter
04/18	139	300	Winter
04/19	141	300	Winter
04/20	142	300	Winter
04/21	143	300	Winter
04/22	144	300	Winter
04/23	145	300	Winter
04/24	146	300	Winter
04/25	148	300	Winter
04/26	149	300	Winter
04/27	150	300	Winter
04/28	151	300	Winter
04/29	153	300	Winter

Date	Min	Max	Race
12/09	35	47	Spring
12/10	35	48	Spring
12/11	35	48	Spring
12/12	36	49	Spring
12/13	36	49	Spring
12/14	36	49	Spring
12/15	36	50	Spring
12/16	37	50	Spring
12/17	37	51	Spring
12/18	37	51	Spring
12/19	37	51	Spring
12/20	38	52	Spring
12/21	38	52	Spring
12/22	38	53	Spring
12/23	38	53	Spring
12/24	39	54	Spring
12/25	39	54	Spring
12/26	39	55	Spring
12/27	39	55	Spring
12/28	40	55	Spring
12/29	40	56	Spring
12/30	40	56	Spring
12/31	40	57	Spring
04/01	73	120	Spring
04/02	74	121	Spring
04/03	74	122	Spring
04/04	75	123	Spring
04/05	75	124	Spring
04/06	76	125	Spring
04/07	76	127	Spring
04/08	77	128	Spring
04/09	77	129	Spring
04/10	78	130	Spring
04/11	78	131	Spring
04/12	79	132	Spring
04/13	79	133	Spring
04/14	80	134	Spring
04/15	80	135	Spring
04/16	81	136	Spring
04/17	82	137	Spring
04/18	82	138	Spring
04/19	83	140	Spring
04/20	83	141	Spring
04/21	84	142	Spring
04/22	84	143	Spring
04/23	85	144	Spring
04/24	85	145	Spring
04/25	86	147	Spring
04/26	87	148	Spring
04/27	87	149	Spring
04/28	88	150	Spring
04/29	88	152	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race
04/30	154	300	Winter
05/01	155	300	Winter
05/02	156	300	Winter
05/03	158	300	Winter
05/04	159	300	Winter
05/05	160	300	Winter
05/06	162	300	Winter
05/07	163	300	Winter
05/08	164	300	Winter
05/09	166	300	Winter
05/10	167	300	Winter
05/11	168	300	Winter
05/12	170	300	Winter
05/13	171	300	Winter
05/14	172	300	Winter
05/15	174	300	Winter
05/16	175	300	Winter
05/17	177	300	Winter
05/18	178	300	Winter
05/19	180	300	Winter
05/20	181	300	Winter
05/21	183	300	Winter
05/22	184	300	Winter
05/23	186	300	Winter
05/24	187	300	Winter
05/25	189	300	Winter
05/26	190	300	Winter
05/27	192	300	Winter
05/28	193	300	Winter
05/29	195	300	Winter
05/30	196	300	Winter
05/31	198	300	Winter
06/01	200	300	Winter
06/02	201	300	Winter
06/03	203	300	Winter
06/04	205	300	Winter
06/05	206	300	Winter
06/06	208	300	Winter
06/07	210	300	Winter
06/08	211	300	Winter
06/09	213	300	Winter
06/10	215	300	Winter
06/11	217	300	Winter
06/12	218	300	Winter
06/13	220	300	Winter
06/14	222	300	Winter
06/15	224	300	Winter
06/16	226	300	Winter
06/17	228	300	Winter
06/18	229	300	Winter
06/19	231	300	Winter
06/20	233	300	Winter

Date	Min	Max	Race
04/30	89	153	Spring
05/01	89	154	Spring
05/02	90	155	Spring
05/03	91	157	Spring
05/04	91	158	Spring
05/05	92	159	Spring
05/06	92	161	Spring
05/07	93	162	Spring
05/08	94	163	Spring
05/09	94	165	Spring
05/10	95	166	Spring
05/11	95	167	Spring
05/12	96	169	Spring
05/13	97	170	Spring
05/14	97	171	Spring
05/15	98	173	Spring
05/16	99	174	Spring
05/17	99	176	Spring
05/18	100	177	Spring
05/19	101	179	Spring
05/20	101	180	Spring
05/21	102	182	Spring
05/22	103	183	Spring
05/23	103	185	Spring
05/24	104	186	Spring
05/25	105	188	Spring
05/26	105	189	Spring
05/27	106	191	Spring
05/28	107	192	Spring
05/29	107	194	Spring
05/30	108	195	Spring
05/31	109	197	Spring
06/01	110	199	Spring
06/02	110	200	Spring
06/03	111	202	Spring
06/04	112	204	Spring
06/05	112	205	Spring
06/06	113	207	Spring
06/07	114	209	Spring
06/08	115	210	Spring
06/09	115	212	Spring
06/10	116	214	Spring
06/11	117	216	Spring
06/12	118	217	Spring
06/13	119	219	Spring
06/14	119	221	Spring
06/15	120	223	Spring
06/16	121	225	Spring
06/17	122	227	Spring
06/18	123	228	Spring
06/19	123	230	Spring
06/20	124	232	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
06/21	235	300	Winter	06/21	125	234	Spring
06/22	237	300	Winter	06/22	126	236	Spring
06/23	239	300	Winter	06/23	127	238	Spring
06/24	241	300	Winter	06/24	127	240	Spring
06/25	243	300	Winter	06/25	128	242	Spring
06/26	245	300	Winter	06/26	129	244	Spring
06/27	247	300	Winter	06/27	130	246	Spring
06/28	249	300	Winter	06/28	131	248	Spring
06/29	251	300	Winter	06/29	132	250	Spring
06/30	253	300	Winter	06/30	133	252	Spring
07/01	255	300	Winter	07/01	133	254	Spring
07/02	257	300	Winter	07/02	134	256	Spring
07/03	259	300	Winter	07/03	135	258	Spring
07/04	261	300	Winter	07/04	136	260	Spring
07/05	263	300	Winter	07/05	137	262	Spring
07/06	266	300	Winter	07/06	138	265	Spring
07/07	268	300	Winter	07/07	139	267	Spring
07/08	270	300	Winter	07/08	140	269	Spring
07/09	272	300	Winter	07/09	141	271	Spring
07/10	274	300	Winter	07/10	142	273	Spring
07/11	277	300	Winter	07/11	143	276	Spring
07/12	279	300	Winter	07/12	143	278	Spring
07/13	281	300	Winter	07/13	144	280	Spring
07/14	284	300	Winter	07/14	145	283	Spring
07/15	286	300	Winter	07/15	146	285	Spring
07/16	288	300	Winter	07/16	147	287	Spring
07/17	291	300	Winter	07/17	148	290	Spring
07/18	293	300	Winter	07/18	149	292	Spring
07/19	295	300	Winter	07/19	150	294	Spring
07/20	298	300	Winter	07/20	151	297	Spring
				07/21	152	300	Spring
				07/22	153	300	Spring
				07/23	154	300	Spring
				07/24	155	300	Spring
				07/25	156	300	Spring
				07/26	157	300	Spring
				07/27	158	300	Spring
				07/28	159	300	Spring
				07/29	160	300	Spring
				07/30	161	300	Spring
				07/31	163	300	Spring
				08/01	164	300	Spring
				08/02	165	300	Spring
				08/03	166	300	Spring
				08/04	167	300	Spring
				08/05	168	300	Spring
				08/06	169	300	Spring
				08/07	170	300	Spring
				08/08	171	300	Spring
				08/09	172	300	Spring
				08/10	174	300	Spring
				08/11	175	300	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
.	.	.	.	08/12	176	300	Spring
.	.	.	.	08/13	177	300	Spring
.	.	.	.	08/14	178	300	Spring
.	.	.	.	08/15	179	300	Spring
.	.	.	.	08/16	181	300	Spring
.	.	.	.	08/17	182	300	Spring
.	.	.	.	08/18	183	300	Spring
.	.	.	.	08/19	184	300	Spring
.	.	.	.	08/20	185	300	Spring
.	.	.	.	08/21	187	300	Spring
.	.	.	.	08/22	188	300	Spring
.	.	.	.	08/23	189	300	Spring
.	.	.	.	08/24	190	300	Spring
.	.	.	.	08/25	192	300	Spring
.	.	.	.	08/26	193	300	Spring
.	.	.	.	08/27	194	300	Spring
.	.	.	.	08/28	195	300	Spring
.	.	.	.	08/29	197	300	Spring
.	.	.	.	08/30	198	300	Spring
.	.	.	.	08/31	199	300	Spring
.	.	.	.	09/01	201	300	Spring
.	.	.	.	09/02	202	300	Spring
.	.	.	.	09/03	203	300	Spring
.	.	.	.	09/04	205	300	Spring
.	.	.	.	09/05	206	300	Spring
.	.	.	.	09/06	207	300	Spring
.	.	.	.	09/07	209	300	Spring
.	.	.	.	09/08	210	300	Spring
.	.	.	.	09/09	211	300	Spring
.	.	.	.	09/10	213	300	Spring
.	.	.	.	09/11	214	300	Spring
.	.	.	.	09/12	216	300	Spring
.	.	.	.	09/13	217	300	Spring
.	.	.	.	09/14	218	300	Spring
.	.	.	.	09/15	220	300	Spring
.	.	.	.	09/16	221	300	Spring
.	.	.	.	09/17	223	300	Spring
.	.	.	.	09/18	224	300	Spring
.	.	.	.	09/19	226	300	Spring
.	.	.	.	09/20	227	300	Spring
.	.	.	.	09/21	229	300	Spring
.	.	.	.	09/22	230	300	Spring
.	.	.	.	09/23	232	300	Spring
.	.	.	.	09/24	233	300	Spring
.	.	.	.	09/25	235	300	Spring
.	.	.	.	09/26	236	300	Spring
.	.	.	.	09/27	238	300	Spring
.	.	.	.	09/28	239	300	Spring
.	.	.	.	09/29	241	300	Spring
.	.	.	.	09/30	243	300	Spring
.	.	.	.	10/01	244	300	Spring
.	.	.	.	10/02	246	300	Spring

Appendix Table B-1. Length-at-date limits for winter and spring chinook according to the Delta Model.

Date	Min	Max	Race	Date	Min	Max	Race
				10/03	247	300	Spring
				10/04	249	300	Spring
				10/05	251	300	Spring
				10/06	252	300	Spring
				10/07	254	300	Spring
				10/08	256	300	Spring
				10/09	257	300	Spring
				10/10	259	300	Spring
				10/11	261	300	Spring
				10/12	262	300	Spring
				10/13	264	300	Spring
				10/14	266	300	Spring
				10/15	268	300	Spring
				10/16	269	300	Spring
				10/17	270	300	Spring

Appendix C. A Brief Examination of Fisher (1992)

Fisher (1992) estimated the growth rate of fall-run chinook under naturalistic conditions in the Tehama/Colusa canal near Red Bluff, during the time when the facility was operated as a hatchery. A generalized condition factor-on-length regression was generated, and fish were then "measured" by counting and weighing batches[1]. By combining 10 years of data and adjusting for emergence times (which were somewhat controlled through the admission/exclusion of potential spawners by facility operators), Fisher generated the growth equation

$$fl = 33.66519 * e^{(.006574 * days)} \qquad \text{(C.1)}$$

where fl is fork length, e is the base of the natural logarithm, and days = number of days since emergence (the "e" is missing from Fisher's draft report). The growth data covered the first 20 - 27 weeks, or to about 100 mm. Fisher's Table 3 (next page) shows his results applied to all four chinook runs, extrapolated to 270 mm.

Fisher did not calculate standard error for either his condition factor-length regression or his growth curve. Rather, he accounted for the uncertainties in growth rate by assigning early and late emergence dates for each run (Table C-1). The reader will note that the spawning times do not overlap, although the lengths for each run in Table 3 overlap the adjacent runs by exactly 1 mm. The dates in table C-1 are far more precise than the broad ranges of emergence times now given in the literature (e.g., Moyle 2002, Table 11, where separate dates are also given for San Joaquin fall run). Fisher stated his belief that the vast majority of fish should emerge very near his expected dates (not given, but in the temporal center of the early and late dates), with very few in the early and late categories. If that were true, and if the growth curve were invariant, then one should expect non-overlapping, or at least minimally-overlapping groups of length at date.

Table C-1. Emergence times of Sacramento River chinook runs from Fisher (1992)

Run Name	Early emergence date	Late emergence date
Fall run	1 October	31 December
Late-fall run	1 January	15 April
Winter run	16 April	15 August
Spring run	16 August	30 September

As a rule, such minimally-overlapping length-at-date plots are not seen, either in Fisher's graphs or in modern ones. More importantly, Fisher did not appear to pay serious attention to the boundaries implied in his Table 3. For example, he concluded (quite reasonably) that all the fish in his Figure 4 (partially reproduced here as Figure C-1) were

[1] Fisher apparently obtained his data from hatchery personnel, whose principal interest was biomass and feeding rations for the fish in the raceways. Ironically, a condition factor cannot be calculated without first measuring the fish. Thus, Fisher worked backwards to obtain length estimates, apparently because the original length data had been discarded.

TABLE 3.

DATA FROM TOFFOUT.WK1 REGRESSION
GROWTH CURVES FOR INDIVIDUAL RACES
(MM FL.)

SPAWNING	FALL RUN			L.FALL RUN			WINTER RUN			SPRING RUN		
	EARLY	PEAK	LATE	EARLY	PEAK	LATE	EARLY	PEAK	LATE	EARLY	PEAK	LATE
TIME	OCT1		DEC31	JAN1		APR15	APR16		AUG15	AUG16		SEP30
EMERGE	DEC10		APR2	APR3		JUN27	JUN28		OCT18	OCT19		DEC9
DEC	34			166	122	89	89	65	45	45	41	34
mid month	37			181	136	99	99	73	49	49	45	37
JAN	41			200	150	110	110	80	54	54	49	41
	45			219	166	122	122	89	59	59	54	45
FEB	49	34		244	181	136	136	99	65	65	59	49
	54	37		270	200	150	150	110	73	73	65	54
MAR	59	41			219	166	166	122	80	80	73	59
	65	45			244	181	181	136	89	89	80	65
APR	73	49	34	34	270	200	200	150	99	99	89	73
	80	54	37	37		219	219	166	110	110	99	80
MAY	89	59	41	41		244	244	181	122	122	110	89
	99	65	45	45	34	270	270	200	136	136	122	99
JUN	110	73	49	49	37			219	150	150	136	110
	122	80	54	54	41			244	166	166	150	122
JUL	136	89	59	59	45	34	34	270	181	181	166	136
	150	99	65	65	49	37	37		200	200	181	150
AUG	166	110	73	73	54	41	41		219	219	200	166
	181	122	80	80	59	45	45	34	244	244	219	181
SEP	200	136	89	89	65	49	49	37	270	270	244	200
	219	150	99	59	73	54	54	41			270	219
OCT	244	166	110	110	80	59	59	45				244
	270	181	122	122	89	65	65	49	34	34		270
NOV		200	136	136	99	73	73	54	37	37	34	
		219	150	150	110	80	80	59	41	41	37	
DEC		244	166	166	122	89	89	65	45	45	41	34
		270	181	181	136	99	99	73	49	49	45	37
JAN			200	200	150	110	110	80	54	54	49	41
			219	219	166	122	122	89	59	59	54	45
FEB			244	244	181	136	136	99	65	65	59	49
			270	270	200	150	150	110	73	73	65	54
MAR					219	166	166	122	80	80	73	59
					244	181	181	136	89	89	80	65
APR					270	200	200	150	99	99	89	73
						219	219	166	110	110	99	80
MAY						244	244	181	122	122	110	89
						270	270	200	136	136	122	99
JUN								219	150	150	136	110
								244	166	166	150	122
JUL								270	181	181	166	136
									200	200	181	150
AUG									219	219	200	166
									244	244	219	181
SEP	VERIFIED AND REVISED 2/26/92								270	270	244	200
	SLOPE REMAINS THE SAME. LENGTH INTERVAL SHIFTED TO											219
OCT	CORRESPOND TO OBSERVED LENGTHS AT HATCHING.											244
	SIZE RANGE UPON HATCHING 28–35 MM.											270

fall-run, despite the extension of the tails of the distributions beyond the growth curves in March and April. In Fisher's Table 3, the emergence dates are given at the top, in the line labeled "EMERGE." Using equation (C.1), it is possible to calculate the lengths in the table with good accuracy (e.g., a late-emerging winter chinook on 15 July would be 270 days post-emergence, giving a length (rounded to nearest mm) of 199 mm , cf 200 mm in the table). By reference to Table 3, it can be verified that the top curve is the

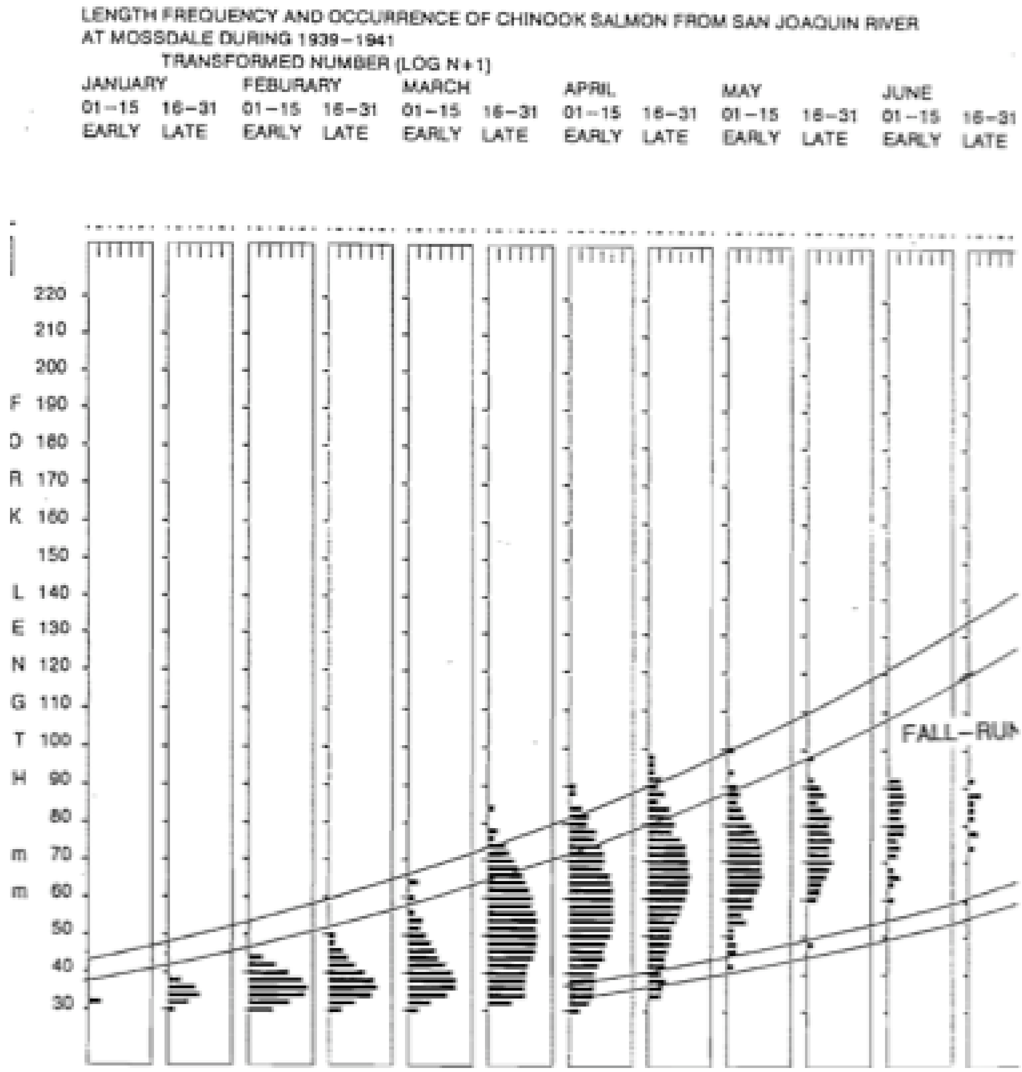

Figure C-1. From Fisher's Figure 4, showing log (length frequency + 1) by length and date of chinook salmon at Mossdale.

growth curve calculated from equation (C.1) for early-emerging fish at the end of the time period named at the top of each column, the next curve down is for early emergents at the beginning of the time period, the next curve down is the predicted length of late-emerging fall-run fish at the end of the time period, and the bottom curve is for late emergents at the end of the time period.

Several differences can be pointed out between Fisher's Table 3 and the Delta Model (DM), partially tabulated in Appendix B:

1. Fisher's gives explicit emergence dates for early and late emergents, whereas the DM does not (presumably these exist somewhere).

2. In Fisher's table, each run overlaps the next by 1 mm, but there are no overlaps in the DM.

3. In Fisher's table, the growth curve is extrapolated beyond the size range from which it was calculated (about 30- 100 mm) to 270 mm, whereas in the DM (origins unclear) the

lengths extend to 300 mm. (Fisher did draw his curves out to 300 mm in his Figure 11, showing chinook length frequencies from the SWP and CVP fish facilities)

4. The DM is not based on Fisher's growth curve; either the emergence dates or the growth rates, or both, are not the same. For example, the DM "definition" of spring chinook contains a wide swath of lengths that Fisher would have called winter-run, and the winter-run lengths include some late-fall-run fish by Fisher's table.