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**Author:**
Kimmerer, Wim J., San Francisco State University

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# Modeling Delta Smelt Losses at the South Delta Export Facilities

Wim J. Kimmerer[1]

## ABSTRACT

I previously estimated proportional losses of delta smelt to the water export facilities in the south Delta (Kimmerer 2008). This note is in response to Miller (2010), who disputes these estimated losses on several grounds. A re-analysis using a better analytical approach suggests a slight downward revision of the previous estimates for adult smelt. The distribution of smelt seems to have shifted northward in the last few years; if so, the smelt may now be less vulnerable to export losses than they previously were, although the reasons for such a shift are a concern. I argue, however, that it is legitimate to attempt such estimates in the absence of perfect information, and that mechanistic analyses are a valid way of estimating population-level impacts even in the absence of statistically significant correlations of estimated impact with subsequent population size.

## KEYWORDS

delta smelt, *Hypomesus transpacificus*, management, water diversions, population ecology

1 Romberg Tiburon Center, San Francisco State University
3152 Paradise Drive, Tiburon CA 94920
*kimmerer@sfsu.edu*

## INTRODUCTION

I previously calculated proportional losses of delta smelt (*Hypomesus transpacificus*) to the water export facilities in the south Delta (Kimmerer 2008). Here I respond to Miller (2010), who presents analyses to show that my estimates of proportional losses were overstated. Miller raises some valid points but misinterprets some of my original analyses, and offers comments that cannot be addressed with available information. His critique also raises, albeit indirectly, two important general issues for quantitatively estimating the impacts of human activities: (1) how such estimates can and should be made in the absence of complete information; and (2) the nature of evidence useful in quantifying these impacts. I first discuss Miller's more specific comments, and then return to these broader issues.

Kimmerer (2008) calculated proportional losses during times when delta smelt are captured in substantial numbers at the fish salvage facilities, i.e., roughly January to March for adults and March to June for larvae and juveniles. The proportional losses for each life stage were estimated using a rather complex procedure to determine inputs to a survival model (modified from Equation 12 in Kimmerer 2008):

$$P_L = 1 - \prod_{d=1}^{D}\left(1-\frac{\Phi_d}{N_d}\right) \qquad (1)$$

where $P_L$ is the proportional loss during the season of vulnerability, that is, the decrement in the population by the end of the season attributable to export pumping. D is the number of days in that season, $N_d$ is the population size on each day, and $\Phi_d$ is the daily loss to the fish facilities, including pre-screen mortality and assuming no successful salvage. Note that this formulation ignores mortality not attributable to export pumping, which was taken into account in the original analysis (see below).

To clarify Miller's arguments and my responses, I consider the following components of these calculations: (1) efficacy of the sampling programs used to estimate model inputs; (2) estimating the number of fish lost to entrainment per day $\Phi_d$; (3) estimating the population size $N_d$; and (4) accumulating daily loss over the season of vulnerability.

## EFFICACY OF SAMPLING

Sampling for fish involves numerous assumptions about their distribution and about the efficiency of the sampling gear used in relation to the particular species and size of fish collected (Rozas and Minello 1997). Generally, in any sampling process, the confidence limits around the estimate being made decrease as the number collected increases. Thus, very small catches do not invalidate a sampling effort, but the results are more uncertain than with large samples.

Three sets of sampling data were used in the original analysis. The Kodiak trawl survey of adults is considered to be an effective method that is roughly 100% efficient for fish in the channels. The 20–mm survey of larval and juvenile fish is most efficient for fish larger than 20mm, but less so for smaller fish. Kimmerer (2008, Equation 20) used a logistic model to correct catches for low gear efficiency for smaller fish. This model is based on the fact that surviving fish must grow through all size classes, and that therefore the abundance of the poorly sampled smaller sizes is constrained by the abundance of larger sizes. The principal assumption of the logistic model was that parameters of the model were constant *within* years but could vary *among* years. Statistical error in fitting the model contributed to rather large uncertainties in proportional losses, as much as a three-fold uncertainty in the relative abundance of the smallest (5 mm) size class. This error was propagated through subsequent analyses of proportional losses.

Miller argues that low catches of smaller fish in the 20–mm survey should not be scaled up using catch-efficiency curves. This is equivalent to saying that gear efficiency cannot be determined for small fish, and implies that the numbers in each size class must be determined independently of those in other size classes. However, he offers no argument why the logistic function cannot be used to estimate abundance of all size classes, how the larger fish might have arisen except by growth of the smaller ones, or what is wrong with providing estimates based on small catches if confidence limits are included. Furthermore, he labels as "unreliable" data from some 20–mm stations with zero catch, without an adequate explanation of why such data should be considered unreliable; 73% of the 20–mm tows from 1995 through 2005 had no delta smelt, but these contribute to the calculations of means and other population parameters.

The south Delta fish facilities sample far more volume and capture larger numbers of fish than the field surveys, but capture efficiency—the ratio of salvage to entrainment—is low and variable. Delta smelt are unlikely to be guided by the louvers, which were designed for and are most efficient for salmon (Bowen and others 2004). Mark–recapture studies with adult delta smelt gave an average 24% recovery of fish at the federal fish facility that had been released in front of the primary louvers. Castillo and others (2009) conducted a mark–recapture study of delta smelt in Clifton Court Forebay and concluded that pre-screen mortality presumably from predation was the largest source of mortality for fish entrained in the forebay, and likely much larger than for other studied fish such as salmon. These studies provide limited support, though not quantitative information, for the low capture efficiency of the salvage facilities.

Kimmerer (2008) found that catch per volume of water sampled differed between the two salvage facilities on a daily basis, but that the overall mean differences were very small. This was the basis for using the same salvage efficiencies for both facilities. The salvage values are useful for indicating the timing and relative magnitude of entrainment events, but underestimate entrainment and mortality of delta smelt many-fold as discussed above. Without calibration to field data, salvage is not a useful proxy for mortality.

Miller reports a lack of correlation between salvage of young delta smelt and estimated flux to the pumps, concluding from this lack of relationship that the calculated flux is biased upward. The reason for this putative bias is not really explained. Three factors interfere with such a correlation: (1) the low and variable efficiency of the salvage facilities, (2) the high variability and small number of samples per survey (six) used in calculating the flux (see below), and (3) the distance from the sampling stations to the export facilities. None of these should introduce bias. I previously showed that the south Delta catches and salvage during springs of 4 years matched reasonably well in timing and magnitude but with a lot of error, and a low but non-zero correlation (Figure 7 in Kimmerer 2008). Thus, there is evidence for substantial statistical error but not for bias.

## ESTIMATES OF FISH FLUX

The flux or entrainment of fish toward the salvage facilities $\Phi_d$ comprises three factors: pre-screen mortality, losses through the louvers, and salvage. Because salvage is likely a small fraction of entrainment (see above), it gives a poor estimate of $\Phi_d$, which must therefore be determined using other information, such as the density and rate of movement of fish in the waterways leading to the fish facilities.

The basis for such calculations (not spelled out by Kimmerer 2008) is a simple hydrodynamic flux calculation for a channel:

$$\Phi_C = A\left[(U + U_s)C - (K_h + K_s)\frac{dC}{dx}\right] \qquad (2)$$

where $\Phi_C$ is the flux of a substance or particles with concentration C, A is cross-sectional area of a channel, U is water velocity, $U_s$ is additional velocity of C (e.g., due to swimming in the positive x direction), $K_h$ is a horizontal dispersion coefficient, $K_s$ is an additional dispersion coefficient due to randomly directed swimming, and the last term is the longitudinal gradient in C. If the gradient is small and the particles are passive, the flux is simply $AU_C = Q_C$, where Q is the volume flow rate. Kimmerer (2008) used this to calculate the flux of young smelt with Q represented by the southward net flow in Old and Middle rivers and C by the catch per unit volume at six 20–mm stations in the south Delta. This calculation was not possible for adults because of low (often zero) catches, so the catches were used to calibrate salvage density (fish per unit volume of water) to catch per volume in the Kodiak trawl, and this calibration factor was applied to all salvage data to estimate flux.

Miller argues that since fish are not passive particles this calculation is invalid, but offers no alternative way to compute the fish flux. Larval fish have very limited swimming abilities and are essentially passive particles before they obtain a swim bladder, after which they can affect their position only through vertical migration. Tidal vertical migrations were found in pelagic fish larvae in the low-salinity zone but the sample size for delta smelt was small, and migration was not detected (Bennett and others 2002). Even the fish and copepods that demonstrably migrate tidally can overcome net seaward flow only in water that is stratified in salinity (Kimmerer and others 1998), which is not the case in the south Delta. The smelt that leave freshwater in early summer are post-larvae over 20mm long with developed swim bladders and initial distribution near the surface (also in the low-salinity zone, Bennett and others 2002). If this behavior applied in freshwater it would move most of the population westward to their brackish rearing habitat except those in the south Delta, which would move toward the pumps. Thus, during spring they can be treated as passive particles at the scale of the south Delta, and Equation 2 applies to these fish. Miller's argument implies that the fish are somehow escaping the southward flow of Old and Middle rivers, but there is no evidence that they are capable of doing that, nor do environmental cues exist that would persuade them to orient away from the export facilities.

Adult smelt move up-estuary during their spawning migration and are, therefore, demonstrably capable of moving against the net downstream flow in the Delta. However, high salvage numbers indicate the existence of a large southward flux of adults. I calculated an efficiency $\Theta$ (Equations 16 and 17 in Kimmerer 2008) relating salvage to the estimated fish flux based on the Kodiak trawl samples in the south Delta, and applied that to salvage to get the fish flux for all days of the season.

Miller argues on several grounds that $\Theta$ was overestimated. The most cogent argument is that there were too many zeros in the data to use a Poisson model to fit the data. I therefore re-fit the model in Equation 17 (Kimmerer 2008) with a zero-inflated Poisson model (Lambert 1992) which has two parameters; the Poisson mean and the proportion of excess zeros. This model was fit using a Bayesian approach in WinBUGS (Lunn and others 2004) using fitting and model checking procedures in Kimmerer and Gould (2010). The resulting estimate of $\Theta$ was 22 with a 95% credible interval of 13 to 33. This estimate is about 76% of the previous estimate but with better resolution. Estimates of mean adult loss in Kimmerer (2008) should, therefore, be reduced by 24%. Miller also argues that the data are contaminated by a single high catch of 17 fish. This might be true if the model were improperly cast as a linear regression, but for a properly formulated model it poses no problem. In any case, the analysis should be based on the data at hand.

Miller also argues that the adults are not passive particles, implying that they can overcome the effects of net flow in the south Delta. That is, the term $U_S$ in Equation 2 may be negative, reducing the actual fish flux $\Phi_C$. In that case salvage would be lower than expected if $U_S$ were zero, and the effect of a negative $U_S$ would be accounted for in the calculation of $\Theta$.

According to Miller, Old and Middle river flows are unrelated to salvage of either adult or young delta smelt and therefore are insufficient for calculation of fish flux. The relationship between these flows and salvage is actually quite obvious, if nonlinear and noisy (Figure 4 in Kimmerer 2008): when these rivers flow southward, salvage is often high, and when they flow northward, salvage is either mostly zero (juveniles, adults in the state facility) or sometimes non-zero (adults for the federal facility only). The latter case is likely due to $U_S$ in Equation 2 being positive for some fish, i.e., toward the export facilities. Thus, while the fish are not entirely behaving as passive particles, their behavior is not necessarily oriented to take them away from the facilities.

The calculations of proportional losses of young smelt were remarkably consonant with predictions made using the DSM2 particle tracking model (Figure 16 in Kimmerer 2008). This supports the use of Old and Middle River flows for the calculations, and the assumption of passive transport for this life stage. Furthermore, the estimate of $\Theta$ above is, if anything, low—considering the estimates to date of pre-screen losses and losses through the louvers.

Delta smelt are more abundant where the water is turbid (Feyrer and others 2007) and, therefore, salvage and salvage-related losses should be more predictable using information about turbidity than without this information. This issue arose after I had finished the final draft of the 2008 paper, but, in any case, turbidity data for the south Delta were not available for the time–period of this study. Ignoring it introduces error in the calculations but there is no reason to expect bias, since all the calculations were based either on salvage (adults) or fish collected in the south Delta (juveniles).

## SIZE OF THE POPULATION

The denominator in Equation 1 is essentially the mean catch in all samples times the volume over which those samples were taken. An alternative is to calculate mean catch per trawl by region of the estuary, multiply by area or volume of each region, and sum the result to get an index of abundance. The assumptions underlying these two approaches are somewhat different, but there are no data to suggest one is superior to the other. The annual abundance indices in several monitoring programs are calculated by region, but simple mean catch per trawl over all stations is closely correlated to these indices (Kimmerer and Nobriga 2005). Thus Miller's calculations of population size using a region–by–region approach are unlikely to be much different from the simpler calculation in Kimmerer (2008).

The fish fluxes Φ were calculated so that efficiency of the sampling gears was factored out of Equation 1. Therefore, the remaining issue for this part of the calculation is whether the samples in the south Delta represented the population there to the same degree that sampling throughout the Delta represented the overall population. Catchability is unlikely to differ between the south Delta and elsewhere (and we have no data either way on this), so the degree of representation boils down to whether the spatial coverage of sampling is adequate to represent the population.

Miller argues the contrary on the basis that high catches of adults in the Sacramento River Deep Water Ship Channel (sampled beginning in February 2005) indicate that most of the fish are in that region and are, therefore, under-sampled. Most of my analyses were for earlier years; furthermore, most of the salvage occurred between mid-December and the end of February (Figure 11 in Kimmerer 2008), when relatively few fish are yet in the north Delta (Figure 1). It does appear that more adults are in the north Delta during more recent years, mainly in the later surveys.

Miller makes a similar argument for young fish, although the argument is muddied by a claim that the 20–mm survey collects too few fish to provide a reliable index of total population size, based on projections of abundance of young fish from calculated abundance and assumed reproductive success of adults. If this were true it would call into question the results of all sampling programs. The stronger part of Miller's argument is the same as for adults: i.e., that a greater proportion of the population is in the north Delta and that it has been under-sampled. The data show an increasing proportion of the total catch in the north Delta stations (Figure 2) as the total catch has decreased. However, that proportion was never more than 8% during the period of this study.

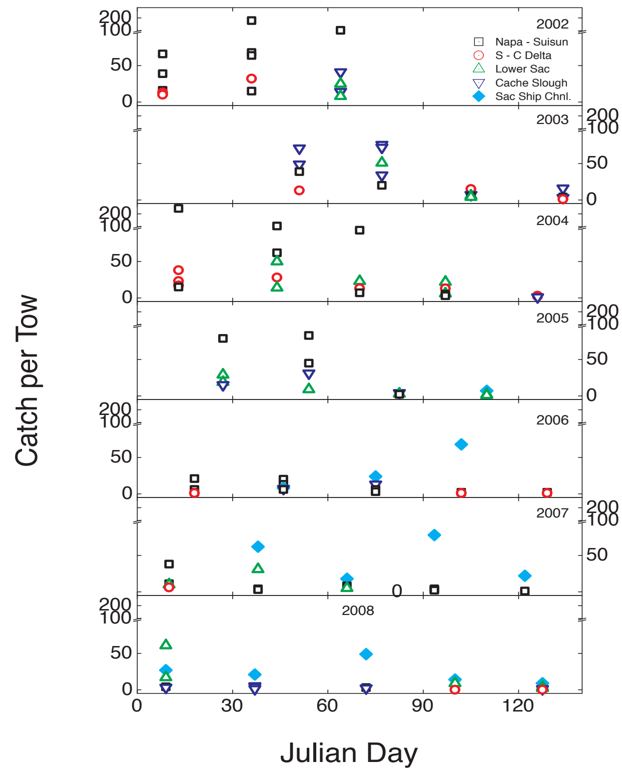


**Figure 1** Delta smelt catch per tow in the Spring Kodiak trawl survey for the five stations with the highest catches during each month's sampling, by year. These stations made up at least 62% of the total catch of the respective surveys. Symbols indicate sampling regions, with stations included as follows: Napa–Suisun: stations <699 plus 801; South–Central Delta: 802 to 999; Lower Sacramento River: 704 to 707; Cache Slough area: 711 to 716; and Sacramento Ship Channel: 719, sampled beginning February 2005.

The apparent northward shift in distribution of adult and young smelt means that the exposure of the delta smelt population to export pumping is less in recent years than it was during the time period of my study. Although this might be considered a benefit, conceivable mechanisms for this shift are not promising for the long–term maintenance of the species. One possible such mechanism is that the south Delta is occupied less by delta smelt because of a degradation of the habitat (e.g., by increasing water clarity). The implications of that for proportional losses to exports would depend on the mechanism keeping abundance low in the south Delta, which are not yet known.

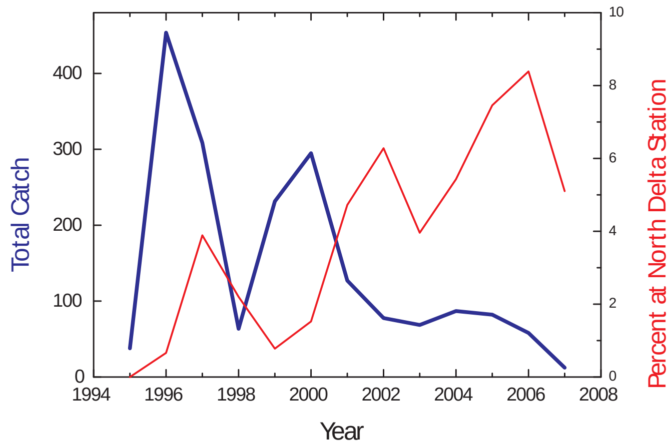


**Figure 2** Delta smelt catch in the 20–mm survey. Heavy blue line, left axis: total catch in all samples; thin red line, right axis: percent of catch from Station 716 in Cache Slough in the north Delta. Note that catches at Station 719 in the Sacramento River Deep Water Ship Channel have been high since sampling at this station began in 2008, but there is no information on whether this is a sampling artifact or a result of smelt movement.

## ACCUMULATING LOSSES OVER THE SEASON

Accumulating losses means calculating the proportional difference between the population that would have existed at the end of the exposure season with and without export losses. This requires that the relative size of the vulnerable population and other mortality be taken into account. For example, a high daily fractional loss early in spring when few young fish had hatched will have a smaller effect on ultimate population size than a high loss after all the fish had hatched.

Equation 1 could be parsed in a number of different ways, but the end result would not be very different using the same values of the fractional loss terms. The calculations are made a bit more difficult by the need to account for natural mortality of juveniles, as explained by Kimmerer (2008). Leaving mortality out of the calculations results in a modest increase in the calculated seasonal losses (Figure 15 in Kimmerer 2008). Although Miller argues that mortality is unlikely to be constant in space or time, the effects of such undeniable but unmeasured variability cannot, therefore, be very large. Since losses of larvae and juveniles were based on catches in the south Delta rather than salvage, an excess of mortality in the south Delta relative to the entire habitat would bias the loss estimates low, not high as Miller claims.

## ALTERNATIVE APPROACHES TO ESTIMATING EXPORT EFFECTS

To date, nobody has reported a relationship between any measure of flow toward the export pumps or losses of delta smelt, and either subsequent population abundance indices or ratios of successive indices. Miller argues that this lack of statistical link to population estimates is evidence that losses calculated mechanistically are unimportant compared to other effects such as food limitation.

This is part of a broader issue: the nature of evidence to be used in estimating the magnitude of human impacts on a biological population. Fundamentally, such impacts can be estimated through correlative measures, or they can be determined mechanistically. I do not believe that Miller is arguing against the use of mechanistic approaches (as some have done), since far more of our current scientific understanding in most fields of science rests on mechanistic than on correlative analyses.

Mechanistic approaches are based on known or inferred processes that influence the population in some way. In the specific case of estimated mortality to a fish population, the key issue is whether subsequent density dependence compensates for that mortality. If not, it is tautological that mortality will proportionally reduce subsequent population size.

Density dependence is a controversial topic mainly because of statistical difficulties, although conceptual problems also contribute. Compensatory density dependence can arise through a wide variety of causes, most involving food supply or predation (Rose and others 2001). Density dependence in striped bass in the San Francisco Estuary apparently compensated for very high losses to the export facilities, at least during a period of relatively high abundance (Kimmerer and others 2000).

Density dependence in stock–recruit relationships for delta smelt were driven largely by high values in the 1970s, although some evidence for density dependence remained in the data after 1981 (Bennett 2005); however, these relationships and the influence of environmental factors on them have likely changed over the intervening decades. The key question for interpretation of export losses of delta smelt is whether density dependence is strong in the post-decline population. This seems unlikely: since 2002 abundance of delta smelt has been too low for most potential mechanisms for compensatory density dependence to exert much influence. If so, the delta smelt population does not compensate for reductions in abundance by, e.g., increased fecundity or reduced mortality. Therefore, losses at any life stage permanently and proportionally reduce the population from the trajectory it would have otherwise have followed.

Correlative measures can be useful to the extent that they offer statistical support for a relationship. However, they cannot establish cause. More importantly, there is a clear difference between a finding that a result does not meet statistical standards of significance, and concluding it is not important. Thus, in making such an argument it seems important to determine what level of impact could be detected by correlative methods.

I determined this level through simulations, assuming density-independent population processes by the arguments above. I used the observed ratio of the fall midwater trawl index to the previous year's index as a stock–recruit index that should be sensitive to losses in the spring. The percentage loss in a given year was set as:

$$P_L = P_{max} \left( \begin{array}{c} 0 \text{ if OMR} \geq 0 \\ \dfrac{\text{OMR}}{\text{OMR}_{min}} \text{ if OMR} < 0 \end{array} \right) \tag{3}$$

where $P_{max}$ is the maximum percentage loss in any year (a free parameter in this simulation), OMR is the mean flow in Old and Middle rivers in spring (negative is southward), and $OMR_{min}$ is the minimum OMR flow (i.e., the maximum southward flow). OMR flows were determined for each spring as described in Kimmerer (2008). In this equation, $P_L$ is zero for positive OMR, and scales linearly with negative OMR to a maximum at $P_{max}$ when OMR = $OMR_{min}$. Alternative scaling would affect the quantitative results but not the qualitative conclusion.

For each year, the simulation ran using flow data from 1981 through 2006, with each year's fall population reduced by the simulated proportional loss during the previous spring. The choice of years to simulate was made to get a representative range of OMR flows, not to simulate an actual population trajectory, and the simulation was intended only to investigate the effects of export losses at low population size where density dependence would have a minimal effect. The flows were randomized among years to eliminate potential confounding factors from actual annual flow patterns. Then, for each integer value of $P_{max}$ from 0 to 100% a regression was calculated between southward Old and Middle river flow (the quantity in parentheses in Equation 3) and the log of the stock–recruit index. The intent was to determine how large $P_{max}$ had to be before losses become detectable in regression analyses.

The results (Figure 3) show that the losses were not generally detectable in the regression until $P_{max}$ reached about 60% to 80%. The levels of loss reported by Kimmerer (2008) were obscured by interannual variability in nearly all simulations, and maximum losses less than 20% were undetectable. Yet a $P_{max}$ of 20% (mean annual loss of ~10%) results in a 10-fold reduction in population size by the end of the 26-year simulation (Figure 3). Repeating the above simulation 10,000 times with $P_{max}$ = 20%, the upper 95% and 90% confidence limits of the regression slope excluded zero (i.e., was statistically detectable) in 5% and 9% of the cases, respectively. Thus, a loss to export pumping on the order reported by Kimmerer (2008) can be simultaneously nearly undetectable in regression analysis, and devastating to the population. This also illustrates how inappropriate statistical significance is in deciding whether an effect is biologically relevant (Stephens and others 2007).

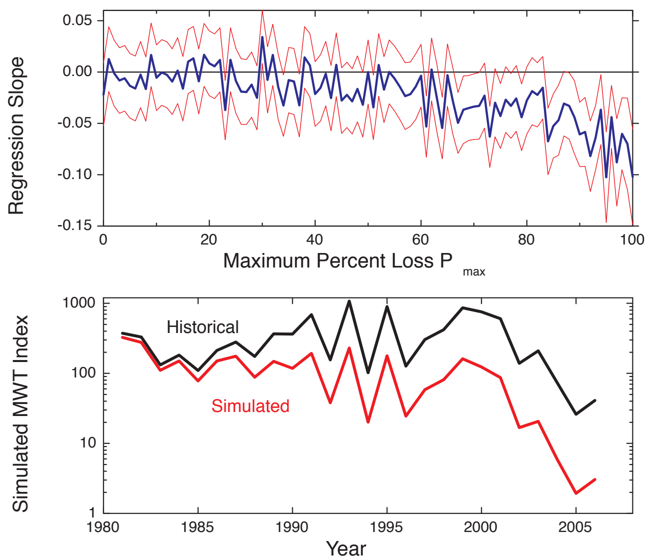


**Figure 3** Results of simulation of ability to detect export loss through regression analysis. Upper panel: individual simulation results giving the slope (thick blue line) and 95% confidence limits (thin red lines) for regressions of the stock-recruit index on southward OMR flow. Lower panel: trajectory of the fall midwater trawl index (upper line) and the same index with a 20% $P_{max}$ value imposed for the entire time series (mean $P_L$ ~10%). This is for illustration only (see text), and does not imply anything about the cause of the decline in delta smelt.

## CONCLUSIONS

Miller raises some valuable points about the data and methods used in calculating proportional losses. He also introduces new developments in understanding (e.g., turbidity effects) and in the delta smelt population (e.g, spatial distribution) that occurred recently. I do not believe these points cast doubt on the overall conclusion of my paper, which is that export–related losses to the delta smelt population during some of the years analyzed were substantial.

I previously reported that export effects had little effect on the striped bass population because of density dependence at levels of population abundance that existed up to 1995 (Kimmerer and others 2001). I also previously determined that export losses of mysids (*Neomysis mercedis*) were unlikely to be important to that population (reported by Orsi and Mecum 1996). During my work on the Environmental Water Account, I continually but unsuccessfully challenged my colleagues in the resource agencies to determine the effect of export pumping on fish populations, and therefore the magnitude of the benefit that the Account was having on fish (see Brown and others 2008). Therefore, my labors on export losses of delta smelt began with a strong skepticism about the importance of these losses, and ended with considerable surprise at their magnitude.

All of that said, neither my paper nor this exchange is the final word on this subject. More sophisticated statistical tools and models could and should be brought to bear on what controls delta smelt abundance, and these should be updated as new data become available. Information from new studies (e.g., Castillo and others 2009; Grimaldo and others 2009) and based on more recent distributional data should also be considered, both in refining understanding of influences on the smelt population and in assessing changes in the population itself.

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# Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR)

Ralph Mac Nally,[1,10] James R. Thomson,[1] Wim J. Kimmerer,[2] Frederick Feyrer,[3] Ken B. Newman,[4] Andy Sih,[5] William A. Bennett,[6] Larry Brown,[7] Erica Fleishman,[8,11] Steven D. Culberson,[9,12] and Gonzalo Castillo[4]

[1]*Australian Centre for Biodiversity, School of Biological Sciences, Monash University, Melbourne 3800 Australia*
[2]*Romburg Tiburon Center, San Francisco State University, 3152 Paradise Drive, Tiburon, California 94920 USA*
[3]*Applied Science Branch, U.S. Bureau of Reclamation, 2800 Cottage Way, Sacramento, California 95825-1898 USA*
[4]*U.S. Fish and Wildlife Service, 4001 N. Wilson Way, Stockton, California 95632 USA*
[5]*Department of Environmental Science and Policy, University of California, Davis, One Shields Avenue, Davis, California 95616 USA*
[6]*Center for Watershed Sciences and Bodega Marine Laboratory, University of California, Davis, P.O. Box 247, Bodega Bay, California 94923 USA*
[7]*U.S. Geological Survey, Placer Hall, 6000 J Street, Sacramento, California 95819-6129 USA*
[8]*National Center for Ecological Analysis and Synthesis, University of California, 735 State Street, Suite 300, Santa Barbara, California 93101 USA*
[9]*CALFED Science Program, 650 Capitol Mall, 5th Floor, Sacramento, California 95814 USA*

*Abstract*. Four species of pelagic fish of particular management concern in the upper San Francisco Estuary, California, USA, have declined precipitously since ca. 2002: delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), striped bass (*Morone saxatilis*), and threadfin shad (*Dorosoma petenense*). The estuary has been monitored since the late 1960s with extensive collection of data on the fishes, their pelagic prey, phytoplankton biomass, invasive species, and physical factors. We used multivariate autoregressive (MAR) modeling to discern the main factors responsible for the declines. An expert-elicited model was built to describe the system. Fifty-four relationships were built into the model, only one of which was of uncertain direction a priori. Twenty-eight of the proposed relationships were strongly supported by or consistent with the data, while 26 were close to zero (not supported by the data but not contrary to expectations). The position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow) and increased water clarity over the period of analyses were two factors affecting multiple declining taxa (including fishes and the fishes' main zooplankton prey). Our results were relatively robust with respect to the form of stock–recruitment model used and to inclusion of subsidiary covariates but may be enhanced by using detailed state–space models that describe more fully the life-history dynamics of the declining species.

*Key words: Bayesian analysis; delta smelt; expert models; longfin smelt; Sacramento River, California, USA; San Joaquin River, California, USA; striped bass; threadfin shad; threatened species; water management.*

## Introduction

Estuaries, especially those associated with large rivers near major cities, are among the ecosystems most adversely affected by land use change (Nichols et al. 1986). Impacts of human actions in all upstream watersheds (catchments) are concentrated in the estuaries (Kennish 2002, Townend 2004). Diversion of water affects the location of boundaries between fresh, brackish, and saline water (Drinkwater and Frank 1994, Gillanders and Kingsford 2002, Gleick 2003). Large settlements often are located along shorelines, which convey contaminants and effects of boating and fishing to estuarine systems (Dauer et al. 2000). Shipping has led to introductions of many aquatic invasive species (Bollens et al. 2002, Williams and Grosholz 2008). Climate change will affect interactions between oceans and estuaries and will reduce catchment inflows in many regions (Scavia et al. 2002, Vicuna and Dracup 2007, Cai and Cowan 2008, Schindler et al. 2008).

The San Francisco Estuary is an archetype of a stressed estuarine system (Kimmerer et al. 2005*a*). The social, economic, and ecological effects of freshwater flows and diversions throughout the San Francisco Estuary have received much attention. Some 25 million Californians and 12 000 $km^2$ of agricultural land rely on water diversions from the delta created by the Sacramento and San Joaquin rivers. Annual agricultural

Manuscript received 22 September 2009; accepted 12 October 2009. Corresponding Editor: M. J. Vander Zanden.
[10] E-mail: ralph.macnally@sci.monash.edu.au
[11] Present address: Bren School of Environmental Science and Management, 2400 Bren Hall, University of California, Santa Barbara, California 93106-5131 USA.
[12] Present address: U.S. Fish and Wildlife Service, Bay-Delta Fish and Wildlife Office, 2800 Cottage Way, Room W-2606, Sacramento, California 95825 USA.

revenue from California's Central Valley, which accounts for about half of the production of fruits and vegetables in the United States, frequently approaches US$15 billion.

Populations of many aquatic species in the estuary have declined since extensive human activities began in the mid-1800s (Bennett and Moyle 1996, Brown and Moyle 2005). However, conflicts over water management recently have intensified because of the apparently precipitous decline in four species of pelagic fish (delta smelt [*Hypomesus transpacificus*], longfin smelt [*Spirinchus thaleichthys*], striped bass [*Morone saxatilis*], and threadfin shad [*Dorosoma petenense*]) since ca. 2002 (Thomson et al. 2010). Delta smelt was listed as threatened under the U.S. and California Endangered Species Acts in 1993. Recent litigation to protect the species resulted in court orders to halt water diversions temporarily (Wanger 2007*a*, *b*). Longfin smelt was listed as threatened under the California Endangered Species Act in 2009, although a petition for federal listing was declined. Striped bass was deliberately introduced to the Sacramento–San Joaquin Delta from the east coast of the United States in 1879 and supports a sport fishery (Moyle 2002). Threadfin shad was introduced into California reservoirs as a forage fish in 1954 and spread to the Delta (Moyle 2002, Feyrer et al. 2009).

To date, models and statistical analyses to identify mechanisms causing fish declines in the San Francisco Estuary generally have been on a species-by-species basis (Jassby et al. 1995, Kimmerer et al. 2001, Bennett 2005). These efforts suggest that several abiotic factors (e.g., water flows, salinity, turbidity), bottom-up biotic effects (e.g., zooplankton abundances, invasion of a filter-feeding, non-native clam [*Corbula amurensis*]), and top-down factors (e.g., incidental mortality associated with water diversions to pumping facilities) may play important roles. However, the relative importance of these factors remains unclear (Sommer et al. 2007). Identification of processes causing declines is critical because possible solutions include major investments in infrastructure, changes in water management, and rehabilitation of species' habitats, which would cost billions of dollars.

Although detailed analyses of the population dynamics of any one declining species are valid, it is plausible that more insight might be gained through multivariate analyses that consider community dynamics, including direct and indirect effects of interacting species and abiotic factors. These analyses might yield inferences on the biotic and abiotic factors that best explain patterns of abundance for multiple species in the community and on the relative influences of density dependence, among-species interactions, and abiotic factors on species abundances.

We used a multivariate statistical technique called multivariate autoregressive modeling (MAR) (Ives et al. 2003) with 40 years of data for pelagic fishes and their principal prey within the upper San Francisco Estuary. In a manner similar to path analysis (Shipley 1997), MAR uses time series data for multiple taxa to estimate the degree of association between the different taxa as well as between covariates and each taxon. Multivariate autoregressive modeling includes autoregressive terms for each species' abundance. Ives et al. (2003) provided a detailed introduction to the underlying theory and assumptions of MAR along with methods for estimating model parameters. Multivariate autoregressive modeling has been used in analyses of community dynamics in lakes in Wisconsin (Ives et al. 2003), Lake Washington (Hampton and Schindler 2006), and Lake Baikal (Hampton et al. 2008).

We developed a Bayesian implementation of MAR. Bayesian methods allow propagation of and account for multiple sources of uncertainty in complex models (Punt and Hilborn 1997) and allow great flexibility in model structure (Cressie et al. 2009). The Bayesian MAR modeling is a complementary approach to methods we used in a companion paper, which presented a Bayesian change point analysis (Thomson et al. 2010). The two methods were developed in tandem to evaluate whether the different strengths of the MAR and change point analyses provided similar inferences about factors potentially underlying causes of declines in the fish species. Multivariate autoregressive modeling is based on a food web structure, which allows both direct and indirect influences on the focal species (fish) to be represented. Moreover, MAR models the dynamics of all species (including prey) simultaneously. It is based on linear relationships (on a log-abundance scale), both within the food web and with covariates, over the entire time period.

Our implementation of MAR is underlain by an expert-elicited model, which draws on expert knowledge to specify whether particular trophic or covariate effects may be influential. The change point analysis is not embedded in a food web context, although availabilities of prey taxa can be used as covariates, but it does explicitly employ time dependence and nonlinearity in covariate relationships between log-abundances of the focal species and covariates. The change point method uses Bayesian variable selection (Green 1995) so that relationships do not need to be specified a priori. Both individual-species (species-specific model parameters) and multiple-species (common hyper-parameter distributions) versions of the change point analyses were implemented (Thomson et al. 2010), with the latter having some overlap, therefore, with the MAR analyses.

Here, we describe the upper San Francisco Estuary, the four species of fish on which we focused and their principal prey, and the set of covariates included in the MAR model. Multivariate autoregressive models are heavily parameterized because they describe many among-taxa interactions and relationships to covariates. Therefore, we developed an expert-elicited, circumscribed model that reduced the number of parameters to be estimated. We review the relative importance of

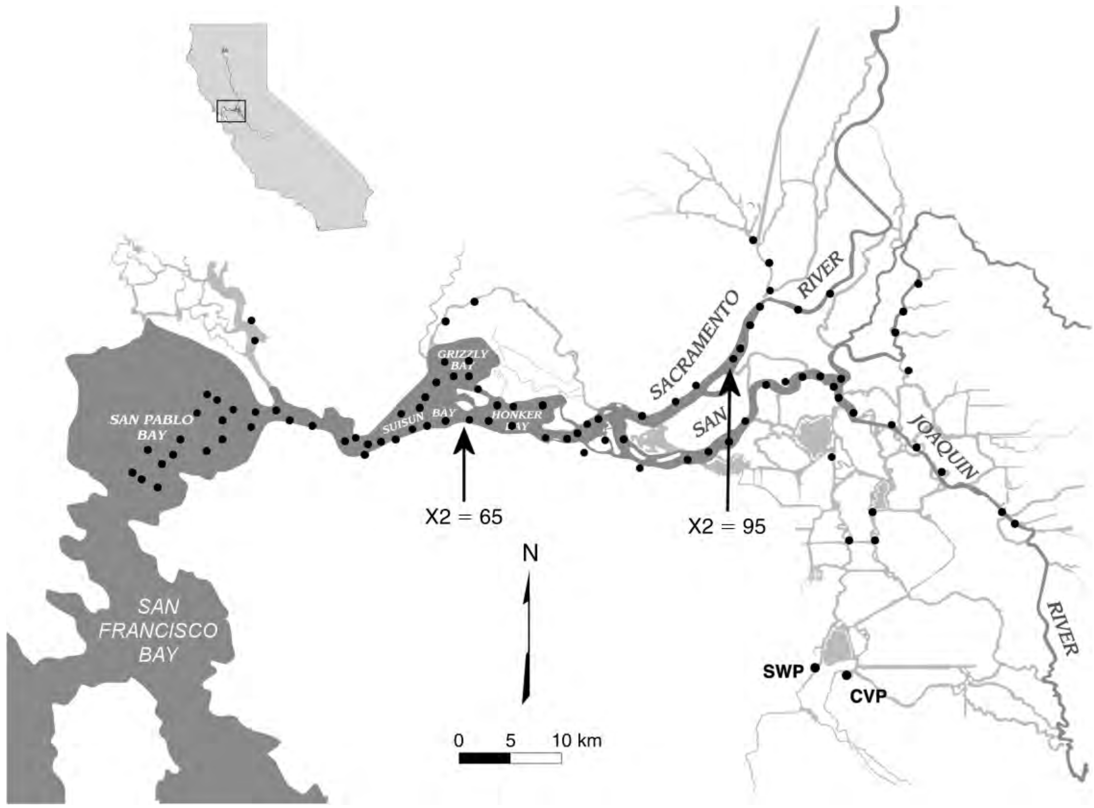


FIG. 1. Location and physiography of the upper San Francisco Estuary, California, USA. The solid circles denote sampling locations of the autumn midwater trawl surveys; arrows indicate two representative positions of the 2‰ isohaline (X2); SWP (State Water Project) and CVP (Central Valley Project) are locations of water exports from the estuary.

different factors in driving the temporal dynamics of our four declining fish species and comment on the usefulness and limitations of MAR models. Last, we comment on the agreement or otherwise between the MAR and change point approaches.

## METHODS

### *The San Francisco Estuary*

The San Francisco Estuary consists of three major regions: San Francisco Bay, the most seaward region; Suisun Bay, an intermediate brackish region; and the generally freshwater Sacramento–San Joaquin Delta (Fig. 1). The watershed has wet winters and dry summers. The Delta is the core of a massive system of dams and canals that store and divert water from the estuary for agricultural, industrial, and domestic use throughout California (Nichols et al. 1986). The water diversion facilities export ~30% of the annual freshwater flow into the Delta, although that percentage has exceeded 60% during many recent summers. Regulations, including standards for the position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow; Jassby et al. 1995), locally termed "X2," have become increasingly stringent.

### *Response variables: declining fish and their principal prey*

Delta smelt is endemic to the San Francisco Estuary and reaches 60–70 mm standard length (SL) (Bennett 2005), feeding on zooplankton, mainly calanoid copepods, throughout life. The delta smelt is weakly anadromous, migrating between the brackish waters of Suisun Bay and the freshwaters of the Delta. Upstream migration begins in the late autumn or early winter and spawning occurs from March through May in freshwater. Most delta smelt spawn ~12 months after hatching, with a small percentage surviving for another year to spawn. Young delta smelt move downstream in early summer and remain in the low-salinity zone (0.5–10‰) until they migrate for spawning.

Longfin smelt is native to the San Francisco Estuary. The species usually reaches 90–110 mm SL (Moyle 2002, Rosenfield and Baxter 2007) and is anadromous. It spawns at age 2 yr in freshwater in the Delta from December to April. Young longfin smelt occur from the low-salinity zone seaward throughout the estuary and into the coastal ocean. Longfin smelt feed on copepods as larvae and mysids and amphipods as young and adults.

Striped bass is a potentially large (>1 m), potentially long-lived (>10 yr) anadromous species. Females begin

TABLE 1. Definitions of variables used in the multivariate autoregressive modeling, years for which data were available, and ranges of values for variables.

| Variable | Years (missing) | Range | Definition |
|---|---|---|---|
| Response variables | | | |
| Delta smelt (*Hypomesus transpacificus*) | 1967–2007 (3) | 0.06–4.02 | autumn (Sep–Dec) midwater trawl, mean total catch per trawl |
| Longfin smelt (*Spirinchus thaleichthys*) | 1967–2007 (3) | 0.03–113.16 | autumn (Sep–Dec) midwater trawl, mean total catch per trawl |
| Striped bass (*Morone saxatilis*) | 1967–2007 (3) | 0.12–59.38 | autumn (Sep–Dec) midwater trawl, mean age-0 catch per trawl |
| Threadfin shad (*Dorosoma petenense*) | 1967–2007 (3) | 1.36–31.21 | autumn (Sep–Dec) midwater trawl, mean total catch per trawl |
| Calanoid copepods, spring | 1972–2007 (1) | 0.98–43.87 | mean biomass of calanoid copepodites and adults during spring (Mar–May) in low-salinity zone |
| Calanoid copepods, summer | 1972–2007 (1) | 2.93–27.62 | mean biomass of calanoid copepodites and adults during summer (Jun–Sep) in low-salinity zone |
| Mysids | 1972–2007 (0) | 0.42–35.05 | mean biomass of mysid shrimp during Jun–Sep in low-salinity zone |
| Covariates | | | |
| Northern anchovy (*Engraulis mordax*) | 1980–2006 (1) | 0.22–490.42 | mean catch per trawl of northern anchovy in the Bay Study midwater trawl (Jun–Sep) in the low-salinity zone |
| "Other zooplankton" in spring | 1972–2006 (0) | 3.79–56.86 | mean biomass of other zooplankton (not including crab and barnacle larvae, cumaceans) during spring (Mar–May) in the freshwater zone |
| Spring chlorophyll *a* (freshwater zone) | 1972–2006 (0) | 2.35–43.54 | mean chl *a* ($mg/m^3$) during spring (Mar–May) in freshwater zone |
| Spring chlorophyll *a* (low-salinity zone) | 1975–2006 (0) | 1.12–21.32 | mean chl *a* ($mg/m^3$) during spring (Mar–May) in low-salinity zone |
| Summer chlorophyll *a* | 1975–2006 (0) | 1.23–20.15 | mean chl *a* ($mg/m^3$) during summer (Jun–Sep) in low-salinity zone |
| Cyclopoid copepod *Limnoithona tetraspina* | 1972–2006 (0) | 0–7.78 | mean biomass of *Limnoithona* copepodites and adults during summer (Jun–Sep) in low-salinity zone |
| Inland silverside (*Menidia beryllina*) | 1994–2006 (0) | 19.88–116.54 | mean catch per seine haul of inland silverside in the USFWS survey during Jul–Sep (for stations within the delta) |
| Largemouth bass (*Micropterus salmoides*) | 1994–2006 (0) | 0.02–8.00 | mean catch per seine haul of largemouth bass in the USFWS survey during Jul–Sep (for stations within the delta) |
| Spring X2 (isohaline) | 1967–2006 (0) | 48.53–91.74 | mean Mar–May position of the 2‰ isohaline (X2) |
| Autumn X2 (isohaline) | 1967–2006 (0) | 60.24–93.18 | mean Sep–Dec position of the 2‰ isohaline (X2) |
| Water clarity | 1967–2006 (0) | 0.44–11.00 | mean Secchi depth (m) for the autumn midwater trawl survey |
| Winter exports | 1967–2006 (0) | 0.13–12.00 | total volume of water ($km^3$) exported by the California State Water Project and Central Valley Project during Dec–Feb |
| Spring exports | 1967–2006 (0) | 0.37–13.00 | total volume of water ($km^3$) exported by the California State Water Project and Central Valley Project during Mar–May |
| Invasive clam *Corbula amurensis* | 1967–2006 (0) | 0–1 | binary variable for presence (1987–2006, 1) or absence (1967–1986, 0) |
| Duration of spawning window for delta smelt | 1975–2007 (0) | 24–85 | no. days for which mean temperature was between 15° and 20°C,† mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta |
| Mean summer water temperature | 1967–2006 (0) | 20.45–23.65 | mean water temperature (°C), mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta during Jun–Sep |

*Notes:* Mean catch per trawl was measured in terms of individuals. Biomass was measured as mg $C/m^3$. The freshwater zone was determined to be $<0.5$‰. The low-salinity zone was determined to be at 0.5–10‰. The X2 position was measured in km upstream from the Golden Gate Bridge.

† Range of water temperatures that best induce spawning by delta smelt (15°C) and limit larval survivorship (20°C).

to spawn at age 4 yr in the Sacramento River and, to a lesser extent, in the San Joaquin River, from April through June. Eggs drift with the current as they develop and hatch. Larvae drift into the low-salinity zone where they grow, later dispersing throughout the estuary. Adults occur primarily in saline waters of the estuary and the coastal ocean, except during spawning migrations. Age-0 striped bass feed mainly on copepods, later switching to macroinvertebrates and then to fish.

Threadfin shad typically is $<100$ mm total length and primarily inhabits freshwater. It switches between filter- and particle-feeding, consuming phytoplankton, zooplankton, and detritus. Most threadfin shad spawn in their second summer, although some may spawn at the end of their first year. Spawning occurs mainly in June and July. Threadfin shad is the most abundant pelagic fish in the upper San Francisco Estuary.

While other fish and plankton groups might be included in our model as response variables, we chose to limit our analysis to species of zooplankton that are especially important for delta smelt, longfin smelt, age-0 striped bass, and threadfin shad. Adult and juvenile (copepodites) calanoid copepods have different relationships with the fish in spring and summer, so we considered the two life stages as different "taxa" in our models. Mysid shrimps were regarded as most important to the fishes in the mid to late summer (Table 1).

### *Covariates*

The covariates used in the MAR (Table 1) relate to factors thought to be important for one or more of the response variables (Table 2). Covariates included fish species that are potential competitors or predators of the four declining fish species (possibly at only certain life-history stages), food for the latter fishes or their crustacean prey (including phytoplankton), competitors (*Limnoithona*) or predators (*Corbula*) of the crustaceans, the primary surrogate of the fishes' habitat (X2) in spring and autumn, amounts of water extracted from the Delta in winter and spring, water clarity (measured using Secchi discs), and two water temperature variables (duration of the delta smelt spawning window, mean summer water temperature).

The expert model (Table 2) was based on extensive, long-term knowledge and experience of several of the authors (W. J. Kimmerer, F. Feyrer, W. A. Bennett, L. Brown, S. D. Culberson, G. Castillo), and justifications for expected relationships were drawn from the literature. Although Bayesian model selection (Green 1995) might have been incorporated into the MAR model, as was done for the complementary change point analyses (Thomson et al. 2010), we believe that there is didactic value in concentrating on the evidential support for the expert-elicited model.

## Statistical Estimation

### *MAR: Gompertz dynamics*

We used a variant of a MAR model (Ives et al. 2003) to represent dynamics of the response variables. We represented population dynamics with the Gompertz model (Dennis et al. 2006). We began with a deterministic version of the Gompertz model (Reddingius 1971):

$$n_{i,t} = n_{i,t-1} \exp(\gamma_i + \delta_i \ln n_{i,t-1}) \tag{1}$$

in which $n_{i,t}$ is abundance of species $i$ at time $t$, $n_{i,t-1}$ is abundance of species $i$ at time $t-1$, $\gamma_i$ is the intrinsic rate of population growth for species $i$, and $\delta_i$, which has been interpreted as the degree of density dependence.

We extended Eq. 1 first by allowing propagation for longer lags (up to $L$ years prior to the current year), that is, an $L$th-order Gompertz model (Zeng et al. 1998):

$$n_{i,t} = n_{i,t-1} \exp(\gamma_i + \sum_{l=1}^{L} \delta_{il} \ln n_{i,t-l}). \tag{2}$$

It is possible that the $\gamma_i$ may vary, so we allowed linear time dependence: $\gamma_i(t) = \gamma_{i,0} + \gamma_{i,1}t$. We expected the $\gamma_{i,1}$ parameters to be $<0$ given the declines in the abundances of the fishes. Taking logarithms, setting $x_{i,t} = \ln n_{i,t}$, and allowing species-specific lags ($L_i$), we have

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l}. \tag{3}$$

Interspecific interactions among the seven taxa included as response variables were incorporated by appending terms relating to the previous year $\beta_{ij} x_{j,t-1}$, excluding self-terms:

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j \neq i}^{J} \beta_{ij} x_{j,t-1}. \tag{4}$$

We included effects of covariates $u_k$ through $\alpha$ coefficients for the current year $t$:

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j \neq i}^{J} \beta_{ij} x_{j,t-1} + \sum_{k=1}^{K} \alpha_{ik} u_{k,t}. \tag{5}$$

### *MAR implementation*

We used a Bayesian framework for implementing the model. There are many advantages to so doing. First, propagation of measurement uncertainties is straightforward using hierarchical models. Second, missing data are easily accommodated and estimated within the same process by which the parameters estimated are made, rather than a clumsier two-stage imputation–estimation approach. Third, we believe that the prior expectations, which also are easily implemented in a Bayesian framework, are critical encapsulations of the state of knowledge before the modeling was undertaken and need to be made explicit, as we have done.

We implemented Eq. 5 using the following model in WinBUGS, version 1.4 (Spiegelhalter et al. 2003):

$$z_{i,t} \sim \mathcal{N}(x_{i,t}, \omega^2_{i,t}) \qquad x_{i,t} \sim \mathcal{N}(\mu_{i,t}, \sigma^2_i) \qquad c'_{k,t} \sim \mathcal{N}(u_{k,t}, \zeta^2_k)$$

$$\mu_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j \neq i}^{J} \beta_{ij} x_{j,t-1} + \sum_{k=1}^{K} \alpha_{ik} u_{k,t} \tag{6}$$

($\mathcal{N}$ denotes the normal distribution). The model states

TABLE 2. Matrix of effects included in the model with explanations.

| Response variable or covariate | Response variable DS | LFS | SB | TFS | CA-SP | CA-SU | MYS | Explanation |
|---|---|---|---|---|---|---|---|---|
| Delta smelt (DS) | | | | | – | – | | Calanoid copepods are consumed by delta smelt (Hobbs et al. 2006). |
| Longfin smelt (LFS) | | | | | – | – | – | Calanoid copepods and mysids are consumed by longfin smelt (Feyrer et al. 2003). |
| Striped bass (SB) | | | | | – | – | – | Calanoid copepods and mysids are eaten by young striped bass (Feyrer et al. 2003, Bryant and Arnold 2007). |
| Threadfin shad (TFS) | | | | | | | | Threadfin shad consume phytoplankton and copepods but are most abundant in freshwater (Turner and Kelley 1966, Feyrer et al. 2007). |
| Calanoids, spring (CA-SP) | + | + | + | | | | | Key food for young fish in spring. |
| Calanoids, summer (CA-SU) | + | + | + | | | | + | Key food for young fish in summer; mysids consume calanoids (Siegfried et al. 1979, Siegfried and Kopache 1980). |
| Mysids (MYS) | | + | + | | | – | | Key food for young longfin smelt and striped bass in summer. |
| Anchovy | | | | | – | – | – | Biomass dominant, consumes all plankton (Kimmerer 2006). |
| Other zooplankton | | | | + | | | | Threadfin shad consume zooplankton in freshwater (Turner and Kelley 1966). |
| Chlorophyll *a*, spring, freshwater | | | | | + | | | |
| Chlorophyll *a*, spring, low-salinity zone | | | | | + | | + | Calanoids eat microplankton, including phytoplankton (Gifford et al. 2007) and respond positively to phytoplankton blooms (Kimmerer et al. 2005*b*). |
| Chlorophyll *a*, summer, low-salinity zone | | | | | | + | + | Mysids eat phytoplankton and small zooplankton (Siegfried and Kopache 1908). |
| *Limnoithona tetraspina* | | | | | | – | | Indirect effect through depression of food resource (ciliates; not measured) (Bouley and Kimmerer 2006, Gifford et al. 2007). |
| Inland silverside | – | | | | – | – | | Silversides consume copepods and potentially delta smelt eggs and larvae (Bennett and Moyle 1996). |
| Largemouth bass | – | | – | – | | | | Potentially important predator on small fish in freshwater (Nobriga and Feyrer 2008). |
| X2, spring | | – | – | | +/– | | – | Effects of spring X2 on subsequent abundance in the following autumn (Jassby et al. 1995, Kimmerer et al. 2009). |
| X2, autumn | – | – | – | | | | | X2 affects surface area available for fish through salinity distribution (Feyrer et al. 2007). |
| Water clarity | – | – | – | – | | | | Turbidity favors all fish at various life-history stages by offering increased protection from predators (Feyrer et al. 2007, Nobriga and Feyrer 2008, Kimmerer et al. 2009). |
| Export flow, winter | – | – | | | | | | Adult smelt are entrained by pumping facilities during winter (Baxter et al. 2008, Kimmerer 2008). |
| Export flow, spring | – | – | – | – | | | | Juvenile and adult smelt and shad and juvenile striped bass are entrained by pumping facilities during spring (Baxter et al. 2008). |
| *Corbula amurensis* | | | | | – | – | | Nauplius larvae of copepods are consumed by *Corbula* (Kimmerer et al. 1994). |
| Spawning window | + | | | | | | | Spawning window for delta smelt is constrained by temperature (Bennett 2005). |
| Mean summer water temperature | – | | | | | | | Delta smelt are negatively influenced by high water temperatures, reducing time spent in the freshwater Delta (Swanson et al. 2000). |

*Notes:* A "+" denotes that the covariate was expected to exert a positive influence on the response variable (e.g., food source). A "–" indicates that the covariate was expected to have a negative influence on the response variable (e.g., by consumption). All null entries were deemed likely to be unimportant by expert knowledge. The abbreviations "X2" refers to the position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow).

that the (ln-transformed) observed values ($z_{i,t}$) represent the true values ($x_{i,t}$). The former have observation errors, which are included by use of (ln-transformed) unobserved values ($x_{i,t}$) and observation errors, $\omega^2_{i,t}$. The observation errors were estimated from SEs of mean values for the response variables for each time period. Given that the $z_{i,t}$ were ln-transformed, we used a Taylor functional expansion to approximate the ln-transformed SEs [$\mathrm{SE}(\ln(\bar{n})) \approx \mathrm{SE}(\bar{n})/\bar{n}$] (Seber 1973, Stuart and Ord 1987). Process variances ($\sigma^2_i$) were allowed to be species-specific and were implemented with priors on $\sigma_i$ of U(0.01, 10) (Gelman 2005) (U = Uniform). The true, unobserved values ($\mu_{i,t}$) are driven by the population dynamic parameters, trophic interactions, and covariates as described by the MAR model (Eq. 5).

Observed covariates $c_{k,t}$ were standardized for all available years of data (subtract mean $\bar{c}_k$, divide by standard deviations $\mathrm{SD}_k$ over all years, $c'_{k,t} = (c_{k,t} - \bar{c}_k)/\mathrm{SD}_k$). Standardizing is helpful for model convergence and for equalizing numerical ranges among different scales of measurement. Uncertainties in covariate measurements (within-year SEs) correspondingly were scaled by the interannual standard deviations (i.e., $\mathrm{SE}_{k,t}/\mathrm{SD}_k$). The model specifies that the true (standardized) covariate values ($u_{k,t}$) are related to the observed standardized values ($c'_{k,t}$) but include the covariate-specific uncertainties [$\zeta_k^2 = (\mathrm{SE}_{k,t}/\mathrm{SD}_k)^2$]. Uncertainties for most covariates were included in the models (a few variables, such as presence of *Corbula*, were regarded as fixed). There were sporadic missing data for some covariates, which we allowed to be interpolated within the Markov chain Monte Carlo (MCMC) modeling. These missing covariate values need to be segregated from the main estimation of effects by using the "cut()" function in WinBUGS. If the uncertainties are not so isolated, the model will "sacrifice" fitting precision for the parameters describing dynamics of the response variables to better "fit" missing covariate values, which is not intended (Carrigan et al. 2007).

### *Priors*

Relatively uninformative priors were assigned for these model parameters:

$$\gamma_{i,0} \sim \mathcal{N}(0,1) \qquad \eta_\gamma \sim \mathcal{N}(0,10^3) \qquad \sigma_\gamma \sim \mathrm{U}(0.01,10)$$

$$\sigma_i \sim \mathrm{U}(0.01,10) \qquad \delta_{il} \sim \mathcal{N}(0,1). \tag{7}$$

Use of standard Normal priors for the $\gamma_0$ and $\delta$ parameters is consistent with the expected values being within approximately $\pm 1$ (i.e., constrained to reasonable values) given the ln-transforms for the response variables and the standardized covariates. From expert elicitation, species-specific lags were 2 (delta smelt), 3 (longfin smelt), 5 (striped bass), 2 (threadfin shad), and 1 (calanoids and mysids).

For the key $\alpha$, $\beta$, and $\gamma_1$ parameters, we used a Weibull distribution to represent the prior beliefs of the expert-elicited model (Table 2). Use of the Weibull allows long tails in the expected direction if these are supported by the data. We used the construction $\psi_0$Weibull(2, 1) + $\psi_1$, where $\psi_0 = 1$ for expected influences in a positive direction and is $-1$ for negative expected influences, while $\psi_1$ is $-0.55$ for expected influences in a positive direction and 0.55 for negative ones. These configurations invest ~3:1 prior probability mass in favor of the expected influence. Only one $\alpha$ parameter had a neutral expected influence (Table 2), so this was assigned a $\mathcal{N}(0, 10^3)$ prior (i.e., low precision). Many of the potential relationships were specifically excluded from the model (i.e., deemed unlikely to be important). For such relationships, coefficients were assigned $\mathcal{N}(0, 10^{-6})$ priors (i.e., 0 with high certainty).

### *Parameter inference*

We inferred importance of model parameters from the probability distributions of the parameters. We computed the proportion of the posterior probability distribution for each parameter exceeding 0 (designated as PPM), which is computed in WinBUGS with the "step()" function. The posterior odds are PPM/(1 − PPM) for a positive parameter and (1 − PPM)/PPM for a negative parameter. The ratio of these posterior odds to the prior odds is termed the odds ratio (OR). Common decision criteria for ORs are 3.2–10 (substantial evidence) and 10–100 (strong evidence) (Jeffreys 1961). For an uninformative prior, in which the ratio of prior probabilities for the parameter is unity, the OR is PPM/(1 − PPM) (or (1 − PPM)/PPM for negative parameters). We used a decision criterion of $\geq$10 for such parameters.

For informative priors, the prior odds were 3 (positive or negative). If the OR $\geq$ 3.2, we concluded that there was substantial support in the data for the expected relationship. If $1 \leq \mathrm{OR} < 3.2$, the data did not invalidate the expectation but there was less support (Jeffreys 1961). If $1 \geq \mathrm{OR} > 1/3.2$, then the data weakly contradicted the expectation. If OR $\leq 1/3.2$, then the prior ratio of 3:1 had been shifted to 1:1 (or more extreme), suggesting that the expected relationship was inconsistent with the data but likely to be null. We interpreted OR $< 1/10$ (viz. from 3:1 prior expectation to 1:3.2 posterior odds) as clear refutation of the expected relationship.

### *Modeling details and model fit*

Parameters were estimated from three MCMC chains of 20 000 iterations after 10 000 iterations of burn-in ("model settling"). We checked MCMC mixing and convergence using the "boa" package (Smith 2006) in *R* (R Development Core Team 2006).

We determined relative importance of the autoregressive (A), among-response variables (R), and covariate (C) factors of the best model. To do so, we calculated the $r^2$ for eight models: null (fitting constant-only averages for the seven response variables), A, R, C, A + R, A + C, R + C, A + R + C (full model). These models were effected by deleting terms from Eq. 6 as appropriate. The $\gamma_i$ terms were retained for all models. The $r^2$ are the squared Pearson correlation coefficients between the $z$ and $\mu$ values from the seven response variables and all years. To decompose variance we used hierarchical partitioning (Chevan and Sutherland 1991, Mac Nally 2000), which identifies independent contributions from individual terms (viz. A, R, and C) and joint variance explanation. We used the R package "hier.part" (Walsh and Mac Nally 2003) to perform the decomposition.

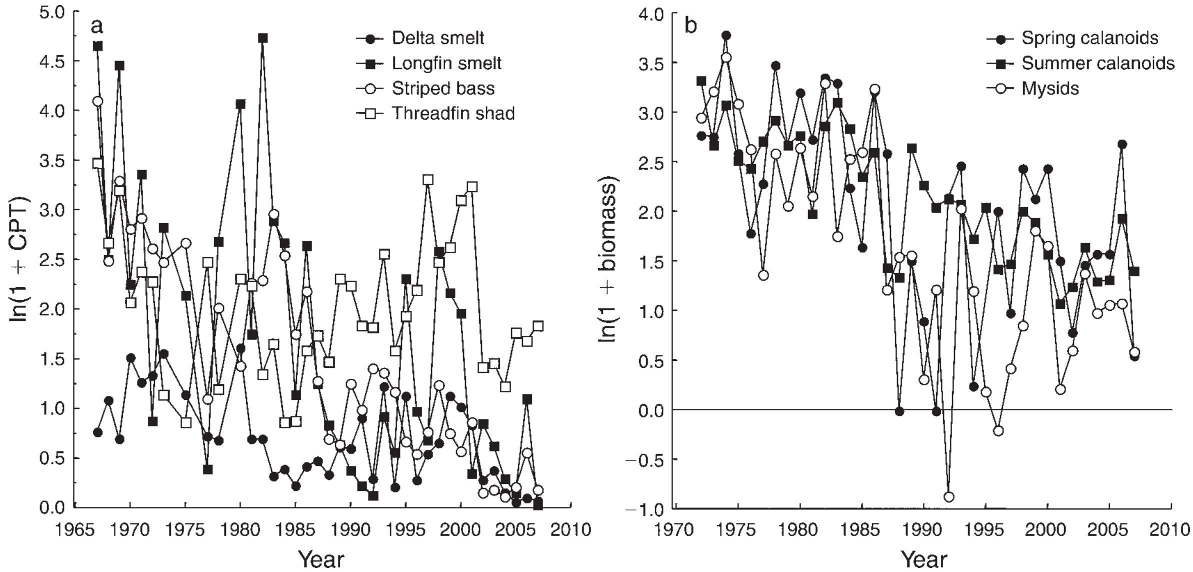


FIG. 2. Population trends (log-transformed) of (a) four fish species (mean catch per trawl [CPT]) and (b) zooplankton taxa (biomass, originally measured in mg C/m$^3$).

## RESULTS

### *Abundance trajectories*

Abundances of all four species of fish declined over the period of data collection, especially since about 2002 (Fig. 2a). Biomasses of the three crustacean groups have been declining consistently since the 1970s, with less evidence of a sudden decline in the 2000s (Fig. 2b).

### *Overall model characteristics*

We used the $r^2$ (squared Pearson correlation coefficient) between the observed values and the posteriors of the fitted means as our measure of model fit. The full model (autoregressive components, among-response variables interactions, covariates) had an $r^2 = 0.69$. This explained variance was decomposed into independent explanatory amounts of (a) 0.13 for the autoregressive components (A), (b) 0.21 for among-response variable components (R), and (c) 0.35 for covariate relationships (C) (hence 1:1.62:2.69). Thus, the covariates were roughly 66% more important in explaining variation than the response variables, which in turn were ~62% more important than autoregressive elements.

### *Specific relationships*

Parameter estimates and related details are provided in Appendix A. Some covariates appeared to affect more than one response variable (Fig. 3a, b). For expectations that seemed strongly supported by the data, the large values of spring X2 (upstream location) were negatively related to abundances of longfin smelt, biomass of calanoids in spring, and biomass of mysids (Fig. 3a). High water clarity was associated negatively with abundances of striped bass and threadfin shad, while high mean summer water temperatures had an inverse relationship with delta smelt abundance (Fig. 3a).

Several expectations were more weakly supported by the data, but were not refuted. Spring exports were negatively associated with abundances of delta smelt and threadfin shad (Fig. 3b). Many of the trophic interactions among response variables were supported to some extent, including negative relationships between the abundance of longfin smelt and delta smelt and biomass of calanoids in summer, negative correlations between abundance of striped bass and calanoid biomass in spring, and a positive relationship between concentration of chlorophyll *a* in spring and biomass of mysids and calanoids. Calanoid biomass in spring and summer was negatively associated with presence of the nonnative clam *Corbula amurensis*, while abundance of largemouth bass and volume of winter exports were negatively associated with abundance of delta smelt (Fig. 3b).

For all four declining fish species, the parameters indicating density dependence ($\delta$) from the previous year were strongly negative, ranging from $-0.79 \pm 0.26$ (mean $\pm$ SD) for threadfin shad to $-1.03 \pm 0.18$ for longfin smelt (Appendix A). Current abundances were positively related to those for two years previous for longfin smelt ($0.30 \pm 0.16$). Other lag effects were deemed unimportant, although a four-year lag (positive) for striped bass had OR = 9.2.

For the $\gamma$ parameters, only one result seemed unexpected. The anticipated negative slope for threadfin shad was positive, with high certainty (OR < 1/57.8; Appendix A). This suggested, counterintuitively, that the intrinsic population growth parameter had increased over the duration of study.

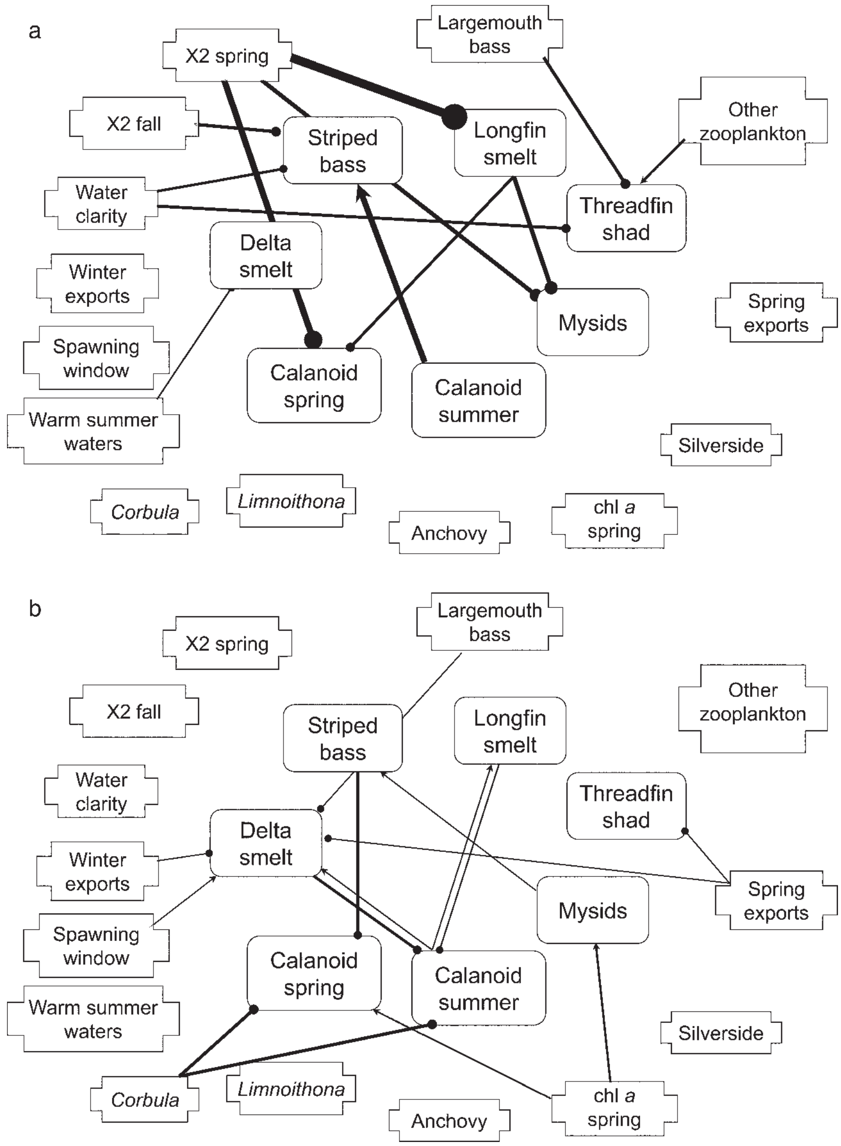


FIG. 3. Relationships supported by the Bayesian multivariate autoregressive analysis of the expert-elicited model, with width of lines proportional to the regression coefficient divided by its standard error. Response variables (focal taxa) are enclosed in rounded boxes while covariates are in boxes with side tabs. Arrows toward a focal taxon indicate a positive effect related to the focal taxon or covariate of line origin, while solid circles indicate negative relationships. (a) Relationships for which the odds ratio $\geq 3.2$. (b) Relationships for which the odds ratio falls between 1 and 3.2. The abbreviation "X2" refers to the 2‰ isohaline.

## DISCUSSION

### *Overview of the MAR results*

The importance of covariates (51% of explained variation) suggests that some aspects of the environment that can be managed are associated with the declining fish species (e.g., X2 and exports). However, other potential remedial actions would be difficult or impossible to enact (e.g., total removal of *Corbula amurensis*). The relatively large proportion of variance explained by interactions among the declining fishes and their prey suggests that trophic interactions also are important, but it is less clear how management actions could modify such relationships.

The MAR analysis largely supported the expert model, suggesting that existing knowledge is sufficient to identify important interactions and processes, although not all relationships were supported. The expert model included 54 relationships, all but one of which was assigned an expected direction (Table 2). The latter was an "uninformed" expectation that calanoids in spring would be affected by spring X2. The direction was found to be strongly negative (Fig. 3a), suggesting that spring calanoid abundance is greater when X2 is more seaward. Of the 53 relationships with expected directions, 13 were strongly supported on the basis of odds ratios (OR) of $\geq$3.2 (Fig. 3a) and 15 were not inconsistent with the expected direction (3.2 $>$ OR $\geq$ 1) (Fig. 3b). The other 25 coefficients had posterior means close to zero, indicating that the data did not support the expected directions.

One advantage of using the MAR approach is that results can be represented easily in a form with which most ecologists are familiar, a (partial) food web (Fig. 3). The predator–prey relationships involving the calanoids and mysids support existing reports of direct and indirect effects on the four declining fish species. For example, abundance of striped bass was positively related to availability of calanoid copepods in summer (Fig. 3a). This was negatively associated with the occurrence of the introduced clam *Corbula amurensis* (Fig. 3b), which has induced an ongoing decrease of $\sim$60% in chlorophyll *a* concentration in the low-salinity zone (Alpine and Cloern 1992). Other indirect food limitation relationships may be the chlorophyll *a* (spring) $\rightarrow$ mysids $\rightarrow$ striped bass and chlorophyll *a* (spring) $\rightarrow$ calanoids (spring) $\rightarrow$ striped bass pathways (Fig. 3b). Longfin smelt abundances had strong negative correlations with calanoids in spring and summer and mysids in spring (Fig. 3a, b). Abundance of delta smelt was related to calanoid biomass in summer (Fig. 3b). These results and relationships of copepods and mysids to chlorophyll *a* concentrations (Fig. 3b) suggest that food web dynamics are important for both smelt species. The isohaline position (X2) in spring had strong negative relationships with spring calanoids and mysids, which also would propagate back through those food pathways (Fig. 3a).

Few covariate relationships were expressed clearly for more than one of the four declining fish species (Fig. 3a, b). Increased water clarity appeared to be related negatively to both striped bass and to threadfin shad (Fig. 3a). Increased water clarity has been attributed to reduction of sediment supply in the rivers (Wright and Schoellhamer 2004) and to sediment capture by submerged aquatic vegetation. Water clarity affects fish feeding (Hecht and Vanderlingen 1992) and vulnerability to predation (Gregory and Levings 1998). Abundance of largemouth bass, a potential predator of the declining fish species (Nobriga and Feyrer 2008), was negatively related to abundance of threadfin shad and, more weakly, to abundance of delta smelt (Fig. 3). Abundance of largemouth bass has increased in the Delta concurrently with expansion of submerged aquatic vegetation (Brown and Michniuk 2007), which provides high-quality habitat for the species. Greater cover of submerged aquatic vegetation also reduces turbidity. Reduced water clarity has been identified as a key component of habitat for delta smelt, at least in autumn (Feyrer et al. 2007). The absence of a discernible relationship between water clarity and abundance of delta smelt may be due to an indirect expression through trophic relationships. Young delta smelt require suspended particles in the water column to feed properly (Baskerville-Bridges et al. 2002, Mager et al. 2002), so reduced prey availability (e.g., summer calanoids) may mask the direct water clarity effect. The multiple effects of temperature, feeding, exports, and introduced species are more consistent with understanding of delta smelt biology (Bennett 2005, Baxter et al. 2008) than are effects of individual covariates per se.

There were clear relationships between warmer summer waters (negative) and duration of water temperatures suitable for spawning (positive) (Fig. 3) and delta smelt, which were consistent with known effects of high temperatures on delta smelt survival (Swanson et al. 2000) and spawning requirements (Bennett 2005).

Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad. Losses of delta smelt previously have been related to exports through entrainment and mortality at pumping facilities and may be important to population dynamics under some circumstances, particularly during dry years (Kimmerer 2008). Effects of spring exports on threadfin shad have not been measured but possibly are important given that this is the only species of the four to occupy freshwater throughout its life cycle and whose main distribution is near the export facilities (Feyrer et al. 2009).

### *Modeling formulation: data and limitations*

Using MAR, we identified plausible results, notwithstanding a number of important caveats within the model framework, which relate to the nature of the underlying data and to the structure of the analytical model.

*Data limitations*.—Three major forms of data limitation inherent in MAR are relevant to our study: (1) characterization of all variables and covariates by using a single value per year; (2) lack of spatially and temporally explicit data; and (3) selection of covariates and their measurement. For the declining fish species, we used an estimate of abundance based on average catch per sampling trawl over $\sim$100 sampling stations over each of the four autumn months (September to December). Fish have been collected by other sampling methods (e.g., beach seine nets), but either not consistently over the duration of the data collection or only recently. We included observation error as the standard error from the $\sim$400 trawls per year, but whether this is the most appropriate measure is arguable (Newman 2008).

Apart from allowing $\gamma_i$ to be time-dependent (albeit linearly), the MAR model assumed process stationarity over the entire duration, which means that the structure of the model and distributions of model parameters are regarded as being the same over the 40+ years. It is possible that population dynamics of the declining taxa changed greatly as a function of population size. It is plausible that per capita reproductive rates, age structures, social (e.g., schooling) behaviors, Allee effects (Stephens and Sutherland 1999), and vulnerability to predation may differ when there are many individuals compared to when there are few. This is a common tenet in conservation biology (Caughley 1994).

Given the high certainty that all four species declined in concert in 2002 (Thomson et al. 2010), we modified Eq. 6 to allow all parameters to have a two-phase structure. The first phase was the 1967–2001 period and the second phase was 2002–2007. Each parameter was represented by a term of the form $\varpi + \delta\varpi$, where $\delta\varpi$ was the deviation in the second phase from values in the first phase. There were no parameters in which $\delta\varpi$ differed substantially from zero using our OR criteria. This suggests that the stationarity assumption of the MAR model is reasonable, although the small number of years in phase two may make changes difficult to detect.

Stakeholders have commissioned extensive correlative analyses (D. Fullerton, W. J. Miller, and B. F. J. Manly, *unpublished data*), which suggest a wide range of possibilities for potential covariates that might have sparked the precipitous declines. We included eight commonly mentioned covariates in additional runs of the MAR model (Appendix B). Our inferences were little changed, which suggests that our expert model was resilient to inclusion of additional variables and that the latter were largely uninformative.

*Model form and structure.*—The MAR model is underlain by the Gompertz population dynamic model (Eq. 1). Inference on stock recruitment is contingent on the form of the model (Maunder 2003). We explored whether our inferences were highly dependent on the use of the Gompertz by replacing it with another widely used formulation, the Ricker model (Appendix C; Zeng et al. 1998). The Ricker model emphasized more strongly several relationships: for example, the negative relationships between striped bass and X2 (autumn) and between spring calanoids and X2 (spring) (Appendix C). The Ricker and Gompertz versions of the MAR model generally provided similar inferences but the Gompertz appeared to resolve with greater precision a larger number of relationships given our criteria for their identification (i.e., using ORs).

The values for the $\delta_{i1}$ coefficients for the four declining fish species suggested strong negative density dependence (values between −0.79 and −1.03 for one-year lag; Appendix A). Such results seem difficult to reconcile biologically given that the fish sampled each year are young-of-the-year and it is difficult to conceive of a mechanism producing such density dependence. It is possible that this apparent contradiction may be a statistical artifact of the parameterization of the usual Gompertz model. Estimates of $\gamma$ and $\delta$ can be highly correlated and identifiability depends upon length of time series (J. Ponciano, *personal communication*). Even if there were estimation problems for $\gamma$ and $\delta$, these probably do not affect our estimates of trophic interactions and covariate relationships. From simulations of a Gompertz model with one covariate, we found that the estimate for the covariate coefficient was unbiased even though the estimates of $\gamma$ and $\delta$ were biased (results not shown).

The MAR formulation assumed linear relationships (on the log-abundance scale) and no interactions among covariates, although many interactions are plausible. Interactions would add substantially to the complexity and difficulty of interpretation of an already highly parameterized model. Inclusion of nonlinear functions and interactions among covariates may reduce capacity to resolve drivers of responses if used injudiciously.

A comparison of major outcomes of the MAR analysis with those of the change point analyses, which did allow nonlinear functions of covariates, showed some commonalities, but also several differences. Relationships with water clarity were important in the change point analyses for delta smelt, striped bass, and longfin smelt, although the relationship for the latter was rather stronger in a multispecies model (Thomson et al. 2010). A correlation of water clarity with abundances of threadfin shad, but not with delta smelt, was identified in MAR. A pervasive relationship of spring X2 with abundances of longfin smelt was clear in both analyses. A correlation of winter exports with delta smelt was evident in the change point, but was weaker in the MAR (Fig. 3b). The MAR analysis, but not the change point analysis, identified a correlation between autumn X2 and striped bass. Spring exports appeared to be related to abundances of threadfin shad in both analyses, although the magnitude of the correlation was less in the MAR. Unlike the change-point analysis, the MAR analysis did not identify a relationship between winter exports and threadfin shad. However, in the change-point analysis the magnitude of the average regression coefficient for winter exports and threadfin shad was substantially less than that for spring exports (Thomson et al. 2010). The trophic interactions evident in the MAR, of which many were pronounced (Fig. 3), were less evident in the model selection procedures used in the change point analysis.

A broader life-history model with a more general state–space approach to modeling the pelagic species decline should be more informative (M. N. Maunder and K. B. Newman, *personal communication*). Such a model would incorporate multiple sources of survey data, including data pertinent to egg, larval, juvenile, and adult phases and covariates appropriate for each stage (Maunder 2004).

### *Estuarine management*

Our application of the MAR model provides evidence from a multivariate analysis of how abiotic habitat factors directly relate to declining fish abundance in the upper San Francisco Estuary and indirectly to these fish populations through the food web. Synthesis of previous univariate analyses have come to similar conclusions, albeit indirectly (Bennett 2005, Baxter et al. 2008). Before the fish species declined precipitously, the abiotic component of their habitat in the estuary was represented mainly as X2 because position of the salinity field was correlated with the abundances of many organisms (Jassby et al. 1995). Recent results have highlighted the importance of other abiotic variables, including water clarity and water temperatures, in the estuary (Feyrer et al. 2007, Nobriga and Feyrer 2008). Our results, which identify trophic relationships, suggest the need to better understand the processes underlying the influence of abiotic conditions on the food web of the estuary. The upper San Francisco Estuary is an exemplar, perhaps an extreme one, of severe, adverse ecological response to many of the stressors to which such systems increasingly are exposed (Fig. 3). Some of the key issues relate to how the isohaline position (X2), which seems to have a profound effect on the declining fish and on their prey, might be managed. While evidence that water exports directly affect striped bass or longfin smelt in a consistent linear manner is weak, there is evidence of potential effects of water exports on delta smelt and threadfin shad. Successfully managing the estuary, at least for the declining fish species, requires a more complete understanding of how the direct effects of water exports interact with the indirect effect of controlling abiotic conditions and the food web.

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## APPENDIX A

Details of parameter estimates for the multivariate autoregressive (MAR) model including credible intervals of odds ratios (all model parameters are listed) (*Ecological Archives* A020-050-A1).

## APPENDIX B

Details of parameter estimates for multivariate autoregressive (MAR) model with and without distinct variables suggested by other analyses (only parameters with large odds ratios are listed) (*Ecological Archives* A020-050-A2).

## APPENDIX C

Details of parameter estimates for multivariate autoregressive (MAR) models underlain by Ricker and Gompertz population-dynamic formulations (only parameters with large odds ratios are listed) (*Ecological Archives* A020-050-A3).

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Delta Flow Factors Influencing Stray Rate of Escaping Adult San Joaquin River Fall-Run Chinook Salmon (*Oncorhynchus tshawytscha*)

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**Author:**
Marston, Dean, California Department of Fish and Game
Mesick, Carl, U.S. Fish and Wildlife Service
Hubbard, Alan, University of California, Berkeley
Stanton, Dale, California Department of Fish and Game
Fortmann-Roe, Scott, University of California, Berkeley
Tsao, Steve, California Department of Fish and Game
Heyne, Tim, California Dept. of Fish and Game

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**Keywords:**
Fall-run, Chinook, Salmon, Stray, Delta, San Joaquin, Sacramento, Exports, Age, Hatchery, Aquaculture and Fisheries, Biostatistics, Hydrology, Population Biology, Probability

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**Abstract:**

Adult salmon that stray when they escape into non-natal streams to spawn is a natural phenomenon that promotes population growth and genetic diversity, but excessive stray rates impede adult abundance restoration efforts. Adult San Joaquin River (SJR) Basin fall-run Chinook salmon (*Oncorhynchus tshawytscha*) that return to freshwater to spawn migrate through the San Francisco Bay and Sacramento–San Joaquin River Delta (Delta). The Delta has been heavily affected by land development and water diversion. During the fall time-period for the years 1979 to 2007 Delta pumping facilities diverted on average 340% of the total inflow volume that entered the Delta from the SJR. The hypothesis tested in this paper is that river flow and Delta exports are not significantly correlated with SJR salmon stray rates. Adult coded-wire-tagged salmon recoveries from Central Valley rivers were used to estimate the percentage of SJR Basin salmon that strayed to the Sacramento River Basin. SJR salmon stray rates were negatively correlated ($P = 0.05$) with the average magnitude of pulse flows (e.g., 10 d) in mid- to late-October and positively correlated ($P = 0.10$) with mean Delta export rates. It was not possible to differentiate between the effects of pulse flows in October and mean flows in October and November on stray rates because of the co-linearity between these two variables. Whether SJR-reduced pulse flow or elevated exports causes increased stray rates is unclear. Statistically speaking the results indicate that flow is the primary factor. However empirical data indicates that little if any pulse flow leaves the Delta when south Delta exports are elevated, so exports in combination with pulse flows may explain the elevated stray rates. For management purposes, we developed two statistical models that predict SJR salmon stray rate: (1) flow and export as co-independent variables; and (2) south Delta Export (E) and SJR inflow (I) in the form of an E:I ratio.

**Supporting material:**

Appendix A: Description of Methods

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# Delta Flow Factors Influencing Stray Rate of Escaping Adult San Joaquin River Fall-run Chinook Salmon (*Oncorhynchus tshawytscha*)

**Dean Marston[†1], Carl Mesick[2], Alan Hubbard[3], Dale Stanton[1], Scott Fortmann–Roe[3], Steve Tsao[1], and Tim Heyne[1]**

## ABSTRACT

Adult salmon that stray when they escape into non-natal streams to spawn is a natural phenomenon that promotes population growth and genetic diversity, but excessive stray rates impede adult abundance restoration efforts. Adult San Joaquin River (SJR) Basin fall-run Chinook salmon (*Oncorhynchus tshawytscha*) that return to freshwater to spawn migrate through the San Francisco Bay and Sacramento–San Joaquin River Delta (Delta). The Delta has been heavily affected by land development and water diversion. During the fall time-period for the years 1979 to 2007 Delta pumping facilities diverted on average 340% of the total inflow volume that entered the Delta from the SJR. The hypothesis tested in this paper is that river flow and Delta exports are not significantly correlated with SJR salmon stray rates. Adult coded-wire-tagged salmon recoveries from Central Valley rivers were used to estimate the percentage of SJR Basin salmon that strayed to the Sacramento River Basin. SJR salmon stray rates were negatively correlated ($P = 0.05$) with the average magnitude of pulse flows (e.g., 10 d) in mid- to late-October and positively correlated ($P = 0.10$) with mean Delta export rates. It was not possible to differentiate between the effects of pulse flows in October and mean flows in October and November on stray rates because of the co-linearity between these two variables. Whether SJR-reduced pulse flow or elevated exports causes increased stray rates is unclear. Statistically speaking the results indicate that flow is the primary factor. However empirical data indicates that little if any pulse flow leaves the Delta when south Delta exports are elevated, so exports in combination with pulse flows may explain the elevated stray rates. For management purposes, we developed two statistical models that predict SJR salmon stray rate: (1) flow and export as co-independent variables; and (2) south Delta Export (E) and SJR inflow (I) in the form of an E:I ratio.

† Corresponding author: *dmarston@dfg.ca.gov*
1 California Department of Fish and Game, Central Region, Fresno, CA
2 U.S. Fish and Wildlife Service, Stockton Fish and Wildlife Office, Lodi, CA
3 University of California, Berkeley, School of Public Health, Division of Biostatistics, Berkeley, CA

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## KEY WORDS

Fall-run, Chinook salmon, stray, Sacramento–San Joaquin Delta, flow, exports, age, hatchery.

## INTRODUCTION

Over the past 2 decades large scale in-river flow and small scale non-flow restoration actions have been implemented to restore fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the San Joaquin River (SJR) basin. The primary purpose of these restoration actions is to ensure that mature fall-run salmon (salmon) return to the SJR basin to spawn. Results from previous studies indicate that Sacramento–San Joaquin River Delta (Delta) flow conditions when salmon escape the ocean (salmon escapement) may influence returning SJR origin salmon stray rates (Mesick 2001). Straying by SJR salmon hinders population goals and necessitates evaluating relationships between Delta flow conditions and SJR salmon straying into the Sacramento Basin. The specific hypothesis tested in this paper is that no statistically significant relationship between fall south Delta inflow and/or export flow conditions, and SJR origin salmon stray rates exists.

It is well established that some proportion of adult salmon, both wild and hatchery origin, stray from one river basin to another upon return to their natal home from the sea (Quinn 1993). Identifying what, if any, Sacramento–San Joaquin River Delta environmental factors increase the likelihood of SJR fall-run to stray into the Sacramento River Basin will help scientists, water project managers, and state and federal government regulators better manage Delta flow conditions (Hallock and others 1970; Mesick 2001) to accomplish their ultimate goal of restoring the SJR Basin fall-run salmon population. Published results of stray rate studies conducted within California rivers are few in number and are essentially limited to Snyder's (1931) work on the Klamath River, Hallock and others' (1970) work on the San Joaquin River, Sholes and Hallock's (1979) work on the Feather River, and Mesick's (2001) work on the San Joaquin River. Where necessary and applicable, stray rate information was gleaned from published stray rate research conducted in river basins in Oregon, Washington, Alaska, and Canada. Since Mesick's (2001) work directly relates to San Joaquin River salmon stray rates, his work is extensively cited.

Adult SJR Basin fall-run Chinook salmon that return to freshwater to spawn must pass through the San Francisco Bay (Bay) and Delta (Figure 1). The Delta has been heavily affected in the last century by land development and water diversion and comprises a labyrinth of man-made and natural channels that convey Delta inflow, direct water for diversion, and/or allow ocean-going ships to dock at Stockton for commerce (Figure 2). The Delta today is effectively managed to store water upstream of the Delta and release it at times, and volumes, when pumping facilities in the south Delta can capture and convey it for agriculture and municipal use. The primary water diversions located in the south Delta are California's State Water Project (SWP) and the federal Central Valley Project (CVP) export pumping facilities located near Byron and Tracy, respectively (Figure 2). The CVP began operations in 1955, and the SWP in 1967. Smaller Delta diversions are made by the Contra Costa Canal Water District (CCC) at Rock Slough and Old River (Figure 2) and by the Solano County Water Agency from the North Bay Aqueduct (NBA) located on Barker Slough.

Historically the CVP, SWP, and CCC pumping facilities operate year-round and collectively have a combined pumping capacity of approximately 394.4 $m^3\ s^{-1}$ (14,000 $ft^3\ s^{-1}$). In the 1990s, because of concern over excessive entrainment of springtime emigrating juvenile Sacramento River and SJR salmon (various races), springtime diversions at the CVP and SWP were greatly curtailed with much of the displaced pumping moved to the fall when the adult fall-run migrate. Between 1979 and 2007, average October–November exports ranged from a low of 18% of SJR Basin flow to a maximum of more than 740%, averaging nearly 340% of the volume of water inflowing from the SJR. Water movements through the historic Old and Middle SJR channels (Figure 1) are affected by Delta pumping because these channels directly feed the CVP and SWP pumps. Most times, the river in these channels downstream of the pumps is pulled back upstream by the pumps. Rock barriers also have been placed in several locations in the south Delta to improve agricultural water quality and quantity by increasing surface water elevation. These barriers are collectively called the south Delta barriers and include the Head of Old River Barrier, Grant Line Canal Barrier, Old River at Tracy Barrier, and the Middle River Barrier (Figure 2). Some of the barriers are impassable for fish. Further, the Stockton Deep Water Ship Channel (SDWSC, Figure 2) can be a migration barrier for returning salmon during the fall because of low dissolved oxygen levels (e.g., $<5$ mg $L^{-1}$) when flows are low (Hallock and others

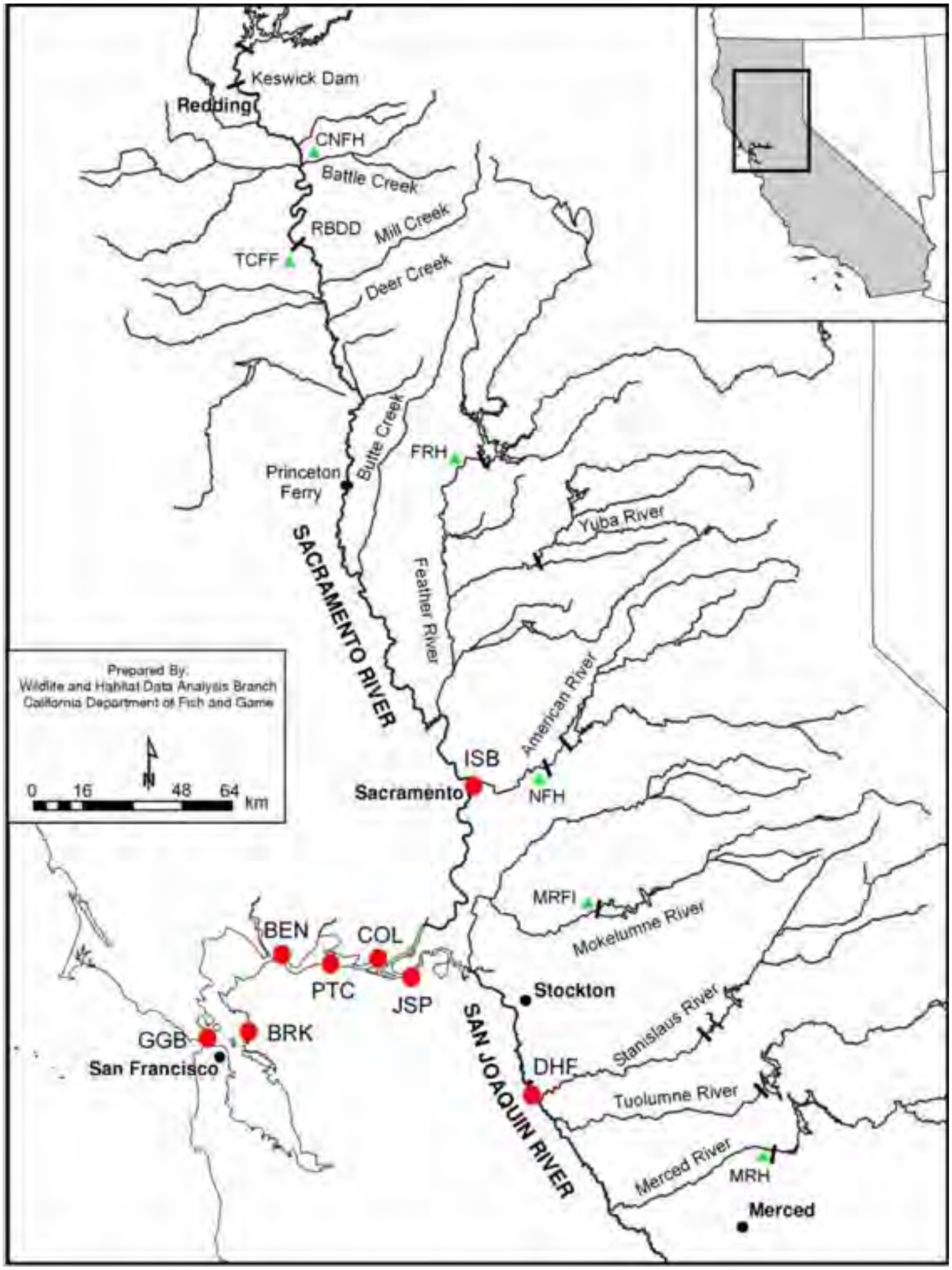


**Figure 1** Map of the major Central Valley rivers, the Merced River Hatchery (MRH), Feather River Hatchery (FRH), Tehama Colusa Fish Facility (TCFF), Coleman National Fish Hatchery (CNFH), Mokelumne River Fish Installation (MRFI), and the Nimbus Fish Hatchery (NFH). Bay releases of tagged juveniles were made between Collinsville (COL) on the Sacramento River, Jersey Point (JSP) on the San Joaquin River, and the Golden Gate Bridge (GGB). Example release sites in the Bay include Berkeley (BRK), Benicia (BEN), and Port of Chicago (PTC). Delta releases were made upstream of COL and JSP to Durham Ferry (DHF) on the San Joaquin River and the I Street Bridge on the Sacramento River (ISB). Inland releases were made upstream of ISB and DHF.

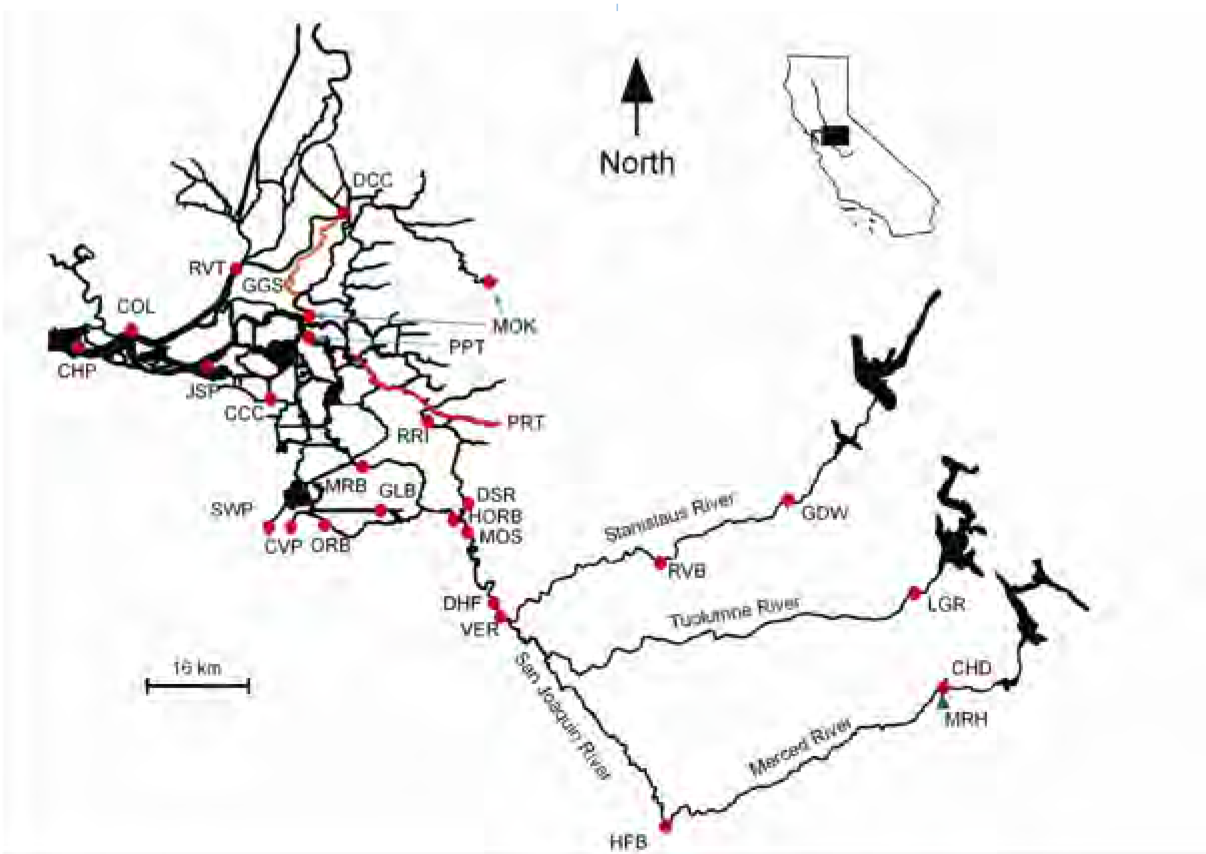


**Figure 2** Map of the San Joaquin River and Delta showing the lowermost dams that block upstream passage for fall-run Chinook salmon including Goodwin Dam (GDW) on the Stanislaus River, La Grange Dam (LGR) on the Tuolumne River, Crocker-Huffman Dam (CHD) on the Merced River, and the Hills Ferry Barrier (HFB) on the mainstem San Joaquin River. The Merced River Hatchery (MRH) is shown as a green triangle. The lower Mokelumne River (MOK) is shown to its confluence with the SJR. Other study locations (red dots) include Riverbank (RVB), the State (SWP), Federal (CVP), and Contra Costa Canal (CCC) pumping facilities, stream gage at Vernalis (VER), Prisoner's Point (PPT), Durham Ferry (DHF), Mossdale (MOS), Dos Reis Road (DSR), Port of Stockton (PRT), Rough and Ready Island (RRI), Rio Vista (RVT), Delta Cross Channel (DCC), and Georgiana Slough (GGS, highlighted orange). The temporary rock barriers at the Head of the Old River (HORB), Grant Line Canal (GLB), Old River Barrier (ORB), and Middle River Barrier (MRB) are shown. The San Joaquin River mainstem downstream of the Port of Stockton (highlighted red) is dredged for ocean-going vessels. As defined here, releases of juvenile salmon in the Delta were made upstream of Jersey Point (JSP) to DHF on the San Joaquin River and upstream of Collinsville (COL) to the I Street Bridge (in the City of Sacramento, which is not shown) on the Sacramento River.

1970) or when water temperatures are high (Hallock and others 1970; Rich 2007). The SDWSC dissolved oxygen barrier can occur when SJR at Vernalis flows are less than approximately 42.5 $m^3\ s^{-1}$ (1,500 $ft^3\ s^{-1}$). Water temperatures in the SJR can reach lethal levels and also block migration (Rich 2007) when temperatures exceed 21 °C to 22 °C (USEPA 2003). Reverse flows, physical barriers or chemical barriers that delay adult salmon migration may increase the likelihood of straying.

Chinook salmon rely primarily on olfactory cues to successfully migrate through the Delta's maze of waterways to home back to their natal river (Groves and others 1968; Mesick 2001). Juvenile salmon imprint by acquiring a series of chemical waypoints at every major confluence that enables them to relocate their river of origin (Quinn 1997; Williams 2006). Juvenile hatchery-reared salmon released downstream gather fewer chemical waypoints and are more likely to stray (CDFG and NOAA Fisheries 2001; Newman 2008). Adult SJR basin Chinook pass through the Delta from late September through November, with peak immigration usually in October (Mesick 2001).

Since olfaction plays such a strong role in a salmon's ability to return (home) to its natal river of origin (Groves and others 1968; Quinn 1997; Williams 2006), providing sufficient water to enable salmon to home in on their natal river is paramount. The Sacramento River basin is approximately 2.5 times larger than the San Joaquin River basin, has a hydrograph dominated by fall and winter rainfall compared to the spring-time snow-melt hydrograph on the SJR, and can provide ten times greater fall Delta inflows than the SJR. Comparatively, the SJR is the most heavily diverted of the two rivers. The mainstem SJR is discontinuous (dry over 90% of the time in one or more reaches) upstream of its confluence with the Merced River (Figure 2) and provides flow to the Delta only in wet years (Rose 2000). Only the major east-side SJR tributaries flow year-round. The SJR is managed to provide fall pulse inflows to the south Delta, typically for 7 to 10 days in late October. The goal is to compensate for the extreme Delta inflow differential between the Sacramento River and SJR basins, to remove the SDWSC dissolved oxygen barrier, and to decrease water temperatures. A secondary purpose of the fall pulse flows is to reduce SJR salmon from straying into the Sacramento River basin by enabling salmon to successfully locate and immigrate into the SJR basin.

The term "straying" has four spatially implied definitions: (1) adult salmon returning to a non-natal river basin; (2) adult salmon returning to a non-natal sub-basin; (3) adult salmon returning to a non-natal tributary; and (4) adult salmon returning to a hatchery in their natal river if naturally spawned. For this reason, stray rates between studies cannot be directly compared without considering which straying definition was used. For the purpose of this paper, the term "stray" means an adult salmon that strayed into the wrong sub-basin of the Central Valley (i.e. the Sacramento River basin rather than the SJR basin).

Mesick (2001) evaluated the effects of SJR flows and Delta export rates during October on adult San Joaquin Chinook salmon stray rates. Mesick reviewed the results of an earlier study (Hallock and others 1970) where adult San Joaquin salmon were tagged, then monitored (1964 to 1967), as they migrated through the Delta under varying environmental conditions (e.g. Delta inflow and export patterns, dissolved oxygen, and water temperature). Mesick also evaluated recovery data of coded-wire-tagged (CWT) adult salmon, released in years 1983 to 1996, that were reared at the California Department of Fish and Game's (CDFG's) Merced River Hatchery.

Mesick (2001) made two important observations from the Hallock and others (1970) data that describe adult migratory behavior through the Delta. First, adult San Joaquin salmon are migrating through the San Joaquin Delta near Prisoner's Point, which is about 5 km upstream from its confluence with the Mokelumne River (Figure 2), primarily during October, when they are likely to be susceptible to low SJR inflow and high Delta export conditions. Second, San Joaquin salmon migrate slowly through the Delta and do not enter the San Joaquin tributaries until approximately 4 weeks after they pass Prisoner's Point even if environmental conditions (dissolved oxygen, water temperature, and both south Delta inflow and exports levels) appear suitable for migration. These observations indicate that hydraulic conditions in the Delta are most likely to affect adult migrations during October rather than in November when they are observed on the spawning grounds in the tributaries.

Mesick (2001) found three primary flow factors that influence San Joaquin salmon stray rates. First, stray rates were directly correlated with the Delta export (E) to San Joaquin River Delta inflow (I) ratio (E:I). Second, the critical period to provide Delta flow protection (conditions conducive to SJR salmon migration) is between October 1st and 21st. Third, pulse flows from the SJR tributaries (the Merced, Tuolumne, and Stanislaus rivers) or, a reduction of Delta exports, that resulted in an E:I ratio of 3 (exports no greater than 300% of SJR inflow at Vernalis) for 8 to 12 days in mid-October were sufficient to keep stray rates at a minimum level (<3%). Mesick (2001) qualified his findings by saying that the accuracy of the estimated numbers of strays was questionable because of the uncertainties about the numbers of fish examined for CWTs within escapement surveys conducted in Central Valley rivers. As a result, he was unable to discern the specific effects of flow versus export rates on SJR Basin salmon stray rates or determine the precise period when flows and export rates had the greatest effect. He qualified his analysis of the Hallock and others (1970) data by stating that although most of the tagged fish migrated into the Sacramento and Mokelumne basins when Vernalis flows were less than about 56.7 $m^3\ s^{-1}$ (2,000 $ft^3\ s^{-1}$) and total exports exceeded 150% of Vernalis flows, there is uncertainty as to whether these were San Joaquin fish that strayed or Sacramento River fish that were captured in the San Joaquin River on their way to the Sacramento River via the Mokelumne River and Delta Cross Channel (Figure 2). He recommended that further studies were needed to refine the CWT return data in terms of the number of fish examined for tags during the carcass surveys and additional surveys for tags in all major tributaries of the Sacramento River Basin, particularly the mainstem Sacramento River.

Building on Mesick's (2001) work, we evaluated relationships between fall Delta flow conditions and San Joaquin salmon stray rates using coded-wire-tag (CWT) data collected from 1979 to 2007. We analyzed the data to determine the probability of an adult SJR salmon straying to the Sacramento River basin, given fall Delta flow conditions during their escapement. Pending analytical results, recommendations for controls that could be implemented as south Delta water quality control standards to provide a reasonable level of protection for returning adult SJR salmon could be considered and implemented. The specific hypothesis assessed, framed as a null hypothesis, is: fall south Delta inflow, export flow level, and barrier installation are not significantly correlated with SJR salmon stray rates.

## METHODS

We developed three data sets in order to evaluate potential relationships between Delta flow patterns and SJR salmon stray rates. The data sets cover the years 1979 to 2007 and include those parameters we believe may significantly influence straying. The first data set includes coded wire tagged (CWT) salmon releases and recoveries of Central Valley fall-run Chinook salmon from which stray rates were determined. The second data set includes fall Delta flow and export conditions. The third data set contains south Delta Barrier (SDB) annual construction dates and operational periods. The 1979 to 2007 time-period represents the principal time-period when Central Valley salmon were coded wire tagged and released, and covers the period having complete brood-year production cohorts. Methods used to develop the stray rate data are complicated and are only summarized here. For a full description of methods used to develop the stray rate data, and to see the stray, hydrodynamic, and barrier data sets used in our analyses, please refer to the Methods Appendix.

Stray rates of ocean-escaping SJR salmon were compared with two fall south Delta inflow indices: the first using average October and November flow (base flow) and the second using a 10-day pulse flow occurring in mid-October to late October into early November. We also looked at Delta export flow levels over the same time periods. Stray rates for SJR salmon were developed from adult inland recoveries of coded-wire-tagged, hatchery-origin juvenile releases into the San Joaquin and Sacramento river basins, Delta, and Bay over a 29-year period (1979 to 2007).

### Adult Salmon Stray Rates

We define salmon strays as the SJR basin fish that returned to the Sacramento River basin to spawn and the Sacramento River basin fish that returned to the SJR basin to spawn. Central Valley fall-run Chinook salmon stray rates were estimated based on CWT recoveries of adult salmon during the spawning surveys that were conducted to estimate escapement. The juvenile salmon with CWTs were produced in Central Valley hatcheries including the Merced River Hatchery (MRH) and the Mokelumne River Fish Installation (MRFI) in the San Joaquin River basin, and the Nimbus Fish Hatchery (NFH), Feather River Hatchery (FRH), and Coleman National Fish Hatchery (CNFH) in the Sacramento River basin (Figure 1). The MRH, MRFI, NFH, FRH, and CNFH are located 271, 120, 134, 236, and 446 km upstream of the Sacramento–San Joaquin River confluence respectively. Juvenile hatchery fish are trucked from the hatchery to various release locations and are not barged as occur in other river systems.

These hatchery-raised juveniles were released into three broad geographical areas identified as the Bay, Delta, and Inland release points. Bay releases occurred between Jersey Point on the San Joaquin and Collinsville on the Sacramento River, westward to the Golden Gate Bridge (Figure 1). Delta releases were made between Durham Ferry and Jersey Point on the SJR, and between the "I" Street Bridge (City of Sacramento) and Collinsville on the Sacramento River (Figure 1). Inland releases were made upstream of Durham Ferry and the "I" Street Bridge. To reduce the confounding effects of stray results caused by differences in juvenile release location (e.g. the farther downstream juveniles are released, the greater the stray probability (Quinn 1997; CDFG and NOAA Fisheries 2001; Newman 2008), only recoveries from inland releases were used to test our hypothesis.

MRH releases used in our analyses did not include any transfers of eggs or juveniles from other hatcheries; whereas, eggs and/or fry were routinely transferred from the FRH and NFH to the MRFI. In general, the MRH released juveniles as yearling-sized fish from 1978 to 1985 during October (mean weight 56 g) and November (mean weight 60 g) and as sub-yearling-sized fish from 1986 to 2006 during April (mean weight 6 g) and May (mean weight 7 g). The FRH primarily released juveniles as yearling-sized fish from 1980 to 2002 during October (mean weight 42 g) and November (mean weight 60 g) and as sub-yearling-sized fish from 1975 to 2006 during April (mean weight 6 g), May (mean weight 6 g), and June (mean weight 8 g). The CNFH primarily released juveniles as sub-yearling-sized fish from 1975 to 2006 during March (mean weight 2 g), April (mean weight 5 g), and May (mean weight 6 g).

Developing stray rate data for Central Valley fall-run salmon required a multi-step approach: (1) assembling inland escapement estimates for each Central Valley river, (2) assembling the expanded number of CWT's recovered within each Central Valley fall-run escapement survey, and (3) identifying the proportion of each CWT code recovered in each Central Valley river. We used the California Department of Fish and Game's (CDFG) fall-run escapement summary (GrandTab) for annual, river-by-river escapement data. We obtained CWT release data from the Pacific States Marine Fisheries Commission's (PSMFC's) Regional Mark Processing Center's Regional Mark Information System (RMIS) (data downloaded in 2011). We utilized CWT recovery data from annual escapement reports and/or personal contact with escapement survey crew leaders when additional information was necessary. The final form of the stray data consisted of annual summaries of the expanded number of fish that homed and strayed. Included in these expanded estimates were adjustments for number of fish that shed their tags, number of ad-clipped fish where tags were not recovered, and recovery number of untagged juvenile fish that were released alongside CWT marked juvenile releases. Annual summaries of hydrological data were also provided as discussed below.

To conduct this analysis, we assumed that CWT salmon recovery trends from juvenile salmon produced by the CDFG's MRH would also represent recoveries from naturally produced fish originating in the Merced, Tuolumne and Stanislaus rivers. Likewise, we assumed that the U.S. Fish and Wildlife Service's CNFH and the CDFG's FRH hatchery release–recovery trends would mirror those for all Sacramento Basin fall-run stocks. We believe this assumption is valid because Pacific salmon primarily home based on freshwater chemical olfactory cues imprinted when, as juveniles, they make their seaward migration (Quinn 1997; Williams 2006) and that water-borne odors would be similar for rivers within the same basin when compared with other basins. This assumption was indirectly corroborated by Barnett–Johnson and others (2008), who characterized Central Valley watersheds by Strontium isotope ($^{87}Sr:^{86}Sr$) ratios for purposes of identifying otolith markers for fall-run salmon, then by Miller and others (2010), who compared the water Sr:Ca (mmol $mol^{-1}$) and Ba:Ca (µmol $mol^{-1}$) ratios for Central Valley rivers to assess juvenile salmon river of origin via otolith Sr:Ca and Ba:Ca ratios. Collectively Barnett–Johnson and others (2008) and Miller and others (2010) found that water chemistry differed between the Sacramento and SJR basins. We did not include the MRFI CWT release–recovery data in our analyses for two reasons. First, the flows in the lower Mokelumne are mixed with Sacramento River basin flows (because of the Delta Cross Channel and Georgiana Slough), which can allow Mokelumne River juvenile salmon to imprint upon both Mokelumne and Sacramento basin water, thus enabling the adults to "correctly" choose either the Sacramento or Mokelumne rivers upon return. Second, egg and/or fry transfers to the MRFI from the FRH and NFH may affect the homing behavior of the MRFI releases.

## Delta Flow Conditions

Delta flow data for the fall period were obtained from Dayflow, which is a program developed, operated and maintained by the California Department of Water Resources (CDWR). The program was initially developed in 1978 to serve "as an accounting tool for determining historical Delta boundary hydrology" (CDWR 2011b). CDWR significantly updated the program in 2000 using Java, enabling input data stored as a HEC-DSS file, and output presented in an ASCII file. The computational scheme was modified in February 2002 based on a better understanding of the complex Delta conveyance system.

According to CDWR, "the Dayflow program presently provides the best estimate of historical mean daily flows: (1) through the Delta Cross Channel and Georgiana Slough; (2) past Jersey Point; and (3) past Chipps Island to San Francisco Bay (net Delta outflow). The degree of accuracy of Dayflow output is affected by the Dayflow computational scheme and the accuracy and limitations of the input data. The input data include the principal Delta stream inflows, Delta precipitation, Delta exports, and Delta gross channel depletions" ("Dayflow").

All Dayflow calculations use daily flows and do not consider the travel time required for the water to move through the various channels in the Delta. The Dayflow computational scheme develops three types of quantities; net Delta outflow estimates at Chipps Island, interior Delta flow estimates at significant locations, and summary and fish-related parameters and indices.

**Table 1** Delta Dayflow variables

| | |
|---|---|
| **SAC** | Measured Sacramento flows at the "I" Street Bridge in Sacramento |
| **SJR** | Measured San Joaquin River flows at Vernalis |
| **RIO** | Calculated Sacramento River flows past Rio Vista |
| **XGEO** | Calculated flows of both the Delta Cross Channel and Georgiana Slough |
| **QWEST** | Calculated San Joaquin River flows at Jersey Point where reverse flows are indicated by a negative number |
| **CCC** | Measured Contra Costa Water District diversions at Rock Slough and Old River |
| **SWP** | Measured State Water Project exports from the Banks Pumping Plant or Clifton Court Intake |
| **CVP** | Measured Central Valley Project exports at Tracy |
| **Exports** | Sum of CCC + SWP + CVP |

The time-period associated with the quantities generated by Dayflow range from October 1, 1955 through September 30, 2010. Our analyses included quantities from the years 1979 through 2007, to compare the results with fall-run Chinook salmon return data. The Dayflow variables are presented in Table 1 and the flow estimates are available at *http://www.water.ca.gov/dayflow/*.

Dayflow includes data representing total Delta exports (EXPORTS), which includes North Bay Aqueduct exports (NBAQ) along with the Contra Costa Water District Canal (CCC), State Water Project (SWP) and Central Valley Project (CVP) exports. NBAQ data were not used because these exports leave the Delta from the north. Therefore, in evaluating total exports for our analyses, we combined the CCC, SWP and CVP exports only. We also considered Old and Middle SJR (OMR) flows as measured at two U.S. Geological Survey (USGS) gaging stations: USGS 11312676 MIDDLE R AT MIDDLE RIVER CA and USGS 11313405 OLD R AT BACON ISLAND CA. The river at these locations is highly affected by both the SWP and CVP pumps that create reverse or upstream flows during the majority of the year. We gathered

**Table 2** Cross-correlation matrix of Delta fall flow variables [a]

| | SAC | Exports | SJR | XGEO | QWEST | QRIO | OMR | Pulse SAC | Pulse Exports | Pulse SJR | Pulse XGEO | Pulse QWEST | Pulse QRIO | Pulse OMR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAC** | 1 | | | | | | | | | | | | | |
| **Exports** | −0.11 | 1 | | | | | | | | | | | | |
| **SJR** | 0.88 | −0.21 | 1 | | | | | | | | | | | |
| **XGEO** | 0.77 | 0.06 | 0.67 | 1 | | | | | | | | | | |
| **QWEST** | 0.82 | −0.58 | 0.88 | 0.67 | 1 | | | | | | | | | |
| **QRIO** | 0.99 | −0.18 | 0.86 | 0.67 | 0.81 | 1 | | | | | | | | |
| **OMR** | 0.40 | −0.90 | 0.54 | 0.15 | 0.78 | 0.45 | 1 | | | | | | | |
| **Pulse SAC** | 0.85 | 0.08 | 0.84 | 0.73 | 0.68 | 0.79 | 0.23 | 1 | | | | | | |
| **Pulse Exports** | 0.03 | 0.91 | −0.07 | 0.08 | −0.44 | −0.02 | −0.74 | 0.28 | 1 | | | | | |
| **Pulse SJR** | 0.84 | −0.18 | 0.98 | 0.63 | 0.84 | 0.82 | 0.52 | 0.84 | −0.02 | 1 | | | | |
| **Pulse XGEO** | 0.70 | −0.01 | 0.68 | 0.88 | 0.66 | 0.60 | 0.21 | 0.83 | 0.09 | 0.64 | 1 | | | |
| **Pulse QWEST** | 0.76 | −0.55 | 0.85 | 0.67 | 0.96 | 0.73 | 0.73 | 0.70 | −0.45 | 0.82 | 0.73 | 1 | | |
| **Pulse QRIO** | 0.80 | 0.13 | 0.79 | 0.58 | 0.60 | 0.78 | 0.18 | 0.96 | 0.35 | 0.80 | 0.65 | 0.60 | 1 | |
| **Pulse QMR** | 0.40 | −0.90 | 0.54 | 0.15 | 0.78 | 0.45 | 0.94 | 0.23 | −0.74 | 0.52 | 0.21 | 0.73 | 0.18 | 1 |

a Table showing co-linearity comparison between various Delta flow metrics, including Sacramento River at Freeport (SAC), combined South Delta Exports (Exports), San Joaquin River at Vernalis (SJR), Delta Cross Channel and Georgiana Slough flow (XGEO), San Joaquin River flow past Jersey Point (QWEST), Sacramento River flow past Rio Vista (QRIO). Pulse metrics equal the average flow during the fall pulse flow time period. Non-pulse flow metrics are average flows for the October and November time period.

OMR flow data for both the October–November base flow period and the 10-day pulse flow period.

Fall Delta base flow (mean October and November flow) and pulse flow (10-day average of highest flow in October–November) data is provided in the Methods Appendix. In addition to average base and pulse flows, flow ratios (by example: the ratio of Delta exports to SJR inflow at Vernalis) are also presented in the Methods Appendix. We also developed a cross-correlation matrix table to identify co-linearity between any flow variables (Table 2).

## South Delta Barriers

We obtained south Delta barrier (SDB) operational data from CDWR's South Delta Temporary Barriers Project (CDWR 2011a). Four barriers comprise CDWR's SDB Project: Head of Old River (HORB), Grant Line Canal, Middle River, and Old River at Tracy. As stated by CDWR, the objectives of the SDB program are three-fold: (1) increase south Delta water levels (e.g., elevation) and circulation patterns to improve agricultural diversion water quality; (2) enhance the operational flexibility of the SWP and CVP; and (3) reduce effects on native and anadromous fish species.

The Head of Old River (HORB) barrier is a rock barrier—and the primary barrier, because it is intended to prevent SJR south Delta inflow from entering the Old River channel, which leads to the Delta export pumping facilities (i.e., the SWP and CVP), and maintains flow within the mainstem SJR and the SDWSC. The tidal effect and Sacramento River Basin flow contribution are greater downstream of the SDWSC than at the Head of the Old River and so the HORB reduces the amount of SJR flows that are diverted at the Delta pumping facilities relative to the amount of Sacramento River Basin flows diverted. Without the HORB, the majority of the SJR inflow enters the Old River depending on the diversion rate at the SWP and CVP (Jassby 2005; SJRGA 2009; ICF 2010). From a fisheries management perspective, the purpose of the HORB is to concentrate flow into the main channel to attract adult immigrating salmon into the main SJR channel during the fall (fall HORB), to deter salmon from using non-main river channels, and keep springtime (spring HORB) emigrating juvenile salmon out of the Old River channel where entrainment into the south Delta pumps is possible.

The fall HORB is installed in most years and typically operates from September 15th to November 30th, which is intended to coincide with the SJR fall Chinook immigration time-period. The remaining three barriers, also temporary rock barriers, serve as agricultural barriers designed to improve water quality and operate during the agricultural irrigation season from April 15 through September 30 each year. From 1979 to 2007, the HORB operated in 19 years, the Old River at Tracy in 15 years, the Middle River in 20 years, and the Grant Line Canal in 11 years. State (CDWR) and federal (U.S. Bureau of Reclamation) agency regulatory requirements—both landowner and local reclamation district entry permits—and physical conditions determine barrier installation and removal dates (CDWR 2011a). By example, high SJR flows that occur in wetter years when upstream reservoir storage must be evacuated might preclude installation and operation of the HORB.

To analyze the influence SDB's have on SJR salmon stray rates we used an ordinal date format to make the SDB's fall operating dates consistent across years. (The SDB operating dates are provided in the Methods Appendix.) To further ensure SDB operational consistency across years, the earliest date a barrier was considered to have been installed was September 1st (ordinal day 245). This date was chosen as the start date to coincide with Delta salmon immigration timing as described in Hallock and others (1970).

## Statistical Analysis

The goals of the statistical analyses include estimating the independent associations of flow and exports upon SJR stray rates (explanatory analysis), as well as determining whether any particular combination of predictors was significantly better at predicting stray rates. The objective of the explanatory analysis was to examine the probability of escaping salmon straying relative to Delta flow conditions. Specifically, given the denominator as adjusted estimates of the number of CWT fish retrieved, we examined whether the probability of being a stray (specifically, a SJR fish returning to the Sacramento River Basin) was a function of various flows: SAC (Sacramento River at Freeport), SJR (San Joaquin River flow at Vernalis), Exports (Delta Exports), QRIO (Sacramento River flow past Rio Vista), QWEST (SJR flow past Jersey Point), and XGEO (Delta Cross Channel and Georgiana Slough flow), and OMR (combined Old and Middle River flow). The individual adult return rates for each CWT code were adjusted by (1) observed carcasses with adipose fin clips but no information for the tag code and (2) releases of unmarked juveniles with CWT marked juveniles that may have affected CWT return rates (see Methods Appendix). They also include stray rate estimates for rivers that lacked direct CWT recovery data, such as the mainstem Sacramento River from 1986 to 2000 (see Methods Appendix). The mean annual return rate for individual tag codes for each adult age was used as the unit of the statistical analysis.

As mentioned above, there is very high correlation among many of the average and pulse flow annual summaries. Due to this co-linearity, we included only pulse flows for the SJR and the corresponding SJR pulse flow period for the exports in our analysis. Also because of the co-linearity of flow variables, we did not analyze ratios between these explanatory variables—not because the other variables are not causally important, but only because the covariance among them is such that it is impossible, given the available data, to distinguish (estimate) the relative effects with the modest sample size (number of years) available. In addition, we examined the number of operating days for each barrier and its association with stray rates. (We note that the number of days and the start day for barrier operations cannot be examined independently in the same model, so we used the number of days as a proxy for both variables).

For each paired analysis between either SJR or export pulse flow level and stray rate we: (1) performed LOWESS smoothing (Cleveland 1979) on the proportions to examine (semi-parametrically) the stray response and provide in visual form the variability of stray rates around the predicted mean; (2) examined the logistic regressions of average trends (in the logit scale) of the probability of being a stray versus these flow levels, adjusting for the age of fish; and (3) derived our *P*-value for resulting trends (relative to flow independence and stray probability) via an age-conditioned pseudo-exact permutation test.

For the multivariable regression models, we used the nonparametric bootstrap (Efron and Tibshirani 1993) to derive inference, treating the year as the unit. We note that sometimes the bootstrap-based *P*-values can be quite different from the corresponding permutation ones (for analyses that are equivalent), suggesting that the dispersion can be so great relative to sample size that even robust inference can be potentially biased, which is why we emphasize the permutation method when appropriate.

For both SJR fall pulse and export flow levels, we (1) performed LOWESS smoothing on the stray proportions (Figures 3 and 4); (2) examined the logistic regressions of "average" trends in the logit scale) of the probability of being a stray versus these flow variables; and (3) derived our *P*-value for these trends (relative to flow independence and stray probability) via bootstrapping. For the bootstrapping, one thousand bootstrapped re-samplings of the data were generated. Coefficients for each re-sampling were estimated and their dispersion was used to calculate the standard error of the estimates. Such bootstrapped estimates are to some level robust when data does not necessarily fully conform to the assumptions of the normal linear regression model. In this case, the data was overdispersed (i.e., there was greater variance than would be predicted by a binomial model) and significance estimates that did not take this into account would have resulted in a high overestimation of statistical significance.

Finally for the pure prediction model procedure we compared the fit of competing models in predicting future stray rates by using a cross-validation technique, with known theoretical properties related to selecting the "optimal" model (Van der laan and others 2007), to compare five simple models (all of them containing indicators for age groups): (1) including log (SJR Pulse Flow) and log (Exports); (2) log(SJR Pulse Flow) and log (pulse OMR flows); (3) log (exports/SJR Pulse Flows) ratio; (4) log (SJR Pulse Flow) alone; and (5) log (Exports) alone. We note that both Models 4 and 5 are sub-models of 1 (for Model 4, it assumes the coefficient associated with log (SJR pulse flow) equals the negative of that on log (exports), whereas for Model 5, it just assumes the coefficient on exports is 0). Thus, under the typical assumptions, a likelihood ratio test could provide a measure of the relative fits of the model. However, in this case, we examine it empirically via 10-fold cross-validation. Specifically, the sample is divided into 10 equal parts (say validation samples) and for each of these, one (a) removes them from the data, (b) fits Models 1 through 5 on the other portion (the so-called training sample), and (c) uses these fits to predict on the left out sample. Thus, the procedure results in a column of observed stray rates, and five predicted stray rates (one for each model) where the predictions were derived independently of the corresponding outcome.

## RESULTS

### Stray Rates in General

Our analysis indicates that the stray rates for Sacramento Basin hatchery origin salmon, released upstream of the Delta, average less than 1% (range = 0 to 6%). Comparatively, for SJR Basin hatchery-origin salmon, stray rates average 18% (range = 0 to 70%). When stray results are considered for Delta and Bay releases, the average Sacramento hatchery-origin stray rates are 0.5% and 1%, respectively. SJR basin hatchery-origin stray rates, corresponding with Delta and Bay releases, are 35% and 85%, respectively.

### Cross Correlation of Delta Flow Variables

Exports correlate negatively to the OMR flows (Old and Middle SJR). As exports increase OMR flows become more negative. All non-export Delta flow variables are highly positively correlated with one another (Table 2). That is, as one variable rises in value so do the others. The positive correlation results indicate that any of the non-export flow variables can be used to some extent as a proxy for all the flow variables. Since SJR fall pulse flow is, biologically speaking, the flow variable of importance it is used as the variable to determine if Delta inflow is significantly correlated with stray rate probability. Due to the extreme co-linearity between fall base flows and 10-day pulse flows (correlation = 0.97), we cannot determine which has the most important influence. If SJR base flow was used as the flow metric instead of pulse flow, the results for pulse flow presented below could be applied to base flow using the following linear regression equation between base and pulse flow levels:

$$SJRBaseFlow = 0.786 \text{ X } SJRPulseFlow,\ R^2 = 0.97$$

## Delta Flow Variables and Stray Rates

Graphical comparisons of the probability of SJR salmon straying as a function of SJR fall pulse flow, south Delta exports, and the ratio (E:I) of south Delta exports (E) to SJR fall pulse flow (I) are provided in Figures 3, 4 and 5, respectively. Though there is a significant amount of variability between years, general trends are identifiable. For SJR fall pulse flow, salmon stray rate probability peaks (~50%) when flow levels are less than 30 $m^3\ s^{-1}$ (1,060 $ft^3\ s^{-1}$) and are reduced substantially (~5%) when pulse flow levels increase to 150 $m^3\ s^{-1}$ (5,297 $ft^3\ s^{-1}$). For south Delta exports, salmon stray rate probability peaks (20%) when export levels exceed 141.6 $m^3\ s^{-1}$ (5,000 $ft^3\ s^{-1}$) and are substantially lower (~3%)

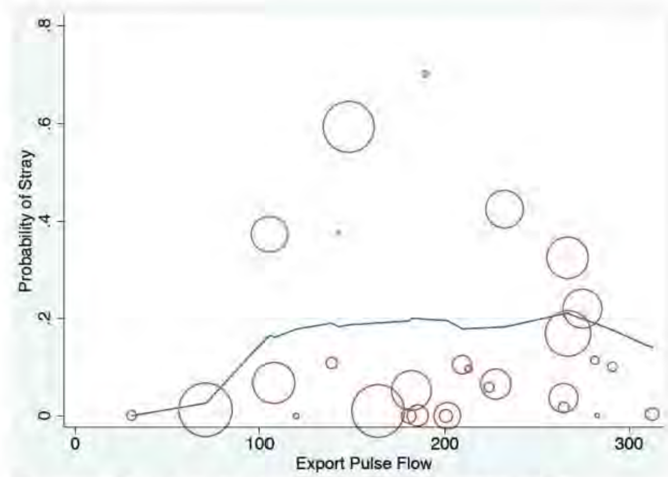


**Figure 4** Plot showing the smooth of probability of San Joaquin River salmon straying as a function of South Delta export level ($m^3\ s^{-1}$). Bubble size reflects relative number of coded-wire-tag recoveries across years. Smooth line is weighted by total recapture size.

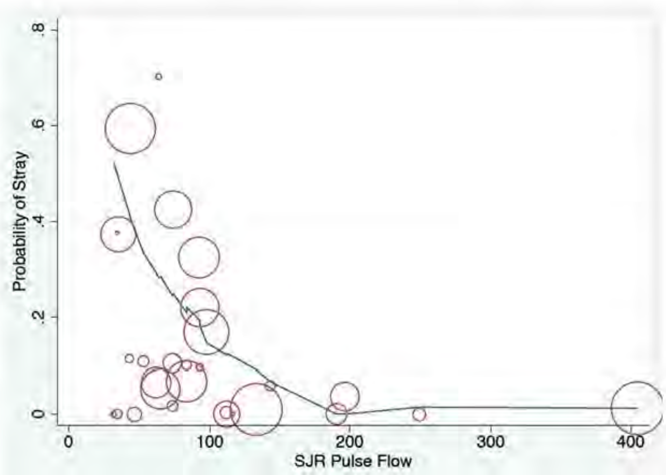


**Figure 3** Plot showing the smooth of probability of San Joaquin River salmon straying as a function of San Joaquin River inflow level ($m^3\ s^{-1}$) to the South Delta. Bubble size reflects relative number of coded-wire-tag recoveries across years. Smooth line is weighted by total recapture size.

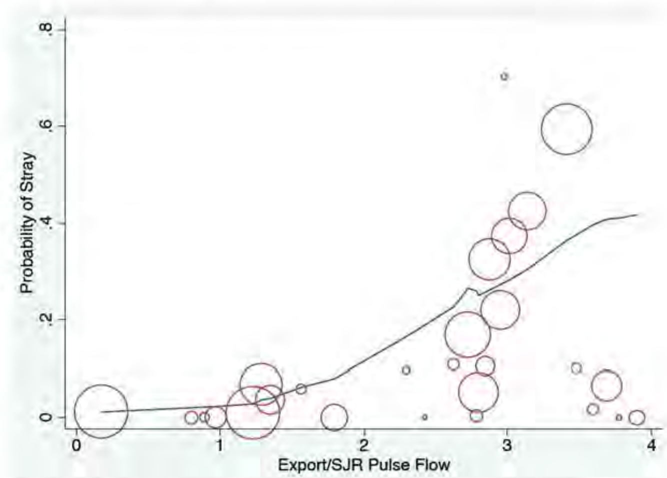


**Figure 5** Plot showing the smooth of probability of San Joaquin River salmon straying as a function of South Delta export (E) ($m^3\ s^{-1}$) to San Joaquin River Pulse Flow (I) level ($m^3\ s^{-1}$) ratio (E:I). Bubble size reflects relative number of coded-wire-tag recoveries across years. Smooth line is weighted by total recapture size.

**Table 3** Results of Delta flow variables and San Joaquin River salmon stray rate

| | Coefficient[a] | Standard error[b] | *p*-value | 95% confidence interval for coefficient | Unadjusted coefficient[c] | Unadjusted *p*-value[c] |
|---|---|---|---|---|---|---|
| **Constant** | 5.349 | 9.231 | 0.562 | −12.74 – 23.44 | | |
| **ln(SJR)** | −2.568 | 0.786 | 0.001 | −4.108 – −1.029 | −1.9 | 0.016 |
| **ln(Exports)** | 1.570 | 0.868 | 0.07 | −0.131 – 3.271 | 0.53 | 0.56 |
| **Age 3[d]** | −0.596 | 0.628 | 0.343 | −1.827 – 0.636 | | |
| **Age 4[d]** | −0.846 | 0.726 | 0.244 | −2.268 – 0.577 | | |

a Example calculation using most likely coefficients. Assume a SJR pulse flow of 8,000 and an Export pulse flow of 6,000 (in cfs; U.S.) for a group of salmon aged 3. The following is used to calculate the probability of straying for this group:

$$\operatorname{logit}(PStray) = 5.35 + (-2.57\ln(8{,}000) + 1.57\ln(6{,}000) + (-0.596\times 1) + (-0.846\times 0)$$

$$\operatorname{logit}(PStray) = \ln\left(\frac{PStray}{1-PStray}\right) = -4.68$$

$$PStray = 0.0092$$

b Standard Error calculated using nonparametric bootstrapping, randomly re-sampling years with replacement (Efron and Tibshirani 1993).
c Coefficient based on unadjusted logistic regression, p-value based on the permutation distribution of corresponding Wald Statistic.
d Age is a dummy variable that is 1 when the salmon is that age and 0 otherwise.

when export flow levels are reduced to 56.6 $m^3\ s^{-1}$ (2,000 $ft^3\ s^{-1}$). For E:I ratio, salmon stray rate probability peaks (~40%) when the ratio approaches a 4:1 level, and is substantially reduced (~10%) when the ratio is less than 2:1.

Table 3 contains the results of the logistic regression that predicts stray rates as a function of SJR fall pulse flow, export flow and salmon age. Of the independent fall Delta pulse inflow variables analyzed, only SJR flow was significant ($P = 0.05$), according to the bootstrapping estimate of error, and has a negative association with SJR salmon stray rate (Figure 3). Combined south Delta export pulse flow was close to significant ($P = 0.10$) and has a positive association with SJR salmon stray rate (Figure 4). The smooth lines depicted in Figures 3 and 4 are weighted by the proportional number of CWT recoveries. Equation 1 determines SJR salmon stray rate, by age, as a function of SJR pulse flow magnitude and south Delta combined export level in non-ratio format.

When the five competing models previously discussed—(1) log (SJR Pulse Flow) and log (Exports), (2) log (SJR Pulse Flow) and log (pulse OMR flows), (3) log (Exports/SJR Pulse Flows), (4) log (SJR Pulse Flow), and (5) log (Exports)—were compared via cross-validation, the results, given the relatively large residual variation seen in all the observed versus the cross-validated predictions (for all the competing models) were quite large, one can not definitely rank the predictive accuracy of any of them versus the others. It appears that models including either SJR flow and exports or both do relatively well, still with relatively modest cross-validated $R^2$ values of around 0.2. It is important to note that we repeated this analysis with many different splits, and also with different cross-validation folds (up to 40-fold) to avoid

**Equation 1**

$$StrayRate = \frac{1}{1+e^{-(1.790-2.568\ln(SJRPulseFlow)+1.570\ln(ExportPulseFlow)-(0.5956Age3)-(0.8455Age4)}}$$

NOTE: To calculate stray rate for age-2 salmon, set both the age-3 and the age-4 terms to zero. For age-3 salmon stray rates, set the age-3 term to 1 and the age-4 term to zero. For age-4 salmon stray rates, set the age-3 term to zero and the age-4 term to 1. For cubic feet per second (cfs; U.S.) units, simply substitute the intercept value of 1.790 with 5.349. The equation beneath Table 3 is the same equation described here but it is converted, for convenience, to standard units.

making conclusions based on any cross-validation configuration. These results suggest that, based on existing data, models that include exports and pulse flow, either as a ratio, or separate terms, appear to be as good or better than competing models with other hydrological measures. It is important to note that these cross validation results, which were intended to evaluate competing model prediction accuracy, do not contradict results obtained from a robust analysis assessing what is a significant association of stray rate. The single factor that is controlling stray rate, from a statistically significant perspective, is SJR flow.

In conclusion, since the biology of salmon indicates that a model including SJR flow is biologically necessary (salmon navigate based upon juvenile river imprinting), we must include SJR flow in a management model. There are several ways to link flow and exports to stray rates. Whether or not to include either co-variate (flow and exports), and how, depends entirely upon the objective. If the objective is explanation, then a model that includes both flow and exports independent of one another is warranted (Model 1). Alternatively, if the goal is pure prediction, then a model that has flow alone (Model 4) is acceptable given that flow is the only variable associated with SJR salmon stray rates at a statistically significant level. However, since we cannot say with statistical certainty whether flow or exports is the primary determinant influencing SJR salmon stray rates, exports can also be included in the management model in the form of an E:I ratio (Model 3). Equation 2 determines SJR salmon stray rate, by age, as a function of south Delta combined export to SJR inflow ratio (E:I).

### South Delta Barriers and SJR Salmon Stray Rate

We also examined the operating days for each of the barriers and their association with stray rates. The total operating days and the initial operating day for each barrier cannot be examined independently in the same model, so we used the total barrier operating days as a proxy for both variables. None of the barriers produced a significant effect on salmon stray rates at either the $P = 0.05$ or 0.10 levels. This indicates that, for south Delta Barriers, neither barrier construction date, nor total operating days, are positively or negatively influencing SJR salmon stray rates in a statistically significant manner. The implication of this finding is that barrier operation for whatever purpose, even if to influence SJR salmon stray rate, is not reducing—or increasing—SJR salmon stray rate at a statistically detectable level.

## DISCUSSION

Our results suggest that the percentage of SJR fall-run Chinook salmon straying into the Sacramento River Basin (1979 to 2007) was as high as 70% (fall 2007). Straying was inversely correlated with pulsed flows in the mainstem SJR at Vernalis ($P = 0.05$) and directly correlated with Delta export levels at a nearly significant level ($P = 0.10$). Our estimated stray rates were more than twice as high as those reported by Mesick (2001), because Mesick did not have complete estimates of the number of adult salmon carcasses that were examined for CWTs during the Sacramento River Basin surveys.

Although stray rates were most highly correlated with pulsed SJR flows, we cannot differentiate between the 10-day pulse flows in October–November and mean

**Equation 2**

$$StrayRate = \frac{1}{1 + e^{-(-3.25 + 2.41\ln(ExportPulseFlow/SJRPulseFlow) - (0.64Age3) - (1.01Age4))}}$$

NOTE: To calculate stray rate for age-2 salmon, set both the age-3 and the age-4 terms to zero. For age-3 salmon stray rates, set the age-3 term to 1 and the age-4 term to zero. For age-4 salmon stray rates, set the age-3 term to zero and the age-4 term to 1. No modifications to this equation are required for cubic feet per second (cfs; U.S.) unit calculations.

October and November base flows. Mean and pulse fall SJR flows are positively cross correlated to a very high degree (adjusted $R$-square of 0.97 at $P = 0.05$). Fall flows are highly regulated (controlled) in the SJR basin and are tied to SJR basin water year type (critical, dry, below normal, above normal, wet); whereby, annual flow schedules are derived pursuant to regulatory instream flow requirements. Thus, as water year type increases as a result of greater snowmelt runoff, both fall base and pulse flows increase concurrently. The cross correlation between mean and pulse flows makes it uncertain which of the two flow metrics is responsible for attracting SJR salmon to their natal river. However, it is logical that since adult salmon migrate over several months that the mean flow rate in September through November would affect the largest number of salmon.

It is uncertain whether SJR flows or Delta exports have the greatest effect on SJR stray rates, because exports were so high in most years that it appears that little if any SJR flow (i.e., olfactory migration cue) was conveyed to the Bay during the fall (Figure 6). The calculated QWEST (SJR flow past Jersey Point and the Central Delta outflow point) flow levels can be strongly negative even in wetter years (2005 and 2006). A negative QWEST flow means that the SJR is flowing 'backward' (i.e. upstream) and tends to occur when the combined SWP and CVP exports exceed the flow in the SJR. October and November QWEST flows for the years from 1979 through 2007 ranged from –70.8 $m^3\ s^{-1}$ (–2,500 $ft^3\ s^{-1}$; 2005) to 651.3 $m^3\ s^{-1}$ (23,000 $ft^3\ s^{-1}$; 1983). Negative fall base and pulse flows at QWEST occurred in 14 (48%) of years analyzed. Even in some years when QWEST is positive for the fall base and pulse flow period, exports may exceed SJR flow but Sacramento flow that has been diverted into the Central Delta (identified as XGEO: flow through the Cross-Delta Canal and the Georgiana Slough) adds to the QWEST. Median XGEO flows (150.4 $m^3\ s^{-1}$; 5,310 $ft^3\ s^{-1}$) from 1979 through 2007 are nearly double the SJR flows (66.1 $m^3\ s^{-1}$; 2,333 $ft^3\ s^{-1}$). Median fall pulse flows show a similar disparity between XGEO flows (145.9 $m^3\ s^{-1}$; 5,152 $ft^3\ s^{-1}$) and SJR flows (83.6 $m^3\ s^{-1}$; 2,951 $ft^3\ s^{-1}$).

Exports and SJR flow are not correlated; thus, both should be included as potential model parameters. A permutation test is the best statistical method to evaluate the individual linkage of each parameter with stray rate, which reveals flow is significant (0.05) and exports are nearly so (0.10). The permutation method does not allow simultaneous assessment of both parameters to get the best inference so another test is used (bootstrapping). The bootstrap method reveals flow is still significant but exports are not. However, we cannot say that exports are not truly significant, given the limited sample size, and, according to the competing model evaluation, a model with exports performed as well as one with SJR pulse flow alone. Therefore both flow and export parameters can be included in a single model in the form of an E:I ratio.

An example of daily SJR fall flow for a single year (2009) is provided in Figure 6 where SJR flow is measured at four gaging stations in the Delta. SJR flows, as measured at Vernalis, indicate that pulse flows experienced at Vernalis (rkm 118; rm 73) are barely detectable at Garwood Bridge (rkm 68; rm 42) and are non-detectable at both Prisoner's Point (rkm 40; rm 25) and Jersey Point (rkm 16; rm 10). In fact, not only did the SJR fall pulse flows in late October not make it to both Prisoner's Point and Jersey Point in 2009, both of these locations had strong negative flows occurring at the same time pulse flows were supposed to be flowing through the south Delta. Note that the flows depicted in Figure 6 give the impression that all SJR pulse flow is constrained within the main SJR channel, but it is not. Given the labyrinthine nature of the south Delta (Figure 2), and the ability of SJR pulse flow to enter and proceed through the SJR Old River channel, SJR pulse flow can re-enter the main SJR channel between Jersey Point (rkm 16; rm 10) and Prisoner's Point (rkm 40; rm 25). If SJR pulse flows that enter the Old River contribute to flow in the SJR at Jersey Point, it may be that SJR salmon that successfully migrate through the south Delta may be detecting the SJR via Old River, rather than mainstem SJR flow. It is also unknown how tidal influence affects fall pulse flow hydraulic continuity and ability of escaping salmon to detect the SJR. Further research is needed to determine whether SJR fall pulse flows do, or do

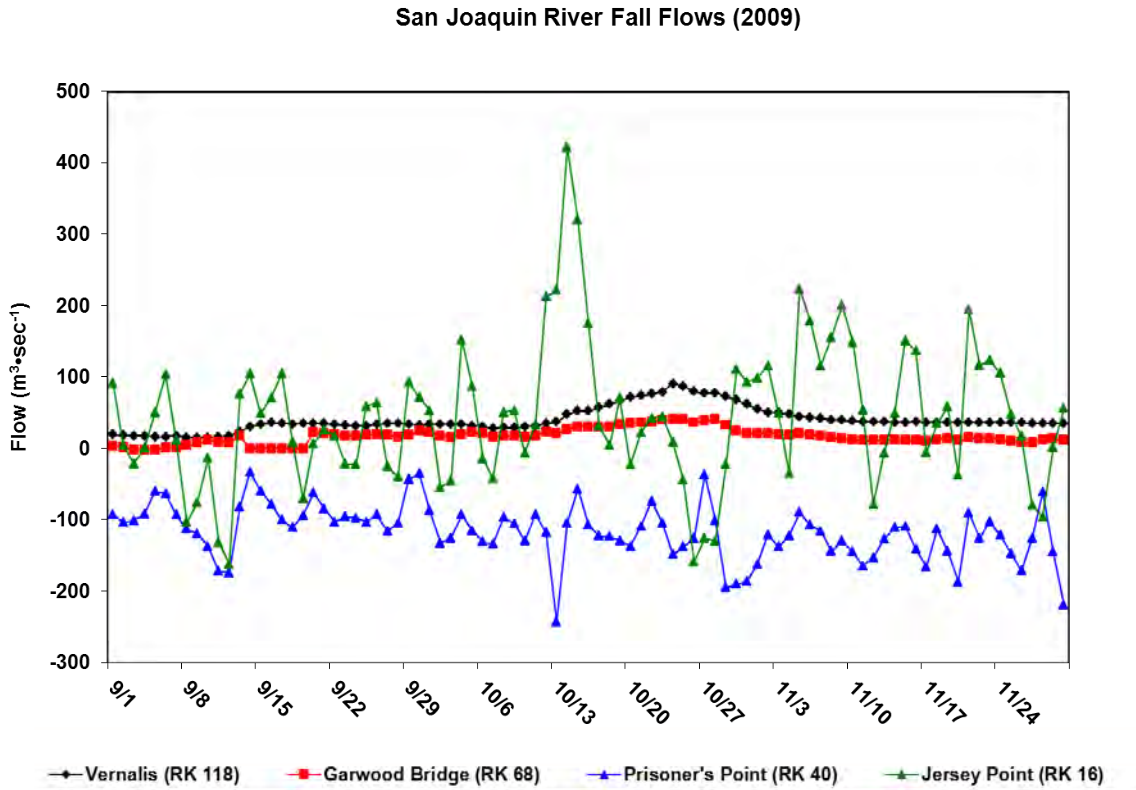


**Figure 6** San Joaquin River flows at four locations from the entrance to the South Delta (Vernalis), through the interior of the Delta (Prisoner's Point and Garwood Bridge), and near the exit point of the Delta (Jersey Point). River kilometer (RK) is the distance measured from the San Joaquin-Sacramento River confluence to each location.

not, make their way to the SJR main river channel upstream of the confluence of the San Joaquin River and Sacramento River.

Our results also indicated that the south Delta barriers, including the fall HORB, have little if any influence on reducing SJR salmon stray rates. Although, the flow through the main SJR channel was reduced if the HORB was not installed, and the majority of the flow was conveyed towards the CVP and SWP pumping facilities via the Old River (Jassby 2005; SJRGA 2009; ICF 2010), the statistical analyses suggest that SJR stray rates were unaffected by whether SJR water flowed in the SDWSC or through the Old and Middle rivers. This is logical because SJR origin migrating adults would need to detect their natal SJR flow at the confluence of the San Joaquin and Sacramento Rivers to home successfully.

## Juvenile Release Location and Stray Rates

Comparing stray rates for Sacramento River and SJR basin hatchery releases by broad geographical location (Figure 7) indicates that there is a ten-fold difference in stray rate for SJR salmon compared to that for Sacramento Basin salmon. Adult salmon stray rates for Sacramento Basin origin juvenile releases made upstream of the Delta averaged 0.1%; whereas, adult salmon stray rates for San Joaquin origin juvenile salmon releases made upstream of the Delta averaged 18%. For both Sacramento and San Joaquin adult salmon, straying increased sharply the farther downstream juvenile salmon were released. Sacramento salmon straying by release location averaged 0.1% (0 to 6.1%), 0.5% (0 to 3.4%), and 1.1% (0 to 7.8%), respectively for inland, Delta, and Bay releases. For San Joaquin salmon, adult straying by juvenile release location averaged 18% (0 to 70.1%), 35% (0 to 75%), and 85% (37.4% to 100%), respectively for inland, Delta, and Bay releases.

The coded-wire-tag release-recovery data indicate that releasing juvenile salmon farther downstream substantially increases juvenile-to-adult survival rates. This practice is called out-planting and while it increases survival, it appears to come at a cost in the form of higher stray rates than if releases occurred upstream at or near the hatchery (Ebel and others 1973; Slatick and others 1975; Ebel 1980). There is conflicting information in the literature about whether or not transportation of juveniles, from point of capture or rearing, to downstream locations, increases straying. Ebel and others (1973), Slatick and others (1975), and Ebel (1980), represent three separate studies documenting the effect of transporting juveniles on their survival and homing success as adult fish. Observed adult recoveries for both transported (barged) and non-transported fish in the Snake–Columbia River system, found that the homing ability of Chinook salmon was not impaired even when juveniles were transported 400 km (249 miles) downstream. Conversely, in a more recent study Keefer and others (2008), who also reported stray results from a long distance juvenile transportation study conducted in the Snake–Columbia River system, found that stray rates were higher for transported (barge) juveniles than for non-transported juveniles. Vreeland and others (1975) and Solazzi and others (1991), who conducted separate juvenile transportation studies using coho salmon (*Onchorhynchus kisutch*), found that transported (trucked) juveniles had lower homing (i.e. higher stray) rates than non-transported juveniles. These studies suggest that transportation of juveniles to downstream locations increases juvenile-to-adult survival but provide contradictory results for influ-

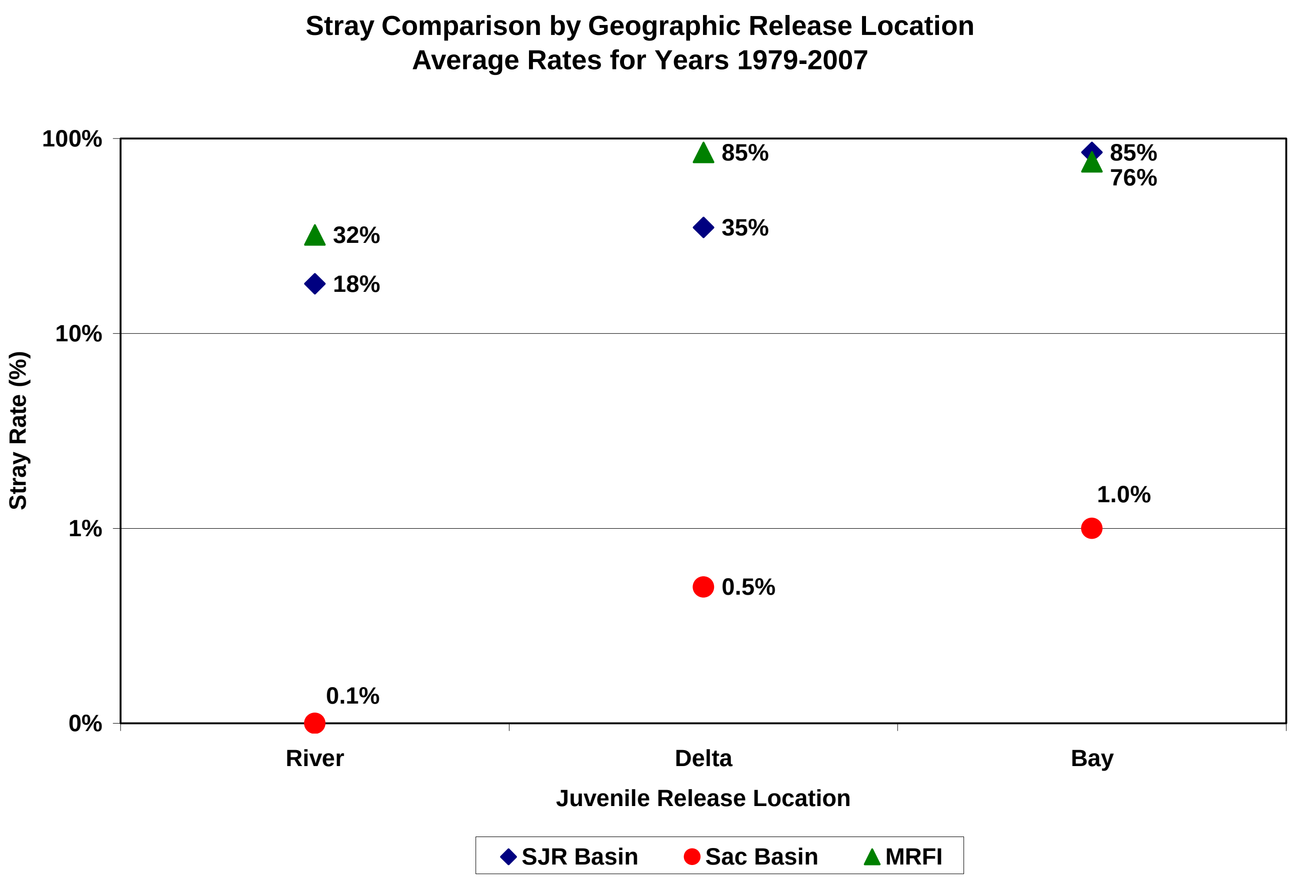


**Figure 7** Plot showing stray rates for Sacramento River and San Joaquin River basin origin fall-run Chinook salmon by geographic location of release (River, Delta, and Bay) from the hatchery of origin during their juvenile emigration

ence upon adult homing. Our results indicate that juveniles released farther downstream will stray at greater rates (Figure 7).

One consequence arising from transporting hatchery juveniles to downstream releases locations is that hatchery fish from the MRH, and MRFI stray throughout the Central Valley at high rates. Though Sacramento River basin salmon exhibited relatively low stray rates (1% or less), regardless of release location in comparison to SJR basin salmon, the straying of Sacramento River basin salmon to the SJR could still be problematic given the order-of-magnitude difference in fall-run escapement between the two basins. For example, from 1979 to 2007, average annual escapement for Sacramento River and SJR adult salmon was 288,313 (ranging from 86,698 to 834,900) and 16,160 (ranging from 590 to 69,847), respectively (CDFG GrandTab 2010). If we assume a 1% stray rate and an escapement of 500,000 spawners for Sacramento River basin salmon, this would result in 5,000 salmon straying into the SJR basin. This level of Sacramento River basin salmon straying into the SJR can swamp SJR escapement, given that the combined SJR escapement has been less than 5,000 spawners in several years during the 1979 through 2007 time-period. This may have significant implications for Central Valley salmon management and may help explain why recent genetic testing indicates that the Central Valley fall-run Chinook salmon population is homogeneous (Banks and others 2000; Williamson and May 2005; Garza and others 2008; California HSRG 2012).

## Stray Rate Comparisons

What is a "normal" (i.e., natural) stray rate for fall-run Chinook salmon? According to Quinn (1997), background levels of between 2% to 5% appear to be normal stray rates for hatchery salmon, but not many studies have been conducted for wild salmon. Williams (2006) reported a Mokelumne River wild fall-run Chinook stray rate of 7.3%, with the caveat that this population is heavily influenced by hatchery production and receives eggs and fry transferred from Sacramento River Basin hatcheries (FRH and NFH). CDFG Mokelumne River Hatchery annual reports confirm that large numbers of eggs and juveniles have been transported from Sacramento River Basin hatcheries (FRH and NFH) to the Mokelumne River Hatchery (Estey 1988; Anderson 2010). What a "normal" stray rate is depends on the definition of stray rate being referenced. There can be a wide range of stray rates for Chinook salmon depending on how straying is defined. Looking closely into the factors that influence straying, such as environmental conditions at the time of return (water temperature and flow rates in both natal rivers and rivers located adjacent to the natal river [Quinn 1997]), there is near unanimous agreement—from studies conducted in the lower Columbia River Basin, U.S. (Quinn 1993), Puget Sound and Strait of Georgia, Southern Canada (Candy and Beacham 2000), and New Zealand (Unwin and Quinn 1993)—that it is relatively rare that adult Chinook salmon stray into non-natal river basins to spawn. For reference and context, in this case the entire Central Valley is a single river basin. In other words, it would be a relatively rare event to have a naturally produced Central Valley salmon stray to a non-Central Valley river basin (say the Klamath River).

Whether or not there exists a difference in stray tendency for wild versus hatchery-reared salmon is largely unknown given the few homing studies conducted using wild salmon. Comparisons of straying between wild and hatchery-reared salmon, though few, have shown results indicating that tagged wild juveniles strayed less as returning adults than hatchery reared-released salmon; although, these results are not consistent. In one study, rearing of juvenile wild fall-run Chinook in a hatchery for a short time period increased their adult straying rate relative to wild fish not reared in the hatchery (McIsaac 1990). However, wild and hatchery-reared juvenile salmon showed similar stray rates in studies with coho salmon (Labelle 1992) and Atlantic salmon (*Salmo salar*; Jonsson and others 1991, as cited in Quinn 1997).

## Straying by Age

The age of adults returning may contribute to stray rate variability in salmon. In some studies, older Chinook salmon strayed more than younger fish

(Quinn and Fresh 1984; McIsaac and Quinn 1988; Quinn and others 1991; Unwin and Quinn 1992; Pascual and Quinn 1994). In contrast, Hard and Heard (1999, as cited in Candy and Beacham 2000) studied stray rates among transplanted Alaskan hatchery populations of Chinook salmon and found that straying is highest for younger fish (jack males). They hypothesized that these fish may stray at higher rates in order to expand their population by straying into non-natal rivers and spawning with uncontested females. We also found that younger age SJR salmon strayed at higher rates than did older salmon though these differences in stray rates were not statistically significant. Candy and Beacham (2000) found no consistent trend of increased stray rate with age.

### Coded Wire Tag Recovery Effort

Candy and Beacham (2000) reported that recovery effort influenced stray rates with the highest stray rates and number of fish recovered occurring in regions where the highest recovery effort occurred. Their finding was consistent with Pascual and others (1995) who found that the highest stray rates occurred in the lower Columbia River and attributed this finding to this area having the highest number of potential recovery sites. Development of the Central Valley fall-run Chinook salmon CWT database uncovered similar findings. Both number of fish tagged (CWT) and CWT recovery effort in the Central Valley has fluctuated widely over time. This variability in both tagging and recovery effort results in high levels of analytical uncertainty because, as described in the Methods Appendix, missing CWT data gaps need to be filled in. That said, both Central Valley CWT tagging and recovery effort have improved over time as resources to conduct monitoring (funding and staffing) have been made available. The constant fractional marking (CFM) program of hatchery produced Central Valley fall-run Chinook salmon initiated in 2007 (PSMFC 2008) will provide more reliable results as CFM continues (Newman and others 2004) and consistent recovery effort throughout the Central Valley occurs (Hicks 2003; Hankin and others 2005).

### Policy and Management Implications

Although this statistical analysis shows that both south Delta exports and SJR flow affect SJR salmon stray rates, the relative role of flow and exports is uncertain, as is the period when flow management affects stray rates. Based on our statistical results alone, the SJR flow metric (either base or pulse) is more predictive metric than one that includes exports. However, since Delta exports can cause severe negative flows in the south Delta, and occurrence of negative flows are likely to negatively affect (disorient) escaping salmon populations that migrate through the Delta because of reduced chemical olfaction cue signals (Keefer and others 2006), further study is warranted to determine whether negative flows make it more difficult for returning SJR salmon to successfully locate and migrate into the SJR.

Since the Merced River (Mesick 2010), Tuolumne River (Mesick 2009), and Stanislaus River (Carl Mesick, USFWS, pers. comm., 2012) salmon populations have been identified as being at a high risk of extinction, we further suggest evaluating whether or not increasing fall south Delta inflows (pulse or base) from each of the tributaries in the SJR could reduce SJR salmon stray rates to a natural level (<5%). Each stream's fall flow contribution might also be managed to be proportional to its unimpaired watershed runoff size (i.e., ecological fair share contribution). This could ensure that each river provides equitable homing cues. Further research on such tributary effects is probably just as important as further monitoring of the effects of exports. Further research is also needed regarding the implementation of the SJR mainstem Friant Restoration Program (SJRRP 2011) and how these new fall flows influence SJR salmon straying.

The state and federal fish agencies should consider studies to determine how the following pairing of factors influences SJR salmon stray rates: (1) the relative roles of south Delta exports and SJR flow; (2) the timing of pulse flows and export reductions; and (3) the role of pulse flows versus base flows. Because of the large number of study factors involved, it may be necessary to test a different set of conditions each year until a statistically valid model can be developed (e.g., ~20 years). The test conditions should include the timing, duration, and magnitude of flow releases, including source of SJR tributary flow releases, and Delta exports. It would be important to hold these conditions constant through the migratory period each year to the extent possible. The homing success and movement timing of adult SJR salmon into and through the Delta and SJR tributaries should also be monitored. The analysis of salmon migration patterns and stray rates should include water quality indices such as water temperature and dissolved oxygen concentration as well as for flow and exports in the Delta. The role of tidal action influence upon stray rates should also be considered.

Lastly, we recommend developing a stray rate target that could consist of a single number, or range, that can be used to evaluate the effectiveness of management actions to achieve the biological management goal. An example goal could be to reduce SJR salmon stray rates to levels that are comparable with Sacramento River fall-run stray rates (i.e. <1% for river releases, see Figure 7). Equalizing salmon stray rates among the Sacramento and SJR basins would facilitate progress toward achieving SJR salmon restoration goals (i.e. reduce genetic homogenization, increase natural spawner abundance, and reduce migration barriers that impede upstream movement of spawners). The recommendation to do the aforementioned studies should not be used as a reason to defer taking action now to improve Delta flow conditions to reduce straying of SJR salmon, given that SJR flow, whether it be base or pulse, has been identified as a controlling factor. Furthering our understanding about how the above mentioned factors influence straying of SJR salmon should be built upon the premise of increasing SJR flow, base and/or pulse, into the south Delta during the fall time-period.

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RESEARCH ARTICLE

# Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes

**Anna M. Sturrock[1¤*], J. D. Wikert[2], Timothy Heyne[3], Carl Mesick[2], Alan E. Hubbard[4], Travis M. Hinkelman[5], Peter K. Weber[6], George E. Whitman[7], Justin J. Glessner[8], Rachel C. Johnson[7,9]**

**1** Institute of Marine Sciences, University of California Santa Cruz, Santa Cruz, California, United States of America, **2** US Fish and Wildlife Service, Lodi, California, United States of America, **3** Tuolumne River Restoration Center, California Department of Fish and Wildlife, La Grange, California, United States of America, **4** School of Public Health, Division of Biostatistics, University of California, Berkeley, California, United States of America, **5** Cramer Fish Sciences, Auburn, California, United States of America, **6** Glenn T. Seaborg Institute, Lawrence Livermore National Laboratory, Livermore, California, United States of America, **7** Department of Animal Sciences, University of California Davis, Davis, California, United States of America, **8** UC Davis Interdisciplinary Center for Plasma Mass Spectrometry, Department of Geology, University of California Davis, Davis, California, United States of America, **9** National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California, United States of America

¤ Current address: Department of Environmental Science, Policy & Management, University of California, Berkeley, California, United States of America
* a.sturrock@berkeley.edu



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## Abstract

The loss of genetic and life history diversity has been documented across many taxonomic groups, and is considered a leading cause of increased extinction risk. Juvenile salmon leave their natal rivers at different sizes, ages and times of the year, and it is thought that this life history variation contributes to their population sustainability, and is thus central to many recovery efforts. However, in order to preserve and restore diversity in life history traits, it is necessary to first understand how environmental factors affect their expression and success. We used otolith $^{87}Sr/^{86}Sr$ in adult Chinook salmon (*Oncorhynchus tshawytcha*) returning to the Stanislaus River in the California Central Valley (USA) to reconstruct the sizes at which they outmigrated as juveniles in a wetter (2000) and drier (2003) year. We compared rotary screw trap-derived estimates of outmigrant timing, abundance and size with those reconstructed in the adults from the same cohort. This allowed us to estimate the relative survival and contribution of migratory phenotypes (fry, parr, smolts) to the adult spawning population under different flow regimes. Juvenile abundance and outmigration behavior varied with hydroclimatic regime, while downstream survival appeared to be driven by size- and time-selective mortality. Although fry survival is generally assumed to be negligible in this system, >20% of the adult spawners from outmigration year 2000 had outmigrated as fry. In both years, all three phenotypes contributed to the spawning population, however their relative proportions differed, reflecting greater fry contributions in the wetter year (23% vs. 10%) and greater smolt contributions in the drier year (13% vs. 44%). These data demonstrate that the expression and success of migratory phenotypes vary with hydrologic regime, emphasizing the importance of maintaining diversity in a changing climate.

## Introduction

Life history diversity is often cited as a crucial component of population resilience, based on theoretical and empirical evidence that asynchrony in local population dynamics reduces long-term variance and extinction risk at both regional and metapopulation scales [1]. Pacific salmon are recognized for their complex life histories, having evolved alongside the shifting topography of the Pacific Rim [2]. In the California Central Valley (CCV), four runs of imperilled Chinook salmon (*Oncorhynchus tshawytscha*) coexist, exhibiting asynchronous spatial and temporal distributions that allow them to exploit a range of ecological niches [3,4]. The maintenance of multiple and diverse salmon stocks that fluctuate independently of each other has been shown to convey a stabilizing 'portfolio effect' to the overall the stock-complex [5,6]. Such 'risk spreading' can also act at finer scales [7,8], such as within-population variation in the timing of juvenile emigration. Preserving and restoring life history diversity remains an integral goal of many salmonid conservation programs [9], yet baseline monitoring data with which to detect and respond to changes in trait expression are scarce and difficult to relate directly to population abundance.

The expression and success of certain traits can be largely driven by hydroclimatic conditions experienced during critical periods of development [10]. CCV Chinook salmon are at the southern margin of their species range, and are subjected to highly variable patterns in precipitation and ocean conditions [4,11]. It is also a highly modified system, with >70% of spawning habitat lost or degraded as a result of mining activities, dam construction, and water diversions [4,12]. The majority of salmon rivers in the CCV experience regulated flows according to 'water year type' (WYT). Optimization of reservoir releases presents considerable challenges, given often limited availability and multiple uses of the water resource, inability to predict annual precipitation, and uncertainty surrounding the direct and indirect effects of flow on salmon survival [13]. Such challenges are particularly critical for the more southerly San Joaquin basin, whose salmon populations fluctuate considerably with river flows experienced during juvenile rearing (Fig 1).

Juvenile Chinook salmon exhibit significant variation in the size, timing and age at which they outmigrate from their natal rivers [3,14]. Selection for one strategy over another may vary as a function of freshwater and/or marine conditions [10,15]. In the CCV, fall-run juveniles typically rear in freshwater for one to four months before smoltification prompts downstream migration toward the ocean [16]. In this system, contributions of the smaller fry and parr outmigrants to the adult population are often assumed to be negligible, as survival tends to correlate with body size [17,18] and there is little evidence for downstream rearing in the San Francisco estuary [19]. However, this has never been explicitly tested for smaller size classes. Indeed, salmon fry are frequently observed rearing in tidal marsh and estuarine habitats in other systems [3], and have been observed in non-natal habitats in the CCV, such as the mainstem Sacramento and San Joaquin Rivers, freshwater delta, and estuary [20]. Juvenile salmon that enter the ocean at a larger size and have faster freshwater growth have demonstrated a survival advantage when faced with poor ocean conditions [18]. Yet intermediate size classes can be better represented in the adult population [21,22], and size-selective mortality can be moderated by a variety of other processes [23]. In a regulated system such as the CCV, identifying the relationships between observable traits, hydroclimatic regime and survival would be invaluable for reducing uncertainty and predicting how populations may respond to climate change and management actions related to water operations.

Quantifying the relative contribution of fry, parr and smolt outmigrants to the adult population has, until now, been largely limited by the methodological challenges associated with reconstructing early life history movements of the adults. Mark-recapture studies using acoustic and coded wire tags (CWT) have provided empirical indices of juvenile survival through stretches of the Sacramento-San Joaquin River Delta (hereafter, "the Delta") [24,25], but are hindered by low rates of return and tend to utilize hatchery fish that may exhibit different rearing behavior and sea-readiness to their wild counterparts [26]. Furthermore, 'fry pulses' tend to be dominated by individuals <45mm FL, which are difficult to mark externally without causing damage or behavioral modifications. No study to date has tracked habitat use of individual salmon over an entire lifecycle to estimate the relative success of juvenile outmigration phenotypes under different flow conditions. Previous studies have tended to rely on correlations between environmental conditions (e.g. flow) experienced during outmigration and the abundance of returns (Fig 1) [27]. Recent advances in techniques using chemical markers recorded in biomineralised tissues provide rare opportunity to retrospectively "geolocate" individual fish in time and space [28]. Given their incremental growth and metabolically inert

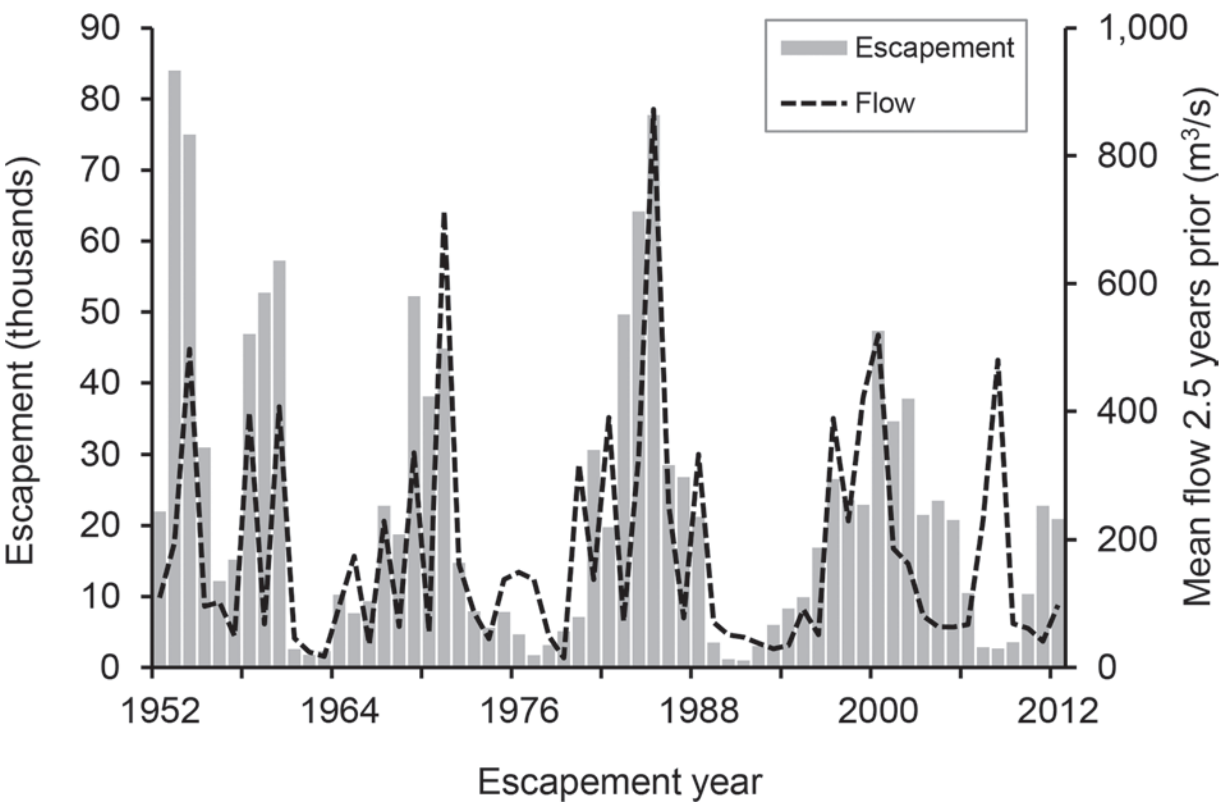


**Fig 1. Relationship between adult salmon returns to the San Joaquin basin and the river flows experienced as juveniles.** Fall-run Chinook salmon returns ('escapement') to the San Joaquin basin from 1952 to 2011 (CDFW GrandTab, www.CalFish.org) relative to mean flows at Vernalis (USGS gauge 11303500, http://waterdata.usgs.gov/nwis) for the January to June outmigration period they experienced 2.5 years previous. Note that adult abundance estimates have not been corrected for age distributions (we assumed that all adults returned at age 3), inter-annual variation in harvest rates or out-of-basin straying. The large deviation in 2007 reflected poor returns that were attributed to poor ocean conditions [96] and resulted in the closure of the fishery. Adapted from [97].

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nature, otoliths ('ear stones') represent a unique natural tag for reconstructing movement patterns of individual fish [29]. The technique relies on differences in the physicochemical environment producing distinct and reproducible "fingerprints" in the otolith. In the CCV, strontium isotopes ($^{87}Sr/^{86}Sr$) are ideal markers because the water composition varies among many of the rivers and is faithfully recorded in the otoliths of Chinook salmon [30–32]. Changes in otolith $^{87}Sr/^{86}Sr$ values can be used to reconstruct time- and age-resolved movements as salmon migrate through the freshwater and estuarine environments [33]. Furthermore, otolith size is significantly related to body size [34,35], allowing back-calculation of individual fork length (FL) at specific life history events [36].

Here, we document metrics of juvenile life history diversity (phenology, size, and abundance) of fall-run Chinook salmon as they outmigrated from the Stanislaus River during an 'above normal' (2000) and 'below normal' (2003) WYT. We used otolith $^{87}Sr/^{86}Sr$ and radius measurements to reconstruct the size at which returning (i.e. "successful") adults from the same cohort had outmigrated, then combined juvenile and adult datasets to estimate the relative contribution and survival of fry, parr and smolt outmigrants. Our main objectives were to determine (1) if a particular phenotype contributed disproportionately to the adult spawning population, (2) whether this could be attributed to selective mortality, and (3) if patterns in phenotype expression and success varied under contrasting flow regimes.

## Study Area

The Stanislaus River (hereafter, "the Stanislaus") is the northernmost tributary of the San Joaquin River, draining 4,627 km$^3$ on the western slope of the Sierra Nevada (Fig 2) [37]. The basin has a Mediterranean climate and receives the majority of its annual rainfall between November and April. Contrasting with the Sacramento watershed in the north, the hydrology of the San Joaquin basin is primarily snowmelt driven [4]. There are over 40 dams in the Stanislaus, which collectively have a capacity of 240% of the average annual runoff [38]. Historically, the Stanislaus contained periodically-inundated floodplain habitat and supported spring- and fall-run Chinook salmon; however, spring-run salmon were extirpated by mining and dam construction, reducing habitat quality and preventing passage to higher elevation spawning grounds [4].

## Materials and Methods

### Ethics statement

This research was conducted in strict accordance with protocols evaluated and approved by the University of California, Santa Cruz Institutional Animal Care and Use Committee for this specific study (permit number BARNR1409). Otolith and scale samples were collected by California Department of Fish and Wildlife (CDFW) staff from adult salmon carcasses (i.e. already expired) as part of their annual carcass survey, permitted under the State legislative mandate to perform routine management actions. No tissue collections were taken from any state- or federally-listed endangered or protected species for this study.

### Juvenile sampling and hydrologic regime

Typically, fall-run Chinook salmon return to the San Joaquin basin from September to early January, and their offspring outmigrate the following January to June [16,39]. Juveniles were sampled as they left the Stanislaus using rotary screw traps (RST) at Caswell Memorial State Park (Fig 2, N 37°42'7.533", W 121°10'44.882). Sampling was terminated when no juveniles had been captured for at least seven consecutive days in June or July [40]. Here, we focused on

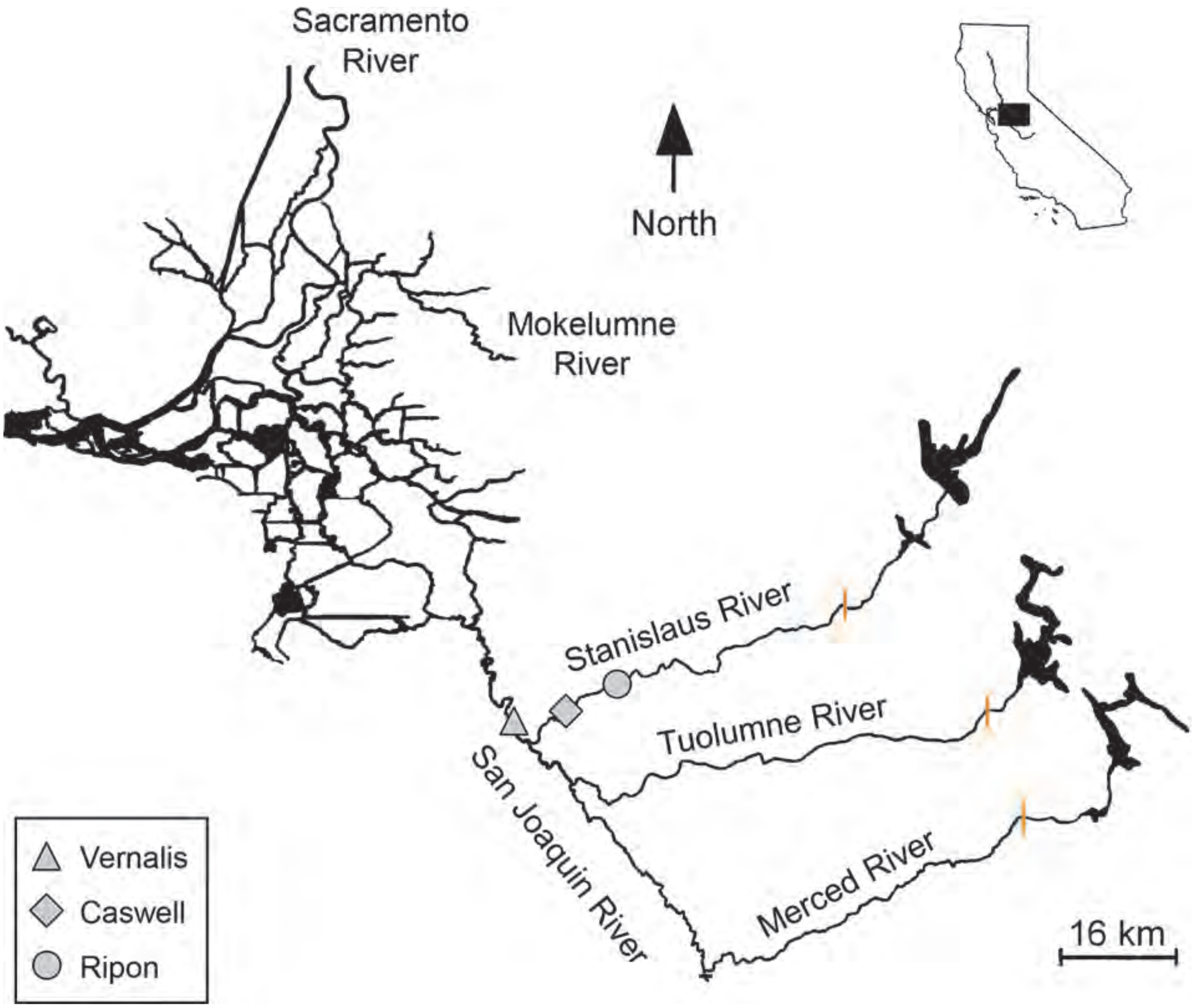


**Fig 2. The San Joaquin basin of the Central Valley, California (inset).** Map showing the major rivers in the San Joaquin basin, and the location of the rotary screw trap site at Caswell Memorial State Park and USGS gauges at Ripon and Vernalis. The upstream barriers to salmon migration in the three main tributaries are indicated by orange bars.

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an 'above normal' (2000) and 'below normal' (2003) WYT, and defined the outmigration period as January 1 to June 30, inclusive. When traps were checked, all fish were counted and up to 50 were randomly selected for fork length (FL) and weight measurements. Given potential subjectivity in visual staging criteria [41], we defined migratory phenotypes (fry, parr and smolt) by size: ≤55mm, >55 to ≤75mm, and >75mm FL, respectively (after [21]). Unmeasured fish were assigned to phenotype using the observed proportions in the measured fish for the same date. For each phenotype, we interpolated missing catch values with a triangular weighted mean [42].

Marked fish were periodically released to develop a statistical model of trap efficiency, which was used to expand counts of fry, parr and smolt-sized outmigrants. Trap efficiency was estimated using a GLM with a quasibinomial error distribution because of overdispersion in capture probabilities. We used the same efficiency model as [42], only using phenotype (fry, parr, smolt) to characterize fish size, rather than FL. We propagated uncertainty by deriving estimated expanded counts from repeated Monte Carlo draws (n = 2000) from the estimated sampling distribution of the estimated coefficients from the logistic efficiency model using R package mvtnorm [43]. Daily flow observations (USGS gauge no. 11303000 at Ripon, www.waterdata.usgs.gov/nwis) were used with the randomly-sampled model coefficients to simulate daily trap efficiency. Passage estimates were then simulated using daily catch and simulated trap efficiencies. We incorporated extra-binomial variation by generating simulated daily catch values from a beta-binomial distribution (based on the simulated efficiencies and passage estimates, as well as the dispersion estimated from the efficiency model). Finally, new daily passage estimates were calculated using simulated catch and trap efficiencies. Thus the final passage estimates incorporate both sampling error (catch) and estimation error (efficiency model). Annual passages estimates and confidence intervals (2.5% and 97.5% quantiles) were generated by summing daily passage estimates for the 6 month outmigration period (i.e. n = 2000 x 180 days).

Measured daily size-frequency distributions were applied directly to the expanded abundance estimates, then grouped into 2mm FL bins. We attempted to produce passage estimates by FL, but the distribution used in the uncertainty propagation procedure (see above) is asymmetric at low catches, resulting in zero-inflation and the median of the resampled distribution often being lower than the observed raw catch.

Turbidity was measured at Caswell using a LaMott turbidity meter [40]; mean daily flow and maximum daily temperature were measured at Ripon (gauge details above). Daily passage estimates, turbidity, flow and temperature were $\log_{10}$ transformed, then averaged for the 6-month outmigration period and compared among years by ANOVA, adjusting for temporal autocorrelation using the Durbin-Watson (DW) test [44]. Pearson's chi-squared test was used to identify differences in the proportion of phenotypes among years. Fry, parr and smolt phenology was summarized using three metrics associated with their date of passage past the trap: the range, interquartile range (IQR), and median (or "peak") outmigration date. Phenotype "migratory periods" were defined as the maximum IQR for both years combined.

## Adult sampling and cohort reconstruction

To track outmigration cohorts 2000 and 2003 into the adult escapement, sagittal otoliths were extracted from Chinook salmon carcasses (aged 2–4 years, 45–112 cm FL) collected in the 2001–2006 CDFW Carcass Surveys (Table 1). Unmarked fish were sampled randomly, but in earlier years, known-hatchery fish with CWTs and clipped adipose fins ("adclipped") were preferentially sampled to assess the accuracy of age estimations. We utilized all otoliths collected from all unmarked fish, but included a subset of CWT fish from outmigration year 2000 (n = 27), which we analyzed blind to assess the accuracy of our natal assignments. Ages were estimated by counting scale annuli [45,46]. Each scale was aged by at least two independent readers and discrepancies resolved by additional reading(s).

**Table 1. Adult sample sizes, age structure and collection periods.**

| | Outmigration cohort 2000 (wetter) | | | Outmigration cohort 2003 (drier) | | |
|---|---|---|---|---|---|---|
| Age | N | % | Collection period | N | % | Collection period |
| 2 | 6 | 7% | 11/20/01–12/06/01 | 2 | 2% | 11/08/04–11/12/04 |
| 3 | 80 | 87% | 10/07/02–12/12/02 | 56 | 67% | 11/02/05–12/15/05 |
| 4 | 6 | 7% | 11/12/03–12/04/03 | 25 | 30% | 11/15/06–12/06/06 |

Otoliths were analyzed from salmon carcasses belonging to adults that had outmigrated in 2000 and 2003, including 27 known-origin fish included as a blind test of our natal assignments.

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## Otolith $^{87}Sr/^{86}Sr$ analyses

Otolith strontium isotope ratios ($^{87}Sr/^{86}Sr$) were measured along a standardized 90° transect [47] by multiple collection laser ablation inductively coupled plasma mass spectrometry (MC-LA-ICPMS; Nu plasma HR interfaced with a New Wave Research Nd:YAG 213 nm laser). Spot analyses were used to allow coupling of chemical data with discrete microstructural features, but otherwise preparation and analysis methods followed those of Barnett-Johnson et al. [32,48]. In brief, otoliths were rinsed 2–3 times with deionized water and cleaned of adhering tissue. Once dry, otoliths were mounted in Crystalbond resin and polished (600 grit, 1500 grit then 3 μm lapping film) until the primordia were exposed. Depending on sample thickness and instrument sensitivity, a 40–55μm laser beam diameter was used with a pulse rate of 10-20Hz, 3–7 J/cm$^2$ fluence, and a dwell time of 25–35 seconds, resulting in individual ablations roughly equivalent to 10–14 days of growth. Where individual ablations exhibited isotopic changes with depth (e.g. at habitat transition zones), only the start of the ablation was used (e.g. S1 Fig). Helium was used as the laser cell carrier gas (0.7–1.0 L/min) to improve sample transmission and was mixed with argon before reaching the plasma source. Krypton interference ($^{86}Kr$) was blank-subtracted by measuring background voltages for 30 s prior to each batch of analyses, and $^{87}Rb$ interferences were removed by monitoring $^{85}Rb$. Isotope voltages were integrated over 0.2 s intervals then aggregated into 1 s blocks. Outliers (>2SD) were rejected. Marine carbonate standards ('UCD Vermeij Mollusk' and *O. tshawytscha* otoliths) were analyzed periodically to monitor instrument bias and drift, producing a mean mass-bias corrected $^{87}Sr/^{86}Sr$ ratio (normalized to $^{86}Sr/^{88}Sr = 0.1194$) within 1SD of the global marine value of 0.70918 (0.70922 ± 0.00008 2SD).

## Strontium isotopes to reconstruct natal origin and size at outmigration

The baseline of natal $^{87}Sr/^{86}Sr$ signatures described in [32] was updated and expanded upon to increase sample sizes and among-year representation, resulting in an 'isoscape' that encompassed all major CCV sources, with many sampled across multiple years and hydrologic regimes. Linear discriminant function analysis (LDFA) was used to predict the natal origin of the sampled adult spawners, assuming equal prior probabilities for all sites (S1 Text). Differences in natal $^{87}Sr/^{86}Sr$ values were tested between years and sites (S1 Text, S1 Table and S2 Fig), and the performance of the LDFA was assessed using known-origin reference samples (S2 Table). Adults in this study were considered strays (not produced in the Stanislaus) when their natal $^{87}Sr/^{86}Sr$ were closer to other sources in the isoscape, and were excluded from further analysis.

For adults that had successfully returned to the Stanislaus, we monitored the change in $^{87}Sr/^{86}Sr$ across the otolith to identify the point at which they had outmigrated as juveniles. The Stanislaus has a significantly lower isotopic value (0.70660 ± 0.00008 SD) than the mainstem San Joaquin River immediately downstream from it (0.70716 ± 0.00013 SD), resulting in a clear increase and inflection point in otolith $^{87}Sr/^{86}Sr$ at natal exit (e.g. Fig 3B). If the inflection point was unclear, sequential spot analyses were analyzed by LDFA, and exit was defined as a >0.3 decrease in posterior probability of Stanislaus-assignment to a probability <0.5. Deviation from the mean $^{87}Sr/^{86}Sr$ Stanislaus value was assumed to reflect considerable time spent in non-natal water, as (1) the Stanislaus $^{87}Sr/^{86}Sr$ signature shows minor variation in otoliths (S1 Table) and water samples collected immediately upstream of the confluence, (2) the RST location is 13.8rkm upstream of the confluence (Fig 2) and (3) the length of time integrated by each laser spot is ~12 days. Therefore, the distance used to back-calculate exit size was from the otolith core to the last natal spot. To improve resolution and accuracy, additional ablations were performed around the transition zone, typically resulting in sub-weekly resolution.

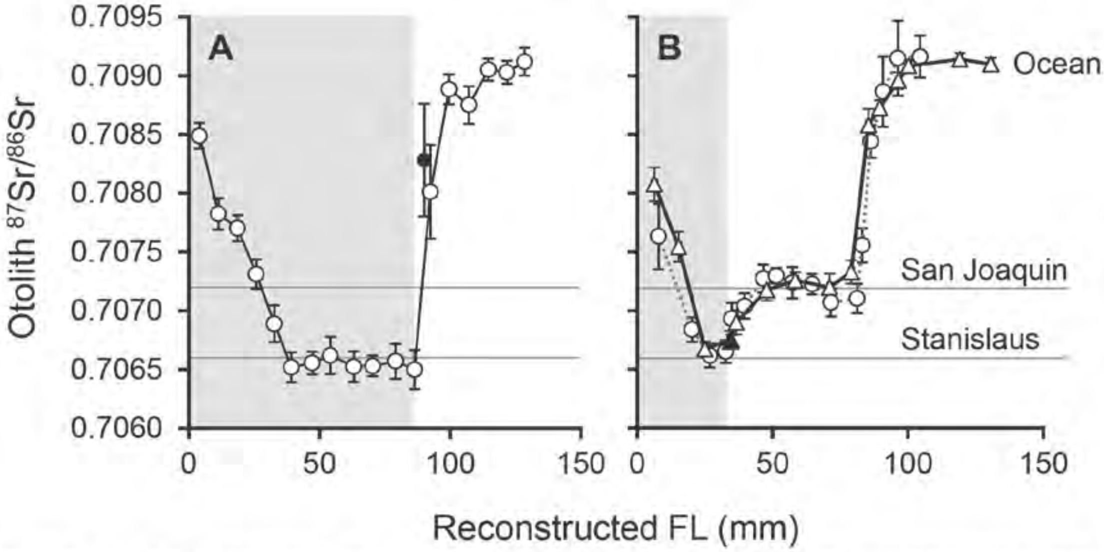


**Fig 3. Otolith $^{87}Sr/^{86}Sr$ reconstructions of a smolt and fry outmigrant.** Otolith $^{87}Sr/^{86}Sr$ profiles against back-calculated FL for two adult Chinook salmon that returned to the Stanislaus River having outmigrated as (A) a smolt and (B) a fry. The shaded box indicates the time spent rearing in the natal river. The fry outmigrant reared for several weeks downstream in the San Joaquin River before migrating out to the ocean, as indicated by both the left (triangles, solid line) and right (circles, dashed line) otolith (back-calculated FL = 33.3mm *vs*. 34.9mm). Mean $^{87}Sr/^{86}Sr$ signatures for the Stanislaus and San Joaquin Rivers, and modern-day ocean are displayed. Black filled symbols indicate 're-spots' carried out to improve sampling resolution. Error bars = 2SE.

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## Reconstructed size at outmigration in the returning adults

The relationship between otolith radius (OR) and FL was first calibrated using juveniles collected from multiple sites in the CCV (S3 Table). All individuals belonged to the same Evolutionarily Significant Unit, which is critical for producing unbiased back-calculation models [49]. As there was no difference in the OR of paired otoliths from single individuals ($n = 30$, $\bar{x}\triangle = 2.5\mu m$, 95% CI = -5.6–10.6μm), left and right otoliths were used interchangeably. OR was measured along the same 90° transect used for isotope analyses, using a Leica DM1000 microscope and Image Pro Plus (7.0.1).

Reconstructed sizes were grouped into 2mm FL bins and categorized as fry, parr or smolt outmigrants based on the criteria of [21]. Size-frequency distributions were compared between the juvenile and adult samples to identify trends indicative of size-selective mortality. The error around the OR-FL calibration line was used to estimate 95% CI around the proportions of fry, parr and smolt outmigrants using random resampling ($n = 5000$) of the residuals. This allowed us to derive the relative contribution of each phenotype to the adult spawning population.

## Survival of juvenile migratory phenotypes

To generate survival indices, we normalized the contribution of each phenotype to the adult population by their abundance within each outmigration cohort based on RST sampling. To estimate spawner abundance ("natural escapement"), we removed adclipped strays from total escapement estimates (GrandTab, available at www.calfish.org) using river- and year-specific tag recovery rates (S4 Table), then separated cohorts using annual age distributions [50] and removed unmarked strays using our otolith natal assignments (see results and S4 Table). We evaluated the use of spawner abundance *vs*. "adult production" (after [51]). While production accounts for different harvest rates among years [52], the two metrics produced similar trends in survival ($r^2 = 0.98$), and we found that escapement, which includes harvest, bycatch and natural mortality between outmigration and spawning, to be more intuitive to interpret.

The otolith-derived proportions (±95% CI) of phenotype $i$ in the escapement ($\beta_i$) were applied to our natural escapement estimates ($E_n$) to estimate the number of fry, parr and smolt spawners ($E_i$), then $E_i$ was compared with the number of outmigrants of phenotype $i$ ($J_i$) to estimate their relative survival ($S_i$):

$$E_i = E_n \beta_i \qquad S_i = E_i / J_i$$

To estimate 95% CI for $S_i$ we combined error in $\beta_i$ and $J_i$ using the delta method. The 95% CI for $S_i$ depends on the estimate and its standard error (SE): $\hat{S}_i,\ SE(\hat{S}_i)$. Assuming independence of $\beta_i$ and $J_i$, we estimated variance as $SE(\log(\hat{S}_i)) \cong \sqrt{(\frac{1}{\hat{J}_i})^2 SE^2(\hat{J}_i) + (\frac{1}{\hat{\beta}_i})^2 SE^2(\hat{\beta}_i)}$. From this, we derived 95% CI for $S_i$ as $(e^{\log(\hat{S}_i) - 1.96 \times SE(\log(\hat{S}_i))}, e^{\log(\hat{S}_i) + 1.96 \times SE(\log(\hat{S}_i))})$. Note that uncertainties in adult escapement were not incorporated into these confidence intervals; however, the RST-expansions used to estimate $J_i$ were deemed likely to introduce the largest amount of error.

## Results

### Juvenile outmigration relative to hydrologic regime

Mean flow and turbidity for the 6 month outmigration period were higher in 2000 than 2003 (DW-adjusted $F_{1,\,361} = 7.52$, $p = 0.006$ and $F_{1,\,257} = 14.53$, $p = 0.0002$, respectively) (Fig 4). In the drier year (2003) the river was warmer during the smolt migratory period (Apr 15-May 18: DW-adjusted $F_{1,\,60} = 4.54$, $p = 0.037$) and peak daily temperatures first exceeded 15°C three weeks earlier (Fig 4).

Peak flows were about five times higher in 2000 than 2003, and accompanied by spikes in turbidity and juvenile migration (Fig 4). The number of outmigrants was an order of magnitude higher in 2000 (Table 2), reflecting significantly higher daily abundances of fry, parr and smolt outmigrants (DW adjusted $F_{1,\,161} = 11.23$, $p < 0.001$; $F_{1,\,196} = 47.99$, $p < 0.001$; $F_{1,\,199} = 6.45$, $p = 0.0118$, respectively). While fry dominated in both years, phenotype contributions differed significantly between years ($X^2 = 223{,}683$, $p < 0.001$), with parr approximately twice as abundant as smolts in 2000, but vice versa in 2003 (Table 2). One yearling (FL = 140mm) was

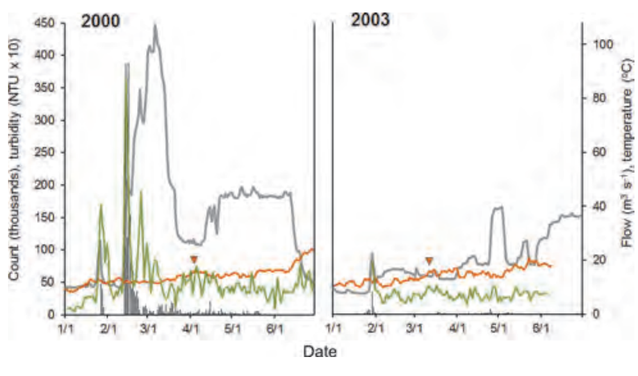


**Fig 4. Daily abundance of juvenile salmon outmigrating in 2000 and 2003 relative to ambient environmental conditions.** Juvenile salmon were sampled by rotary screw traps at Caswell as they outmigrated from the Stanislaus, and raw counts were expanded into daily abundance estimates (vertical bars) based on trap efficiency models. River flow (grey line) and maximum daily temperature (orange line) were measured at Ripon (data available at http://cdec.water.ca.gov/). Turbidity (green line) was measured at Caswell [40]. The first instance of temperatures reaching 15°C is indicated by an arrow on each plot.

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**Table 2. Abundance and migration timing of juvenile migratory phenotypes.**

| Outmigration cohort | Migratory phenotype | N (95% CI) | Proportion of the sample | Duration of migratory period (range) | Duration of "peak" migratory period (interquartile range) | Peak migration date (median) |
|---|---|---|---|---|---|---|
| 2000 (wetter) | Fry | 1,837,656 (1,337,351–2,495,523) | 0.85 | 115 d (Jan 2-Apr 25) | 4 d (Feb 14-Feb 17) | Feb 16 |
| | Parr | 212,042 (141,238–310,174) | 0.10 | 116 d (Feb 4-May 29) | 29 d (Mar 18-Apr 15) | Apr 1 |
| | Smolt | 101,467 (70,181–145,793) | 0.05 | 110 d (Mar 8-Jun 25) | 34 d (Apr 15-May 18) | May 9 |
| | TOTAL | 2,151,165 (1,577,638–2,911,393) | | | | |
| 2003 (drier) | Fry | 79,862 (59,795–103,916) | 0.50 | 80 d (Jan 23-Apr 12) | 4 d (Jan 27-Jan 30) | Jan 29 |
| | Parr | 25,729 (17,889–36,282) | 0.16 | 118 d (Feb 5-June 2) | 27 d (Mar 18-Apr 13) | Mar 21 |
| | Smolt | 55,465 (38,415–76,289) | 0.34 | 107 (Feb 24-Jun 10) | 21 d (Apr 18-May 8) | Apr 25 |
| | TOTAL | 161,056 (119,868–209,151) | | | | |

The abundance and proportions of fry, parr and smolt outmigrants sampled by rotary screw traps, and the timing of their outmigration from the Stanislaus River in 2000 and 2003.

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captured in the RST in 2000, but none in 2003, otherwise the size range of outmigrants was similar between years (25-115mm in 2000 *vs*. 27-115mm in 2003).

Phenology varied between phenotypes and years (Table 2 and Fig 5). In general, migratory windows were shorter and earlier in the drier year, with smolt outmigration ceasing 15 days earlier in 2003 than in 2000. The peak migratory periods were similar across years for fry and parr, the former exhibiting a compressed interquartile range (4 d) that was tightly correlated with the start of winter flow pulses (Fig 5).

## Natal origin of unmarked adults

The unmarked adults from outmigration cohorts 2000 and 2003 comprised 18% and 51% hatchery strays, respectively, primarily from the Mokelumne, Merced, and Feather River

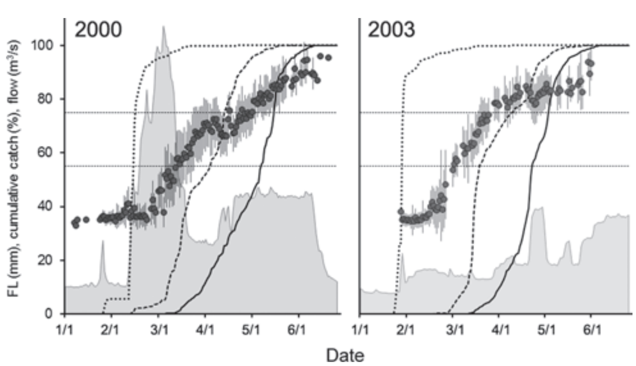


**Fig 5. Size and phenology of juveniles outmigrants relative to river flow in 2000 and 2003.** Mean (±SD) daily fork length (FL) of juvenile outmigrants, and cumulative percentage of fry (short dashed line), parr (long dashed line) and smolt (solid line) outmigrants relative to flow (filled area). Reference lines indicate the size categories used to define the migratory phenotypes: fry (≤55mm), parr (55-75mm) and smolts (>75mm).

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**Table 3. Natal assignments of unmarked adults based on otolith $^{87}Sr/^{86}Sr$.**

| Natal source | Outmigration cohort 2000 (%) | Outmigration cohort 2003 (%) |
|---|---|---|
| Stanislaus River | 82 | 49 |
| Mokelumne River Hatchery | 11 | 39 |
| Merced River Hatchery | 2 | 1 |
| Feather River Hatchery | 5 | 7 |
| Nimbus Hatchery | 2 | 2 |
| Thermalito Rearing Annex [a] | | 1 |

Natal assignments of unmarked adults fish captured in the Stanislaus River between 2001 and 2006 that outmigrated in 2000 and 2003.
[a] Part of the Feather River Hatchery

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Hatcheries (Table 3). These individuals were removed from subsequent analyses, ensuring that size back-calculations were calculated only for Stanislaus-origin fish that had experienced the same outmigration conditions as the RST-sampled juveniles.

## Back-calculation of size at outmigration

A strong, positive relationship was observed between OR and FL ($r^2$ = 0.92, n = 224, $p < 0.001$; FL = 0.171 (±0.003 SE) x OR—12.76 (±1.54 SE)), remaining linear across the full range of FLs reconstructed in the current study. This relationship was used to reconstruct FLs for individual $^{87}Sr/^{86}Sr$ profiles (e.g. Fig 3). The back-calculated size at which returning adults had outmigrated from the Stanislaus ranged from 31.3mm to 86.6mm in 2000, and 46.0mm to 90.5mm in 2003 (Fig 6). No yearlings were detected in the adult returns in either year.

To explore reproducibility of the method, paired left and right otoliths were analyzed from a subset of adults (n = 3 fry and n = 1 smolt outmigrant). All fish were assigned to the same migratory phenotype using either otolith, and the mean difference between back-calculated FLs was 2.3mm (e.g. Fig 3B).

## Contribution and survival of juvenile migratory phenotypes

The relative abundance of the migratory phenotypes in the escapement differed significantly to the outmigrating juvenile population in both 2000 ($X^2$ = 20,931, p<0.0001) and 2003 ($X^2$ = 1,381, p<0.0001). The phenotype composition of the adult population also differed significantly between years ($X^2$ = 749, $p$<0.0001), reflecting higher fry contributions in the wetter year (23% in 2000 *vs*.10% in 2003) and higher smolt contributions in the drier year (44% in 2003 *vs*. 13% in 2000). Despite representing only 10–16% of the outmigrating juveniles (Table 2), parr were the most commonly observed phenotype in the surviving adult populations (46–64%, Table 4), although parr and smolt contributions to the escapement were near-identical in 2003 (46% vs. 44%, respectively). Conversely, fry outmigrants represented 10–23% of the adult escapement, despite representing 50–85% of the juvenile sample (Tables 2 & 4). The lowest survival was observed in individuals <45mm, particularly in 2003, when the smallest outmigrant in the adult sample had left the river at 46mm FL, while the smallest individual captured in the RST was 27mm FL (Fig 6). Conversely, in 2000, 11% of the adults had left at FLs ≤46mm (the smallest at 31.3mm), compared with 80% of the original juvenile population (the smallest at 25mm; Fig 6).

In both years, fry survival downstream of the Stanislaus ($S_{fry}$) was significantly lower than parr or smolt survival (p<0.05). $S_{parr}$ was approximately double $S_{smolt}$ in both years, but the confidence intervals were overlapping (Table 4). Generally, outmigrant survival downstream of

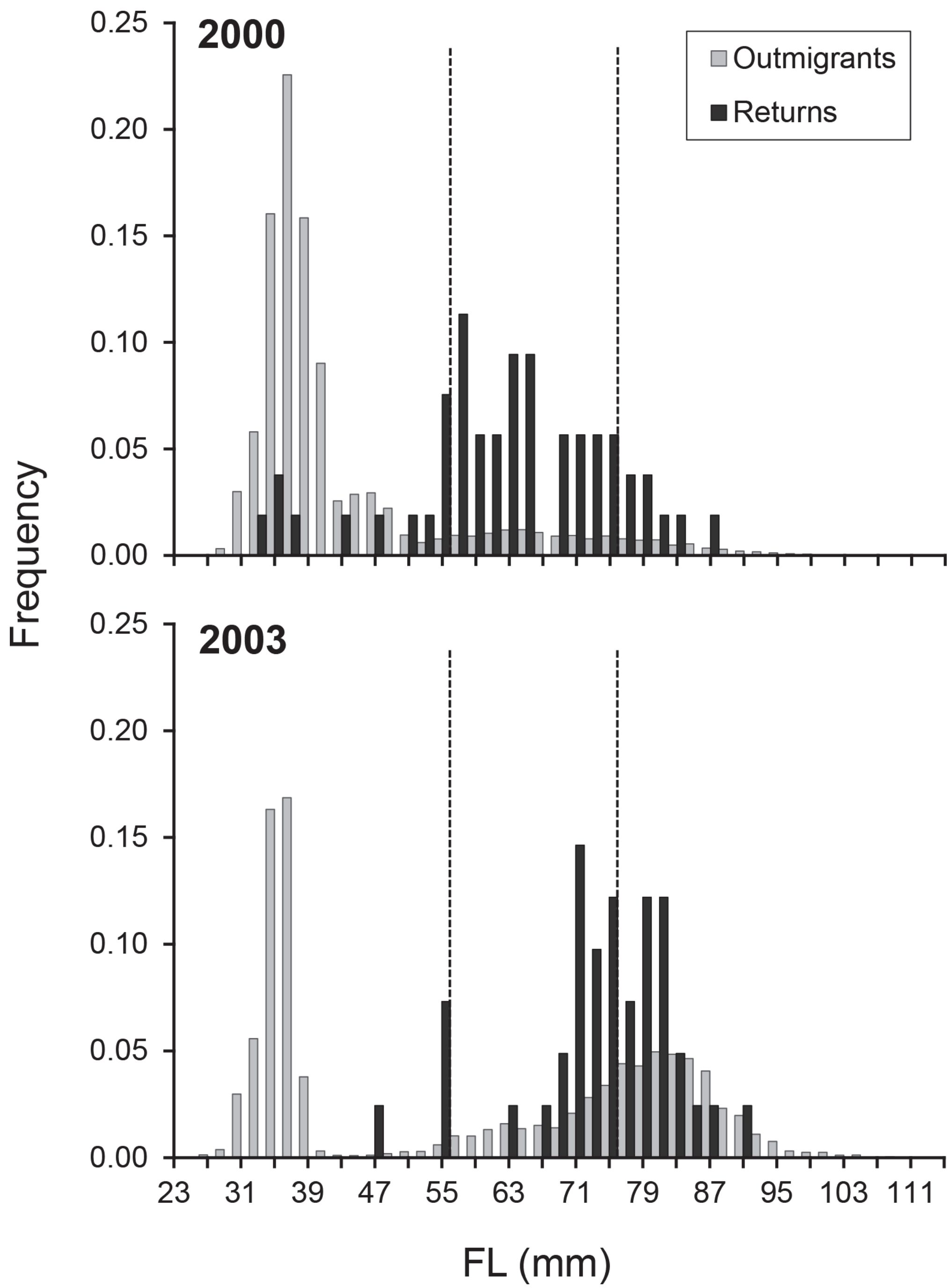


**Fig 6. Size-at-outmigration of the juveniles and surviving adults that left freshwater in 2000 and 2003.** Size-frequency distributions showing the fork length (FL) at which juveniles outmigrated from the Stanislaus River in 2000 and 2003 (grey bars) and the reconstructed size-at-outmigration of the returning (i.e. "successful") adults from the same cohort (black bars). FLs given in 2mm bins (where the x-axis represents ≤ that value, e.g. "55" = FL 53.01–55.0mm). Size classes used to categorize fry, parr and smolt outmigrants are indicated by dashed lines.

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the Stanislaus was slightly higher in the drier year (2003) than the wetter year (2000), but significant differences were not detected (Table 4).

**Table 4. Contribution and survival of fry, parr and smolt outmigrants to the adult escapement.**

| Outmigration cohort | Phenotype | Contribution to the adult escapement (%) [a] | No. spawners produced [a] | Survival (%) [b] |
|---|---|---|---|---|
| 2000 (wetter) | Fry | 23 (19–36) | 1,334 (1112–2113) | 0.07 (0.04–0.12) |
| | Parr | 64 (43–66) | 3,781 (2557–3892) | 1.78 (1.15–2.76) |
| | Smolt | 13 (9.4–25) | 778 (556–1446) | 0.77 (0.39–1.52) |
| 2003 (drier) | Fry | 10 (2.4–12) | 148 (37–186) | 0.19 (0.1–0.33) |
| | Parr | 46 (34–61) | 705 (520–928) | 2.74 (1.73–4.34) |
| | Smolt | 44 (34–59) | 668 (520–891) | 1.2 (0.78–1.87) |

[a] 95% CI in parentheses, derived from error around the FL back-calculation model.

[b] 95% CI in parentheses, derived from error around the FL back-calculation and RST efficiency models

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## Discussion

In this study we document the expression of juvenile salmon migratory phenotypes under two contrasting flow regimes and provide new insights into their contribution to the adult spawning population and ultimate survival. We observed variable expression and survivorship of fry, parr and smolt life histories within and between years, yet all three phenotypes consistently contributed to the adult spawning population. This result challenges the common perception in the CCV, that smolt outmigrants are the dominant phenotype driving adult population abundance. Our key findings in the context of the salmon life cycle in order to link the datasets, methods, and processes examined in the study (Fig 7). Overall, the wetter year (2000) was characterized by higher numbers of juvenile outmigrants and adult returns, despite fewer adult spawners contributing to the cohort the previous fall. Using the number of parental spawners as a coarse proxy for juvenile production, these trends suggest higher in-river mortality in the drier year (2003). Given similar downstream (outmigration-to-return) survival rates, these data suggest that for the two focus years of the study, cohort strength was primarily determined within the natal river, prior to juvenile outmigration.

### Juvenile outmigration behavior and phenotype expression

Juvenile outmigration timing in salmonids is inextricably linked to large-scale patterns in hydroclimatic regime and local-scale patterns in the magnitude, variation, and timing of flows [14,42]. In the Stanislaus, increases in flow were accompanied by pulses of outmigrants in both years, though greatly amplified during the turbid storm events of 2000. Correlations between fry migration, flow, and turbidity are commonly reported in the literature [14,53,54], and are suggested to have evolved as a result of reduced predation from visual piscivores [14,27,55,56]. The peak in migration in late January 2003 contained 85% of the year's total fry outmigrants and coincided with a managed water release that resulted in mean river flows of 28.4 $m^3 s^{-1}$ [57]. This pulse flow appeared to stimulate fry migration, but comprised relatively clear water (~8 NTU) and contained outmigrants almost entirely <40mm FL (Fig 5). In both years, the larger parr- and smolt-sized fish also appeared to respond to instream flows, exhibiting smaller migration pulses from March through May, coincident with both natural and managed flows (Fig 4) [58,59].

The date and periods of peak migration were generally earlier and shorter in 2003, particularly for smolts. While warmer conditions can result in faster growth rates [60], smoltification in juvenile Chinook salmon is significantly impaired at temperatures above 15°C [61] and this critical temperature was reached at Ripon three weeks earlier in 2003, prior to the onset of peak parr migration. As the reduction in juvenile abundance in 2003 occurred in spite of greater

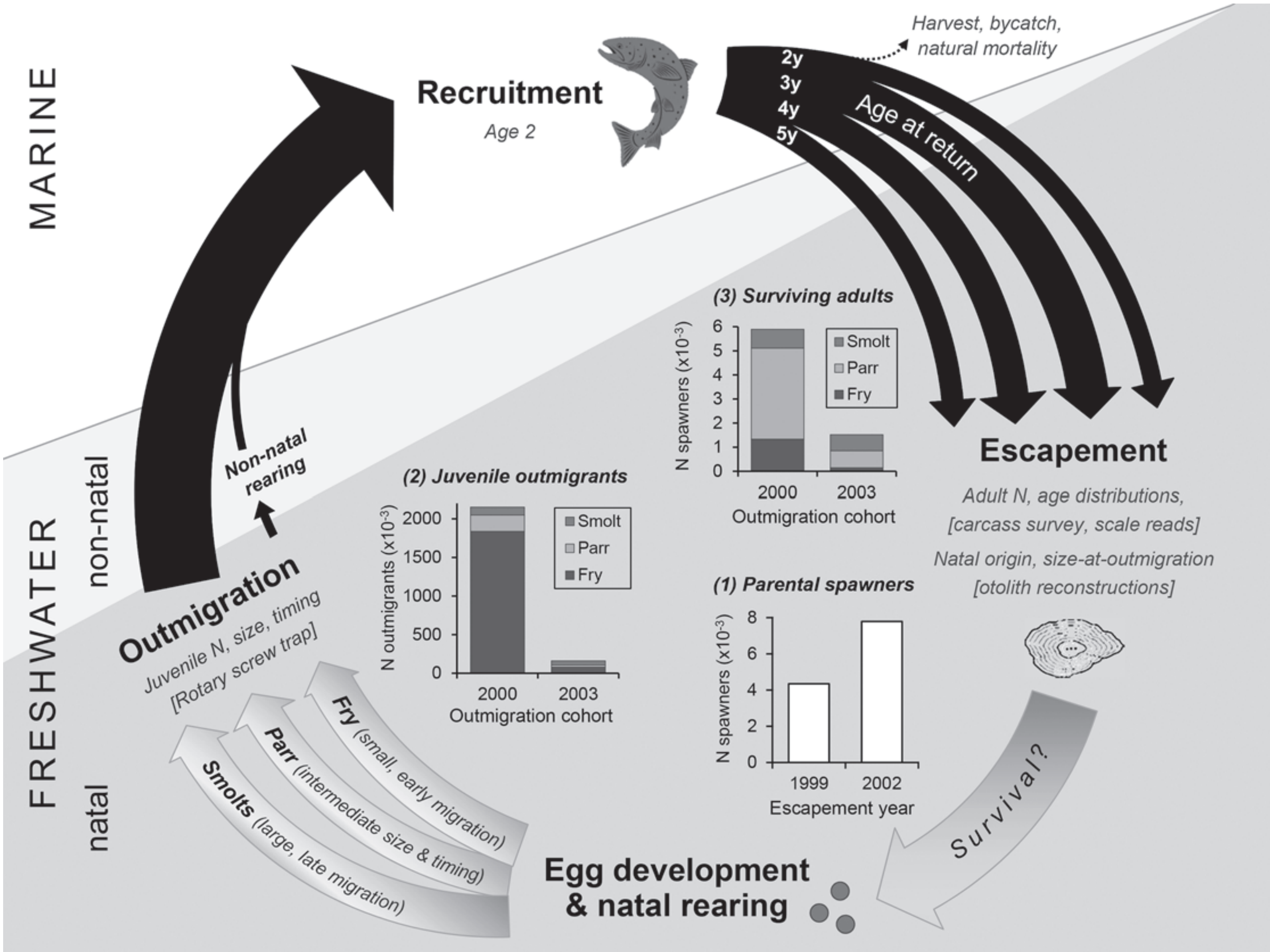


**Fig 7. Schematic to conceptualize the data sources, methods and results presented in this study.** This figure outlines the life cycle of fall-run Chinook salmon in the California Central Valley. Inset plot (1) demonstrates the abundance of parental spawners in the 1999 and 2002 escapement that contributed to the two focus years. Inset plots (2) and (3) illustrate the abundance and proportions of migratory phenotypes (fry, parr and smolts) observed in the juvenile sample (based on RST sampling) and in the adult escapement (based on otolith reconstructions), respectively. Arrow widths (not to scale) illustrate the typical proportions of 2, 3, 4 and 5 year olds observed in the adult escapement; note that age 5 fish tend to comprise <1% of the returns [50].

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numbers of parental spawners (Fig 7), we hypothesize that the truncation of migratory periods was driven by in-river mortality rather than altered migration timing or faster transitions between size classes. Juveniles tend to encounter less floodplain habitat, and increased predation rates and physiological stress in warmer, drier years [62], which likely resulted in a lower carrying capacity in the natal tributary [63] and increased density dependent mortality [64,65].

## Survival of migratory phenotypes

Although lower flows and warmer temperatures in the Stanislaus may have contributed to the lower outmigrant production observed in 2003, our results suggest that after exiting the natal river, there was no significant difference in juvenile survival. Survival rates were, if anything, marginally higher in 2003, contradicting many tagging studies which find reduced salmon survival through the freshwater delta during low flow conditions [24,66–68]. This discrepancy is likely due to differences in the sampling design and the time period represented by the different indices. Tagging studies generally release larger hatchery fish in similar sized batches during the later months of the outmigration season, when warmer conditions likely increase their vulnerability to predation [62]. Conversely, our survival estimates were based on variable numbers of fish over a larger size spectrum and broader migratory window, incorporating mortality events in all habitats downstream of the natal river, including the mainstem river, delta, estuary and ocean. However, we assume that differences in our survival indices would be driven by selective mortality events occurring during outmigration and early ocean residence. In support of this, there was no relationship between back-calculated size at outmigration and return FL ($r^2$ $<0.01$, $p>0.05$), implying that size-selective mortality did not vary by phenotype in the adult fish. However, marine distributions of adult salmon can be non-random [69], and if driven by timing at ocean entry, the migratory phenotypes could have been subjected to different ocean processes and mortality rates even as adults.

**Parr and smolt outmigrants.** Life history theory predicts selection to favor different phenotypes under different hydrologic regimes, maintaining behavioral and phenotypic diversity [70]. Yet in the current study, parr consistently exhibited the greatest contribution to the adult population and the highest survival rates. Greater representation of intermediary-sized juveniles has also been observed in some years in the ocean fisheries of Chinook [21] and Atlantic salmon [22], contradicting the expected directionality of size-selective mortality. Generally, larger or faster-growing individuals within a population are thought to have a selective advantage as a result of greater feeding opportunities, lower vulnerability to predation and greater tolerance of environmental perturbations [71]. However, the strength of size-selection in juvenile CCV Chinook salmon can vary as a function of ocean productivity [18], highlighting the importance of maintaining life history diversity in outmigration strategies. Without large-scale field experiments, it is not possible to definitively ascertain why smolts were not the most successful phenotype, however the San Joaquin basin is at the southernmost reaches of the species distribution [3] and its salmon populations are exposed to high temperatures, poor water quality, and significant water diversions [72,73]. This frequently results in river conditions that could impair growth and smoltification, and increased vulnerability to predation and disease [62], particularly at the end of the season when smolt-sized fish are most prevalent. Thus, the survival advantage of parr is likely attributable to both size and migration timing, analogous to the marine-orientated "critical size and period hypothesis" proposed by Beamish and Mahnken [74]. Furthermore, current flow practices in the San Joaquin basin include managed releases in April and May, intended to improve the survival of smolts [75]. These managed flows typically occur after most parr have left their natal tributaries, potentially selecting for this phenotype by providing downstream benefits as they migrate through (or rear in) the San Joaquin River and freshwater Delta.

**Fry outmigrants.** Little is known about the factors driving fry behavior or survival, yet the numbers that outmigrated during the wetter year (2000) were orders of magnitude higher, when they also contributed more than double the number of adult survivors (23% in 2000 *vs.* 10% in 2003). While fry consistently exhibited lower survival rates than their conspecifics (Table 4), reflecting the typical direction for size-selective mortality [71], the fact that any survived to contribute to the adult population, let alone contributing >20% of the adult returns, is a significant finding. Based on these data, their sheer abundance during high flow conditions at least partially helps to explain the increases in returns following wet outmigration conditions in the San Joaquin watershed (Fig 1). Early-migrating fry and parr may represent a significant portion of the population that can access favorable downstream rearing habitats in high flow years and survive to contribute to the adult population. Indeed, our otolith reconstructions indicated that all of the smallest (≤46mm FL) fry outmigrants in the surviving adult population (n = 4 in 2000, n = 1 in 2003) had spent several weeks rearing in the San Joaquin mainstem prior to leaving freshwater (e.g. Fig 3B). These data corroborate the extended transit times of CWT-tagged fish released in the San Joaquin basin and freshwater Delta in wetter years (averages of 16 d in 2000 vs. 6 d in 2003), although their mean size also differed (81mm vs. 87mm, respectively) [58]. Fry are observed in downstream freshwater and estuarine habitats in the CCV [20,76], and were probably more common when the Delta was a large tidal wetland [14,24,53]. This study confirms that these individuals can survive and contribute meaningfully to adult returns.

Currently there are no genetic data to support or refute a heritable component to early outmigration behavior, but it could otherwise meet the criteria of an adaptive trait, given that its expression is associated with "differential survival" and there is evidence for "a mechanism of selection" [77]. There is still some debate as to whether fry pulses during high flow events represent displacement due to reduced swimming ability or a deliberate behavior that might be considered a 'strategy' [3,14]. While catastrophic floods undoubtedly result in riverbed scouring and some fry displacement, not all individuals outmigrate during these events. Conversely, some fry migration is observed during periods with no pulse flows [78]. Given the frequency with which this phenotype is reported and the considerable rearing potential of downstream habitats, it is conceivable that fry dispersal is a heritable strategy, representing a 'migratory contingent' within the population [79,80]. Indeed, their consistent contribution to the adult population (observed here and in [21]) conclusively demonstrates that fry migration can be successful. If, however, early outmigration is purely an expression of phenotypic plasticity, it is likely that multiple factors are involved in stimulating the behavioral switch, including hydrology, intraspecific interactions [3] and density dependent mechanisms [65,81–83]. Irrespective of the underlying mechanisms, quantifying the relative success of migratory phenotypes across a broader range of hydrologic regimes is fundamental to understanding how environmental conditions and water operations contribute to salmon population dynamics.

## Otolith strontium isotopes and sources of uncertainty

One of the most significant advances of the current study was the pairing of RST sampling with otolith reconstructions. This process enabled us to compare fish size at a specific time and location across life stages, and provided a unique method for generating survival estimates into adulthood. CWT studies and acoustic telemetry have provided valuable insights into survival through particular stretches of the CCV [25,75], but tend to focus on larger fish and provide no information about the long-term success of particular traits. In addition, acoustic tags have focused on understanding flow-survival relationships for smolts, which are physiologically ready for seaward migration and likely use the mainstem rivers, delta, and estuary differently than fry or parr, which may exhibit prolonged rearing. Otolith $^{87}Sr/^{86}Sr$ ratios are an ideal natural tag as they vary among many of the rivers in the CCV, resulting in high classification scores for natal assignments (S1 and S2 Tables) [30,32,84]. Sr isotopes also represent a unique and sensitive marker for reconstructing downstream movements and non-natal rearing patterns in the freshwater system (e.g. Fig 3B). While seasonal variation in $^{87}Sr/^{86}Sr$ values have been reported in certain systems [85] and interannual variations were detected for some sites (S1 Table), these were minor compared with most of the geographic differences, with the majority of sites exhibiting classification scores >70% even when pooled across years (S2 Table). Importantly, the Stanislaus exhibited a stable and distinct isotopic signature; with 96% of juveniles correctly classified using jack-knife resampling (S2 Table). Identification of natal origin represents a significant advantage of using otolith Sr isotopes over element concentrations. This was critical for pairing RST- and otolith-derived datasets and providing confidence that our size reconstructions were not skewed by hatchery smolts.

A high occurrence of straying of fall-run Chinook salmon occurs between the San Joaquin and Sacramento basins [86–88], potentially due to the relative outflows during the return migration as well as hatchery release practices [89]. However the extent to which hatchery fish are functioning to sustain the San Joaquin salmon populations has gone largely undetected until recently [86,87]. In the current study, hatchery strays represented 18–51% of the unmarked fish, reducing the number of samples available to inform outmigration strategies of wild fish and increasing analytical costs. However, the removal of strays was vital to ensure that FL reconstructions were only performed on individuals that had experienced the same conditions as the RST-sampled juveniles. The implementation of 100% visual identification of hatchery fish [90] would increase the feasibility and efficiency of future life history diversity studies in this system.

We attempted to reduce and account for sources of uncertainty, but the low number of focus years and sample sizes, and the potential for error propagation limit the strength of our inferences. With greater representation of 2 and 4 year olds in our adult sample, a more sophisticated analysis using age-specific natal assignments could have been carried out. While no yearlings were detected in the surviving adults, their rarity in the RST-sampled outmigrant population indicate that larger sample sizes would be required to ascertain the success of this strategy with any confidence. Similarly, our approach for assigning natal origin based on otolith chemistry following yolk sac absorption means that individuals that outmigrated as yolk sac fry could have been misclassified as strays. However, yolk sac fry are rarely observed in the outmigrant population (0.1% of the 2001–2011 RST catch at Caswell), so this was deemed unlikely to significantly influence our results.

## Management implications

The complex biophysical properties of freshwater systems have led to the evolution of dynamic habitat mosaics [91] and diverse salmon life histories and distributions. The observed life history diversity likely provides within-population buffering, an as yet understudied component of the portfolio effect [5,6]. These data add to the mounting evidence that managing and conserving life history diversity is necessary to support resilient salmon populations, particularly in the face of climate change and projected human population growth [9,10]. Diversity in phenotypic traits is thought to produce a more stable population complex by decoupling population dynamics and buffering variance [6]. However, population resilience does not necessarily immediately translate into population abundance. In a highly regulated system such as the CCV, there is debate as to whether environmental unpredictability dictates a need to manage salmon stocks for diversity and resilience, or whether our understanding of (and control over) the relevant processes is sufficient to manage purely for abundance. Such topics are complicated by socio-economic and ecological trade-offs, however, by improving our understanding of how juvenile life history strategies are expressed and respond to different flow regimes, we may be able to optimize both. Currently, the portfolio effect for CCV salmon stocks is weak and deteriorating [92] and San Joaquin populations face serious future challenges, given predicted 25–40% reductions in snowmelt by 2050 [93]. CCV salmon exhibit diverse outmigration timings that have evolved over geological time scales in response to the unpredictable hydroclimatic conditions characteristic of the region [11]. Yet modern-day water and hatchery management practices tend to constrain outmigration timing. For example, alterations to the natural hydrograph, such as suppression of winter pulse flows, likely to truncate migratory windows, reduce the variability in outmigration timing, and significantly suppress the fry life history type. Such simplification and truncation of life history diversity could significantly reduce the resiliency of the stock-complex and exacerbate the risk of a temporal mismatch with favorable ocean conditions [94]. Indeed, the only clear deviation from the flow-driven relationship in Fig 1 was attributed to juveniles entering the ocean during a suboptimal period and resulted in the closure of the fishery in 2008. Perhaps with more diverse, resilient stocks, the consequences would have been less extreme. Largely without direct empirical support, hatchery and flow management practices tend to focus on optimizing the success of the largest, smolt-sized juveniles that are assumed to contribute the most to adult returns [14,21,24]. Here, we found that all phenotypes contributed to the reproductive adult population, with smolts comprising less than half of the surviving adults following two contrasting flow regimes. Without otolith reconstruction data for additional years, species, and watersheds, the broader inferences one can make regarding the influence of hydroclimatic regime on juvenile salmon survival are limited. However our data and a previous study [21] indicate that assumptions regarding size-selective mortality and smolt-focused management schemes need to be tested on a species, system and hydroclimatic basis.

This study has demonstrated the value of a combined RST and otolith geochemistry study to reconstruct patterns in the expression and survival of salmon migratory phenotypes. The results show that under paired years of low and high flow conditions, parr outmigrants comprised a significant portion of the returning adult population, while fry made smaller, but substantial contributions. Future efforts should focus on reducing the error in juvenile production estimates in order to produce more meaningful survival estimates, and understanding the demographic role that fry and parr play in salmon population dynamics. Management actions that promoted the expression and survival of fry in natal and downstream rearing habitats could result in demographic and genetic benefits to the population. Recognition of the importance of hydrodynamic regime and life history diversity should provide guidance to system managers when reassessing goals and future management strategies [5,95]. It is also important that management actions consider carefully-designed monitoring programs to detect changes in stock abundance and life history diversity at appropriate temporal and spatial scales.

## Supporting Information

**S1 Text. Testing the performance of the Sr isoscape.**
(DOCX)

**S1 Fig. Time-resolved plot of a single spot ablation at a habitat transition.** This plot (macro developed by C. Donohoe) shows how the isotopic composition of the otolith can change with sample depth (equivalent to analysis time). Typically we would use ~20 seconds of data per spot (A), but in cases like this we would use only the surface material (B) to avoid signal attenuation and to ensure consistency between otolith $^{87}Sr/^{86}Sr$, microstructure and distance analyses.
(DOCX)

**S2 Fig. Median $^{87}Sr/^{86}Sr$ natal values for major sources of Chinook salmon in the California Central Valley.** Values are based on juvenile otoliths and/or water samples. The mainstem San Joaquin River (SJR) isotopic signature is displayed, but was not included as a potential natal source. Boxes represent 25-75$^{th}$ percentiles, whiskers represent 5-95$^{th}$ percentiles. Site codes are defined in S1 Table. Isotopic signatures not significantly different ($p > 0.05$, Tukey's test) are joined by brackets. Mean ocean $^{87}Sr/^{86}Sr$ is indicated by a dashed line.
(TIF)

**S1 Table. $^{87}Sr/^{86}Sr$ isoscape used to train the LDFA and assign unknown adult otoliths to natal location.** Data based on known-origin otolith (O) and/or water (W) samples. Interannual differences were tested by ANOVA or Welch's Test when data exhibited unequal variance. Differences among sites are shown in S2 Fig Underlined years represent water samples collected Oct 1997 to Apr 1998 that were pooled into a single water year (1998).
(DOCX)

**S2 Table. Natal assignments and correct classification scores of known-origin samples.** Assignments based on $^{87}Sr/^{86}Sr$ values and jackknife resampling. Site codes are defined in S1 Table. Equal prior probabilities were given to all sites and sites are ordered by increasing mean $^{87}Sr/^{86}Sr$ value. The training dataset (n = 290) comprised both juvenile otoliths and water samples. Counts are for actual rows by predicted columns. Samples from the Stanislaus River (STA) are highlighted in bold, while groups of sites with statistically overlapping $^{87}Sr/^{86}Sr$ signatures ($p>0.05$, Tukey's test) are shown in italics and S2 Fig
(DOCX)

**S3 Table. Reference samples used to calibrate the fork length back-calculation model.**
(DOCX)

**S4 Table. The number of adult spawners produced by the 2000 and 2003 outmigration cohorts ("natural escapement")**
(DOCX)

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## Author Contributions

Conceived and designed the experiments: RCJ JDW. Performed the experiments: AMS RCJ TH JJG PKW GEW. Analyzed the data: AMS RCJ TMH AEH CM. Contributed reagents/materials/analysis tools: TH. Wrote the paper: AMS RCJ.

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**State Water Resources Control Board**
**California Environmental Protection Agency**

# Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem

Prepared Pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009

CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

**August 3, 2010**

STATE WATER RESOURCES
CONTROL BOARD
*P.O. Box 100*
*Sacramento, CA 95812-0100*
*(916) 341-5250*
*http://www.waterboards.ca.gov*

**State Water Resources Control Board**
**California Environmental Protection Agency**

# Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem

Prepared Pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009


Report prepared by:

Phil Crader, Senior Environmental Scientist
Les Grober, Environmental Program Manager
Adam Ballard, Senior Environmental Scientist
Chris Foe, Staff Environmental Scientist
Diane Riddle, Staff Environmental Scientist
David La Brie, Engineering Associate
Mark Gowdy, Water Resources Control Engineer
Erin Mahaney, Senior Staff Counsel



With assistance from:

Barbara Leidigh, Senior Staff Counsel
Lucas Sharkey, Water Resources Control Engineer
Jean McCue, Water Resources Control Engineer
Dramy Saechao, Office Technician
Stephen Craig, Associate Information Systems Analyst
Duran Fiack, Student Assistant

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- The California Department of Fish and Game for working collaboratively with the State Water Board on development of species life history requirements and for reviewing portions of the draft report
- The United States Fish and Wildflie Service and National Marine Fisheries Service for reviewing portions of the draft report
- All the participants of the proceeding for providing information and serving on panels to answer questions during the proceeding

The State Water Board, however, is responsible for any errors and for all interpretations of the information in this report.

**STATE WATER RESOURCES CONTROL BOARD**
**RESOLUTION NO. 2010-0039**

DETERMINING DELTA FLOW CRITERIA PURSUANT TO THE DELTA REFORM ACT

WHEREAS:

1. Water Code section 85086, contained in the Sacramento-San Joaquin Delta Reform Act of 2009 (Stats. 2009 (7th Ex. Sess.) ch. 5) (commencing with Wat. Code, § 85000), requires the State Water Resources Control Board (State Water Board) to develop, within nine months of enactment of the statute, new flow criteria for the Sacramento-San Joaquin Delta (Delta) ecosystem that are necessary to protect public trust resources. The purpose of the flow criteria is to inform planning decisions for the Delta Plan and the Bay Delta Conservation Plan. The statute specifies that the flow criteria shall not predetermine any issue that may arise in the State Water Board's subsequent consideration of a permit.

2. In accordance with Water Code section 85086, subdivision (c)(1), the State Water Board conducted a public process in the form of an informational proceeding to collect information used to develop the flow criteria. The State Water Board conducted the informational proceeding on March 22-24, 2010, and considered the information submitted in connection with that proceeding in developing the flow criteria.

3. The State Water Board has prepared a report determining flow criteria for the Delta ecosystem necessary to protect public trust resources. In developing the flow criteria, the State Water Board reviewed existing water quality objectives and used the best available scientific information. The flow criteria include the volume, timing, and quality of flow necessary under different hydrologic conditions.

THEREFORE BE IT RESOLVED THAT:

**1.** In accordance with the Delta Reform Act, the State Water Board approves the report determining new flow criteria for the Delta ecosystem that are necessary to protect public trust resources.

2. The Executive Director is directed to submit the Delta flow criteria report to the Delta Stewardship Council for its information within 30 days of the adoption of this resolution.

**CERTIFICATION**

The undersigned Clerk to the Board does hereby certify that the foregoing is a full, true, and correct copy of a resolution duly and regularly adopted at a meeting of the State Water Board held on August 3, 2010.

AYE: Chairman Charles R. Hoppin
Vice Chair Frances Spivy-Weber
Board Member Arthur G. Baggett, Jr.
Board Member Tam M. Doduc
Board Member Walter G. Pettit

NAY: None

ABSENT: None

ABSTAIN: None

Jeanine Townsend

Jeanine Townsend
Clerk to the Board

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# Acronyms and Abbreviations

| | |
|---|---|
| AFRP | Anadromous Fish Restoration Program |
| AR | American Rivers |
| Bay-Delta | San Francisco Bay/Sacramento-San Joaquin Delta Estuary including Suisun Marsh |
| Bay-Delta Plan | Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary |
| BDCP | Bay Delta Conservation Program |
| CCWD | Contra Costa Water District |
| Central Valley Regional Board | Central Valley Regional Water Quality Control Board |
| CEQA | California Environmental Quality Act |
| CESA | California Endangered Species Act |
| cfs | cubic feet per second |
| Council | Delta Stewardship Council |
| CSPA | California Sportfishing Protection Alliance |
| CVP | Central Valley Project |
| CWIN | California Water Impact Network |
| DEFG | Delta Environmental Flows Group |
| Delta | Confluence of the Sacramento River and San Joaquin River (as defined in Water Code section 12220) |
| Delta Plan | Delta Stewardship Council comprehensive, long-term management plan for the Delta |
| Delta Reform Act | Sacramento-San Joaquin Delta Reform Act of 2009 |
| DFG | California Department of Fish and Game |
| DO | dissolved oxygen |
| DOI | United States Department of the Interior |
| DSM2 | Delta Simulation Model |
| DWR | California Department of Water Resources |
| DWSC | Stockton Deep Water Ship Channel |
| E/I | Export/Inflow ratio |
| EC | Electrical Conductivity |
| EDF | Environmental Defense Fund |
| ESA | Endangered Species Act |
| FERC | Federal Energy Regulatory Commission |
| FMWG | Fisheries Management Work Group |
| FMWT | Fall mid-water trawl |
| IEP | Interagency Ecological Program |
| LSZ | Low Salinity Zone |
| MAF | million acre-feet |
| mg/L | milligrams per liter |
| mmhos/cm | millimhos per centimeter |
| NAS | National Academy of Sciences |
| NCCPA | State Natural Community Conservation Planning Act |
| NDOI | Net Delta Outflow Index |
| NEPA | National Environmental Policy Act |
| NHI | Natural Heritage Institute |

| | |
|---|---|
| NMFS | National Marine Fisheries Service |
| NRDC | Natural Resources Defense Council |
| OCAP | Long-Term Operations Criteria and Plan for Coordination of the Central Valley Project and the State Water Project |
| OMR | Old and Middle River |
| Opinion | Biological Opinion |
| PCFFA | Pacific Coast Federation of Fishermen's Associations |
| POD | Pelagic Organism Decline |
| ppt | parts per thousand |
| psu | practical salinity unit |
| PTM | Particle Tracking Model |
| RMP | Regional Monitoring Program |
| RPA | Reasonable and Prudent Alternatives |
| San Francisco Regional Board | San Francisco Bay Regional Water Quality Control Board |
| SB 1 | Senate Bill No. 1 of the 2009-2010 Seventh Extraordinary Session (Stats. 2009 (7th Ex. Sess.) ch. 5, § 39) |
| SFWC | State and Federal Water Contractors |
| SJRA | San Joaquin River Agreement |
| SJRGA | San Joaquin River Group Authority |
| SJRRP | San Joaquin River Restoration Program |
| SRWTP | Sacramento Regional Wastewater Treatment Plant |
| State Water Board | State Water Resources Control Board |
| SWG | Smelt Working Group |
| SWP | State Water Project |
| TBI | The Bay Institute |
| TNC | The Nature Conservancy |
| USACE | U.S. Army Corps of Engineers |
| USBR | United States Bureau of Reclamation |
| USEPA | United States Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Service |
| VAMP | Vernalis Adaptive Management Plan |
| WOMT | Water Operations Management Team |

# 1. Executive Summary

The Sacramento-San Joaquin Delta (Delta) is a critically important natural resource for California and the nation. It is both the hub of California's water supply system and the most valuable estuary and wetlands on the western coast of the Americas. The Delta is in ecological crisis, resulting in high levels of conflict that affect the sustainability of existing water policy in California. Several species of fish have been listed as protected species under the California Endangered Species Act (CESA) and under the federal Endangered Species Act (ESA). These two laws and other regulatory constraints have restricted water diversions from the Delta in an effort to prevent further harm to the protected species.

In November 2009, California enacted a comprehensive package of four policy bills and a bond measure intended to meet California's growing water challenges by adopting a policy of sustainable water supply management to ensure a reliable water supply for the State and to restore the Delta and other ecologically sensitive areas. One of these bills, Senate Bill No. 1 (SB 1) (Stats. 2009 ($7^{th}$ Ex. Sess.) ch 5, § 39) contains the Sacramento-San Joaquin Delta Reform Act of 2009 (Delta Reform Act), Water Code section 85000 et seq. The Delta Reform Act establishes a Delta Stewardship Council (Council), tasked with developing a comprehensive, long-term management plan for the Delta, known as the Delta Plan, and providing direction to multiple state and local agencies that take actions related to the Delta. The comprehensive bill package also sets water conservation policy, requires increased groundwater monitoring, and provides for increased enforcement against illegal water diversions.

The Delta Reform Act requires the State Water Board to use a public process to develop new flow criteria for the Delta ecosystem. During this process, participants cautioned the the State Water Board on the limitations of any flow criteria (Fleenor *et al*., 2010):

> "How much water do fish need?" has been a common refrain in Delta water management for many years… it is highly unlikely that any fixed or predetermined prescription will be a "silver bullet". The performance of native and desirable fish populations in the Delta requires much more than fresh water flows. Fish need enough water of appropriate quality over the temporal and spatial extent of habitats to which they adapted their life history strategies. Typically, this requires habitat having a particular range of physical characteristics, appropriate variability, adequate food supply and a diminished set of invasive species. While folks ask "How much water do fish need?" they might well also ask, "How much habitat of different types and locations, suitable water quality, improved food supply and fewer invasive species that is maintained by better governance institutions, competent implementation and directed research do fish need?" The answers to these questions are interdependent. We cannot know all of this now, perhaps ever, but we do know things that should help us move in a better direction, especially the urgency for being proactive. We do know that current policies have been disastrous for desirable fish. It took over a century to change the Delta's ecosystem to a less desirable state; it will take many decades to put it back together again with a different physical, biological, economic, and institutional environment."

The State Water Board concurs with this cautionary note. The State Water Board further cautions that flow and physical habitat interact in many ways, but they are not interchangeable.

The best available science suggests that current flows are insufficient to protect public trust resources.

## 1.1 Legislative Directive and State Water Board Approach

**Legislative Directive**

Water Code section 85086 (See Appendix B), contained in the Delta Reform Act, was enacted as part of the comprehensive package of water legislation adopted in November 2009. Water Code section 85086 requires the State Water Resources Control Board (State Water Board) to use the best available scientific information gathered as part of a public process conducted as an informational proceeding to develop new flow criteria for the Delta ecosystem to protect public trust resources. The purpose of the flow criteria is to inform planning decisions for the Delta Plan and the BDCP. The Legislature intended to establish an accelerated process to determine the instream flow needs of the Delta in order to facilitate the planning decisions required to meet the objectives of the Delta Plan. Accordingly, Water Code section 85086 requires the State Water Board to develop the flow criteria within nine months of enactment of the statute and to submit its flow criteria determinations to the Council within 30 days of their development.

**State Water Board Approach**

In determining the extent of protection to be afforded public trust resources through the development of the flow criteria, the State Water Board considered the broad goals of the planning efforts the criteria are intended to inform, including restoring and promoting viable, self-sustaining populations of aquatic species. Given the accelerated time frame in which to develop the criteria, the State Water Board's approach to developing criteria was limited to review of instream needs in the Delta ecosystem, specifically fish species and Delta outflows, while also receiving information on hydrodynamics and major tributary inflows. The State Water Board's flow criteria determinations are accordingly limited to protection of aquatic resources in the Delta.

**Limitations of State Water Board Approach**

When setting flow objectives with regulatory effect, the State Water Board reviews and considers all the effects of the flow objectives through a broad inquiry into all public trust and public interest concerns. For example, the State Water Board would consider other public trust resources potentially affected by Delta outflow requirements and impose measures for the protection of those resources, such as requiring sufficient water for cold water pool in reservoirs to maintain temperatures in Delta tributaries. The State Water Board would also consider a broad range of public interest matters, including economics, power production, human health and welfare requirements, and the effects of flow measures on non-aquatic resources (such as habitat for terrestrial species). The limited process adopted for this proceeding does not include this comprehensive review.

**The State Water Board's Public Trust Responsibilities in this Proceeding**

Under the public trust doctrine, the State Water Board must take the public trust into account in the planning and allocation of water resources, and to protect public trust uses whenever feasible. (*National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419, 446.) Public trust values include navigation, commerce, fisheries, recreation, scenic, and ecological values. "[I]n determining whether it is 'feasible' to protect public trust values like fish and wildlife in a particular instance, the [State Water] Board must determine whether protection of those values, or what level of protection, is 'consistent with the public interest.'" (*State Water Resources*

*Control Bd. Cases* (2006) 136 Cal.App.4th 674, 778.) The State Water Board does not make any determination regarding the feasibility of the public trust criteria and consistency with the public interest in this report.

In this forum, the State Water Board has not considered the allocation of water resources, the application of the public trust to a particular water diversion or use, water supply impacts, or any balancing between potentially competing public trust resources (such as potential adverse effects of increased Delta outflow on the maintenance of coldwater resources for salmonids in upstream areas). Any such application of the State Water Board's public trust responsibilities, including any balancing of public trust values and water rights, would be conducted through an adjudicative or regulatory proceeding. Instead, the State Water Board's focus here is solely on identifying public trust resources in the Delta ecosystem and determining the flow criteria, as directed by Water Code section 85086.

**Future Use of This Report**

None of the determinations in this report have regulatory or adjudicatory effect. Any process with regulatory or adjudicative effect must take place through the State Water Board's water quality control planning, water rights processes, or public trust proceedings in conformance with applicable law. In the State Water Board's development of Delta flow objectives with regulatory effect, it must ensure the reasonable protection of beneficial uses, which may entail balancing of competing beneficial uses of water, including municipal and industrial uses, agricultural uses, and other environmental uses. The State Water Board's evaluation will include an analysis of the effect of any changed flow objectives on the environment in the watersheds in which Delta flows originate, the Delta, and the areas in which Delta water is used. It will also include an analysis of the economic impacts that result from changed flow objectives.

Nothing in either the Delta Reform Act or in this report amends or otherwise affects the water rights of any person. In carrying out its water right responsibilities, the State Water Board may impose any conditions that in its judgment will best develop, conserve, and utilize in the public interest the water to be appropriated. In making this determination, the State Water Board considers the relative benefit to be derived from all beneficial uses of the water concerned and balances competing interests.

The State Water Board has continuing authority over water right permits and licenses it issues. In the exercise of that authority and duty, the State Water Board may, if appropriate, amend terms and conditions of water right permits and licenses to impose further limitations on the diversion and use of water by the water right holder to protect public trust uses or to meet water quality and flow objectives in Water Quality Control Plans it has adopted. The State Water Board must provide notice to the water permit or license holder and an opportunity for hearing before it may amend a water right permit or license.

If the DWR and/or the USBR in the future request the State Water Board to amend the water right permits for the State Water Project (SWP) and/or the Central Valley Project (CVP) to move the authorized points of diversion for the projects from the southern Delta to the Sacramento River, Water Code section 85086 directs the State Water Board to include in any order approving a change in the point of the diversion of the projects appropriate Delta flow criteria. At that time, the State Water Board will determine appropriate permit terms and conditions. That decision will be informed by the analysis in this report, but will also take many other factors into consideration, including any newly developed scientific information, habitat conditions at the time, and other policies of the State, including the relative benefit to be derived from all beneficial uses of water. The flow criteria in this report are not pre-decisional in regard to any State Water Board action. (See e.g., Wat. Code, § 85086, subd. (c)(1).)

The information in this report illustrates to the State Water Board the need for an integrated approach to management of the Delta. Best available science supports that it is important to directly address the negative effects of other stressors, including habitat, water quality, and invasive species, that contribute to higher demands for water to protect public trust resources. The flow criteria highlight the continued need for the BDCP to develop an integrated set of solutions and to implement non flow measures to protect public trust resources.

## *1.2 Summary Determinations*

This report contains the State Water Board's determinations as to the flows that protect public trust resources in the Delta, under the narrow circumstances analyzed in this report. As required, the report includes the volume, timing, and quality of flow for protection of public trust resources under different hydrologic conditions. The flow criteria represent a technical assessment only of flow and operational requirements that provide fishery protection under existing conditions. The flow criteria contained in this report do not represent flows that might be protective under other conditions. The State Water Board recognizes that changes in existing conditions may alter the need for flow. Changes in existing conditions that may affect flow needs include, but are not limited to, reduced reverse flows in Delta channels, increased tidal habitat, improved water quality, reduced competition from invasive species, changes in the point of diversion of the SWP and CVP, and climate change.

**Flow Criteria and Conclusions**

The numeric criteria determinations in this report must be considered in the following context:

- The flow criteria in this report do not consider any balancing of public trust resource protection with public interest needs for water.
- The State Water Board does not intend that the criteria should supersede requirements for health and safety such as the need to manage water for flood control.
- There is sufficient scientific information to support the need for increased flows to protect public trust resources; while there is uncertainty regarding specific numeric criteria, scientific certainty is not the standard for agency decision making.

The State Water Board has considered the testimony presented during the Board's informational proceeding to develop flow criteria and to support the following summary conclusions. Several of these summary conclusions rely in whole or in part on conclusions and recommendations made to the State Water Board by the Delta Environmental Flows Group (DEFG)[1] and the University of California at Davis Delta Solutions Group[2].

1. The effects of non-flow changes in the Delta ecosystem, such as nutrient composition, channelization, habitat, invasive species, and water quality, need to be addressed and integrated with flow measures.

[1] The Delta Environmental Flows Group of experts consists of William Bennett, Jon Burau, Cliff Dahm, Chris Enright, Fred Feyrer, William Fleenor, Bruce Herbold, Wim Kimmerer, Jay Lund, Peter Moyle, and Matthew Nobriga.

[2] The Delta Solutions Group consists of William Bennett, William Fleenor, Jay Lund, and Peter Moyle.

2. Recent Delta flows are insufficient to support native Delta fishes for today's habitats.[3] Flow modification is one of the immediate actions available although the links between flows and fish response are often indirect and are not fully resolved. Flow and physical habitat interact in many ways, but they are not interchangeable.

3. In order to preserve the attributes of a natural variable system to which native fish species are adapted, many of the criteria developed by the State Water Board are crafted as percentages of natural or unimpaired flows. These criteria include:

   - 75% of unimpaired Delta outflow from January through June;
   - 75% of unimpaired Sacramento River inflow from November through June; and
   - 60% of unimpaired San Joaquin River inflow from February through June.

   It is not the State Water Board's intent that these criteria be interpreted as precise flow requirements for fish under current conditions, but rather they reflect the general timing and magnitude of flows under the narrow circumstances analyzed in this report. In comparison, historic flows over the last 18 to 22 years have been:

   - approximately 30% in drier years to almost 100% of unimpaired flows in wetter years for Delta outflows;
   - about 50% on average from April through June for Sacramento River inflows; and
   - approximately 20% in drier years to almost 50% in wetter years for San Joaquin River inflows.

4. Other criteria include: increased fall Delta outflow in wet and above normal years; fall pulse flows on the Sacramento and San Joaquin Rivers; and flow criteria in the Delta to help protect fish from mortality in the central and southern Delta resulting from operations of the State and federal water export facilities.

5. The report also includes determinations regarding variability and the natural hydrograph, floodplain activation and other habitat improvements, water quality and contaminants, cold water pool management, and adaptive management:
   - Criteria should reflect the frequency, duration, timing, and rate of change of flows, and not just volumes or magnitudes. Accordingly, whenever possible, the criteria specified above are expressed as a percentage of the unimpaired hydrograph.

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[3] This statement should not be construed as a critique of the basis for existing regulatory requirements included in the 2006 Bay-Delta Plan and biological opinions. Those requirements were developed pursuant to specific statutory requirements and considerations that differ from this proceeding. Particularly when developing water quality objectives, the State Water Board must consider many different factors including what constitutes reasonable protection of the beneficial use and economic considerations. In addition, the biological opinions for the SWP and CVP Operations Criteria and Plan were developed to prevent jeopardy to specific fish species listed pursuant to the federal Endangered Species Act; in contrast, the flow criteria developed in this proceeding are intended to halt population decline and increase populations of certain species.

- Inflows should generally be provided from tributaries to the Delta watershed in proportion to their contribution to unimpaired flow unless otherwise indicated.
- Studies and demonstration projects for, and implementation of, floodplain restoration, improved connectivity and passage, and other habitat improvements should proceed to provide additional protection of public trust uses and potentially allow for the reduction of flows otherwise needed to protect public trust resources in the Delta.
- The Central Valley and San Francisco Regional Water Quality Control Boards should continue developing Total Maximum Daily Loads (TMDLs) for all listed pollutants and adopting programs to implement control actions.
- The Central Valley Regional Water Quality Control Board should require additional studies and incorporate discharge limits and other controls into permits, as appropriate, for the control of nutrients and ammonia.
- Temperature and water supply modeling and analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals.
- A strong science program and a flexible management regime are critical to improving flow criteria. The State Water Board should work with the Council, the Delta Science Program, BDCP, the Interagency Ecological Program (IEP), and others to develop the framework for adaptive management that could be relied upon for the management and regulation of Delta flows.
- The numeric criteria included in this report are all criteria that are only appropriate for the current physical system and climate; as other factors change the flow needs advanced in this report will also change. As physical changes occur to the environment and our understanding of species needs improves, the long-term flow needs will also change. Actual flows should be informed by adaptive management.
- Only the underlying principles for the numeric criteria and other measures are advanced as long term criteria.

6. Past changes in the Delta may influence migratory cues for some fishes. These cues are further scrambled by a reverse salinity gradient in the south Delta. It is important to establish seaward gradients and create more slough networks with natural channel geometry. Achieving a variable more complex estuary requires establishing seasonal gradients in salinity and other water quality variables and diverse habitats throughout the estuary. These goals in turn encourage policies which establish internal Delta flows that create a tidally-mixed upstream- downstream gradient (without cross-Delta flows) in water quality. Continued through-Delta conveyance is likely to continue the need for in-Delta flow requirements and restrictions to protect fish within the Delta.

7. Restoring environmental variability in the Delta is fundamentally inconsistent with continuing to move large volumes of water through the Delta for export. The drinking and agricultural water quality requirements of through-Delta exports, and perhaps even some current in-Delta uses, are at odds with the water quality and variability needs of desirable Delta species.

8. The Delta ecosystem is likely to dramatically shift within 50 years due to large scale levee collapse. Overall, these changes are likely to promote a more variable, heterogeneous estuary. This changed environment is likely to be better for desirable estuarine species; at least it is unlikely to be worse.

9. Positive changes in the Delta ecosystem resulting from improved flow or flow patterns will benefit humans as well as fish and wildlife.

10. In order to prevent further channelization of riparian corridors and infill of wetland habitats, the Delta Stewardship Council should consider developing a plan to coordinate land use policy within the Delta between the city, county, State, and federal governments.

Ecosystems are complex; there are many factors that affect the quality of the habitat that they provide. These factors combine in ways that can amplify the effect of the factors on aquatic resources. The habitat value of the Delta ecosystem for favorable species can be improved by habitat restoration, contaminant and nutrient reduction, changes in diversions, control of invasive species, and island flooding. Each of these non-flow factors has the potential to interact with flow to affect available aquatic habitat in Delta channels.

The State Water Board supports the most efficient use of water that can reasonably be made. The flow improvements that the State Water Board identifies in this report as being necessary to protect public trust resources illustrate the importance of addressing the negative effects of these other stressors that contribute to higher than necessary demands for water to provide resource protection. Future habitat improvements or changes in nutrients and contaminants, for example, may change the response of fishes to flow. Addressing other stressors directly will be necessary to assure protection of public trust resources and could change the demands for water to provide resource protection in the future. Uncertainty regarding the effects of habitat improvement and other stressors on flow demands for resource protection highlights the need for continued study and adaptive management to respond to changing conditions.

The flow criteria identified in this report highlight the need for the BDCP to develop an integrated set of solutions, to address ecosystem flow needs, including flow and non-flow measures. Although flow modification is an action that can be implemented in a relatively short time in order to improve the survival of desirable species and protect public trust resources, public trust resource protection cannot be achieved solely through flows – habitat restoration also is needed. One cannot substitute for the other; both flow improvements and habitat restoration are essential to protecting public trust resources.

## *1.3 Background and Next Steps*

**Informational Proceeding**

The State Water Board held an informational proceeding on March 22, 23, and 24, 2010, to receive scientific information from technical experts on the Delta outflows needed to protect public trust resources. The State Water Board also received information at the proceeding on flow criteria for inflow to the Delta from the Sacramento and San Joaquin rivers and Delta hydrodynamics. The State Water Board did not solicit information on the need for water for other beneficial uses, including the amount of water needed for human health and safety, during the informational proceeding. Nor did the State Water Board consider other policy considerations, such as the state goal of providing a decent home and suitable living environment for every Californian.

**Analytical Methods**

The State Water Board received a wide range of recommendations for the volume, quantity and timing of flow necessary to protect public trust resources. Recommendations were also received on non-flow related measures.  State Water Board determinations of flow criteria rely upon four types of information:

- Unimpaired flows
- Historical impaired inflows that supported more desirable ecological conditions
- Statistical relationships between flow and native species abundance
- Ecological functions-based analysis for desirable species and ecosystem attributes

The State Water Board emphasizes, however, information based on ecological functions, followed by information on statistical relationships between flow and native species abundance.

In all cases, the flow criteria contained in this report are those supported by the best available scientific information submitted into the record for this proceeding.  The conceptual bases for all of the criteria in this report are supported by scientific information on function-based species or ecosystem needs.  In other words, there is sufficiently strong scientific evidence to support the need for flows necessary to support particular functions.  This does not necessarily mean that there is scientific evidence to support *specific* numeric criteria.  Criteria are therefore divided into two categories: Category "A" criteria have more and better scientific information, with less uncertainty, to support specific numeric criteria than do Category "B" criteria.  The State Water Board followed the following steps to develop flow criteria and other measures:

1. Establish general goals and objectives for protection of public trust resources in the Delta
2. Identify species to include based on ecological, recreational, or commercial importance.
3. Review and summarize species life history requirements
4. Summarize numeric and other criteria for each of: Delta outflow, Sacramento River inflow, San Joaquin River inflow, and Hydrodynamics, including Old and Middle River flows
5. Review other flow-related and non-flow measures that should be considered
6. Provide summary determinations for flow criteria and other measures

In developing its flow criteria, the State Water Board reviewed the life history requirements of the following pelagic and anadromous species:

- Chinook Salmon (various runs)
- American Shad.
- Longfin Smelt
- Delta Smelt
- Sacramento Splittail
- Starry Flounder
- Bay Shrimp
- Zooplankton

The flow criteria needed to protect public trust resources are more than just the sum of each species-specific flow need.  The State Water Board also considered the following issues to make its flow criteria determinations:

- Variability, flow paths, and the natural hydrograph
- Floodplain activation and other habitat improvements

- Water quality and contaminants
- Cold water pool management
- Adaptive management

The Board also made other specific determinations for other measures based on review of these issues.

**Regulatory Authority of the State Water Board**

The State Water Board was established in 1967 as the State agency with jurisdiction to administer California's water resources. The State Water Board is responsible for water allocation as well as for water quality planning and water pollution control. In carrying out its water quality planning functions under both State and federal law, the State Water Board formulates and adopts state policy for water quality control, which includes water quality principles and guidelines for long-range resource planning, water quality objectives, and other principles and guidelines deemed essential by the State Water Board for water quality control. The State Water Board has adopted a Water Quality Control Plan for the Delta (Bay-Delta Plan). The plan is implemented in part through conditions imposed in both water quality and water right permits.

The State Water Board administers the water rights program for the State, including issuing water right permits. More than two-thirds of the residents of California and more than two million acres of highly productive farmlands receive water exported from the Delta, primarily, although not exclusively, through the SWP and CVP. In addition to the SWP and CVP, there are many other diversions from the Delta and from tributaries to the Delta including the East Bay Municipal Utilities District, the San Francisco Public Utilities Commission, and Contra Costa Water District, to name a few.

**Regulatory Actions by Other Agencies**

In addition to the State Water Board, other state and federal agencies have authority to take regulatory action that can affect Delta inflows, outflows, and hydrodynamics. As indicated below, the United States Fish and Wildlife Service (USFWS), the National Marine Fisheries Service (NMFS), and the California Department of Fish and Game (DFG) have authority to impose regulatory conditions that affect water diversions from the Delta. The Federal Energy Regulatory Commission (FERC) also has authority over non-federal hydropower projects that can change the timing and quantity of inflows to the Delta. Over the next six years, there are 16 hydropower projects on tributaries to the Sacramento and San Joaquin rivers with potential to affect Delta tributary flows that have ongoing or pending proceedings before the FERC.

**Next Steps**

The State Water Board will submit its flow criteria determinations to the Council for its information within 30 days of completing its determinations as required by Water Code section 85086.

The flow criteria contained in this report will be submitted to the Council to inform the Delta Plan. The Council is required to develop the Delta Plan to implement the State's co-equal goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The Council is to develop the Delta Plan by January 2012.

The flow criteria will also inform the BDCP. The BDCP is a multispecies conservation plan being developed pursuant to the ESA and the State Natural Community Conservation Planning Act (NCCPA), administered by the USFWS and the NMFS and the DFG, respectively. The

CESA and the federal ESA generally prohibit the "take" of species protected pursuant to the acts. Both acts contain provisions that allow entities to seek approvals from the resources agencies, which approvals allow limited take of protected species under some circumstances. The BDCP is intended to meet all regulatory requirements necessary for USFWS and NMFS to issue Incidental Take Permits to allow incidental take of all proposed covered species as a result of covered activities undertaken by DWR, certain SWP contractors, and Mirant Corporation, and to issue biological opinions under the ESA to authorize incidental take for covered actions undertaken by USBR and CVP contractors. The BDCP is also intended to address all of the requirements of the NCCPA for aquatic, wetland, and terrestrial covered species of fish, wildlife, and plants and Delta natural communities affected by BDCP actions and is intended to provide sufficient information for DFG to issue permits under the CESA for the taking of the species proposed for coverage under the BDCP.

Finally, the flow criteria in this report will also inform the State Water Board's on-going and subsequent proceedings, including the review and development of flow objectives in the San Joaquin River, a comprehensive update to the 2006 Bay-Delta Plan, and the associated water rights proceedings to implement these Bay-Delta Plan updates.

# 2. Introduction

The purpose of this report is to identify new flow criteria for the Sacramento-San Joaquin Delta (Delta) ecosystem to protect public trust resources in accordance with the Delta Reform Act of 2009, Water Code § 85000 et seq. The flow criteria, which do not have any regulatory or adjudicative effect, may be used to inform planning decisions for the new Delta Plan being prepared by the newly created Delta Stewardship Council (Council) and the Bay Delta Conservation Plan (BDCP). The public trust resources that are the subject of this proceeding include those resources affected by flow, namely, native and valued resident and migratory aquatic species, habitats, and ecosystem processes. The State Water Resources Control Board (State Water Board or Board) has developed flow criteria to protect these resources that incorporate measures regarding Delta outflows and Delta inflows and has recommended other measures relevant to the protection of public trust resources. After approval by the State Water Board, this report will be submitted to the Council.

# 3. Purpose and Background

## *3.1 Background and Scope of Report*

Pursuant to Water Code section 85086, subdivision (c), enacted on November 12, 2009, in Senate Bill No. 1 of the 2009-2010 Seventh Extraordinary Session (Stats. 2009 (7$^{th}$ Ex. Sess.) ch. 5, § 39) (SB 1), the State Water Board is required to "develop new flow criteria for the Delta ecosystem necessary to protect public trust resources." The purpose of this report is to comply with the Legislature's mandate to the State Water Board.

Given the limited amount of time the State Water Board had to develop the criteria, the Board initially focused on Delta outflow conditions as a primary driver of ecosystem functions in the Delta. In determining the extent of protection to be afforded public trust resources through the development of the flow criteria, the State Water Board considered the broad goals of the planning efforts the criteria are intended to inform, including restoring and promoting viable, self-sustaining populations of aquatic species. The specific goals for protection are discussed in more detail below.

The notice for this proceeding focused the proceeding on Delta outflows. During the proceeding, however, the State Water Board received useful information from participants regarding Sacramento River inflows, San Joaquin River inflows, and Delta hydrodynamics (including Old and Middle River flows, San Joaquin River at Jersey Point flows, and San Joaquin River inflow to export ratios) that is relevant to protection of public trust resources in the Delta ecosystem. The hydrodynamic criteria included in this reportare largely dependent on exports and on San Joaquin River inflows, and do not directly affect the outflows considered in this proceeding. The State Water Board believes, however, that this information should be transmitted to the Council for its use in informing the Delta Plan and BDCP. Because the notice for the proceeding focused on Delta outflows, and some of the participants did not submit scientific information on inflows and hydrodynamics for the State Water Board's consideration, the record for inflows and hydrodynamics may not be as complete, and the analyses for these flow parameters accordingly may be limited. As a result, these criteria do not constitute formal criteria within the scope of the informational proceeding as noticed, but instead are submitted to the Council with the acknowledgement that they are based on the limited information received by the State Water Board.

### 3.1.1 The Legislative Requirements

In November 2009, legislation was enacted comprising a comprehensive water package for California. In general, the legislation is designed to achieve a reliable water supply for future generations and to restore the Delta and other ecologically sensitive areas. The package includes a bond bill and four policy bills, one of which is SB 1.

In the Delta Reform Act, the Legislature found and declared, among other matters, that:

> "The Sacramento-San Joaquin Delta watershed and California's water infrastructure are in crisis and existing Delta policies are not sustainable. Resolving the crisis requires fundamental reorganization of the state's management of Delta watershed resources. (Wat. Code, § 85001, subd. (a).)
>
> By enacting this division, it is the intent of the Legislature to provide for the sustainable management of the Sacramento-San Joaquin Delta ecosystem, to provide for a more reliable water supply for the state, to protect and enhance the quality of water supply from the Delta, and to establish a governance structure that will direct efforts across state agencies to develop a legally enforceable Delta Plan." (Wat. Code, § 85001, subd. (c).)

Among other provisions, SB 1 establishes the Delta Stewardship Council, which is charged with responsibility to develop, adopt, and commence implementation of a Delta Plan, a comprehensive, long-term management plan for the Delta, by January 1, 2012. The legislation also establishes requirements for inclusion of the BDCP, a multispecies conservation plan, into the Delta Plan. For purposes of informing the planning efforts for the Delta Plan and BDCP, SB 1 requires the State Water Board, pursuant to its public trust obligations, to develop new flow criteria for the Delta ecosystem necessary to protect public trust resources. (Wat. Code, § 85086, subd. (c).) Regarding the flow criteria, the Legislature provided that the flow criteria shall:

- include the volume, quality, and timing of water necessary for the Delta ecosystem;
- be developed within nine months of enactment of SB 1;

- be submitted to the Council within 30 days of completion;
- inform planning decisions for the Delta Plan and the BDCP;
- be based on a review of existing water quality objectives and the use of the best available scientific information;
- be developed in a public process by the State Water Board as a result of an informational proceeding conducted under the board's regulations set forth at California Code of Regulations, title 23, sections 649-649.5, in which all interested persons have an opportunity to participate.
- not be considered predecisional with regard to any subsequent State Water Board consideration of a permit, including any permit in connection with a final BDCP;
- inform any State Water Board order approving a change in the point of diversion of the State Water Project or the federal Central Valley Project from the southern Delta to a point on the Sacramento River;

### 3.1.2 The State Water Board's Public Trust Obligations

As stated above, SB 1 requires the State Water Board to develop new flow criteria to protect public trust resources in the Delta ecosystem pursuant to the Board's public trust obligations. The purpose of the public trust is to protect commerce, navigation, fisheries, recreation, ecological values, and fish and wildlife habitat. Under the public trust doctrine, the State of California has sovereign authority to exercise continuous supervision and control over the navigable waters of the state and the lands underlying those waters. (*National Audubon Society v. Superior Court* (*Audubon*) (1983) 33 Cal.3d 419.) A variant of the public trust doctrine also applies to activities that harm a fishery in non-navigable waters. (*People v. Truckee Lumber Co.* (1897) 116 Cal. 397, see *California Trout, Inc. v. State Water Resources Control Board* (1989) 207 Cal.App.3d 585, 630.)

In *Audubon*, the California Supreme Court held that California water law is an integration of the public trust doctrine and the appropriative water right system. (*Audubon*, *supra*, 33 Cal.3d at p. 426.) The state has an affirmative duty to take the public trust into account in the planning and allocation of water resources. The public trust doctrine requires the State Water Board to consider the effect of a diversion or use of water on streams, lakes, or other bodies of water, and "preserve, so far as consistent with the public interest, the uses protected by the trust." (*Audubon*, *supra*, 33 Cal.3d at p. 447.) Thus, before the State Water Board approves a water diversion, it must consider the effect of the diversion on public trust resources and avoid or minimize any harm to those resources where feasible. (*Id.* at p. 426.) Even after an appropriation has been approved, the public trust imposes a duty of continuing supervision. (*Id.* at p. 447.)

The purpose of this proceeding is to receive scientific information and develop flow criteria pursuant to the State Water Board's public trust obligations. In this forum, the State Water Board will not consider the allocation of water resources, the application of the public trust to a particular water diversion or use, or any balancing between potentially competing public trust resources. The State Water Board has also not considered minimum or maximum flows needed to protect public health and safety. Any such application of the State Water Board's public trust responsibilities, including any balancing of public trust values and water rights, would be conducted through an adjudicative or regulatory proceeding. Instead, the State Water Board's focus here is solely on identifying public trust resources in the Delta ecosystem within the scope of SB 1 and determining the flows necessary to protect those resources.

### 3.1.3 Public Process

The Water Code directs the State Water Board to develop the flow criteria in a public process in the form of an informational proceeding conducted pursuant to the Board's regulations. (Wat. Code, § 85086, subd. (c)(1); Cal. Code Regs., tit. 23, §§ 649-649.5.) The State Water Board conducted this informational proceeding to receive the best available scientific information to use in carrying out its mandate to develop new flow criteria for the Delta ecosystem necessary to protect public trust resources. (Wat. Code, § 85086, subd. (c)(1).) On December 16, 2009, the State Water Board issued the notice for the public informational proceeding to develop the flow criteria. For the informational proceeding, the State Water Board required the participants to submit a Notice of Intent to Appear by January 5, 2010. The State Water Board received 55 Notices of Intent to Appear for the informational proceeding.

On January 7, 2010, the State Water Board conducted a pre-proceeding conference to discuss the procedures for the informational proceeding mandated by Water Code section 85086, subdivision (c). Topics for the pre-proceeding conference included coordination of joint presentations, use of presentation panels, time limits on presentations, and electronic submittal of written information. The conference was used only to discuss procedural matters and did not address any substantive issues.

On January 29, 2010, the State Water Board issued a revised notice amending certain procedural requirements and posted a preliminary list of reference documents. Written testimony, exhibits, and written summaries, along with lists of witnesses and lists of exhibits, were due on February 16, 2010. The State Water Board gave participants and interested parties an opportunity to submit written questions regarding the written testimony, exhibits, and written summaries by March 9, 2010. All submittals were posted on the State Water Board's website.

On March 22 through 24, the State Water Board held the public informational proceeding to develop flow criteria for the Delta ecosystem. The State Water Board received a technical introduction by the Delta Environmental Flows Group (DEFG)[4] at the beginning of the proceeding. The group prepared two documents and an associated list of references that were submitted as State Water Board exhibits:

- Key Points on Delta Environmental Flows for the State Water Resources Control Board, February 2010
- Changing Ecosystems: a Brief Ecological History of the Delta, February 2010

A subset of the group, the UC Davis Delta Solutions Group, prepared three additional papers (which were also submitted as State Water Board exhibits):

- Habitat Variability and Complexity in the Upper San Francisco Estuary
- On Developing Prescriptions for Freshwater Flows to Sustain Desirable Fishes in the Sacramento-San Joaquin Delta

[4] The Delta Environmental Flows Group consists of William Bennett, Jon Burau, Cliff Dahm, Chris Enright, Fred Feyrer, William Fleenor, Bruce Herbold, Wim Kimmerer, Jay Lund, Peter Moyle, and Matthew Nobriga. This group of professors, researchers, and staff from various resource agencies was assembled by State Water Board staff with the intent of informing the Delta flow criteria informational proceeding.

- Ecosystem Investments for the Sacramento-San Joaquin Delta: Development of a Portfolio Framework

Over the course of the hearing, the State Water Board received information from expert witnesses in response to questions posed by Board members. The expert witnesses, representing various participants, as well as experts from the DEFG, were grouped into five panels in order to focus the discussions on specific aspects of the Delta flow criteria. These panels addressed the following topics: hydrology, pelagic fish, anadromous fish, other stressors, and hydrodynamics.

At the conclusion of the informational proceeding, participants were given approximately 20 days to submit closing comments. On July 21, 2010, the draft report was released for public review and comment.

### 3.1.4 Scope of This Report

Due to the limited nine-month time period in which the State Water Board must develop new flow criteria, the notice for the informational proceeding requested information on what volume, quality, and timing of Delta outflows are necessary under different hydrological conditions to protect public trust resources pursuant to the State Water Board's public trust obligations and the requirements of SB 1. Delta outflows are of critical importance to various ecosystem functions, water supply, habitat restoration, and other planning issues. The effect of Delta outflows in protecting public trust resources necessarily involves complex interactions with other flows in the Delta and with non-flow parameters including water quality and the physical configuration of the Delta. This report recognizes the role of source inflows used to meet Delta outflows, Delta hydrodynamics, tidal action, hydrology, water diversions, water project operations, and cold water pool storage in upstream reservoirs, and relies upon information submitted on these related topics to inform its determinations.

The State Water Board intends that the flow criteria developed in this proceeding should meet the following general goal regarding the protection of public trust resources:

- Halt the population decline and increase populations of native species as well as species of commercial and recreational importance by providing sufficient flow and water quality at appropriate times to promote viable life stages of these species.

To meet this goal, the State Water Board also sought to develop criteria that are comprehensive and that can be implemented without undue complexity. This report is limited to consideration of flow criteria needed under the existing physical conditions, so therefore does not consider or anticipate changes in habitat or modification of water conveyance facilities. The State Water Board does, however, identify other measures that should be considered in conjunction with, and to complement, the flow criteria.

A number of factors outside the scope of the legislative mandate to develop new flow criteria could affect public trust resources and some other factors could affect the interaction of flows with the environment. These factors include contaminants, water quality parameters, future habitat restoration measures, water conveyance facilities modification, and the presence of non-native species.

### 3.1.5 Concurrent State Water Board Processes

The State Water Board has a number of ongoing proceedings that may be informed by the development of flow criteria. Some of these proceedings will result in regulatory requirements that affect flow, or otherwise affect the volume, quality, or timing of flows into, within, or out of the Delta. In July 2008, the State Water Board adopted a strategic work plan for actions to protect beneficial uses of the San Francisco Bay/Delta (Bay-Delta). In accordance with the work plan, the State Water Board recently completed a periodic review of the 2006 Water Quality Control Plan for the Bay-DeltaEstuary (Bay-Delta Plan) that recommended the Delta Outflow objectives, as well as other flow objectives, for further review in the water quality control planning process. Currently, the State Water Board is in the process of reviewing the southern Delta salinity and the San Joaquin River flow objectives contained in the Bay-Delta Plan.

**Clean Water Act Water Quality Certifications**

Several non-federal hydropower projects with potential to affect Delta tributary flows have ongoing or pending proceedings before the Federal Energy Regulatory Commission (FERC) that will result in the issuance of new licenses that will govern operations for the 30-50 year term. The relicensing process allows state and federal agencies to prescribe conditions to achieve certain objectives such as state water quality standards and the protection of listed species. New license conditions may include instreams flows requirements or other conditions to protect aquatic species. For example, the new license for the Oroville Dam will require changes in minimum flow requirements and changes in facilities and operations to meet certain water temperature requirements to protect Chinook salmon, steelhead, and green sturgeon. By 2016, more than 25 Delta tributary dams will go through the relicensing process.

The State Water Board will rely upon the FERC license application and the National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) documents prepared for the projects, and may require submittal of additional data or studies, to inform its Clean Water Act Section 401 Water Quality Certifications for the projects. The Board's water quality certification will be issued as soon as possible after the environmental documents and any other needed studies are complete, after which FERC will issue a new license. The conditions in the water quality certification are mandatory and must be included in the FERC license.

Information developed as part of the relicensing of these projects will be used to inform on-going Bay Delta proceedings, and any information developed in the State Water Board's Bay Delta proceedings will be used to inform the two water quality certifications.

Table 1 summarizes the dams, tributaries, and license expiration dates for FERC projects in the Delta watershed. Several of these projects are upstream of major dams and reservoirs in the Sacramento and San Joaquin river watershed so operational changes would have little or no direct effect upon Delta flows.

**Table 1. Delta Watershed FERC Projects**

| River | Dam(s) | Storage Capacity (acre-feet) | Owner | Status of Proceeding | FERC License Expiration |
|---|---|---|---|---|---|
| Feather | Oroville | 3.5 million | Department of Water Resources (DWR) | Near completion | January 2007 |
| West Branch Feather | Philbrook, Round Valley | 6,200 | Pacific Gas and Electric Company (PG&E) | Near Completion | October 2009 |
| South Feather | Little Grass Valley | 90,000 | South Feather Water and Power Agency | Near completion | March 2009 |
| Upper North Fork Feather | Lake Almanor | 1.1 million | PG&E | Near Completion | October 2004 |
| Pit River | McCloud, Iron Canyon,Pit 6, 7 | 110,000 | PG&E | Ongoing | July 2011 |
| North Yuba | New Bullards Bar | 970,000 | Yuba County Water Agency | Pre-Licensing meetings started | March 2016 |
| Middle and South Yuba, Bear | Yuba-Bear Project, 10+ dams | 210,000 | Nevada Irrigation District | Ongoing | April 2013 |
| Middle & South Yuba, Bear | Drum-Spaulding Project, 10+ dams | 150,000 | PG&E | Ongoing | April 2013 |
| Middle Fork American River | French Meadows, Hell Hole | 340,000 | Placer County Water Agency | Ongoing | February 2013 |
| South Fork American River | Loon Lake, Slab Creek | 400,000 | Sacramento Municipal Utility District | Near completion | July 2007 |
| South Fork American River | Chili Bar | 1,300 | PG&E | Near completion | July 2007 |
| Tuolumne | New Don Pedro | 2 million | Turlock Irrigation District | To commence late 2010 | April 2016 |
| Merced | New Exchequer/ McSwain | 1 million | Merced Irrigation District | Ongoing | February 2014 |
| Merced | Merced Falls | 650 | PG&E | Ongoing | February 2014 |
| San Joaquin | Mammoth Pool | 120,000 | Southern California Edison | Near Completion | November 2007 |
| San Joaquin | Huntington, Shaver, Florence | 320,000 | Southern California Edison | Near Completion | February 2009 |

### 3.1.6 Delta Stewardship Council and Use of This Report

In accordance with the legislative requirements described above, the State Water Board will submit this report, containing its Delta flow criteria determinations, to the Council within 30 days after this report has been completed. This report will be deemed complete on the date the State Water Board adopts a resolution approving transmittal of the report to the Council.

Additionally, SB 1 requires any order approving a change in the point of diversion of the State Water Project (SWP) or the Central Valley Project (CVP) from the southern Delta to a point on the Sacramento River to include appropriate flow criteria and to be informed by the analysis in this report. (Wat. Code, § 85086, subd. (c)(2).) The statute also specifies, however, that the criteria shall not be considered predecisional with respect to the State Water Board's subsequent consideration of a permit. (*Id*., § 85086, subd. (c)(1).) Thus, any process with regulatory or adjudicative effect must take place through the State Water Board's water quality control planning or water rights processes in conformance with applicable law. Any person who wishes to introduce information produced during this informational proceeding, or the State Water Board's ultimate determinations in this report, into a later rulemaking or adjudicative proceeding must comply with the rules for submission of information or evidence applicable to that proceeding.

## *3.2 Regulatory Setting*

### 3.2.1 History of Delta Flow Requirements

The State Water Rights Board (a predecessor to the State Water Board) first had an opportunity to consider flow requirements in the Delta when it approved water rights for much of the U.S. Bureau of Reclamation's (USBR) CVP in Water Right Decision 990 (D-990) (adopted in 1961), but it did not impose any fish protection conditions in D-990. In 1967, the State Water Rights Board included fish protections in D-1275 approving the water right permits for the SWP. Effective December 1, 1967, the State Water Rights Board and the State Water Quality Control Board were merged in a new agency, the State Water Board, which exercises both the water quality and water rights adjudicatory and regulatory functions of the state. The State Water Board adopted a new water quality control policy for the Delta and Suisun Marsh in October 1968, in Resolution 68-17. The resolution specified that the objectives would be implemented through conditions on the water rights of the CVP and SWP.

To implement the water quality objectives, the State Water Board adopted Water Right Decision 1379 (D-1379) in 1971[5]. D-1379 established new water quality requirements in both the SWP and CVP permits, including fish flows, and rescinded the previous SWP requirements from D-1275 and D-1291. D-1379 was stayed by the courts and eventually was superseded by Water Right Decision 1485 (D-1485).

In April 1973, in Resolution 73-16, the State Water Board adopted a water quality control plan to supplement the State water quality control policies for the Delta.

[5] In 1971, the State Water Board approved interim regional water quality control plans for the entire State, including the Delta and Suisun Marsh. Subsequently, the State Water Board approved long-term objectives for the Delta and Suisun Marsh in the regional plans for the Sacramento-San Joaquin Delta Basin and the San Francisco Bay Basin.

In August 1978, the State Water Board adopted both D-1485 and the 1978 Delta Plan. Together the 1978 Delta Plan and D-1485 revised existing objectives for flow and salinity in the Delta's channels and ordered USBR and DWR to meet the objectives. In 1987, the State Water Board commenced proceedings to review the 1978 Delta Plan and D-1485. The Board held a hearing at numerous venues in California and released a draft water quality control planin 1988, but subsequently withdrew it and resumed further proceedings.

In 1991, the State Water Board adopted the 1991 water quality control plan. This is the first Bay-Delta plan to adopt objectives for dissolved oxygen (DO) and temperature. The 1991 Bay-Delta plan did not amend either the flow or water project operations objectives adopted in the 1978 Delta Plan.[6] The United States Environmental Protection Agency (USEPA) approved the objectives in the plan for salinity for municipal, industrial, and agricultural uses, and approved the new DO objectives for fish and wildlife, but disapproved the Delta outflow objectives for the protection of fish and wildlife carried over from the 1978 Delta Plan. The USEPA adopted its own Delta outflow standards in 1994 to supersede the State's objectives.

In the summer of 1994, after the USEPA had initiated its process to develop standards for the Delta, the State and federal agencies with responsibility for management of Bay-Delta resources signed a Framework Agreement, agreeing that: (1) the State Water Board would update and revise its 1991 Bay-Delta Plan to meet federal requirements and would initiate a water right proceeding to implement the plan, after which the USEPA would withdraw its fish and wildlife objectives; (2) a group would be formed to coordinate operations of the SWP and CVP with all regulatory requirements in the Delta; and (3) the State and federal governments would undertake a joint long-term solution finding process to resolve issues in the Bay-Delta. In December 1994, representatives of the State and federal governments, water users, and environmental interests agreed to the implementation of a Bay-Delta protection plan. The plan and institutional documents to implement it are contained in a document titled "Principles for Agreement on Bay-Delta Standards between the State of California and the Federal Government." This is commonly referred to as the "Bay-Delta Accord" or "Principles Agreement."

In 1995 the State Water Board adopted the 1995 Bay-Delta Plan, which is consistent with the Principles Agreement.[7] In response to a water right change petition filed by DWR and USBR, the State Water Board then adopted Water Right orders that temporarily allowed DWR and USBR to operate the SWP and CVP in accordance with the 1995 Plan while the State Water Board conducted water right proceedings for a water right decision that would implement the 1995 Bay-Delta Plan. The hearing commenced in 1998 and concluded in 1999. During the 1998-99 water right hearing, DWR and USBR and their water supply contractors negotiated with a number of parties. In 1999, the State Water Board adopted Decision 1641 (D-1641) and subsequently revised D-1641 in 2000.

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[6] After adopting the 1991 Plan, the State Water Board conducted a proceeding to establish interim water right requirements for the protection of public trust uses in the Delta. The State Water Board released a draft water right decision known as "Decision 1630" (D-1630), but did not adopt it.

[7] USEPA approved the 1995 Bay-Delta Plan. By approving the 1995 Bay-Delta Plan, the USEPA supplanted its own water quality standards with the standards in the 1995 Bay-Delta Plan. (*State Water Resources Control Board Cases* (2006) 136 Cal.App.4th 674,774-775 [39 Cal.Rptr.3d 189]; 33 U.S.C. § 1313(c)(2)(A),(c)(3).)

### 3.2.2 Current State Water Board Flow Requirements

The current Bay-Delta flow requirements are contained in the 2006 Bay-Delta Plan and in D-1641. D-1641 implements portions of the 1995 Bay-Delta Plan. D-1641 accepts the contribution that certain entities, through their agreements, will make to meet the flow-dependent water quality objectives in the 1995 Plan, and continues the responsibility of DWR and USBR for the remaining measures to meet the flow-dependent objectives and other responsibilities. In addition, D-1641 recognizes the San Joaquin River Agreement (SJRA) and approves, for a period of twelve years, the conduct of the Vernalis Adaptive Management Plan (VAMP) under the SJRA instead of meeting the San Joaquin River pulse flow objectives in the 1995 Plan. The 2006 Bay-Delta Plan is consistent with D-1641 and makes only minor changes to the 1995 Bay-Delta Plan, allowing the staged implementation of the San Joaquin River spring pulse flow objectives and other minor changes. The 2006 Bay-Delta Plan also identifies a number of issues requiring additional review and planning including: the pelagic organism decline (POD), climate change, Delta and Central Valley salinity, and San Joaquin River flows.

Current Delta outflow requirements, set forth in Tables 3 and 4 in both the 2006 Bay-Delta Plan and D-1641, take two basic forms based on water year type and season: 1) specific numeric Delta outflow requirements; and 2) position of X2, the horizontal distance in kilometers up the axis of the estuary from the Golden Gate Bridge to where the tidally averaged near-bottom salinity is 2 practical salinity units (psu). The Delta outflow requirements are expressed in Table 3 as a Net Delta Outflow Index (NDOI). The NDOI is a calculated flow expressed as Delta Inflow, minus net Delta consumptive use, minus Delta exports. Each component is calculated as described in the 2006 Bay-Delta Plan and D-1641. An electrical conductivity (EC) measurement of 2.64 mmhos/cm at Collinsville station C2 can be substituted for the NDOI during February through June. The most downstream location of either the maximum daily average or the 14-day running average of this EC level is commonly referred to as the position of “X2” in the Delta. Table 4 specifies EC measurements at two specific locations and alternatively allows an NDOI calculation at these locations.

### 3.2.3 Special Status Species

The California Endangered Species Act (CESA) states that all native species of fishes, amphibians, reptiles, birds, mammals, invertebrates, and plants, and their habitats, threatened with extinction and those experiencing a significant decline which, if not halted, would lead to a threatened or endangered designation, will be protected or preserved. The federal Endangered Species Act of 1973 (ESA) provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend. A number of species discussed in this report are afforded protections under CESA and ESA. These species and the protections are discussed below.

The longfin smelt (*Spirinchus thaleichthys*) is currently a candidate for threatened species status under the CESA. (DFG 1, p. 9.) In March 2009, the California Fish and Game Commission (Commission) made a final determination that the listing of longfin smelt as a threatened species was warranted and the rulemaking process to officially add the species to the CESA list of threatened species found in the California Code of Regulations was initiated. Upon completion of this rulemaking process, the longfin smelt’s status will officially change from candidate to threatened. (DFG 1, p. 9.) Its status remains unresolved at the federal level. (USFWS 2009.) The delta smelt (*Hypomesus transpacificus*) is listed as endangered and threatened pursuant to the CESA and ESA, respectively. (DFG 1, p. 14; USFWS 1993.) In April 2010, the United States Fish and Wildlife Service (USFWS) considered a petition to reclassify the delta smelt from threatened to endangered. After review of all available scientific and commercial information, the USFWS found that reclassifying the delta smelt from a threatened to an endangered species is warranted, but precluded by other higher priority listing actions. (USFWS 2010.)

Sacramento winter-run Chinook salmon *(Oncorhynchus tshawytscha)* is listed as endangered pursuant to the CESA and ESA. (NMFS 1994; NMFS 2005; DFG 2010.) Central Valley spring-run Chinook salmon (*O. tshawytscha*) is listed as threatened pursuant to both the CESA and ESA. (NMFS 1999; NMFS 2005; DFG 2010.) Central Valley fall/late fall-run Chinook salmon (*O. tshawytscha*) are classified as species of special concern by the National Marine Fisheries Service (NMFS). (NMFS 2004.) Central Valley steelhead (*O. mykiss*) is listed as threatened under the ESA (NMFS 1998; NMFS 2006a.) Southern Distinct Population Segment of North American green sturgeon (*Acipenser medirostris*) is listed as threatened under the ESA. (NMFS 2006b.)

### 3.2.4 State Incidental Take Permit for Longfin Smelt

The CESA prohibits the take[8] of any species of wildlife designated as an endangered, threatened, or candidate species[9] by the Commission. The Department of Fish and Game (DFG), however, may authorize the take of such species by permit if certain conditions are met (Cal. Code Regs., tit 14, § 783.4). In 2009, DFG issued an Incidental Take Permit for Longfin Smelt to the DWR for the on-going and long-term operation of the SWP. The permit specifies a number of conditions, including two flow measures (Conditions 5.1 and 5.2) intended to minimize take of the longfin smelt and provide partial mitigation for the remaining take by: 1) minimizing entrainment; 2) improving estuarine processes and flow; 3) improving downstream transport of longfin smelt larvae; and 4) providing more water that is used as habitat (increasing habitat quality and quantity) by longfin smelt than would otherwise be provided by the SWP.

**Longfin Smelt Incidental Take Permit (2009), p. 9-10, Condition 5.1.**
This Condition is not likely to occur in many years. To protect adult longfin smelt migration and spawning during December through February period, the Smelt Working Group (SWG) or DFG SWG personnel staff shall provide Old and Middle River (OMR) flow advice to the Water Operations Management Team (WOMT) and to Director of DFG weekly. The SWG will provide the advice when either: 1) the cumulative salvage index (defined as the total longfin smelt salvage at the CVP and SWP in the December through February period divided by the immediately previous FMWT longfin smelt annual abundance index) exceeds five (5); or 2) when a review of all abundance and distribution survey data and other pertinent biological factors that influence the entrainment risk of adult longfin smelt indicate OMR flow advise is warranted. Permittee shall ensure the OMR flow requirement is met by maintaining the OMR flow 14-day running average is no more negative than -5,000 cfs and the initial 5-day running average is not more negative than -6,250 cfs. During any time OMR flow restrictions for the USFWS's 2008 Biological Opinion for delta smelt are being implemented, this condition (5.1) shall not result in additional OMR flow requirements for protection of adult longfin smelt. Once spawning has been detected in the system, this Condition terminates and 5.2 begins. Condition 5.1 is not required or would cease if previously required when river flows are 1) > 55,000 cfs in

[8] Pursuant to Fish and Game Code section 86, "'Take' means hunt, pursue, catch, capture, or kill, or attempt to hunt, pursue, catch, capture or kill."

[9] "Candidate species" are species of wildlife that have not yet been placed on the list of endangered species or the list of threatened species, but which are under formal consideration for listing pursuant to Fish and Game Code section 2074.2

the Sacramento River at Rio Vista; or 2) > 8,000 cfs in the San Joaquin River at Vernalis. If flows go below 40,000 cfs in the Sacramento River at Rio Vista or 5,000 cfs in the San Joaquin River at Vernalis, the OMR flow in Condition 5.1 shall resume if triggered previously. Review of survey data and other pertinent biological factors that influence the entrainment risk of adult longfin smelt may result in a recommendation to relax or cease an OMR flow requirement.

**Longfin Smelt Incidental Take Permit (2009), p. 10-11, Condition 5.2.**
To protect larval and juvenile longfin smelt during January -June period, the SWG or DFG SWG personnel shall provide OMR flow advice to the WOMT and the DFG Director weekly. The OMR flow advice shall be an OMR flow between -1,250 and -5,000 cfs and be based on review of survey data, including all of the distributional and abundance data, and other pertinent biological factors that influence the entrainment risk of larval and juvenile longfin smelt. When a single Smelt Larval Survey (SLS) or 20 mm Survey sampling period results in: 1) longfin smelt larvae or juveniles found in 8 or more of the 12 SLS or 20mm stations in the central and south Delta (Stations 809, 812, 901, 910, 912, 918, 919) or, 2) catch per tow exceeds 15 longfin smelt larvae or juveniles in 4 or more of the 12 survey stations listed above, OMR flow advice shall be warranted. Permittee shall ensure the OMR flow requirement is met by maintaining the OMR flow 14-day running average no more negative than the required OMR flow and the 5-day running average is within 25% of the required OMR. This Conditions OMR flow requirement is likely to vary throughout Jan through June. Based on prior analysis, DFG has identified three likely scenarios that illustrate the typical entrainment risk level and protective measures for larval smelt over the period: High Entrainment Risk Period - Jan through Mar OMR range from -1,250 to -5,000 cfs; Medium Entrainment Risk Period - April and May OMR range from -2000 to -5,000 cfs, and Low Entrainment Risk Period - June OMR -5,000 cfs. When river flows are: 1) greater than 55,000 cfs in the Sacramento River at Rio Vista; or 2) greater than 8,000 cfs in the San Joaquin River at Vernalis, the Condition would not trigger or would be relaxed if triggered previously. Should flows go below 40,000 cfs in Sacramento River at Rio Vista or 5,000 cfs in the San Joaquin River at Vernalis, the Condition shall resume if triggered previously. In addition to river flows, the SWG or DFG SWG personnel review of all abundance and distribution survey data and other pertinent biological factors that influence the entrainment risk of longfin smelt may result in a recommendation by DFG to WOMT to relax or cease an OMR flow requirement.

### 3.2.5 Biological Opinions

In 2008 and 2009, the USBR and the DWR concluded consultations regarding the effects of continued long-term operations of the Central CVP and SWP with the USFWS and the NMFS, respectively. Those consultations led to the issuance of biological opinions that require implementation of reasonable and prudent alternatives (RPAs) to avoid jeopardizing the continued existence and potential for recovery of delta smelt (*Hypomesus transpacificus*), Sacramento River winter-run Chinook salmon *(Oncorhynchus tshawytscha)*, Central Valley spring-run Chinook salmon (*O. tshawytscha*), Central Valley steelhead (*O. mykiss*), Southern Distinct Population Segment of North American green sturgeon (*Acipenser medirostris*), and Southern Resident killer whales *(Orcinus orca)*.

Pursuant to Section 7 of the ESA, federal agencies must insure that their actions do not jeopardize the continued existence of threatened or endangered species or adversely modify their designated critical habitat. The regulations (50 CFR 402.02) implementing Section 7 of the ESA define RPAs as alternative actions, identified during formal consultation, that: 1) can be implemented in a manner consistent with the intended purpose of the action; 2) can be implemented consistent with the scope of the action agency's legal authority and jurisdiction; 3) are economically and technologically feasible; and, 4) would, the USFWS or NMFS believes, avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat. (USFWS 2008, p.279.)

Numerous anthropogenic and other factors (e.g., pollutants and non-native species) that may adversely affect listed fish species in the region are not under the direct control of the CVP or the SWP and as such are not addressed in the biological opinions.

**USFWS Biological Opinion**

On December 15, 2008, the USFWS issued a biological opinion on the Long-Term Operational Criteria and Plan (OCAP) for coordination of the CVP and SWP (UFWS Opinion). The RPA in the USFWS Opinion, divided into six actions, applies to delta smelt and focuses primarily on managing flow regimes to reduce entrainment of delta smelt and on the extent of suitable water conditions in the Delta, as well as on construction or restoration of habitat. (USFWS 2008, pp.329-381.) Flow related components of the RPA include:

- A fixed duration action to protect pre-spawning adult delta smelt from entrainment during the first flush, and to provide advantageous hydrodynamic conditions early in the migration period. This action limits exports so that the average daily net OMR flow is no more negative than -2,000 cubic-feet per second (cfs) for a total duration of 14 days, with a 5-day running average no more negative than -2,500 cfs (within 25 percent) (Action 1, p.329).

- An adaptive process to continue to protect pre-spawning adults from entrainment and, to the extent possible, from adverse hydrodynamic conditions after the action identified above. The range of net daily OMR flows will be more no more negative than -1,250 to -5,000 cfs. From the onset of this action through its termination, the Delta Smelt Working Group would provide weekly recommendations for specific net OMR flows based upon review of the sampling data, from real-time salvage data at the CVP and SWP, and utilizing the most up-to-date technological expertise and knowledge relating population status and predicted distribution to monitored variables of flow and turbidity. The USFWS will make the final determination (Action 2, p.352).

- Upon completion of Actions 1 and 2 or when Delta water temperatures reach 12°C (based on a 3-station average of daily average water temperature at Mossdale, Antioch, and Rio Vista) or when a spent female delta smelt is detected in the trawls or at the salvage facilities, the projects shall operate to maintain net OMR flows no more negative than -1,250 to -5000 cfs based on a 14-day running average with a simultaneous 5-day running average within 25% of the applicable 14-day OMR flow requirement. Action continues until June 30th or when Delta water temperatures reach 25˚C, whichever comes first (Action 3, p.357).

- Improve fall habitat, both quality and quantity, for delta smelt through increasing Delta outflow during fall (fall X2). Subject to adaptive management, provide sufficient Delta outflow to maintain average X2 for September and October no greater (more eastward) than 74 km in the fall following wet years and 81km in the fall following above normal years. The monthly average X2 must be maintained at or seaward of these values for each individual month and not averaged over the two month period. In November, the inflow to CVP/SWP reservoirs in the Sacramento Basin will be added to reservoir releases to provide an added increment of Delta inflow and to augment Delta outflow up

- To minimize entrainment of larval and juvenile delta smelt at the State and federal south Delta export facilities or from being transported into the south and central Delta, where they could later become entrained, do not install the Head of Old River Barrier (HORB) if delta smelt entrainment is a concern. If installation of the HORB is not allowed, the agricultural barriers would be installed as described in the Project Description of the biological opinion. If installation of the HORB is allowed, the Temporary Barrier Project flap gates would be tied in the open position until May 15 (Action 5, p. 377).

- Implement habitat restoration activities designed to improve habitat conditions for delta smelt by enhancing food production and availability to supplement the benefits resulting from the flow actions described above. DWR shall implement a program to create or restore a minimum of 8,000 acres of intertidal and associated subtidal habitat in the Delta and Suisun Marsh. The restoration efforts shall begin within 12 months of signature of this biological opinion and be completed within a 10 year period (Action 6, p. 379).

## **NMFS Biological Opinion**

On June 4, 2009, NMFS issued its Biological and Conference Opinion on the OCAP (NMFS Opinion), which provides RPA actions to protect winter-run and spring-run Chinook salmon, Central Valley steelhead, green sturgeon, and killer whales from project effects in the Delta and upstream areas. (NMFS 3.) The RPA consists of five actions with a total of 72 subsidiary actions. Included within the RPA are actions related to: formation of technical teams, research and adaptive management, monitoring and reporting, flow management, temperature management, gravel augmentation, fish passage and reintroduction, gate operations and installation (Red Bluff Diversion Dam, Delta Cross Channel Gate, South Delta Improvement Program), funding for fish screening, floodplain and other habitat restoration, hatchery management, export restrictions, CVP and SWP fish collection facility modifications, and fish collection and handling. The flow related components of the opinion include:

- In the Sacramento River Basin – flow requirements for Clear Creek; release requirements from Whiskeytown Dam for temperature management; cold water pool management of Shasta Reservoir; development of flow requirements for Wilkins Slough; and restoration of floodplain habitat in the lower Sacramento River basin to better protect Chinook salmon, steelhead, and green sturgeon. (*Id at* pp.587-611.)

- In the American River - flow requirements and cold water pool management requirements to provide protection for steelhead. (*Id at* pp. 611-619.)

- In the San Joaquin River Basin – cold water pool management, floodplain inundation flows, and flow requirements for the Stanislaus River (NMFS 3, pp. 619-628, Appendix 2-E) and an interim minimum flow schedule for the San Joaquin River at Vernalis during April and May effective through 2011 for the protection of steelhead. (*Id at* pp. 641-645.)

- In the Delta – Delta Cross-Channel Gate operational requirements; net negative flow requirements toward the export pumps in Old and Middle rivers; and export limitations based on a ratio of San Joaquin River flows to combined SWP and CVP export during April and May for the protection of Chinook salmon and steelhead. (*Id. at* pp. 628-660.)

It is important to note that the flow protections described in the project description and RPA are the minimum flows necessary to avoid jeopardy. (NMFS written summary, p.3.) In addition, NMFS considered provision of water to senior water rights holders to be non-discretionary for purposes of the ESA as it applies to Section 7 consultation with the USBR, which constrained development of RPA Shasta storage actions and flow schedules. San Joaquin River flows at Vernalis were constrained by the NMFS Opinion's scope extending only to CVP New Melones operations. Operations on other San Joaquin tributaries were not within the scope of the consultation. (*Id.*)

**Recent Litigation**

Both the USFWS Opinion and the NMFS Opinion are the subject of ongoing litigation in the United States District Court for the Eastern District of California. Plaintiffs challenged the validity of the opinions under various legal theories, including claims under the ESA and the NEPA. Most recently, this year plaintiffs Westlands Water District and San Luis Delta Mendota Water Authority sought preliminary injunctions against the implementation of certain RPAs identified by NMFS and USFWS in their biological opinions for the protection of Delta smelt and Central Valley steelhead and salmonids. In May 2010, Judge Wanger issued a ruling concluding that injunctive relief was appropriate with respect to the NMFS biological opinion PRA Action IV.2.1, which limits pumping based on San Joaquin River inflow from April 1 through May 31, and RPA Action IV.2.3, which imposes restrictions on negative OMR flows in generally between January 1 and June 15. Later that month, he also ruled that injunctive relief was appropriate with respect to RPA Component 2 of Action 3 of the USFWS Opinion, which requires net OMR flows to remain between -1,250 and -5,000 cfs during a certain period for the protection of larval and juvenile delta smelt. The validity of the biological opinions likely will continue to be litigated in the foreseeable future, creating uncertainty about implementation of the RPAs.

## *3.3 Environmental Setting*

Figure 1 is a map of the Bay-Delta Estuary that was included in the 2006 Bay-Delta Plan. The map depicts the location of monitoring stations used to collect baseline water quality data for the Bay-Delta Estuary and stations used to monitor compliance with water quality objectives set forth in the Bay-Delta Plan.

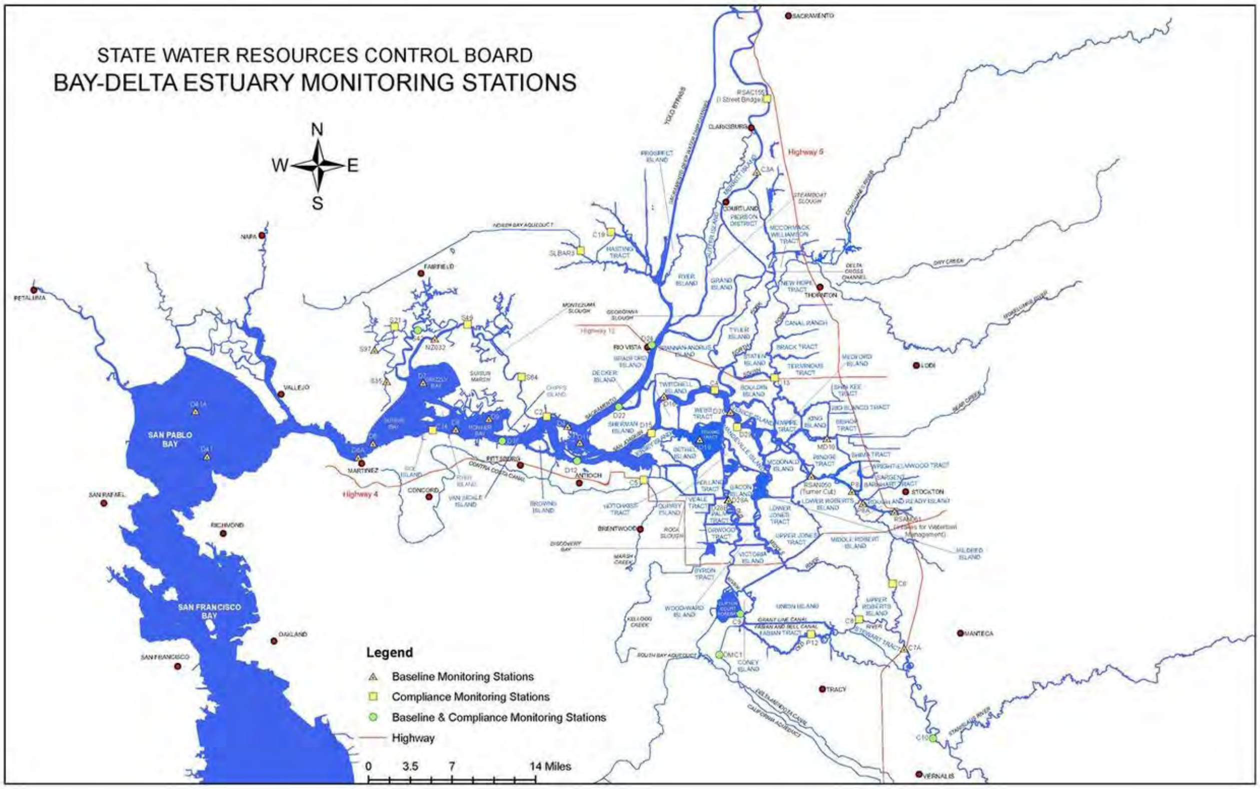



**Figure 1. Map of the Bay-Delta Estuary**

## 3.3.1 Physical Setting

The Delta is located where California's two major river systems, the Sacramento and San Joaquin rivers, converge from the north and south and are joined by several tributaries from the Central Sierras to the east, before flowing westward through the San Francisco Bay to the Pacific Ocean. The Sacramento and San Joaquin rivers drain water from the Central Valley Basin, which includes about 40 percent of California's land area.

Outflow from the Delta enters Suisun Bay just west of the confluence of the Sacramento and San Joaquin rivers. Suisun Marsh, which is located along the north shore of Suisun Bay, is one of the few major marshes remaining in California and is the largest remaining brackish wetland in Western North America. The marsh is subject to tidal influence and is directly affected by Delta outflow. Suisun Marsh covers approximately 85,000 acres of marshland and water ways and provides a unique diversity of habitats for fish and wildlife.

### The Old Delta

The Delta formed as a freshwater marsh through the interaction of river inflow and the strong tidal influence of the Pacific Ocean and San Francisco Bay. The growth and decay of tules and other marsh plants resulted in the deposition of organic material, creating layers of peat that formed the soils of the marsh. Hydraulic mining during the Gold Rush era washed large amounts of sediment into the rivers, channels and bays, temporarily burying the wetlands. The former wetland areas were reclaimed into more than 60 islands and tracts that are devoted primarily to farming. A network of levees protects the islands and tracts from flooding, because most of the islands lie near or below sea level due to the erosion and oxidation of the peat soils.

As shown in Figure 2 (Courtesy, Chris Enright, DWR, using Atwater data), prior to reclamation, the channels in the Delta were connected in a dendritic, or tree-like, pattern and may have included 5 to 10 times as many miles of interconnected channels as it does today, with largely unidirectional flow.

**Figure 2. The Old Delta (*ca.* 1860).**

**The Recent Delta**

Today's Delta covers about 738,000 acres, of which about 48,000 acres are water surface area, and is interlaced with about 700 miles of waterways. As shown in Figure 3 (Courtesy, Chris Enright, DWR, using Atwater data), today's remaining Delta waterways have been greatly modified to facilitate the bi-directional movement of water and the river banks have been armored to protect against erosion, thus changing the geometry of the stream channels and eliminating most of the natural vegetation and habitat of the aquatic and riparian environment. The interconnected geometry and channelized sloughs of the present Delta result in much less variability in water quality than the past dendritic pattern, and today's mostly open ended sloughs results in water quality and habitat being relatively homogenous throughout the system. (Moyle et al. 2010.)

**Figure 3. The Recent Delta**

**The Changing Delta**

The Delta Environmental Flows Group (DEFG 2) describes in *Changing Ecosystems: a Brief Ecological History of the Delta* how the Delta has undergone significant physical and biological modification over the past 150 years. Initial development occurred during the Gold Rush when large amounts of sediment washed into the Delta, followed by diking and dredging of rivers. This was followed by increasing diversions and developments, including fixing of levees and channels, and most recently with large-scale dam development and diversions from the Delta. The Moyle et al. history also suggests what is likely to happen in the future:

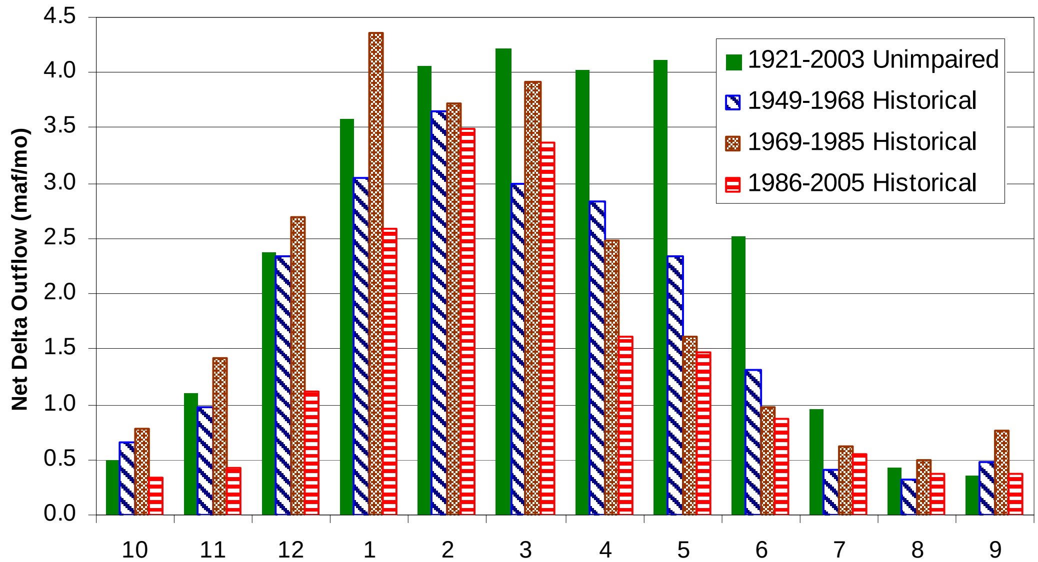
> "The Delta ecosystem is likely to dramatically shift again within 50 years due to large-scale levee collapse in the Delta and Suisun Marsh. Major levee failures are inevitable due to continued subsidence, sea level rise, increasing frequency of large floods, and high probability of earthquakes. These significant changes will create large areas of open water and increased salinity intrusion, as well as new tidal and subtidal marshes. Other likely changes include reduced freshwater inflow during prolonged droughts, altered hydraulics from reduced export pumping, and additional alien invaders (e.g., zebra and quagga mussels). The extent and effects of all these changes are unknown but much will depend on how the estuary is managed in response to change or even before change takes place. Overall, these major changes in the estuary's landscape are likely to promote a more variable, heterogeneous estuary, especially in the Delta and Suisun Marsh. This changed environment is likely to be better for desirable estuarine species; at least it is unlikely to be worse."

### 3.3.2 Hydrology/Hydrodynamics

California's climate and hydrology are Mediterranean, which is characterized by most precipitation falling during the winter-spring wet season, a dry season extending from late spring through early fall, and high inter-annual variation in total runoff. The life history strategies of all native estuarine Delta fishes are adapted to natural variability. (Moyle and Bennett 2008, as cited in Fleenor et al. 2010.) Although the unimpaired flow record does not indicate precise, or best, flow requirements for fish under current conditions, the general timing (e.g., seasonality), magnitudes, and directions of flows seen in the unimpaired flow record are likely to remain important for native species under contemporary and future conditions. (Fleenor et al. 2010.)

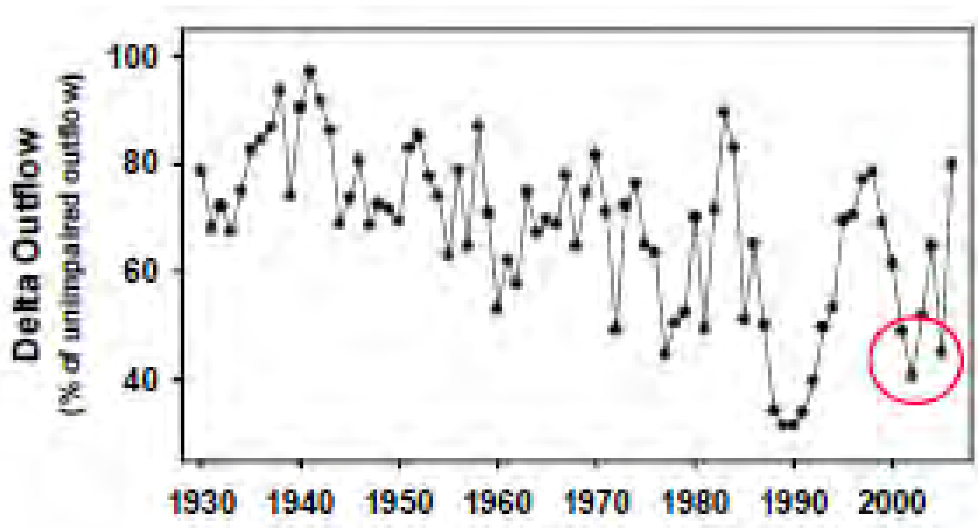
Inflow to the Delta comes primarily from the Central Valley Basin's Sacramento and San Joaquin river systems and is chiefly derived from winter and spring runoff originating in the Cascade and Sierra Nevada mountains, with minor amounts from the Coast Ranges. Precipitation totals vary annually with about 80 percent of the total occurring between the end of October and the beginning of April. Snow storage in the high Sierra delays the runoff from that area until the snow melts in April, May, and June. Normally, about half of the annual runoff from the Central Valley Basin occurs during this period. In recent years, the Sacramento River contributed roughly 75 to 80% of the Delta inflow in most years, while the San Joaquin River contributed about 10 to 15%. The minor flows of the Mokelumne, Cosumnes, and Calaveras rivers, which enter into the eastern side of the Delta, contributed the remainder of the inflow to the Delta.

Net Delta outflow represents the difference between the sum of freshwater inflows from tributaries to the Delta and the sum of exports and net in-Delta consumptive uses. (Kimmerer 2004, DOI 1, p.17.) As noted above, the majority of the freshwater flow into the Delta occurs in winter and spring; however, upstream storage and diversions have reduced the winter-spring flow and increased flow in summer and early fall. (Figure 4, Kimmerer 2002b; Kimmerer 2004; DOI 1, p. 16.) The April-June reductions are largely the result of the San Joaquin River diversions. (Fleenor et al. 2010.) During the summer-fall dry season the Delta channels essentially serve as a conveyance system for moving water from reservoirs in the north to the CVP and SWP export facilities, as well as the smaller Contra Costa Water District facility, for subsequent delivery to farms and cities in the San Joaquin Valley, southern California, and/or other areas outside the watershed. (Kimmerer 2002b.) Figure 5 shows the reduction in annual Delta outflow as a percentage of unimpaired outflow. The combined effects of water exports and upstream diversions reduced average annual net outflow from the Delta from unimpaired conditions by 33% and 48% during the 1948 – 1968 and 1986 – 2005 periods, respectively. (Fleenor et al. 2010.)




This figure shows monthly average net delta outflows (in million acre-feet per month) compared to the unimpaired flows from 1921-2003. Unimpaired flow data is from DWR (2006) and other from Dayflow web site. (Source: Fleenor et al. 2010, Figure 7.)

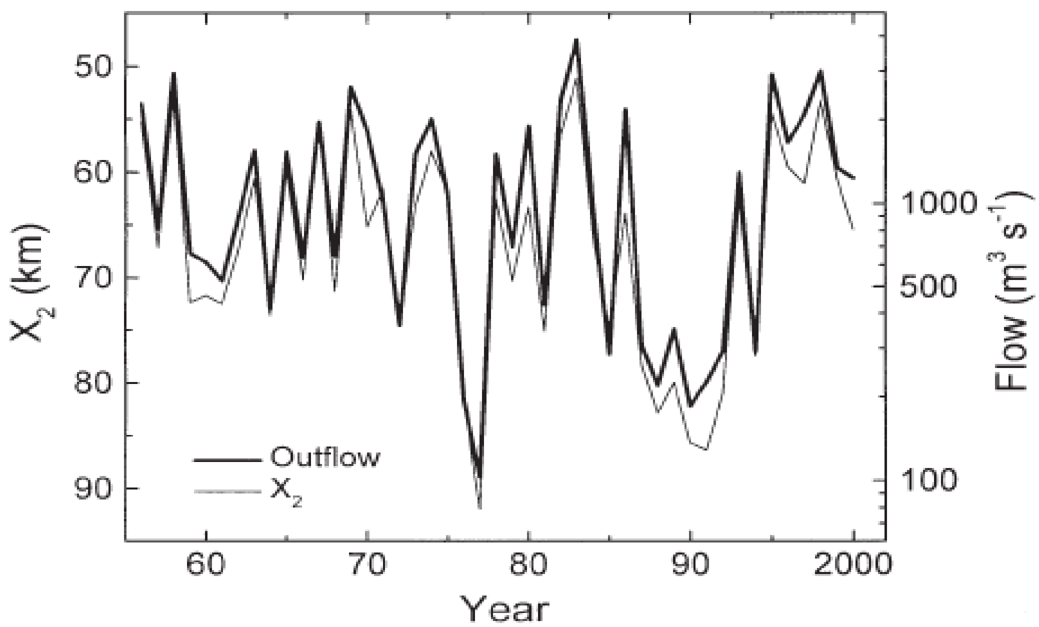
**Figure 4. Monthly Average Net Delta Outflows from Fleenor et al. 2010**




Delta outflow shown as a percentage of unimpaired outflow (1930-2005); in the last decade annual outflow is reduced by more than 50% in 2001, 2002, and 2005. (Source: TBI 2007, as cited in DOI 1, p. 17.)

**Figure 5. Delta Outflow as a Percent of Unimpaired Outflow from TBI 2007**

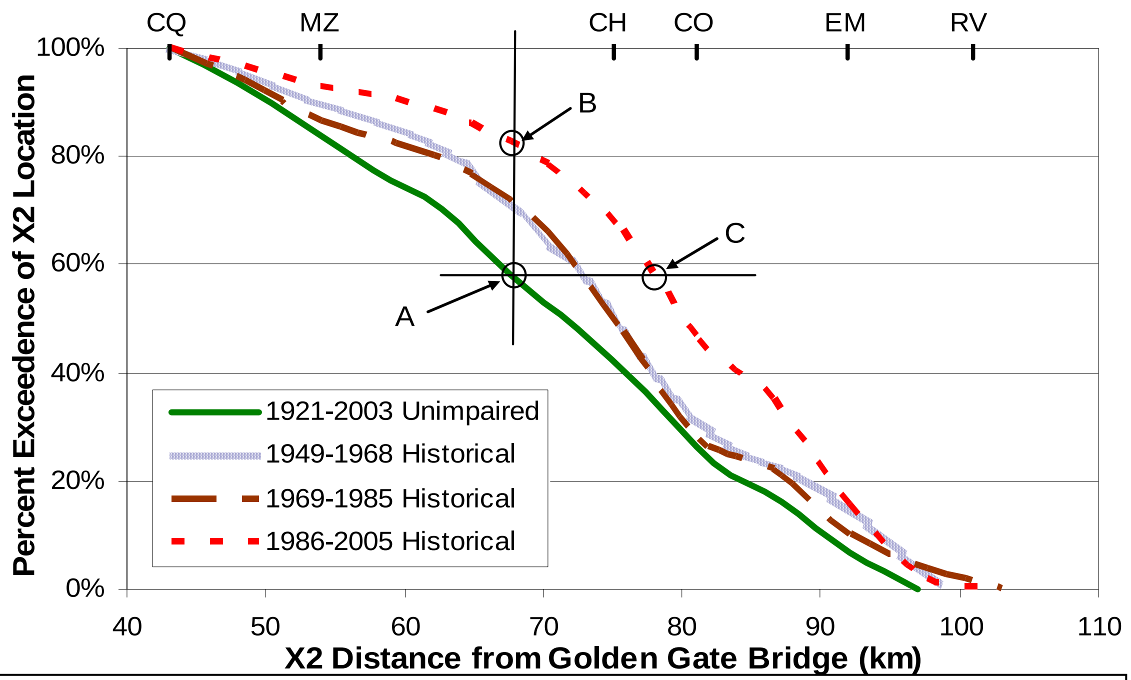
Delta outflows and the position of X2 are closely and inversely related, with a time lag of about two weeks. (Jassby et al. 1995; Kimmerer 2004.) A time series of the annual averages for January to June of X2 and Delta outflow is depicted in Figure 6. X2 is defined as the horizontal distance in kilometers up the axis of the estuary from the Golden Gate Bridge to where the tidally averaged near-bottom salinity is 2 practical salinity units (psu). (Jassby et al. 1995, Kimmerer 2002a.) The position of X2 roughly equates to the center of the low salinity zone (defined as salinity of 0.5 to 6 psu). (Kimmerer 2002a.) The X2 objectives in the 2006 Bay-Delta Plan were designed to restore a more natural hydrograph and salinity pattern by requiring maintenance of the low salinity zone at specified points and durations based on the previous month's Eight River Index. (State Water Board 2006a.) The relationships between outflow and several measures of the health of the Bay-Delta Estuary have been known for some time (Jassby *et al*. 1995) and are the basis for the current X2 objectives.




Time series of X2 (thin line, left axis, scale reversed) and flow (heavy line, right axis, log scale), annual averages for January to June; flow data from DWR; X2 calculated as in Jassby et al. (1995) (Source: Kimmerer 2002a, Figure 3).

**Figure 6. X2 and Delta Outflow for January to June from Kimmerer 2002a**

Both Delta outflow and the position of X2 have been altered as a result of numerous factors including development and operation of upstream storage and diversions, land use changes, and increasing water demand. Hydrodynamic simulations conducted by Fleenor et al. (2010) indicate that the position of X2 has been skewed eastward in the recent past, as compared to unimpaired conditions and earlier impaired periods, and that the variability of salinity in the western Delta and Suisun Bay has been significantly reduced (Figure 7). The higher X2 values shown in this figure (refer to Point 'B') indicate the low salinity zone is farther upstream for a more prolonged period of time. Point 'B' demonstrates that during the period from 1986 to 2005 the position of X2 was located upstream of 71 km nearly 80% of the time, as opposed to unimpaired flows which were equally likely to place X2 upstream or downstream of the 71 km location (50% probability). (Fleenor *et al*. 2010.) Historically, X2 exhibited a wide seasonal range tracking the unimpaired Delta outflows; however, seasonal variation in X2 range has been reduced by nearly 40%, as compared to pre-dam conditions. (TBI 2003, as cited in DOI 1, pp. 21-22.)




This graph shows the cumulative probability distributions of daily X2 locations showing unimpaired flows (green solid line) and three historical periods, 1949-1968 (light solid blue line), 1969-1985 (long-dashed brown line) and 1986-2005 (short-dashed red line), illustrating progressive reduction in salinity variability from unimpaired conditions. Paired letters indicate geographical landmarks: CQ, Carquinez Bridge; MZ, Martinez Bridge; CH, Chipps Island; CO, Collinsville; EM, Emmaton; and RV, Rio Vista (Source: Fleenor et al. 2010, Figure 8).

**Figure 7. Cumulative Probability of Daily X2 Locations from Fleenor *et al*. 2010**

In their key points on Delta environmental flows for the State Water Board, the DEFG (DEFG 1) noted that the recent flow regimes both harm native species and encourage non-native species and provided the following justification:

> "The major river systems of the arid western United States have highly variable natural flow regimes. The present-day flow regimes of western rivers, including the Sacramento and San Joaquin, are highly managed to increase water supply reliability for agriculture, urban use, and flood protection (Hughes et al. 2005, Lund et al. 2007). Recent Delta inflow and outflow regimes appear to both harm native species and encourage non-native species. Inflow patterns from the Sacramento River may help riverine native species in the north Delta, but inflow patterns from the San Joaquin River encourage non-native species. Ecological theory and observations overwhelmingly support the argument that enhancing variability and complexity across the estuarine landscape will support native species. However, the evidence that flow stabilization reduces native fish abundance in the upper estuary (incl. Delta) is circumstantial:
>
> 1) High winter-spring inflows to the Delta cue native fish spawning migrations (Harrell and Sommer 2003; Grimaldo et al. 2009), improve the reproductive success of resident native fishes (Meng et al. 1994; Sommer et al. 1997; Matern et al. 2002; Feyrer 2004), increase the survival of

juvenile anadromous fishes migrating seaward (Sommer *et al*. 2001; Newman 2003), and disperse native fishes spawned in prior years (Feyrer and Healey 2003; Nobriga et al. 2006).

2) High freshwater outflows (indexed by X2) during winter and spring provide similar benefits to species less tolerant of freshwater including starry flounder, bay shrimp, and longfin smelt (Kimmerer 2002; Kimmerer *et al*. 2009). Freshwater flows provide positive benefits to native fishes across a wide geographic area through various mechanisms including larval-juvenile dispersal, floodplain inundation, reduced entrainment, and increased up-estuary transport flows. Spring Delta inflows and outflow have declined since the early 20th century, but average winter-spring X2 has not had a time trend during the past 4-5 decades (Kimmerer 2004).

3) The estuary's fish assemblages vary along the salinity gradient (Matern et al. 2002; Kimmerer 2004), and along the gradient between predominantly tidal and purely river flow. In tidal freshwater regions, fish assemblages also vary along a gradient in water clarity and submerged vegetation (Nobriga et al. 2005; Brown & Michniuk 2007), and smaller scale, gradients of flow, turbidity, temperature and other habitat features (Matern et al. 2002; Feyrer & Healey 2003). Generally, native fishes have their highest relative abundance in Suisun Marsh and the Sacramento River side of the Delta, which are more spatially and temporally variable in salinity, turbidity, temperature, and nutrient concentration and form than other regions.

4) In both Suisun Marsh and the Delta, native fishes have declined faster than non-native fishes over the past several decades (Matern et al. 2002; Brown and Michniuk 2007). These declines have been linked to persistent low fall outflows (Feyrer et al. 2007) and the proliferation of submerged vegetation in the Delta (Brown and Michniuk 2007). However, many other factors also may be influencing native fish declines including differences in sensitivity to entrainment (sustained or episodic high "fishing pressure" as productivity declines), and greater sensitivity to combinations of food-limitation and contaminants, especially in summer-fall when many native fishes are near their thermal limits.

The weight of the circumstantial evidence summarized above strongly suggests flow stabilization harms native species and encourages non-native species, possibly in synergy with other stressors such as nutrient loading, contaminants, and food limitation."

## Diversion and Use

Irrigation is the primary use of water in the Sacramento and San Joaquin river watershed. Water is used to a lesser extent to meet municipal, industrial, environmental, and instream needs. Water is also exported from the Central Valley Basin for many of these same purposes. Local irrigation districts, municipal utility districts, county agencies, private companies and corporations, and State and federal agencies have developed surface water projects throughout the basin to control and conserve the natural runoff and provide a reliable water supply for beneficial uses. Many of these projects are used to produce hydroelectric power and to enhance recreational opportunities. Flood control systems, water storage facilities, and diversion works exist on all major streams in the basin, altering the timing, location, and quantity of water and the habitat associated with the natural flow patterns of the basin. (State Water Board 1999.)

The major surface water supply developments of the Central Valley include the CVP, other federal projects built by the USBR and the U.S. Army Corps of Engineers (USACE), the SWP, and numerous local projects (including several major diversions). The big rim dams, developed mostly since the 1940s, dramatically changed river flow patterns. The dams were built to provide flood protection and a reliable water supply. Collection of water to storage decreased river flows in winter and spring, and changed the timing of high flow periods (except for extreme flood flows). The San Joaquin River has lost most of its natural summer flows because the majority of the water is exported via the Friant project or diverted from the major tributaries for use within the basin. Even though natural flows have been substantially reduced, agricultural return flows during the summer have actually resulted in higher flows than would have occurred under unimpaired conditions at times. Winter and spring flows collected to storage by the State and federal projects in the Sacramento Basin are released in the late spring and throughout the summer and fall, largely to be rediverted from the Delta for export. The federal pumping plants in the southern Delta started operating in the 1950s, exporting water into the Delta-Mendota Canal. The State pumps and the California Aqueduct started operating in the late 1960s, further increasing exports from the Delta. (Moyle, et al. 2010.)

## In-Delta Diversions and Old and Middle River Reverse Flows

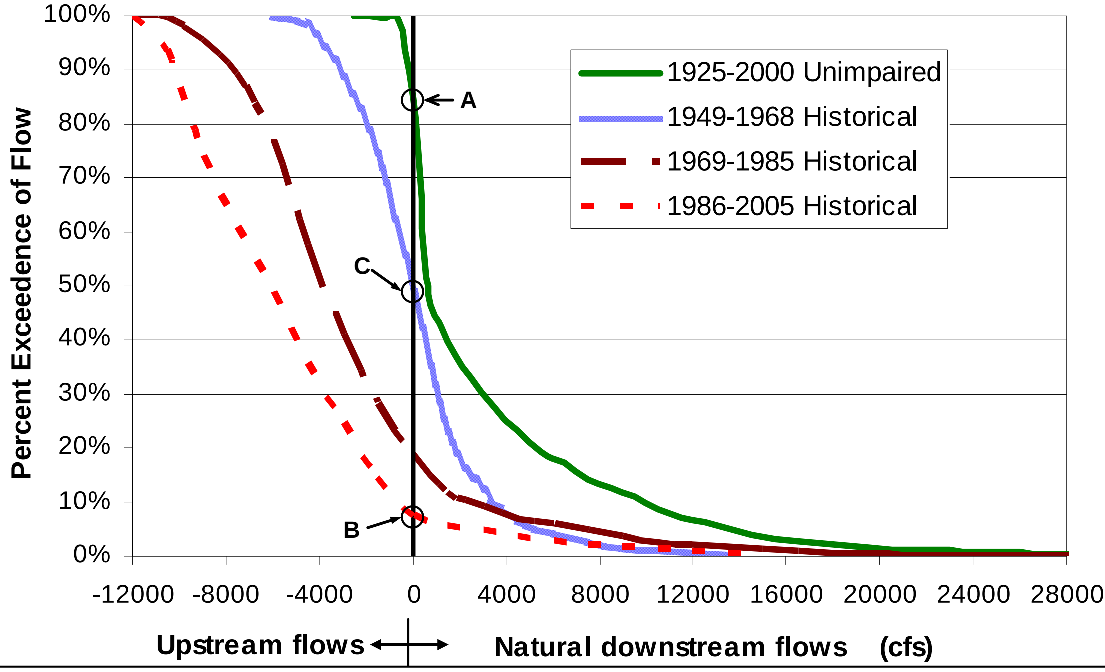
The USBR and the DWR are the major diverters in the Delta. The USBR exports water from the Delta at the Tracy Pumping Plant and the Contra Costa Water District diverts CVP water at Rock Slough and Old River under a water supply contract with the USBR. The DWR exports from the Delta at the Banks Delta Pumping Plant and Barker Slough to serve the SWP contractors. Operation of the CVP and SWP Delta export facilities are coordinated to meet water quality and flow standards set by the Board, the USACE, and by fisheries agencies. In addition, there are approximately 1,800 local diversions within the Delta that amount to a combined potential instantaneous flow rate of more than 4,000 cfs. (State Water Board 1999.)

Net OMR reverse flows are now a regular occurrence in the Delta (Figure 8). Net OMR reverse flows are caused by the fact that the major freshwater source, the Sacramento River, enters on the northern side of the Delta while the two major pumping facilites, the SWP and CVP, are located in the south (Figure 1). This results in a net water movement across the Delta in a north-south direction along a web of channels including Old and Middle rivers instead of the more natural pattern from east to west or from land to sea. Net OMR is calculated as half the flow of the San Joaquin River at Vernalis minus the combined SWP and CVP pumping rate. (CCWD closing comments, p. 2.) A negative value, or a reverse flow, indicates a net water movement across the Delta along Old and Middle river channels to the State and Federal pumping facilities. Fleenor *et al* (2010) has documented the change in both the magnitude and frequency of net OMR reverse flows as water development occurred in the Delta (Figure 8). The 1925-2000 unimpaired line in Figure 8 represents the best estimate of “quasi-natural” or net OMR values before most modern water development. (Fleenor et al. 2010.) The other three lines represent changes in the frequency and magnitude of net OMR flows with increasing development. Net OMR reverse flows are estimated to have occurred naturally about 15% of the time before most modern water development, including construction of the major pumping facilities in the South Delta (point A, Figure 8). The magnitude of net OMR reverse flows was seldom more negative than a couple of thousand cfs. In contrast, between1986-2005 net OMR reverse flows had become more frequent than 90 percent of the time (Point B). The magnitude of net OMR reverse flows may now be as much as -12,000 cfs. High net OMR reverse flows have several negative ecological consequences. First, net reverse OMR flows draw fish, especially the weaker swimming larval and juvenile forms, into the SWP and CVP export facilities. The export facilities have been documented to entrain most species of fish present in the upper estuary. (Brown *et al*. 1996,.) Approximately 110 million fish were salvaged at the SWP pumping facilities and returned to the Delta over a 15 year period, (Brown et al. 1996.) However, this number underestimates the actual number of fish entrained, as it does not include losses at the CVP nor does it account for fish less than 20 mm in length which are not collected and counted at the fish collection facilities. Second, net OMR reverse flows reduce spawning and rearing habitat for native species, like delta smelt. Any fish that enters the Central or Southern Delta has a high probability of being entrained and lost at the pumps. (Kimmerer and Nobriga, 2008.) This has restricted their habitat to the western Delta and Suisun and Grizzly bays. Third, net OMR reverse flows have led to a confusing environment for migrating juvenile salmon leaving the San Joaquin Basin. Through-Delta exports reduce salinity in the central and southern Delta and as a result juvenile salmon migrate from higher salinity in the San Joaquin River to lower salinity in the southern Delta, contrary to the natural historical conditions and their inherited migratory cues. Finally, net OMR reverse flows reduce the natural variability in the Delta by drawing Sacramento River water across and into the Central Delta. The UC Davis Delta Solutions Group recommends:

> "Achieving a variable, more complex estuary requires establishing seaward gradients in salinity and other water quality variables…These goals in turn encourage policies which… establish internal Delta flows that create a tidally-mixed, upstream-downstream gradient (without cross-Delta flows) in water quality… and … restoring environmental variability in the Delta is fundamentally inconsistent with continuing to move large volumes of water through the Delta for export. The drinking and agricultural water quality requirements of through-Delta exports, and perhaps even some current in-Delta uses, are at odds with the water quality and variability needs of desirable Delta species."
> (Moyle et al., 2010.)

Net OMR reverse flow restrictions are included in the USFWS Opinion (Actions 1 through 3), the NMFS Opinion (Action IV.2.3), and the DFG Incidental Take Permit (Conditions 5.1 and 5.2) for the protection of delta smelt, salmonids, and longfin smelt, respectively. (NMFS 3. p. 648; USFWS 2008, DFG 2009.) Additional net OMR reverse flow restrictions are recommended in this report for protection of longfin and delta smelt and Chinook salmon.

Further north in the Delta, the Delta Cross Channel is used to divert a portion of the Sacramento River flow into the interior Delta channels. The purpose of the Delta Cross Channel is to preserve the quality of water diverted from the Sacramento River by conveying it to southern Delta pumping plants through eastern Delta channels rather than allowing it to flow through more saline western Delta channels. The Delta Cross Channel is also operated to protect fish and wildlife beneficial uses (specifically Chinook salmon), while recognizing the need for fresh water to be moved through the system. With a capacity of 3,500 cfs, the Delta Cross Channel can divert a significant portion of the Sacramento River flows into the eastern Delta, particularly in the fall.




Cumulative probability distribution of sum of Old and Middle River flows (cfs) resulting from through Delta conveyance showing unimpaired flows (green solid line) and three historical periods, 1949-1968 (solid light blue line), 1969-1985 (long-dashed brown line) and 1986-2005 (short-dashed red line) (Source: Fleenor et al. 2010, Figure 9).

**Figure 8. OMR Cumulative Probability Flows from Fleenor et al. 2010**

### 3.3.3 Water Quality

Water quality in the Delta may be negatively impacted by contaminants in sediments and water, low DO levels, and blue green algal blooms. Additionally, changes in hydrology and hydrodynamics affect water quality. The conversion of tidal wetlands to leveed Delta islands has altered the tidal exchange and prism. These changes can contribute to spatial and temporal shifts in salinity and other physical and chemical water quality parameters (temperature, DO, contaminants, etc.).

**Contaminants**

The Delta and San Francisco Bay are listed under section 303(d) of the Federal Clean Water Act as impaired for a variety of toxic contaminants that may contribute to reduced population abundance of important fish and invertebrates. The contaminants include: organophosphate and pyrethrin pesticides, mercury, selenium and unknown toxicity. In addition, low DO levels periodically develop in the San Joaquin River in the Stockton Deep Water Ship Channel (DWSC) and in Old and Middle rivers. The low DO levels in the DWSC inhibit the upstream migration of adult fall-run Chinook salmon and adversely impact other resident aquatic organisms. The Central Valley and San Francisco Regional Boards are systematically developing Total Maximum Daily Loads (TMDLs) for all listed pollutants and adopting programs to implement control actions.

There is concern that a number of non-303(d) listed contaminants, such as ammonia, pharmaceuticals, endocrine disrupting compounds and blue-green algal blooms could also limit biological productivity and impair beneficial uses. More work is needed to determine their impact on the aquatic community. Sources of these contaminants include: agricultural, municipal, and industrial wastewater; urban storm water discharges; discharges from wetlands; and channel dredging activities.

Ammonia has emerged as a contaminant of special concern in the Delta. Recent hypotheses are that ammonia is causing toxicity to delta smelt, other local fish, and zooplankton, and is reducing primary production rates in the Sacramento River below the Sacramento Regional Wastewater Treatment Plant (SRWTP) and in Suisun Bay. A third, newer, hypothesis is that ammonia and nitrogen to phosphorus ratios have altered phytoplankton species composition, and these changes have had a detrimental effect on zooplankton and fish population abundance. (Glibert, 2010.)

The SRWTP is the primary source of ammonia to the Delta. (Jassby 2008.) The SRWTP has converted the Delta from a nitrate to an ammonia dominated nitrogen system. (Foe et al. 2010.) Seven-day flow-through bioassays by Werner et al. (2008, 2009) have demonstrated that ammonia concentrations in the Delta are not acutely toxic to delta smelt. Monthly nutrient monitoring by Foe *et al*. (2010) has demonstrated that ammonia concentrations are below the recommended USEPA (1999) chronic criterion for the protection of juvenile fish. Results from the nutrient monitoring suggest that ammonia-induced toxicity to fish is not regularly occurring in the Delta.

Elevated ammonia concentrations inhibit nitrate uptake and that appears to be one factor preventing spring diatom blooms from developing in Suisun Bay. (Dugdale et al. 2007; Wilkerson et al. 2006.) One of the primary hypotheses for the POD is a decrease in the availability of food at the base of the food web. (Sommer et al. 2007.) Staff from the San Francisco Regional Board has informed the Central Valley Regional Board that ammonia may be impairing aquatic life beneficial uses in Suisun Bay (letter to Kathy Harder with the Central Valley Regional Board from Bruce Wolfe of the San Francisco Regional Board dated June 4, 2010).

Ammonia concentrations are higher in the Sacramento River below the SRWTP than in Suisun Bay. This led to a hypothesis that ammonia might be inhibiting nitrate uptake and reducing primary production rates in the Sacramento River and downstream Delta, as occurs in Suisun Bay. Experimental results for the Sacramento River are more ambiguous than for Suisun Bay. (Parker *et al*., 2010.) Five-day cubitainer grow out experiments conducted using water collected above and below the SRWTP usually demonstrated more chlorophyll in water collected below the SRWTP. Short-term bottle primary production rate measurements conducted using water collected above and below the SRWTP also demonstrate no decrease in the rate when normalized by the amount of chlorophyll in the bottle. However, effluent dosed into upstream Sacramento River water at environmentally realistic concentrations does show a decrease in primary production. Elevated ammonia concentrations consistently decrease nitrate uptake. Whether the shift in nitrogen utilization indicates that different algal species are beginning to grow in the ammonia rich water is not known. A recent paper by Glibert (2010) demonstrates significant correlations between the form and concentration of nutrients discharged by the SRWTP, and changes in phytoplankton, zooplankton, and fish abundance in the Delta.

## Salinity

Elevated salinity can impair the uses of water by municipal, industrial, and agricultural users and by organisms that require lower salinity levels. There are at least three factors that may cause salinity levels to exceed water quality objectives in the Delta: saltwater intrusion from the Pacific

Ocean and San Francisco Bay moving into the Delta on high tides during periods of relatively low flows of fresh water through the Delta; salts from agricultural return flows, municipalities, and other sources carried into the southern and eastern Delta with the waters of the San Joaquin River; and localized increases in salinity due to irrigation return flows into dead-end sloughs and low-capacity channels (null zones). The effects of saltwater intrusion are seen primarily in the western Delta. Due to the operation of the State and federal export pumping plants near Tracy, the higher salinity areas caused by salts in the San Joaquin River tend to be restricted to the southeast corner of the Delta. Null zones, and the localized areas of increased salinity associated with them, exist predominantly in three areas of the Delta: Old River between Sugar Cut and the CVP intake; Middle River between Victoria canal and Old River; and the San Joaquin River between the head of Old River and the City of Stockton.

## Suspended Sediments and Turbidity

Turbidity in the Delta is caused by factors that include suspended material such as silts, clays, and organic matter coming from the major tributary rivers; planktonic algal populations; and sediments stirred up during dredging operations to maintain deep channels for shipping. Turbidity affects large river and estuarine fish assemblages because some fishes survive best in turbid (muddy) water, while other species do best in clear water. Studies suggest that changes in specific conductance and turbidity are associated with declines in upper estuary habitat for delta smelt, striped bass, and threadfin shad. Laboratory studies have shown that delta smelt require turbidity for successful feeding.

Turbidity in the Delta has decreased through time. The primary hypotheses to explain the turbidity decrease are: (1) reduced sediment supply; (2) sediment washout from very high inflows during the 1982 to 1983 El Nino; and (3) trapping of sediment by submerged aquatic vegetation. (Wright and Schoellhamer 2004, Jassby et al. 2005, Nobriga et al. 2005, and Brown and Michniuk 2007 as cited in Nobriga et al. 2008.)

## Dissolved Oxygen

Low DO levels are found along the lower San Joaquin River and in certain localized areas of the Delta. Dissolved oxygen impairment is caused, in part, by loads of oxygen demanding substances such as dead algae or waste discharges. Low DO in the Delta occurs mainly in the late summer and coincides with low river flows and high temperatures. Fish vary greatly in their ability to tolerate low DO concentrations, based on the environmental conditions the species has evolved to inhabit. Salmonids are relatively intolerant of low DO concentrations. Within the lower San Joaquin River, DO concentrations can become sufficiently low to impair the passage and/or cause mortality of migratory salmonids. (DFG 3, p. 3; DOI 1, p. 25; TBI/NRDC 3, p. 26.)

The DWSC is a portion of the lower San Joaquin River between the City of Stockton and the San Francisco Bay that has been dredged to allow for the navigation of ocean-going vessels to the Port of Stockton. A 14-mile stretch of the DWSC, from the City of Stockton to Disappointment Slough, is listed as impaired for DO and, at times, does not meet the objectives set forth in the San Joaquin Riverwater quality control plan. Studies have identified three main contributing factors to the problem: loads of oxygen demanding substances that exert an oxygen demand (particularly the death and decay of algae); DWSC geometry, which reduces the assimilative capacity for loads of oxygen demanding substances by reducing the efficiency of natural re-aeration mechanisms and by magnifying the effect of oxygen demanding reactions; and, reduced flow through the DWSC, which reduces the assimilative capacity by reducing upstream inputs of oxygen and increasing the residence time for oxygen demanding reactions. (Central Valley Regional Board 2003.)

### 3.3.4 Biological Setting

The Bay-Delta Estuary is one of the largest, most important estuarine systems for fish and waterfowl production on the Pacific Coast of the United States. The Delta provides habitat for a wide variety of freshwater, estuarine, and marine fish species. Channels in the Delta range from dead-end sloughs to deep, open water areas that include several flooded islands that provide submerged vegetative shelter. The complex interface between land and water in the Delta provides rich and varied habitat for wildlife, especially birds. The Delta is particularly important to waterfowl migrating via the Pacific Flyway as these birds are attracted to the winter-flooded fields and seasonal wetlands. (State Water Board 1999.)

#### <u>Existing Setting</u>

A wide variety of fish are found throughout the waterways of the Central Valley and the Bay-Delta Estuary. About 90 species of fish are found in the Delta. Some species, such as the anadromous fish, are found in particular parts of the Bay-Delta Estuary and the tributary rivers and streams only during certain stages of their life cycle. The Delta's channels serve as a migratory route and nursery area for Chinook salmon, striped bass, white and green sturgeon, American shad, and steelhead trout. These anadromous fishes spend most of their adult lives either in the lower bays of the estuary or in the ocean, moving inland to spawn. Resident fishes in the Bay-Delta Estuary include delta smelt, longfin smelt, threadfin shad, Sacramento splittail, catfish, largemouth and other bass, crappie, and bluegill.

Food supplies for Delta fish communities consist of phytoplankton, zooplankton, benthic invertebrates, insects, and forage fish. The entrapment zone, where freshwater outflow meets and mixes with the more saline water of the Bay, concentrates sediments, nutrients, phytoplankton, some fish larvae, and other fish food organisms. Biological standing crop (biomass) of phytoplankton and zooplankton in the estuary has generally been highest in this zone. However, the overall productivity at the lower trophic levels has decreased over time. (State Water Board 1999.)

#### <u>Non-Native and Invasive Species</u>

Invasive aquatic organisms are known to have deleterious effects on the Delta ecosystem. These effects include reductions in habitat suitability, reductions in food supply, alteration of the aquatic food-web, and predation on or competition with native species. There are many notable examples of exotic species invasions in the Bay-Delta, so much so, that the Delta has been labeled "the most invaded estuary on earth."

Of particular importance potentially in the recent decline in pelagic organisms is the introduction of the Asian clam, *Corbula amurensis*. The introduction of the clam has lead to substantial declines in the lower trophic production of the Bay-Delta Estuary. In addition to reductions in planktonic production caused by *Corbula*, the planktonic food web composition has changed dramatically over the past decade or so. Once dominant copepods in the food web have declined leading to speculation that estuarine conditions have changed to favor alien species. The decrease in these desirable copepods may further increase the likelihood of larval fish starvation or result in decreased growth rates. (State Water Board 2008.)

The proliferation of invasive, aquatic weeds, such as *Egeria densa*, which filter out particulate materials and further reduce planktonic growth, are also having a impact on the Bay-Delta. Areas with low or no flow, such as warm, shallow, dead-end sloughs in the eastern Delta also support objectionable populations of plants during summer months including planktonic blue-green algae and floating and semi-attached aquatic plants such as water primrose, water hyacinth, and *Egeria densa*. All of these plants contribute organic matter that reduces DO levels in the fall, and the floating and semi-attached plants interfere with the passage of small boat traffic. In addition, native fishes in the Bay-Delta face growing challenges associated with competition and predation by non-native fish. (State Water Board 1999; State Water Board 2008.)

**<u>Recent Species Declines</u>**

Historical fisheries within the Central Valley and the Bay-Delta Estuary were considerably different than the fisheries present today. Many native species have declined in abundance and distribution, while several introduced species have become well established. The Sacramento perch is believed to have been extirpated from the Delta; however, striped bass and American shad are introduced species that, until recently, have been relatively abundant and have contributed substantially to California's recreational fishery. (State Water Board 1999.)

In 2005, scientists with the Interagency Ecological Program (IEP) announced observations of a precipitous decline in several pelagic organisms in the Delta, beginning in 2002, in addition to declining levels of zooplankton. Zooplankton are the primary food source for older life stages of species such as delta smelt. The decline in pelagic organisms included delta smelt, striped bass, longfin smelt, and threadfin shad. Scientists hypothesized that at least three general factors may be acting individually, or in concert, to cause this recent decline in pelagic productivity: 1) toxic effects; 2) exotic species effects; and 3) water project effects. Scientists and resources agencies have continued to investigate the causes of the decline, and have prepared plans that identify actions designed to help stabilize the Delta ecosystem and improve conditions for pelagic fish species. (State Water Board 2008.)

In January of 2008, the Pacific Fisheries Management Council reported unexpectedly low Chinook salmon returns to California, particularly to the Central Valley, for 2007. Adult returns to the Sacramento River, the largest of Central Valley Chinook salmon runs, failed to meet resource management goals (122,000-180,000 spawners) for the first time in 15 years. (State Water Board 2008.) The Sacramento River fall Chinook salmon escapement to the Central Valley was estimated to be 88,000 adults in 2007; 66,000 in 2008; and 39,530 – the lowest on record -- in 2009. (PCFFA 2.) The NMFS concluded that poor ocean conditions were a major factor contributing to the low fall-run abundance; however, other conditions may exacerbate these effects. (State Water Board 2008.)

In April 2008, the Pacific Fisheries Management Council and the Commission adopted the most restrictive ocean and coastal salmon seasons ever for California by closing the ocean and coastal fishery to commercial and recreation fishing for the 2008 fishing season. The Commission further banned salmon fishing in all Central Valley rivers, with the exception of limited fishing on a stretch of the Sacramento River. (State Water Board 2008.) The ban on all salmon fishing was extended through the 2009 season, but the restrictions were eased somewhat for 2010.

### 3.3.5 How Flow-Related Factors Affect Public Trust Resources

Flow is important to sustaining the ecological integrity of aquatic ecosystems, including the public trust resources that are the subject of this proceeding. Flow affects water quality, food resources, physical habitat, and biotic interactions. Alterations in the natural flow regime affect aquatic biodiversity and the structure and function of aquatic ecosystems.

In its key points on Delta environmental flows for the State Water Board, the DEFG (DEFG 1) noted that:

- Flow related factors that affect public trust resources include more than just volumes of inflow and outflow and no single rate of flow can protect all public trust resources at all times. The frequency, timing, duration, and rate of change of flows, the tides, and the occurrence of overbank flows, all are important. Seasonal, interannual, and spatial variability in flows, to which native species are adapted, are as important as the quantity of flow. Biological responses to flows rest on combinations of quantity, timing, duration, frequency and how these inputs vary spatially in the context of a Delta that is geometrically complex, highly altered by humans, and fundamentally tidally driven.

- Recent flow regimes in the Delta have contributed to the decline of native species and encouraged non-native species. Flows into and within the estuary affect turbidity, salinity, aquatic plant communities, and nutrients that are important to both native and non-native species. However, flows and habitat structure are often mismatched and now favor non-native species.

- Flow is a major determinant of habitat and transport. The effects of flow on transport and habitat are controlled by the geometry of the waterways. Further, because the geometry of the waterways will change through time, flow regimes needed to maintain desired habitat conditions will also change through time. Delta inflow is an important factor affecting the biological resources of the Delta because inflow has a direct effect on flood plain inundation, in-Delta net channel flows, and net Delta outflows.

- Flow modification is one of the few immediate actions available to improve conditions to benefit native species. However, habitat restoration, contaminant and nutrient reduction, changes in diversions, control of invasive species, as well as flood plain inundation and island flooding all interact with flow to affect aquatic habitats.

# 4. Methods and Data

The notice for the informational proceeding requested scientific information on the volume, quality, and timing of water needed for the Delta ecosystem under different hydrologic conditions to protect public trust resources pursuant to the State Water Board's public trust obligations and the requirements of SB 1. Specifically, the notice focused on Delta outflows, but also requested information concerning the importance of the source of those flows and information concerning adaptive management, monitoring, and special study programs. In addition to the requested information concerning Delta outflows, the State Water Board also received information on Sacramento River inflows, San Joaquin River inflows, hydrodynamics including Old and Middle River flows, and other information that is relevant to protection of public trust resources in the Delta ecosystem. This section presents the recommendations received by the State Water Board and discusses approaches used to evaluate the recommendations and develop flow criteria responsive to SB1.

## 4.1 Summary of Participants' Submittals

Information submitted by interested parties over the course of this proceeding has resulted in the development of a substantive record; submittals are available on the State Water Board's website at:
http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/entity_index.shtml

The exhibits include discussions pertaining to: the State Water Board's public trust obligations; methodologies that should be used to develop flow criteria; the importance of the source of flows when determining outflows; means by which uncertainty should be addressed; and specific recommendations concerning Delta outflows, Sacramento and San Joaquin river inflows, hydrodynamics, operation of the Delta Cross Channel Gates, and floodplain activation.

The State Water Board received a wide range of recommendations for the volume, quantity and timing of flow necessary to protect public trust resources. Delta outflow recommendations ranged from statements that the current state of scientific understanding does not support development of numeric Delta flow criteria that differ from the current outflow objectives included in D-1641 (DWR closing comments; SFWC closing comments) to flow volumes during above normal and wet water year types that are two to four times greater than currently required under D-1641 (TBI/NRDC closing comments; AR/NHI closing comments; EDF closing comments, CSPA closing comments; CWIN closing comments). Appendix A: Summary of Participant Recommendations, provides summary tables of the recommendations received for Delta outflows, Sacramento River inflows, San Joaquin River inflows, hydrodynamics, floodplain inundation, and Delta Cross Channel Gate closures.

## 4.2 Approach to Developing Flow Criteria

Fleenor et al. (2010) examined the following four approaches for prescribing environmental flows for the Delta:

- Unimpaired (quasi-natural) inflows
- Historical impaired inflows that supported more desirable ecological conditions
- Statistical relationships between flow and native species abundance
- The appropriate accumulation of flows estimated to provide specific ecological functions for desirable species and ecosystem attributes based on available literature.

Fleenor *et al*. (2010) concludes:

> "Generally, approaches that rely on data from the past will become more risky as the underlying changes in the Delta accumulate. However, since the objective is to provide flows for species which evolved under past conditions, information on past flows and life history strategies of fish provide considerable insight and context. Aggregate statistical approaches, which essentially establish correlations between past conditions and past species abundance, are likely to be less directly useful as the Delta changes. However, statistical approaches will continue to be useful, especially if developed for causal insights. More focused statistical relationships can be of more enduring value in the context of more causal models, even given underlying changes. In the absence of more process-based science, empirical relationships might be required for some locations and functions on an interim basis. Insights and information can be gained from each approach. Given the importance of the problem and the uncertainties involved,

the strengths of each approach should be employed to provide greater certainty or improve definition of uncertainties."

Among other things, the Fleenor report recommends:

1. Flow prescriptions should be supported preferably by causally or process-based science, rather than correlative empirical relationships or other statistical relationships without supporting ecological basis. Having a greater causal basis for flow prescriptions should make them more effective and readily adapted to improvements in knowledge and changing conditions in the Delta. A more explicit causal basis for flow prescriptions will also create incentives for improved scientific understanding of this system and its management as well as better integration of physical, chemical, and biological aspects of the problem.
2. Ongoing managed and unmanaged changes in the Delta will make any static set of flow standards increasingly irrelevant and obsolete for improving conditions for native fishes. Flows should be tied to habitat, fish, hydrologic, and other management conditions, as well as our knowledge of the system. Flows needed for fish native to the Delta will change.

Information received during this proceeding supports these conclusions and recommendations. The record for this proceeding contains a mix of data and analyses that uses the four approaches identified by Fleenor et al. (2010):

- Unimpaired flows
- Historical impaired inflows that supported more desirable ecological conditions
- Statistical relationships between flow and native species abundance
- Ecological functions-based analysis for desirable species and ecosystem attributes

All four types of information are relied upon to develop the flow criteria in this report. Emphasis, however, is placed on ecological function-based information, followed by information on statistical relationships between flow and native species abundance. In all cases, the criteria are supported by the best available scientific information submitted into the record for this proceeding. The species and ecosystem function-based needs assessments and criteria in this report are supported by references to specific scientific and empirical evidence, and cite to exhibits and testimony in the record or conclusions in published and peer reviewed articles. Criteria based upon statistical relationships between flow and native species abundance are also supported by references to specific scientific and empirical evidence, and cite to exhibits and testimony in the record or conclusions in published and peer reviewed articles.

Furthermore, the conceptual bases for all of the criteria in this report are supported by scientific information on function-based species or ecosystem needs. In other words, there is sufficiently strong scientific evidence to support the need for functional flows. This does not necessarily mean that there is scientific evidence to support *specific* numeric criteria. Recommendations are therefore divided into two categories: Category "A" criteria have more and better scientific information, with less uncertainty, to support specific numeric criteria than do Category "B" criteria. In all cases, the assumptions upon which the criteria are based are identified and discussed. The following steps were followed to develop flow criteria and other recommendations:

1. Establish general goals and objectives for protection of public trust resources in the Delta
2. Identify species to include based on ecological, recreational, or commercial importance
3. Review and summarize species life history requirements, including description of:
    - general life history and species needs
    - population distribution and abundance
    - population abundance and relationship to flow
    - specific population goals
    - species-specific basis for flow criteria
4. Summarize numeric and other criteria for each of: Delta outflows, Sacramento River inflows, San Joaquin River inflows, and hydrodynamics
5. Review other flow-related and non-flow measures that should be considered
6. Provide summary determinations for flow criteria and other measures

The following information was assembled and considered for each species, if available in the record for this proceeding:

- Life history information including timing of migrations
- Seasons or time periods when flow characteristics are most important
- Relationships of species abundance or habitat to Delta outflows, Delta inflows, hydrodynamics, or water quality parameters linked to flow, etc.
- Species environmental requirements (e.g., DO, temperature preferences, salinity, X2 location, turbidity, toxicity to specific pollutants, etc.)
- Relationship of species abundance to invasive species, to the extent possible
- Key quantifiable population responses or habitat characteristics linked to flow
- Mechanisms or hypotheses about mechanisms that link species abundance, habitat, and other metrics to flow or other variables

### 4.2.1 Biological and Management Goals

The goal of this report is discussed in Section 3.1.4 (Scope of this Report). The following biological and management goals are used to guide the development of criteria that support species life history requirements.

***<u>Biological Goals</u>***

- Depending on water year type or hydrologic condition, provide sufficient flow to increase abundance of desirable species that depend on the Delta (longfin smelt, delta smelt, starry flounder, bay shrimp, American shad, and zooplankton).

- Create shallow brackish water habitat for longfin smelt, delta smelt, starry flounder, bay shrimp, American shad, and zooplankton in Suisun Bay (and farther downstream).

- Provide floodplain inundation of appropriate timing and sufficient duration to enhance spawning and rearing opportunities to support Sacramento splittail, Chinook salmon, and other native species.

- Manage net OMR reverse flows and other hydrodynamic conditions to protect sensitive life stages of desirable species.

- Provide sufficient flow in the San Joaquin River to transport salmon smolts through the Delta during spring in order to contribute to attainment of the State Water Board's salmon protection water quality objective. (2009 Bay-Delta Plan, p. 14.)

- Provide sufficient flow in the Sacramento River to transport salmon smolts through the Delta during the spring in order to contribute to the attainment of the salmon protection water quality objective. (*Id.*)

- Provide sufficient flow in eastside streams that flow to the Delta, including the Mokelumne and Consumes rivers, to transport salmon smolts to the Delta during the spring in order to contribute to the attainment of the salmon protection water quality objective.

- Maintain water temperatures and DO in mainstem rivers that flow into the Delta and their tributaries at levels that will support adult Chinook salmon migration, egg incubation, smolting, and early-year and late-year juvenile rearing.

***Management Goals***

- Combine freshwater flows needed to protect species and ecosystem functions in a manner that is comprehensive, does not double count flows, uses an appropriate time step, and is well-documented

- Establish mechanisms to evaluate Delta environmental conditions, periodically review underpinnings of the biological objectives and flow criteria, and change biological objectives and flow criteria when warranted

- Periodically review new research and monitoring to evaluate the need to modify biological objectives and flow criteria

- Do not recommend overly complex flow criteria so as not to infer a greater understanding of specific numeric flow criteria than the available science supports

### 4.2.2 Selection of Species[10]

Information received during the informational proceeding links the abundance and habitat of several key species that live in, move through, or otherwise depend upon for their survival, the Delta and its ecosystem. DFG Exhibits 1 through 4 present information on the relationship between abundance and the quantity, quality, and timing of flow for the following species: (1) Chinook salmon, (2) Pacific herring, (3) longfin smelt, (4) prickly sculpin, (5) Sacramento splittail, (6) delta smelt, (7) starry flounder, (8) white sturgeon, (9) green sturgeon, (10) Pacific lamprey, (11) river lamprey, (12) bay shrimp, (13) mysid shrimp and a copepod, *Eurytemora affinis*, and (14) American shad. In general, the available data and information indicates:

- For many species, abundance is related to timing and quantity of flow (or the placement of X2).
- For many species, more flow translates into greater species production or abundance.
- Species are adapted to use the water resources of the Delta during all seasons of the year, yet for many species, important life history stages or processes consistently

[10] This section is largely drawn from DFG exhibits 1 through 4.

coincide with the winter-spring seasons and its associated increased flows because this is the reproductive season for most native fishes, and the time that most salmonid fishes are emigrating.

- The source, quantity, quality, and timing of Central Valley tributary outflow affects the same characteristics of mainstem river flow into and through the Delta. Flows in all three of these areas, Delta outflows, tributary inflows, and hydrodynamics, influence production and survival of Chinook salmon in both the San Joaquin River and Sacramento River basins.
- Some invasive species negatively influence native species abundance.

This report is consistent with DFG's recommendation to establish flow criteria for species of priority concern that will benefit most by improving flow conditions. (DFG closing comments, p. 3.) Table 2 (from DFG closing comments p.4) identifies select species that have the greatest ecological, commercial, or recreational importance and are influenced by Delta inflows (including mainstem river tributaries) or Delta outflows. The table identifies the species life stage most affected by flows, the mechanism most affected by flows, and the time when flows are most important to the species.

**Table 2. Species of Importance (from DFG closing comments p.4)**

| **Priority Species** | **Life Stage** | **Mechanism** | **Time When Water Flows are Most Important** | **Reference** |
|---|---|---|---|---|
| Chinook salmon (San Joaquin River basin) | Smolt | Outmigration | March – June | DFG Exhibit 1 – page 2; DFG Exhibit 3 – pages 7-10, 21-35. |
| Chinook salmon (Sacramento River basin) | Juvenile | Outmigration | November – June | DFG Exhibit 1 – page 1-2, 6-8 |
| Chinook salmon (San Joaquin River tributaries) | Egg/fry | Temperature, DO, upstream barrier avoidance | October – March | DFG Exhibit 3, pages 2-4; DFG Exhibit 4 |
| Longfin smelt | Egg | Freshwater-brackish habitat | December – April | DFG Exhibit 1 – page 2, 9-12 |
| Longfin smelt | Larvae | Freshwater-brackish habitat; transport; turbidity | December – May | DFG Exhibit 1 – page 2, 9-12 |
| Sacramento Splittail | Adults | Floodplain inundating flows | January – April | DFG Exhibit 1 – page 2, 13-14 |
| Sacramento Splittail | Eggs and larvae | Floodplain habitat persistence | January – May | DFG Exhibit 1 – page 3, 13-14 |

| Priority Species | Life Stage | Mechanism | Time When Water Flows are Most Important | Reference |
|---|---|---|---|---|
| Delta smelt | Larvae and Pre-adult | Transport; habitat | March – November September – November | DFG Exhibit 1 – page 2,14-15 |
| Starry flounder | Settled juvenile; Juvenile-2 yr old | Estuary attraction; habitat | February – May | DFG Exhibit 1 – page 3, 15-16 |
| Bay shrimp | Late-stage larvae and small juveniles | Transport | February – June | DFG Exhibit 1 – page 4; 22-25 |
| Bay shrimp | Juveniles | Nursery habitat | April – June | DFG Exhibit 1 – page 4; 22-25 |
| Mysid shrimp (zooplankton) | All | Habitat | March – November | DFG Exhibit 1 – page 5; 25-26 |
| *Eurytemora affinis* (zooplankton) | All | Habitat | March – May | DFG Exhibit 1 – page 5; 25-26 |
| American shad | Egg/larvae | Transport; dispersal; habitat | March – June | DFG Exhibit 1 – page 5; 26-28 |

While many species found in the Delta are of ecological, commercial, and/or recreational interest, specific flow needs for some of those species may not be directly addressed in this report because: they overlap with the needs of more sensitive species otherwise addressed in the report; the relationships between flow and abundance of those species are not well understood; or the needs of those species may be outside the scope of this report. For example, placement of X2 at certain locations in the Delta to protect longfin smelt or starry flounder will also protect striped bass (*Morone saxatilis*). Striped bass survival from egg to 38 mm is significantly increased as X2 shifts downstream in the estuary. (Kimmerer 2002a.) Kimmerer et al. (2009) showed that as X2 location moved downstream, several measures of striped bass survival and abundance significantly increased, as did several measures of striped bass habitat. Similarly, it is assumed that improved stream flow conditions for Chinook salmon will benefit steelhead, but additional work is needed to assure that these flow criteria are adequate for the protection of steelhead. Adult steelhead in the Central Valley migrate upstream beginning in June, peaking in September, and continuing through February or March. (Hallock *et al*. 1961, Bailey 1954, McEwan and Jackson 1996, as cited in SJRRP FMWG 2009.) Spawning occurs primarily from January through March, but may begin as early as December and may extend through April. (Hallock et al. 1961, as cited in McEwan and Jackson 1996.) Steelhead also rear in tributaries to the Delta throughout the year. Consequently, additional inflow criteria may be needed to protect steelhead at times when flows are not specifically recommended to protect Chinook salmon. As will be discussed in the species needs section for Chinook salmon, additional flow criteria may also be needed to protect various runs and life-stages of Chinook salmon. Adequate information is not currently available, however, upon which to base criteria.

Other species are influenced by very high and infrequent flows, far in excess of what could be provided by the State and federal water projects because they occur only during very wet years when project operations are not controlling. For example, white sturgeon are influenced by high winter and spring Delta and river flows (March-June Delta outflow greater than 60,000 cfs) that attract migrating adults, cue spawning, transport larvae, and enhance nursery habitat. These types of flows occur episodically in very wet years. Historical flow patterns combined with the unique life history (long-lived, late maturing, long intervals between spawning, high fecundity) result in infrequent strong recruitment.

There is adequate information in the record, and adequate time to evaluate life history requirements and develop species-specific flow criteria for the following species:

- Chinook Salmon (various runs) (primarily mirgration flows)
- American Shad
- Longfin Smelt
- Delta Smelt
- Sacramento Splittail
- Starry Flounder
- Bay Shrimp
- Zooplankton

### 4.2.3 Life History Requirements – Anadromous Species

Following are life history and species-specific requirements for Chinook Salmon (including Sacramento River winter-run, Central Valley spring-run, Central Valley fall-run, and Central Valley late fall-run) and American shad.

**Chinook Salmon (Sacramento River Winter-Run, Central Valley Spring-Run, Central Valley Fall-Run, and Central Valley Late Fall-Run)**

***Status***

Sacramento River winter-run Chinook salmon is listed as endangered pursuant to the ESA and the CESA. Central Valley spring-run Chinook salmon is listed as threatened pursuant to both the ESA and the CESA. Central Valley fall/late fall-run Chinook salmon are classified as species of special concern pursuant to the ESA.[11]

***Life History[12]***

Chinook salmon exhibit two generalized freshwater life history types (Healey 1991). Adult “stream-type” Chinook salmon enter freshwater up to several months before spawning, and juveniles reside in freshwater for a year or more, whereas “ocean-type” Chinook salmon spawn soon after entering freshwater and migrate to the ocean as fry or parr within their first year. Adequate instream flows and cool water temperatures are more critical for the survival of Chinook salmon exhibiting a stream-type life history due to over-summering by adults and/or juveniles.

[11] Source: http://www.dfg.ca.gov/fish/Resources/Chinook/index.asp

[12] This section was largely extracted from NMFS 3, pages 76 through 79.

Chinook salmon typically mature between 2 and 6 years of age (Myers et al. 1998). Freshwater entry and spawning timing generally are thought to be related to local water temperature and flow regimes. Runs are designated on the basis of adult migration timing. However, distinct runs also differ in the degree of maturation of the fish at the time of river entry, thermal regime, and flow characteristics of their spawning sites, and the actual time of spawning (Myers et al. 1998). Both winter-run and spring-run tend to enter freshwater as immature fish, migrate far upriver, and delay spawning for weeks or months. Fall-run enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry (Healey 1991).

During their upstream migration, adult Chinook salmon require streamflows sufficient to provide olfactory and other orientation cues used to locate their natal streams. Adequate streamflows are necessary to allow adult passage to upstream holding habitat. The preferred temperature range for upstream migration is 38ºF to 56ºF (Bell 1991, DFG 1998). Boles (1988) recommends water temperatures below 65ºF for adult Chinook salmon migration, and Lindley et al. (2004) report that adult migration is blocked when temperatures reach 70ºF, and that fish can become stressed as temperatures approach 70ºF.

Information on the migration rates of adult Chinook salmon in freshwater is scant and primarily comes from the Columbia River basin (Matter and Sanford 2003). Keefer et al. (2004) found migration rates of Chinook salmon ranging from approximately 10 kilometers (km) per day to greater than 35 km per day and to be primarily correlated with date, and secondarily with discharge, year, and reach, in the Columbia River basin. Matter and Sanford (2003) documented migration rates of adult Chinook salmon ranging from 29 to 32 km per day in the Snake River.

Adult Chinook salmon inserted with sonic tags and tracked throughout the Delta and lower Sacramento and San Joaquin rivers were observed exhibiting substantial upstream and downstream movement in a random fashion, for several days at a time, while migrating upstream (CALFED 2001). Adult salmonids migrating upstream are assumed to make greater use of pool and mid-channel habitat than channel margins (Stillwater Sciences 2004), particularly larger salmon such as Chinook salmon, as described by Hughes (2004). During their upstream migration, adults are thought to be primarily active during twilight hours.

Spawning Chinook salmon require clean, loose gravel in swift, relatively shallow riffles or along the margins of deeper runs, and suitable water temperatures, depths, and velocities for redd construction and adequate oxygenation of incubating eggs. Chinook salmon spawning typically occurs in gravel beds that are located at the tails of holding pools (USFWS 1995). The range of water depths and velocities in spawning beds that Chinook salmon find acceptable is very broad. The upper preferred water temperature for spawning Chinook salmon is 55ºF to 57ºF (Chambers 1956, Smith 1973, Bjornn and Reiser 1991, and Snider 2001).

Incubating eggs are vulnerable to adverse effects from floods, siltation, desiccation, disease, predation, poor gravel percolation, and poor water quality. Studies of Chinook salmon egg survival to hatching conducted by Shelton (1995) indicated 87% of fry emerged successfully from large gravel with adequate subgravel flow. The optimal water temperature for egg incubation ranges from 41ºF to 56ºF [44ºF to 54ºF (Rich 1997), 46ºF to 56ºF (NMFS 1997), and 41ºF to 55.4ºF (Moyle 2002)]. A significant reduction in egg viability occurs at water temperatures above 57.5ºF and total embryo mortality can occur at temperatures above 62ºF (NMFS 1997). Alderdice and Velsen (1978) found that the upper and lower temperatures resulting in 50% pre-hatch mortality were 61ºF and 37ºF, respectively, when the incubation temperature was held constant. As water temperatures increase, the rate of embryo malformations also increases, as well as the susceptibility to fungus and bacterial infestations. The length of development for Chinook salmon embryos is dependent on the ambient water temperature surrounding the egg pocket in the redd. Colder water necessitates longer development times as metabolic processes are slowed. Within the appropriate water temperature range for embryo incubation, embryos hatch in 40 to 60 days, and the yolk-sac fry remain in the gravel for an additional 4 to 6 weeks before emerging from the gravel.

During the 4 to 6 week period when alevins remain in the gravel, they utilize their yolk-sac to nourish their bodies. As their yolk-sac is depleted, fry begin to emerge from the gravel to begin exogenous feeding in their natal stream. Fry typically range from 25 mm to 40 mm at this stage. Upon emergence, fry swim or are displaced downstream (Healey 1991). The post-emergent fry disperse to the margins of their natal stream, seeking out shallow waters with slower currents, finer sediments, and bank cover such as overhanging and submerged vegetation, root wads, and fallen woody debris, and begin feeding on zooplankton, small insects, and other microcrustaceans. Some fry may take up residence in their natal stream for several weeks to a year or more, while others are displaced downstream by the stream’s current. Once started downstream, fry may continue downstream to the estuary and rear there, or may take up residence in river reaches farther downstream for a period of time ranging from weeks to a year (Healey 1991).

Fry then seek nearshore habitats containing riparian vegetation and associated substrates important for providing aquatic and terrestrial invertebrates, predator avoidance, and slower velocities for resting (NMFS 1996). The benefits of shallow water habitats for salmonid rearing have been found to be more productive than the main river channels, supporting higher growth rates, partially due to higher prey consumption rates, as well as favorable environmental temperatures (Sommer et al. 2001).

When juvenile Chinook salmon reach a length of 50 to 57 mm, they move into deeper water with higher current velocities, but still seek shelter and velocity refugia to minimize energy expenditures (Healey 1991). Catches of juvenile salmon in the Sacramento River near West Sacramento exhibited larger-sized juveniles captured in the main channel and smaller-sized fry along the margins (USFWS 1997). When the channel of the river is greater than 9 to 10 feet in depth, juvenile salmon tend to inhabit the surface waters (Healey 1982). Migrational cues, such as increasing turbidity from runoff, increased flows, changes in day length, or intraspecific competition from other fish in their natal streams, may spur outmigration of juveniles from the upper Sacramento River basin when they have reached the appropriate stage of maturation (Kjelson et al. 1982, Brandes and McLain 2001).

As fish begin their emigration, they are displaced by the river’s current downstream of their natal reaches. Similar to adult movement, juvenile salmonid downstream movement is crepuscular. Juvenile Chinook salmon migration rates vary considerably presumably depending on the physiological stage of the juvenile and hydrologic conditions. Kjelson *et al*. (1982) found Chinook salmon fry to travel as fast as 30 km per day in the Sacramento River, and Sommer et *al.* (2001) found travel rates ranging from approximately 0.5 miles up to more than 6 miles per day in the Yolo Bypass. As Chinook salmon begin the smoltification stage, they prefer to rear further downstream where ambient salinity is up to 1.5 to 2.5 parts per thousand (ppt, Healey 1980, Levy and Northcote 1981).

Fry and parr may rear within riverine or estuarine habitats of the Sacramento River, the Delta, and their tributaries (Maslin et al. 1997, Snider 2001). Within the Delta, juvenile Chinook salmon forage in shallow areas with protective cover, such as intertidal and subtidal mudflats, marshes, channels, and sloughs (McDonald 1960, Dunford 1975, Meyer 1979, Healey 1980). Cladocerans, copepods, amphipods, and larvae of diptera, as well as small arachnids and ants are common prey items (Kjelson et al. 1982, Sommer et al. 2001, MacFarlane and Norton 2002). Shallow water habitats are more productive than the main river channels, supporting higher growth rates, partially due to higher prey consumption rates, as well as favorable environmental temperatures (Sommer et al. 2001). Optimal water temperatures for the growth of juvenile Chinook salmon in the Delta are between 54ºF to 57ºF (Brett 1952). In Suisun and San Pablo bays, water temperatures reach 54ºF by February in a typical year. Other portions of the Delta (*i.e*., South Delta and Central Delta) can reach 70ºF by February in a dry year. However, cooler temperatures are usually the norm until after the spring runoff has ended.

Within the estuarine habitat, juvenile Chinook salmon movements are dictated by the tidal cycles, following the rising tide into shallow water habitats from the deeper main channels, and returning to the main channels when the tide recedes (Levings 1982, Levy and Northcote 1982, Levings et al. 1986, Healey 1991). As juvenile Chinook salmon increase in length, they tend to school in the surface waters of the main and secondary channels and sloughs, following the tides into shallow water habitats to feed (Allen and Hassler 1986). In Suisun Marsh, Moyle et al. (1989) reported that Chinook salmon fry tend to remain close to the banks and vegetation, near protective cover, and in dead-end tidal channels. Kjelson et al. (1982) reported that juvenile Chinook salmon demonstrated a diel migration pattern, orienting themselves to nearshore cover and structure during the day, but moving into more open, offshore waters at night. The fish also distributed themselves vertically in relation to ambient light. During the night, juveniles were distributed randomly in the water column, but would school up during the day into the upper 3 meters of the water column. Available data indicate that juvenile Chinook salmon use Suisun Marsh extensively both as a migratory pathway and rearing area as they move downstream to the Pacific Ocean. Juvenile Chinook salmon were found to spend about 40 days migrating through the Delta to the mouth of San Francisco Bay and grew little in length or weight until they reached the Gulf of the Farallones (MacFarlane and Norton 2002). Based on the mainly oceantype life history observed (*i.e.*, fall-run), MacFarlane and Norton (2002) concluded that unlike other salmonid populations in the Pacific Northwest, Central Valley Chinook salmon show little estuarine dependence and may benefit from expedited ocean entry.

### *Population Distribution and Abundance*

Four seasonal runs of Chinook salmon occur in the Central Valley, with each run defined by a combination of adult migration timing, spawning period, and juvenile residency and smolt migration periods. (Fisher 1994 as cited in Yoshiyama et al. 2001 p. 73.) The runs are named after the season when adults move upstream to migrate-- winter, spring, fall, and late-fall. The Sacramento River basin supports all four runs resulting in adult salmon being present in the basin throughout the year. (Stone 1883a; Rutter 1904; Healey 1991; Vogel and Marine 1991 as cited in Yoshiyama *et. al,* 2001 p. 73.) Historically, different runs occurred in the same streams staggered in time to correspond to the appropriate stream flow regime for which that species evolved, but overlapping. (Vogel and Marine 1991; Fisher 1994 as cited in Yoshiyama et al., 2001, p. 73.) Typically, fall and late-fall runs spawn soon after entering natal streams and spring and winter runs typically "hold" for up to several months before spawning. (Rutter 1904; Reynolds and others 1993 as cited in Yoshiyama *et. al,* 2001, p. 73.) These runs and their life-cycle timing are summarized in Table 3 and described in more detail below.

<u>Winter-Run</u> - Due to a need for cool summer flows, Sacramento River winter-run originally likely only spawned in the upper Sacramento River tributaries, including the McCloud, Pit, Fall, and Little Sacramento rivers and Battle Creek. (NMFS 5, p. 16.) As a result of construction of

Shasta and Keswick Dams, today all spawning habitat above Keswick Dam has been eliminated and approximately 47 of the 53 miles of habitat in Battle Creek has been eliminated. (Yoshiyama et al. 1996, as cited in NMFS 5, p. 16.) Currently, winter-run habitat is likely limited to the Sacramento River reach between Keswick Dam downstream of the Red Bluff Diversion Dam. (NMFS 5, p. 16.)

The winter-run population is currently very vulnerable due to its low population numbers and the fact that only one population exists. (Good et al. 2005, as cited in NMFS 5, p. 16.) In the late 1960s escapement was near 100,000 fish declining to fewer than 200 fish in the 1990s. (*Id*.) Recent escapement estimates from 2004 to 2006 averaged 13,700 fish. (DFG Website 2007, as cited in NMFS 5, p. 16.) However, in 2007 and 2008 escapements were less than 3,000 fish. Since 1998, hatchery produced winter-run have been released likely contributing to the observed increased escapement numbers. (Brown and Nichols 2003 as cited in NNFS 5, p. 16.) In addition, a temperature control device was installed on Shasta Dam in 1997 likely improving conditions for winter-run. (NMFS 5, p. 18.)

<u>Spring-Run</u> - Historically, spring-run were likely the most abundant salmonid in the Central Valley inhabiting headwater reaches of all major river systems in the Central Valley in the absence of natural migration barriers. (NMFS 5, p. 28.) Since the 1880s, construction of dams and other factors have significantly reduced the numbers and range of spring-run in the Central Valley. (*Id*.) Currently, the only viable populations occur on Mill, Deer, and Butte creeks, but those populations are small and isolated. (DFG 1998, as cited in NMFS 5, p. 28.) In addition, the Feather River Fish Hatchery which opened in 1967 produces spring-run salmon. However, significant hybridization of these hatchery fish with fall-run has occurred. (NMFS 5, p. 28-31.)

Historically, Central Valley spring-run numbers were estimated to be as large as 600,000 fish. (DFG 1998 as cited in NMFS 5, p. 28.) Nearly 50,000 spring-run adults were counted on the San Joaquin River prior to construction of Friant Dam. (Fry 1961 as cited in NMFS 5, p. 28.) Shortly after construction of Friant Dam, spring-run were extirpated on the San Joaquin River. (Yoshiyama et al. 1998 as cited in NMFS 5, p. 28.) Since 1970, estimates of spring-run populations in the Sacramento River have been as high as 30,000 fish and as low as 3,000 fish. (NMFS 5, p. 28.)

<u>Fall-Run</u> - Historically, fall run likely occurred in all Central Valley streams that had adequate flows during the fall months, even if the streams were intermittent during other parts of the year. (Yoshiyama *et. al* 2001, p. 74.) Due to their egg-laden and deteriorating physical condition, fall-run likely historically spawned in the valley floor and lower foothill reaches and probably were limited in their upstream migration. (Rutter 1904 as cited in Yoshiyama *et. al* 2001, p. 74.)

Currently, fall-run Chinook inhabit both the Sacramento and San Joaquin river basins and are currently the most abundant of the Central Valley races, contributing to large commercial and recreational fisheries in the ocean and popular sportfisheries in the freshwater streams. Fall-run Chinook are raised at five major Central Valley hatcheries which release more than 32 million smolts each year. In the past few years, there have been large declines in fall-run populations with escapements of 88,0000 and 66,000 fish in 2007 and 2008. (NMFS 2009, p. 4.) NMFS concluded that the recent declines were likely primarily due to poor ocean conditions in 2005 and 2006. (*Id*.) Other factors contributing to the decline of fall-run include: loss of spawning grounds due to dams and other factors, degradation of spawning habitat from water diversions, introduced species, altered sediment dynamics, hatchery practices, degraded water quality, and loss of riparian and estuarine habitat. (*Id*.)

Late-Fall Run - Historically, late fall-run probably spawned in the mainstem Sacramento River and major tributary reaches and possibly in the San Joaquin River upstream of its tributaries. (Hatton and Clark 1942; Van Cleve 1945; Fisher 1994 as cited in Yoshiyama *et. al* 2001.) Today, late-fall run are mostly found in the upper Sacramento River where the river remains deep and cool enough in the summer for juvenile rearing. (Moyle 2002, p. 254.) The late fall-run has continued low, but potentially stable abundance. (NMFS 2009, p. 4.) Estimates from 1992 ranged from 6,700 to 9,700 fish and in 1998 were 9,717 fish. However, changes in estimation methods, lack of data, and hatchery influences make it difficult to accurately estimate abundance trends for this run. (*Id*.)

**Table 3. Generalized Life History Timing of Central Valley Chinook Salmon Runs**

| | **Migration Period** | **Peak Migration** | **Spawning Period** | **Peak Spawning** | **Juvenile Emergence Period** | **Juvenile Stream Residency** |
|---|---|---|---|---|---|---|
| **Sacramento River Basin Late Fall-Run** | October–April | December | Early January–April | February–March | April-June | 7-13 months |
| **Winter-Run** | December-July | March | Late April-early August | May-June | July-October | 5-10 months |
| **Spring-Run** | March-September | May- June | Late August-October | Mid-September | November-March | 3-15 months |
| **Fall Run** | June-December | September-October | Late September-December | October-November | December-March | 1-7 months |
| **San Joaquin (Tuolumne River) Fall-Run** | October-early January | November | Late October-January | November | December-April | 1-5 months |

Source: Yoshiyama *et al*. (1998) as cited in Moyle 2002, p. 255.

### *Population Abundance and Relationship to Flow*

Delta outflows and inflows affect rearing conditions and migration patterns for Chinook salmon in the Delta watershed. Freshwater flow serves as an important cue for upstream adult migration and directly affects juvenile survival and abundance as they move downstream through the Delta. (DOI 1, p. 23.) Decreased flows may decrease migration rates and increase exposure to unsuitable water quality and temperature conditions, predators, and entrainment at water diversion facilities. (DFG 1, p. 1.) For the most part, relationships between salmon survival and abundance have been developed using tributary inflows rather than Delta outflows, however, the Delta is an extension of the riverine environment until salmon reach the salt water interface. (DOI 1, p. 29.) Prior to development and channelization, the Delta provided hospitable habitat for salmon. With channelization and other development, the environment is no longer hospitable for salmon. As a result, the most beneficial Delta outflow pattern for salmon may currently be one that moves salmon through the Delta faster. (*d*.)

Salmon respond behaviorally to variations in flows. Monitoring shows that juvenile and adult salmon begin migrating during the rising limb of the hydrograph. (DOI 1, p. 30.) For juveniles, pulse flows appear to be more important than for adults. (*Id*.) For adults, continuous flows through the Delta and up to each of the natal tributaries appears to be more important. (*Id*.) Flows and water temperatures are also important to maintain populations with varied life history strategies in different year types to insure continuation of the species over different hydrologic and other conditions. For salmon migrating as fry within a few days of emigration from redds, increased flows provide improved transport downstream and improved rearing habitat, and for salmon that stay in the rivers to rear, increased flows provide for increased habitat and food production. (DOI 1, 30.)

### *Population Abundance Goal*

The immediate goal is to significantly improve survival of all existing runs of Chinook salmon that migrate through the Delta in order to facilitate positive population growth in the short term and subsequently achieve the narrative salmon protection objective identified in the 2006 Bay-Delta Plan to double the natural production of Chinook salmon from the average production from 1967 to 1991 consistent with the provisions of State and federal law. (State Water Board 2006a, p. 14.)

### *Species- Specific Recommendations*

<u>Delta Outflow</u>

No specific Delta outflow criteria are recommended for Chinook salmon. Any flow needs would generally be met by the following inflow criteria and by the Delta outflow criteria determined for estuarine dependant species discussed elsewhere in this report.

<u>Sacramento River Inflows</u>

The 2006 Bay-Delta Plan includes flow objectives for the Sacramento River at Rio Vista for the protection of fish and wildlife beneficial uses from September through December ranging from 3,000 to 4,500 cfs. (State Water Board 2006a, p. 15.) These flow objectives are in part intended to provide attraction and transport flows and suitable habitat conditions for Chinook salmon. (State Water Board 2006b, p. 49.) The 2006 Bay-Delta Plan includes Delta outflow objectives for the remainder of the year, which effectively provide Sacramento River inflows. However, the Bay-Delta Plan does not include any specific Sacramento River flow requirements for the remainder of the year, including the critical spring period.

Habitat alterations in the Delta limit Sacramento River salmon production primarily through reduced survival during the outmigrant (smolt) stage. Decreases in flow through the estuary, increased temperatures, and the proportion of flow diverted through the Delta Cross Channel and Georgiana Slough on the Sacramento River are associated with lower survival in the Delta of marked juvenile fall-run Sacramento River salmon. (DOI 1, p. 24.) In 1981 (p. 17-18) and 1982 (p. 404), Kjelson et al. reported that flow was positively correlated with juvenile fall-run Chinook salmon survival through the Delta and that temperature was negatively correlated with survival. In testimony before the State Water Board in 1987 Kjelson presented additional analyses that again showed that survival of fall-run Chinook salmon smolts through the Delta between Sacramento and Suisun Bay was found to be positively correlated to flow and negatively correlated to water temperature. (p. 36.) Smolt survival increased with increasing Sacramento River flow at Rio Vista, with maximum survival observed at or above about 20,000 and 30,000 cfs from April through June (p. 36), while no apparent relationship was found at flows between 7,000 and 19,000 cfs (p. 27), suggesting a potential threshold response to flow. Smolt survival was also found to be highest when water temperatures were below 66ºF. (p. 61.) In addition to increased survival, juvenile abundance has also been found to be higher with greater Sacramento River flow. (DFG 3, pp. 1 and 6.) The abundance of juvenile Chinook salmon leaving the Delta at Chipps Island was found to be highest when Rio Vista flows averaged above 20,000 cfs from April through June. (*Id*.)

Dettman et al. (1987) reanalyzed data from the 1987 Kjelson experiments and found a positive correlation between an index of spawning returns, based on coded-wire tagged fish, and both

June and July outflow from the Delta. (p. 1.) In 1989, Kjelson and Brandes updated and confirmed Kjelson's 1987 findings again reporting that survival of smolts through the Delta from Sacramento to Suisun Bay was highly correlated to mean daily Sacramento River flow at Rio Vista. (p. 113.) In the State Water Board's 1992 hearings, USFWS (1992) presented additional evidence, based on data collected from 1988 to 1991, that increased flow in the Delta may increase migration rates of both wild and hatchery fish migrating from the North Delta (Sacramento and Courtland) to Chipps Island. (DOI 1, p. 26.)

In 2001, Brandes and McLain confirmed the relationships between water temperature, flow, and juvenile salmonid survival. (p. 95.) In 2006, Brandes et al. updated findings regarding the relationship between Sacramento River flows and survival and found that the catch of Chinook salmon smolts surveyed at Chipps Island between April and June of 1978 to 2005 was positively correlated with mean daily Sacramento River flow at Rio Vista between April and June. (p. 41-46.)

In addition to the flow versus juvenile fall-run Chinook salmon survival relationships discussed above, several studies show that loss of migrating salmonids within Georgiana Slough and the interior Delta is approximately twice that of fish remaining in the mainstem Sacramento River. (Kjelson and Brandes 1989; Brandes and McLain 2001; Vogel 2004, 2008; and Newman 2008 as cited in NMFS 3, p. 640). Recent studies and modeling efforts have found that increasing Sacramento River flow such that tidal reversal does not occur in the vicinity of Georgiana Slough and at the Cross Channel Gates would lessen the proportion of fish diverted into channels off the mainstem Sacramento River. (Perry et al. 2008, 2009.) Thus, closing the Delta Cross Channel and increasing the flow on the Sacramento River to levels where there is no upstream flow from the Sacramento River entering Georgiana Slough on the flood tide during the juvenile salmon migration period (November to June) will likely reduce the number of fish that enter the interior Delta and improve survival. (DOI 1, p. 24.) To achieve no bidirectional flow in the mainstem Sacramento River near Georgiana Slough, flow levels of 13,000 (personal communication Del Rosario) to 17,000 cfs at Freeport are needed. (DOI 1, p. 24.)

Monitoring of emigration of juvenile Chinook salmon on the lower Sacramento River near Knights Landing also indicates a relationship between timing and magnitude of flow in the Sacramento River and the migration timing and survival of Chinook salmon approaching the Delta from the upper Sacramento River basin. (Snider and Titus 1998, 2000a, 2000b, 2000c, and subsequent draft reports and data as cited in DFG 1, p. 7.) The emigration timing of juvenile late fall, winter, and spring-run Chinook salmon from the upper Sacramento River basin depends on increases in river flow through the lower Sacramento River in fall, with significant precipitation in the basin by November to sustain downstream migration of juvenile Chinook salmon approaching the Delta. (Titus 2004 as cited in DFG 1, p. 7.) Sacramento River flows at Wilkins Slough of 15,000 to 20,000 cfs following major precipitation events are associated with increased emigration. (DFG 1, p. 7 and NMFS 7, p. 2-4.)

Delays in precipitation producing flows result in delayed emigration which may result in increased susceptibility to in-river mortality from predation and poor water quality conditions. (DFG 1, p. 7.) Allen and Titus (2004) suggest that the longer the delay in migration, the lower the survival of juvenile salmon to the Delta. (as cited in DFG 1, p. 7.) DFG indicates that juvenile Chinook salmon appear to need increases in Sacramento River flow that correspond to flows in excess of 20,000 cfs at Wilkins Slough by November with similar peaks continuing past the first of the year. (DFG 1, p. 7.) Pulse flows in excess of 15,000 to 20,000 cfs may also be necessary to erode sediment in the upper Sacramento River downstream of Shasta to create turbid inflow pulses to the Delta. (AR/NHI 1, p. 32.)

Salmon are the only species considered for the Sacramento River inflow criteria; discussion of the flow criteria for Sacramento River inflows is therefore continued in Section 5.2, Sacramento River Inflow criteria.

San Joaquin River Inflows

Currently the Merced, Tuolumne, and Stanislaus river tributaries to the San Joaquin River support fall-run Chinook salmon. Historically spring-run also inhabited the basin. Pursuant to the San Joaquin River Restoration effort, there are plans to reintroduce spring-run Chinook salmon to the main-stem river beginning in 2012. Since the 1980s (1980-1989), San Joaquin basin fall-run Chinook salmon escapement numbers have declined from approximately 26,000 fish to 13,000 fish in the 2000s (2000-2008). (TBI/NRDC 3, p. 22.) Flow related conditions are believed to be a significant cause of this decline.

The 2006 Bay-Delta Plan includes flow objectives for the San Joaquin River at Vernalis, largely for the protection of fall-run Chinook salmon. The plan includes base flows during the spring (February through June with the exception of mid-April through mid-May) that vary between 700 and 3,420 cfs based on water year type and required location of X2. To improve juvenile fall-run Chinook salmon outmigration, the Plan also includes spring pulse flows (mid-April through mid-May) that vary between 3,110 and 8,620 cfs, however, those flows have never been implemented and have instead been replaced with the Vernalis Adaptive Management Plan (VAMP) flow targets for the past 10 years. The VAMP flows are lower than the pulse flow objectives and vary between 2,000 and 7,000 cfs based on existing flows and other conditions. (State Water Board 2006a, p. 24-26.) The 2006 Bay-Delta Plan also includes a flow objective of 1,000 to 2,000 cfs during October to support adult fall-run Chinook salmon migration. (State Water Board 2006b, p. 15-16.) The 2006 Bay-Delta Plan does not include any specific flow requirements during the remainder of the year. (State Water Board 2006b, pg. 50.)

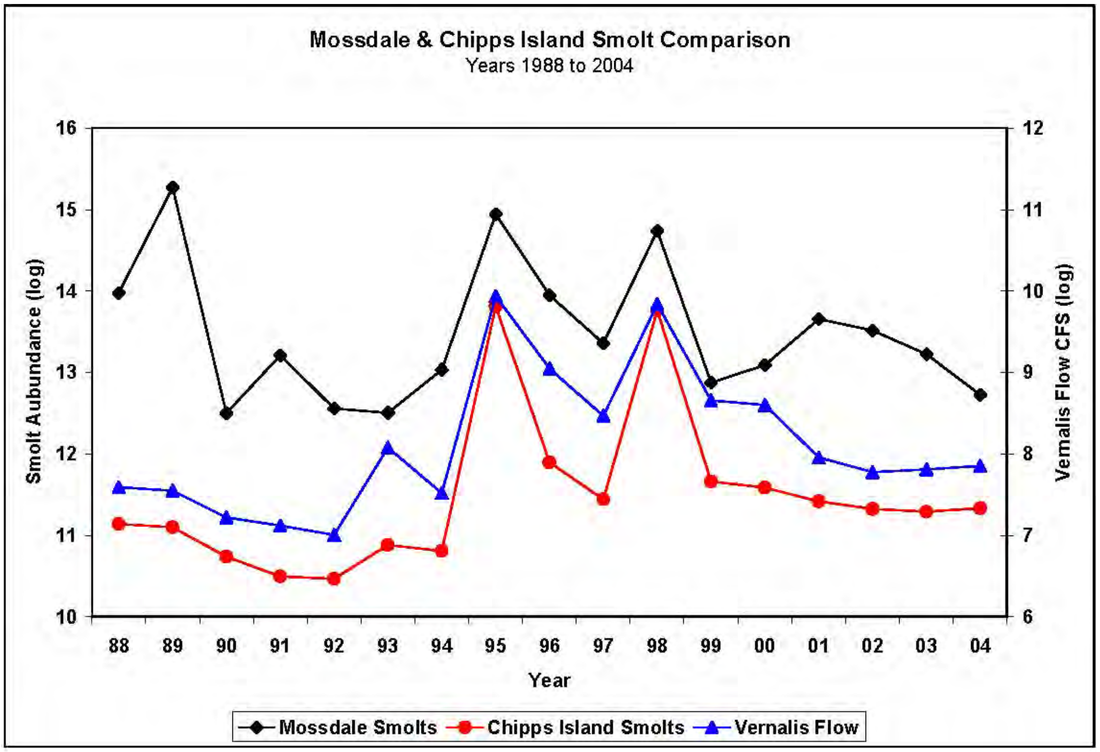
Inflows from the San Joaquin River affect various life stages of Chinook salmon including adult migration, spawning, egg incubation, juvenile rearing, and juvenile emigration to the ocean. Evidence indicates that to maintain a viable Chinook salmon population, escapements should not decline below approximately 833 adult salmon per year (a total of 2,500 salmon in 3 years), and fluctuations in escapement between wet and dry years should be reduced by increasing dry year escapements and the percentages of hatchery fish should be reduced to no more than 10%. (Lindley and others 2007, as cited in CSPA 14, p. 3-4.) Mesick estimates that the Tuolumne River population is currently at a high risk of extinction (Mesick 2009); and that the Stanislaus and Merced river populations are also likely soon to be at a high risk of extinction due to high percentages of hatchery fish. (CSPA 7, p.4.)

Mesick estimates that the decline in escapement on the Tuolumne River from 130,000 salmon in the 1940s to less than 500 in recent years is primarily due to inadequate minimum instream flow releases from La Grange Dam in late winter and spring during non-flood years. (CSPA 14, p. 1.) Mesick suggests that escapement has been primarily determined by the rate of juvenile survival, which is primarily determined by the magnitude and duration of late winter and spring flows since the 1940s. (CSPA 14, p. 2.) Mesick indicates that other analyses show that spawner abundance, spawning habitat degradation, and the harvest of adult salmon in the ocean have not caused the decline in escapement. (CSPA 14, p. 1.)

Successful adult Chinook salmon migration depends on environmental conditions that cue the response to return to natal streams. Optimal conditions help to reduce straying and maintain egg viability and fecundity rates. (DFG 3, p. 2 and CSPA 7, p. 1.) Analyses of flow needs for the protection of adult fall-run migration conducted by Hallock and others from 1964 to 1967 indicate that the presence of Sacramento River water in the central and south Delta channels results in migration delays for both San Joaquin River and Sacramento River basin salmon. (Hallock et al., 1970 as cited in DOI 1, p. 25.) These analyses also show that reverse flows on the San Joaquin River delay and potentially hamper migration. (*Id.*) In addition, analyses by Hallock show that water temperatures in excess of 65˚ F and low DO conditions of less than 5 mg/l in the San Joaquin River near Stockton act as a barrier to adult migration. (as cited in AFRP 2005, p. 11.) Delayed migration may result in reduced gamete viability under elevated temperatures and mortality to adults prior to spawning. (AFRP 2005, p. 12.)

Mesick found that up to 58% of Merced River Hatchery Chinook salmon strayed to the Sacramento River Basin when flows in the San Joaquin River were less than 3,500 cfs for ten days in late October, but stray rates were less than 6% when flows were at least 3,500 cfs. (CSPA 14, p. 15 and CSPA 7, p. 1.) Mesick indicates that providing 1,200 cfs flows from the tributaries to the San Joaquin River (Merced, Tuolumne, and Stanislaus) for ten days in late October increases escapement by an average of 10%. (Mesick 2009 as cited in CSPA 7, p. 1.) The 2005 AFRP includes similar recommendations for flows of 1,000 cfs from each of the San Joaquin River tributaries. (AFRP, p. 12.) Such flows would likely improve DO conditions, temperatures, and olfactory homing fidelity for San Joaquin basin salmon. (Harden Jones 1968, Quinn et al. 1989, Quinn 1990 as cited in EDF 1, p. 48.) To achieve olfactory homing fidelity and continuous flows for adult migration, the physical source of this water is at least as important as the volume or rate of flow, especially given that the entire volume of the San Joaquin River during the fall period is typically diverted at the southern Delta export facilities. (EDF 1. p. 48.) Even in the absence of exports, it is necessary for the scent of the San Joaquin basin watershed to enter the Bay in order for adult salmonids to find their way back to their natal rivers. (NMFS 2009, p.407 as cited in EDF 1, p. 48.)

Outmigration success of juvenile Chinook salmon is affected by multiple factors, including water diversions and conditions related to flow. Data show that smolt survival and resulting adult production is better in wet years. (Kjelson and Brandes, 1989, SJRGA, 2007 as cited in DOI 1, p. 24.) VAMP analyses indicate that San Joaquin River flow at Vernalis is positively associated with the probability of survival for outmigrating smolts from Dos Reis (downstream of the Old River bifurcation) to the Delta (Jersey Point). (Newman, 2008 as cited in DOI 1, p. 24.) A positive relationship has also been shown between salmon survival indices and flow at Jersey Point for fish released at Jersey Point. (USFWS 1992, p. 21 as cited in DOI 1, p. 24.) Data indicate that maximum San Joaquin basin adult fall-run chinook salmon escapement may be achieved with flows exceeding 20,000 cfs at Vernalis during the smolt emigration period of April 15 through June 15. (2006 VAMP report page 65; DOI 1, p. 25.) As indicated below in Figure 9, DFG found that more spring flow from the San Joaquin River tributaries results in more juvenile salmon leaving the tributaries, more salmon successfully migrating to the South Delta, and more juvenile salmon surviving through the Delta. (DFG 3, p. 17.) DFG concludes that the primary mechanism needed to substantially produce more smolts at Jersey Point is to substantially increase the spring Vernalis flow level (magnitude, duration, and frequency) which will produce more smolts leaving the San Joaquin River tributaries, and produce more smolts surviving to, and through, the South Delta. (DFG 3, p. 17-18.) DFG indicates that random rare and unpredictable poor ocean conditions may cause stochastic high mortality of juvenile salmon entering the ocean, but that the overwhelming evidence is that more spring flow results in higher smolt abundance, and higher smolt abundance equates to higher adult production. (DFG 3, p.17.)




Note: This figure shows the relationship of smolt abundance (log transformed) at Mossdale to estimate smolt abundance at Chipps Island by average spring (3/15 to 6/15) Vernalis flow level (log transformed). To estimate the number of smolts at Chipps Island the smolt survival vs. flow level relationship developed by Dr. Hubbard was applied on a daily basis to the Mossdale smolt abundance and out-migration pattern. Smolt abundance at Chipps Island (or stated differently smolt survival through the Delta on an annual basis) can change by an order of magnitude pending Vernalis flow rate. (DFG 3, p. 16.)

**Figure 9. Salmon Smolt Survival and San Joaquin River Vernalis Flows**

Elevated flows during the smolt outmigration period function as an environmental cue to trigger migration, facilitate transport of juveniles downstream, improve migration corridor conditions to inundate floodplains, reduce predation and improve temperature and other water quality conditions; these are all functions that are currently extremely impaired on the San Joaquin River. (e.g., “Steelhead stressor matrix,” NMFS 2009 as cited in TBI/NRDC 3, p. 7.) Under the 2006 Bay-Delta Plan, elevated flows are limited to approximately the mid-April to mid-May period. However, outmigration timing in the San Joaquin River basin occurs over a prolonged time frame from mid-March through June. (TBI/NRDC 3, p. 12-13.) This restricted window may impair population viability by limiting survival of fish that migrate outside of this time period, thus reducing the life history diversity and the genetic diversity of the population. (TBI/NRDC 3, p. 11-12.) Diverse migration timing increases population viability by making it more likely that at least some portion of the population is exposed to favorable ecological conditions in the Delta and into the ocean. (Smith et al. 1995 as cited in TBI/NRDC 3, p. 12.)

Temperature conditions in the San Joaquin River basin may limit smolt outmigration and survival. Lethal temperature thresholds for Pacific salmon depend, to some extent, on acclimation temperatures. (Myrick and Cech 2004 as cited in TBI/NRDC 3, p. 18.) Central Valley salmonids are generally temperature-stressed through at least some portion of their freshwater life-cycle. (e.g. Myrick and Cech 2004, 2005 as cited in TBI/NRDC 3, p. 18.) Lethal temperature effects commence in a range between 71.6˚ and 75.2˚ F (Baker et al.1995 as cited in TBI/NRDC 3, p. 18), with sub-lethal effects occurring at lower temperatures. Access to food also affects temperature responses. When fish have adequate access to food, growth increases with increasing temperature, but when food is limited (which is typical), optimal growth occurs at lower temperatures. (TBI/NRDC 3, p 18.) Marine and Cech (2004) observed decreased growth, smoltification success, and predator avoidance at temperatures above 68˚ F and that fish reared at temperatures between 62.6˚ and 68˚ F experienced increased predation compared to fish reared at between 55.4˚ and 60.8˚ F. (as cited in TBI/NRDC 3, p. 18.) Several studies indicate that optimal rearing temperatures for Chinook salmon range from 53.6˚ to 62.6F (Richter and Kolmes 2005 as cited in TBI/NRDC 3, p. 18.) Mesick found that Tuolumne River smolt outmigration rates and adult recruitment were highest when water temperatures were at or below 59˚F when smolts were migrating in the lower river. (Mesick 2009, p. 25.) Elevated temperatures may also affect competition between different species. (Reese and Harvey 2002 as cited in TBI/NRDC 3, p. 18.)

Temperature is determined by a number of factors including reservoir releases, channel geometry, and ambient air temperatures. As a result, a given flow may achieve different water temperatures depending on the other conditions listed above. Cain estimates that flows over 5,000 cfs in late spring (April to May) generally provide water temperatures (below 65˚ F) suitable for Chinook salmon, but that flows less than 5,000 cfs may be adequate to provide sufficient temperature conditions. (Cain 2003 as cited in TBI/NRDC 3, p 13-14.) Mesick indicates that salmon smolt survival can be improved by maintaining water temperatures near 59˚F from March 15 to May 15 and as low as practical from May 16 to June 15. (CSPA 7, p. 2-3.) To maintain mean water temperatures near 59˚F and maximum temperatures below 65˚F from March 15 to May 15 in the tributaries downstream to the confluence with the San Joaquin River, Mesick indicates that flows need to be increased in response to average air temperature. (CSPA 7, p. 3.)

There are several different estimates for flow needs on the San Joaquin River during the spring period to improve or double salmon populations on the San Joaquin River. The USFWS's 2005 *Recommended Streamflow Schedules to Meet the AFRP Doubling Goal in the San Joaquin River Basin* (2005 AFRP) concludes that the declines in salmon in the San Joaquin River basin primarily resulted from reductions in the frequency and magnitude of spring flooding in the basin from 1992-2004 compared to the baseline period of 1967-1991. (2005 AFRP, p. 1.) The AFRP states that the most likely method to increase production of fall-run Chinook salmon is to increase flows from February to March to increase survival of juveniles in the tributaries and smolts in the mainstem and then to increase flows from April to mid-June to increase smolt survival through the Delta. (*Id*.) Using salmon production models for the San Joaquin River Basin, the AFRP provides recommendations for the amount of flow at Vernalis that would be needed to double salmon production in the San Joaquin River basin. On average, over the four month period of February to May, the AFRP recommends that flows range from less than 4,000 cfs in critical years to a little more than 10,000 cfs in wet years. From March through June, AFRP recommends that flows average between about 4,500 cfs in critical years to more than 12,000 cfs in wet years. (2005 AFRP, p. 8-10.)

Using a non-linear regression empirical data driven fall-run Chinook salmon production model, DFG developed flow recommendations for the San Joaquin River from March 15 through June 15 to double Chinook salmon smolt production. DFG developed a variety of modeling scenarios to evaluate the effects of various combinations of flow magnitudes and durations in order to identify the combination of flow levels varied by water year type to achieve doubling of juveniles. Base flows for the March 15 through June 15 period vary between 1,500 cfs in critical years to

6,315 cfs in wet years. Pulse flow recommendations vary between 7,000 cfs and 15,000 cfs for durations of 31 to 70 days depending on water year type. (DFG 3, p. 34.)

In analyzing the relationship between Vernalis flow and cohort return ratios of San Joaquin River Chinook salmon, TBI/NRDC found that Vernalis average March through June flows of approximately 4,600 cfs corresponded to an equal probability for positive population growth or negative population growth. (TBI/NRDC 3, p. 24.) TBI/NRDC found that average March through June flows exceeding 5,000 cfs resulted in positive population growth in 84% of years with only 66% growth in years with flows less than 5,000 cfs. (*Id.)* TBI/NRDC found that flows of 6,000 cfs produced a similar response as the 5,000 cfs flows and flows of 4,000 cfs or lower resulted in significantly reduced population growth of only 37% of years. (*Id*.) The TBI/NRDC analysis suggests that 5,000 cfs may represent an important minimum flow threshold for salmon survival on the San Joaquin River. (*Id*.) Based on abundance to prior flow relationships, TBI/NRDC estimates that average March through June inflows of 10,000 cfs are likely to achieve the salmon doubling goal. (TBI/NRDC 3, p. 16-17.)

In addition to fall pulse flows for adult migration and spring flows to support juvenile emigration, additional flows on the San Joaquin River may be needed at other times of year to support Chinook salmon and their habitat. The 2006 Bay-Delta Plan does not include base flow objectives for the San Joaquin River. However, the Central Valley Regional Board's Water Quality Control Plan for the Sacramento and San Joaquin River Basins does include a year round DO objective of 5.0 mg/l at all times on the San Joaquin River within the Delta. (Central Valley Regional Board 2009,. III-5.0). The 2006 Bay-Delta Plan and the Central Valley Basin Plan also include a DO objective of 6.0 mg/L between Turner Cut and Stockton from September 1 through November 30. (*Id*.)

Current flow conditions on the San Joaquin River result in DO conditions below the existing DO objectives in the fall and winter in lower flow years. These conditions may result in delayed migration and mortality to San Joaquin River Chinook salmon, steelhead and other species. Increased flows would improve DO levels in the lower San Joaquin River. Additional flows at other times of year in the tributaries to the San Joaquin River would also provide improved conditions for steelhead inhabiting tributaries to the San Joaquin River (NMFS 3, p. 105) and would have additional benefits by reducing nutrients pollution and biological oxygen demand. (TBI/NRDC 3, p. 27.)

To reduce crowding of spawning adults during the fall, increased flows in the tributaries may also be needed from November through January to ensure protection of Chinook salmon. (AFRP, p. 12.) However, there is no evidence that increased flows would reduce spawner crowding or improve juvenile production. (*Id*.) Habitat modeling indicates that flows of up to 300 cfs on the San Joaquin River tributaries may provide optimum physical habitat during the fall. (AFRP 2005, p. 14.)

To maintain the ecosystem benefits of a healthy riparian forest, minimum flows and ramping rates for riparian recruitment may also be needed during late spring and early summer. (AFRP 2005, p. 14.) To protect over-summering steelhead and salmon, flows in the tributaries during the summer and fall are needed. To maintain minimal habitat of a suitable temperature (less than 65˚ F), flows between 150 and 325 cfs may be needed on each of the tributaries to the San Joaquin River. (AFRP 2005, pp. 14-15.)

The magnitude, duration, timing, and source of San Joaquin River inflows are important to San Joaquin River Chinook salmon migrating through the Delta and several different aspects of their life history.  Inflows are needed to provide appropriate conditions to cue upstream adult migration to the San Joaquin River and its tributaries, adult holding, egg incubation, juvenile rearing, emigration from the San Joaquin River and its tributaries, and other functions.  San Joaquin River inflows are important during the fall to provide attraction flows and are especially important during juvenile emigration periods.  Flows on tributaries to the San Joaquin River are also important for egg incubation and rearing, in addition to migration.

As with the Sacramento River inflows, Chinook salmon are the only species considered for the San Joaquin River inflow criteria; discussion of flow criteria for San Joaquin River inflows is therefore continued in Section 5.3, San Joaquin River inflow criteria.

<u>Hydrodynamics</u>
All Central Valley Chinook salmon must migrate out of the Delta as juveniles and back through the Delta as adults returning to spawn.  In addition, many Central Valley Chinook salmon also rear in the Delta for a period of time.  (DOI 1, p. 53.)  Delta exports affect salmon migrating through and rearing in the Delta by modifying tidally dominated flows in the channels.  It is, however, difficult to quantitatively evaluate the direct and indirect effects of these hydrodynamic changes.  Delta exports can cause a false attraction flow drawing fish to the export facilities where direct mortality from entrainment may occur.  (DOI 1, p. 29.)  More important than direct entrainment effects, however, may be the indirect effects caused by export operations increasing the amount of time salmon spend in channelized habitats where predation is high. (*Id*.)  Steady flows during drier periods (as opposed to pulse flows that occur during wetter periods) may increase these residence time effects.  (DOI 1.)

Direct mortality from entrainment at the south Delta export facilities is most important for San Joaquin River and eastside tributary salmon (and steelhead).  (DOI 1, p. 29.)  Juvenile salmonids emigrate downstream on the San Joaquin River during the winter and spring. Salmonids from the Calaveras River basin and the Mokelumne River basin also use the lower San Joaquin River as a migration corridor.  This lower reach of the San Joaquin River between the Port of Stockton and Jersey Point has many side channels leading toward the export facilities that draw water through the channels to the export pumps.  (NMFS 3, p. 651.)  Particle tracking model (PTM) simulations and acoustic tagging studies indicate that migrating fish may be diverted into these channels and may be affected by flow in these channels. (Vogel 2004, SJRGA 2006, p. 68, SJRGA 2007, pp. 76-77, and NMFS 3, p. 651.)  Analyses indicate that tagged fish may be more likely to choose to migrate south toward the export facilities during periods of elevated diversions than when exports are reduced.  (Vogel 2004.)

Similarly, salmon that enter the San Joaquin River through Georgiana Slough from the Sacramento River may also be vulnerable to export effects.  (NMFS 3, p. 652.)  While fish may eventually find their way out of the Central Delta channels after entering them, migratory paths through the Central Delta channels increase the length and time that fish take to migrate to the ocean increasing their exposure to predation, increased temperatures, contaminants, and unscreened diversions.  (NMFS 3, p. 651-652.)

PTM analyses indicate that as net reverse flows in Old and Middle rivers increase from -2,500 cfs to -3,500 cfs, particle entrainment changes from 10% to 20% and then again to 40% when flows are -5,000 cfs and 90% when flows are -7,000 cfs. (*Id*.)  Based on these findings, NMFS's Opinion includes requirements that exports be reduced to limit negative net Old and Middle river flows to -2,500 cfs to -5,000 cfs depending on the presence of salmonids from January 1 through June 15.  (NMFS 3, p. 648.)

In addition to effects of net reverse flows in Old and Middle rivers, analyses concerning the effects of net reverse flows in the San Joaquin River at Jersey Point were also conducted and documented in the USFWS, 1995 *Working Paper on Restoration Needs, Habitat Restoration Actions to Double the Natural Production of Anadromous Fish in the Central Valley California* (1995Working Paper). These analyses show that net reverse flows at Jersey Point decrease the survival of smolts migrating through the lower San Joaquin River. (USFWS 1992b as cited in USFWS 1995b, p. 3Xe-19.) Net reverse flows on the lower San Joaquin River and diversions into the central Delta may also result in reduced survival for Sacramento River fall-run Chinook salmon. (USFWS 1995b, p. 3Xe-19) Based on these factors, the 1995 Working Paper includes a recommendation to maintain positive flows at Jersey Point of 1,000 cfs in critical and dry years, 2,000 cfs in below- and above-normal years, and 3,000 cfs in wet years from October 1 through June 30 to improve survival for all races and stocks of juvenile salmon and steelhead migrating through and rearing in the Delta. (*Id.*)

In addition to relationships between reverse flows and entrainment effects, flows on the San Joaquin River versus exports also appear to be an important factor in protecting San Joaquin River Chinook salmon. Various studies show that, in general, juvenile salmon released downstream of the effects of the export facilities (Jersey Point) have higher survival out of the Delta than those released closer to the export facilities. (NMFS 3-Appendix 3, p. 74.) Studies also indicate that San Joaquin basin Chinook salmon production increases when the ratio of spring flows to exports increases. (DFG 2005, SJRGA 2007 as cited in NMFS 3-Appendix 3, p. 74.) However, it should be noted that flow at Vernalis appears to be the controlling factor. Increased flows in the San Joaquin River in the Delta may also benefit Sacramento basin salmon by reducing the amount of Sacramento River water that is pulled into the central Delta and increasing the amount of Sacramento River water that flows out to the Bay. (NMFS 3, Appendix 3, p. 74-75.) Based on these findings, the NMFS Opinion calls for export restrictions from April 1 through May 31 with Vernalis flows to export ratios ranging from 1.0 to 4.0 based on water year type, with unrestricted exports above flows of 21,750 cfs at Vernalis, in addition to other provisions for health and safety requirements. (NMFS 3, Appendix 3, p.73-74.)

Analyses by TBI/NRDC indicate that Vernalis flow to export ratios above 1.0 during the San Joaquin basin juvenile salmon outmigration period in the spring consistently correspond to higher escapement estimates two and half years later, with more than 10,000 fish in 76% of years. (TBI/NRDC 4, p. 11.) Vernalis flows to export ratios of less than 1.0 correspond to lower escapement estimates two and half years later, with more than 10,000 fish in only 33% of years. (*Id.*) TBI/NRDC estimates that Vernalis flows to export ratios of greater than 4.0 would reach population abundance goals. (TBI/NRDC 4, pp. 11-12.)

Vernalis flows to export ratios also appear to be important during the fall period to provide improved migration conditions for adult fall-run San Joaquin basin Chinook salmon. Adult fall-run San Joaquin basin Chinook salmon migrate upstream through the Delta primarily during October when San Joaquin River flows are typically low. (AFRP 2005, p. 12.) As a result, when exports are high, little if any flow from the San Joaquin basin may make it out to the ocean to help guide San Joaquin basin salmon back to the basin to spawn. (*Id.*) Analyses indicate that increased straying occurs when more than 400% of the flow at Vernalis is exported at the Delta pumping facilities (equivalent to a Vernalis flow to export ratio of 0.25). (*Id.*) Straying rates decreased substantially when export rates were less than 300% of Vernalis flow. (*Id.*)

Export related criteria for salmon are provided in section 5.4, Hydrodynamic Recommendations.

Floodplain Flows

Juvenile salmon will rear on seasonally inundated floodplains when available. Such rearing in the Central Valley, in the Yolo Bypass and the Cosumnes River floodplain, has been found to have a positive effect on growth and apparent survival of juvenile Central Valley salmon through the Delta. (Sommer *et al*. 2001 and Jeffres *et al*. 2005 as cited in DOI 1, p. 27 and Sommer *et al*. 2005 and Jeffres *et al*. 2008 as cited in NMFS 3, p. 609.) The increased growth rates may be due to increased temperatures and increased food supplies. (DOI 1, p. 27, DFG 3, p. 3.) Floodplain rearing provides conditions that promote larger and faster growth which improves outmigration, predator avoidance, and ultimately survival. (Stillwater Science 2003 as cited in DFG 3, p. 6.) Increased survival may also be related to the fact that ephemeral floodplain habitat and other side-channels provide better habitat conditions for juvenile salmon than intertidal river channels during high flow events when, in the absence of such habitat, juvenile salmon may be displaced to these intertidal areas. (Grosholz and Gallo 2006 as cited in DOI 1, p. 27 and Stillwater Science as cited in DFG 3, p. 6.) The improved growing conditions provided by floodplain habitat are also believed to improve ocean survival resulting in higher adult return rates. (Healy 1982, Parker 1971 as cited in DOI 1, p. 28.)

While floodplain habitat is generally beneficial to salmon, it may also be detrimental under certain conditions. Areas with engineered water control structures have comparatively higher rates of stranding. (Sommer *et al*. 2005 as cited in DOI 1, p. 28.) In addition, high temperatures, low DO, and other water quality conditions that may occur on floodplains may adversely affect salmon. (DFG 3, p. 6.) Reduced depth may also make salmon more susceptible to predation. (*Id*.) Water depths of 30 cm or more are believed to reduce the risk of avian predation. (Gawlik 2002 as cited in DFG 3, p. 6.) Further, the most successful native fish are those that use the floodplain for rearing, but leave before the floodplain becomes disconnected to the river. (Moyle *et al*. 2007, DFG 3, p. 6.) From a restoration perspective, projects should be designed to drain completely to minimize formation of ponds in order to avoid stranding. (Jones and Stokes, 1999 as cited in DOI 1, p. 28.) Bioenergetic modeling indicates that with regard to increased temperatures, increased food availability may be sufficient to offset increased metabolic demands from higher water temperatures. (DFG 3, p. 6.) However, as temperatures increase, juveniles may be unable to migrate to areas of lower temperatures due to reduced swimming ability. (DFG 3, p. 7.) As a result, as summer temperatures increase, floodplain habitat should also decrease. (*Id*.)

The timing of floodplain inundation for the protection of Central Valley Chinook salmon should generally occur from winter to mid-spring to coincide with the peak juvenile Chinook salmon outmigration period (which itself generally coincides with peak flows) and to avoid non-native access to the floodplain (which would generally occur in late-spring). (AR/NHI 1, p. 25.) The benefits of floodplain inundation generally increase with increasing duration, with even relatively short periods of two-weeks providing potential benefits to salmon. (Jeffres *et al*., 2008 as cited in AR/NHI 1, p. 25.) Benefits to salmon may also increase with increasing inter-annual frequency of flooding. Repeated pulse flows and associated increased residence times may be associated with increased productivity which would benefit salmon growth rates and potentially reduce stranding. (*Id*.)

Table 4, developed by AR/NHI, provides estimated thresholds for inundating floodplain habitat under existing and potentially modified conditions. Inundation threshold refers to the discharge when floodwaters begin to inundate the floodplain. Target discharge is the amount of water necessary to produce substantial inundation and flow across the floodplain. (Source: AR/NHI 1, p. 30.)

Floodplain inundation criteria for protection of salmon are provided in section 5.6.2, Floodplain Activation, under Other Measures.

**Table 4. Inundation Thresholds for Floodplains and Side Channels at Various Locations Along the Sacramento River**

| Location | Stage (in feet) | Inundation Threshold (cfs) | Target Discharge (avg. cfs) | Gauge Location | Source |
|---|---|---|---|---|---|
| Freemont Weir<br>Existing crest<br>Proposed notch | <br>33.5<br>17.5 | <br>56,000<br>23,100 | <br>63,000<br>35,000 | <br>Verona<br>Verona | <br>USGS<br>USGS |
| Sutter Bypass<br>Tisdale weir<br>Tisdail with notch<br>Lower Sutter Bypass | <br>45.5<br><br>25 | <br>21,000<br><br>30,000 | <br><br><br>30,000 | <br>Colusa<br><br>Verona | <br>NOAA; Feyrer<br><br>USGS |
| Upper Sacramento Meander belt side channels | Various | 10,000 | 12,000 | Red Bluff | USGS |

## American Shad (*Alosa sapidissima*)

### *Status*

This species is not listed pursuant to either the ESA or CESA.

### *Life History*[13]

The American shad (*Alosa sapidissima*) is an anadromous fish, introduced into California in the late 1880s, that has become an important sport fish within the San Francisco Estuary. American shad range from Alaska to Mexico and use major rivers between British Columbia and the Sacramento watershed for spawning. (Moyle 2002.)

American shad adults, at 3 to 5 years of age, return from the ocean and migrate into the freshwater reaches of the Sacramento and San Joaquin rivers during March through May, with peak migration occurring in May (Stevens *et al*. 1987). Within California, the major spawning run occurs in the Sacramento River up to Red Bluff and in the adjoining American, Feather, and Yuba rivers with lesser use of the Mokelumne, Cosumnes, and Stanislaus rivers and the Delta (Moyle 2002). Spawning takes place from May through early July (Stevens *et al*. 1987). Following their first spawning event, American shad will return annually to spawn up to seven years of age (Stevens *et al*. 1987). It is believed that river flow will affect the distribution of first time spawners, with numbers of newly mature adults spawning in rivers proportional to flows at the time of arrival (Stevens *et al*. 1987). Spawning takes place in the main channels of the rivers with flows washing negatively buoyant eggs downstream. Depending upon temperature, larvae hatch from eggs in 3 to 12 days and will remain planktonic for 4 weeks (Moyle 2002).

[13] This section was largely extracted from DFG Exhibit 1, pages 26-27.

The lower Feather River and the Sacramento River from Colusa to the northern Delta provide the major summer nursery for larvae and juveniles. Flows drive the transport of young downstream, with wet years changing the location of the concentration of young and their nursery area further downstream into the northern Delta (Stevens *et al*. 1987). Out migration of young American shad through the Delta occurs from June through November (Stevens 1966). American shad spawned and rearing in the Delta and those that travel through the Delta during out migration are vulnerable to entrainment at the State and federal pumping facilities; catches at the facilities in some years have numbered in the millions (Stevens and Miller 1983). During migration to the ocean, young fish feed upon zooplankton, including copepods, mysids, and cladocerans, as well as amphipods (Stevens 1966, Moyle 2002). Most American shad migrate to the ocean by the end of their first year, but some remain in the estuary (Stevens *et al*. 1987).

### *Population Abundance and its Relationship to Flow*

Year class strength correlates positively with river flow during the spawning and nursery period (April-June). (Stevens and Miller 1983.) American shad exhibit a weak but significant relationship to X2, (Kimmerer 2002a). After 1987, the relationship changed such that abundance increased per unit flow. (Kimmerer 2002a, Kimmerer 2009.) The X2 versus abundance relationship has remained intact into recent years. (Kimmerer *et al*. 2009.) In addition, Kimmerer *et al*. (2009) found that American shad had a habitat relationship (defined by salinity and Secchi depth) to X2 that appeared consistent with its relationship of abundance to X2 (i.e., slopes for abundance versus X2 and habitat versus X2 were similar), which provides some support for the idea that increasing quantity of habitat could explain the X2 relationship for this species (a possible causal mechanism for the abundance versus X2 relationship). Stevens and Miller (1983) determined that the apparent general effect of high flow on all of the species they examined, including American shad, is to increase the quality and quantity of nursery habitat and more widely disperse the young fish, thus reducing density-dependent mortality.

### *Population Goal*

The immediate goal is to maintain viable populations of this species by providing sufficient flows to facilitate attraction of spawners, survival of eggs and larvae, and dispersal of young fish to suitable nursery habitats.

### *Species-Specific Recommendations*

<u>Delta Outflow</u>

The DFG's current science-based conceptual model is that placement of X2 in Suisun Bay represents the best interaction of water quality and landscape for fisheries production given the current estuary geometry. (DFG 2, p. 6.) Maintaining X2 at 75 km and 64 km corresponds to net Delta outflows of approximately 11,400 cfs and 29,200 cfs, respectively. As noted by DFG, X2, in this instance, is a surrogate for tributary and mainstem river inflows to the Delta that support egg and larval survival. The species specific flow criteria to protect American shad shown in Table 5 are consistent with those submitted by DFG. (closing comments, p. 7.)

<u>Inflows</u>

No explicit recommendations for inflows to support American shad were identified in the record. The DFG provided outflow criteria for this species based on positioning X2 in Suisun Bay (DFG closing comments, p. 7); noting that in this instance X2 is a surrogate for tributary and mainstem river inflows. As noted above, year class strength correlates positively with river flow during the spawning and nursery period (April to June). (Steven and Miller 1983.) Flows must be sufficient to attract American shad spawners into Sacramento River tributaries, transport and disperse the young fish to suitable nursery habitat, and reduce the probability of entrainment of young fish and their food organisms in water diversions. (DFG 1987 [Exh 23, p. 23].) Water development has reduced flows during the spring and early summer periods which are most critical in this respect. (*Id.*) The spawning and nursery period, during which inflows appear to be most critical for this species, generally correspond to important periods for other more sensitive species (e.g., salmon outmigration, longfin smelt spawning and rearing). It is anticipated that by providing sufficient flows to meet the outflow criteria recommended above, favorable river conditions will be provided to support American shad spawning and rearing.

Old and Middle River Flows

American shad spawned and rearing in the Delta and those that travel through the Delta during out migration are vulnerable to entrainment at the State and Federal export facilities; in some years catches at the facilities have numbered in the millions. (Stevens and Miller 1983.) Although evaluations of screening efficiency comparable to studies for striped bass and salmon had not been completed for American shad, DFG believed in 1987 that larger fish in the fall were screened fairly efficiently, while screening efficiencies for newly metamorphosed juveniles in the late spring and early summer were quite low. (DFG 1987 [Exh 23, p. 20].) American shad are notoriously intolerant of handling. Tests have shown that losses of American shad that were successfully screened exceeded 50%during the summer months, with slightly lower mortalities during the cooler fall months. (DFG 1987 [Exh 23, p. 22].) These high handling mortalities suggest the only practical strategy for reducing losses may be pumping schedules that minimize shad entrainment. (*Id.*). However, no recommendations specific to American shad for net OMR flows or pumping restrictions were identified in the record. Net OMR flow criteria are intended to protect salmon, delta smelt, and longfin smelt populations and are also likely to reduce the number of American shad entrained at the export facilities. In addition, restrictions stipulated in the OCAP Biological Opinions (NMFS 3, pp. 648-653; USFWS 2008) will also reduce entrainment of American shad.

**Table 5. Delta Outflows to Protect American Shad**

| Effect or Mechanism | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning; Nursery | All | -- | -- | -- | X2[1] – 75 to 64 km (~11400 – 29200 cfs) | | | -- | -- | -- | -- | -- | -- |
| [1] For this species, X2 is a surrogate for tributary and mainstem river inflows to the Delta that support egg and larval survival. Source: DFG 1, p. 26; DFG 2, p. 6, DFG closing comments, p. 7. | | | | | | | | | | | | | |

### 4.2.4 Life History Requirements – Pelagic Species

Following are life history and species-specific requirements for longfin smelt, Delta smelt, Sacramento splittail, starry flounder, Bay shrimp, and zooplankton

**Longfin Smelt (*Spirinchus thaleichthys*)**

***Status***

Longfin smelt is listed as a candidate for threatened status under the CESA. (DFG 2010.)

***Life History***

Longfin smelt are a native species that live two years with females reproducing in their second year. Both juveniles and adults feed on zooplankton. Longfin smelt is an anadromous, open water species moving between fresh and salt water. Adults spend time in San Francisco Bay and may go outside the Golden Gate for short periods. Adults aggregate in Suisun Bay and the western Delta in late fall and migrate upstream to spawn in freshwater as water temperatures drop below 18˚C. (Baxter *et al*. 2009.) The spawning habitat is between the confluence of the Sacramento and San Joaquin rivers (around Point Sacramento) to Rio Vista on the Sacramento side and Medford Island on the San Joaquin River. Spawning activity appears to decrease with distance from the low salinity zone, so the location of X2 influences how far spawning migrations extend into the Delta. (Baxter *et al*. 2009.) Spawning takes place between November and April with peak reproduction in January. Eggs are deposited on the bottom and hatch between December and May into buoyant larvae. Peak hatch is in February. Net Delta outflow transports the larvae and juvenile fish to higher salinity water.

### *Population Abundance and its Relationship to Flow*

The population abundance of longfin smelt is positively correlated with spring Delta outflow and inversely related to net OMR spring reverse flows. The correlations are interpreted to mean that net Delta outflow and net reverse OMR flows are, at least partially, responsible for controlling the abundance of longfin smelt. Modifications in the two flow regimes are intended to begin to stabilize and increase the population abundance of longfin smelt. Each correlation is discussed below.

The population abundance of longfin smelt is positively related to Delta outflow during winter and spring. (Jassby *et al*. 1995; Rosenfield and Baxter 2007; Kimmerer 2002a; Kimmerer *et al*. 2009.) The statistically strongest outflow averaging period is January-June. The abundance relationships are from the fall mid-water trawl (FMWT) survey, the bay study mid-water trawl, and the bay study otter trawl. All three surveys show statistically significant positive relationships between the abundance of juveniles/adults and Delta outflow. There has been a decrease in the carrying capacity of the estuary since 1988, presumably because of the invasion of the clam *Corbula*, but the overall winter spring relationship is still statistically significant. More spring outflow results in more smelt as measured by all three indices. The biological basis for the spring outflow relationship is not known. Baxter et al. (2009) speculate that the larvae may benefit from increased downstream transport, increased food production, and a reduction in entrainment losses at the SWP and CVP pumps.

The population abundance of juvenile and adult longfin smelt, as measured by the FMWT index, is also inversely related to the number of fish salvaged at the SWP and CVP pumping facilities. (TBI/NRDC 4, pp. 19-20.) High pumping rates at the two facilities cause net OMR reverse flows which passively move all age groups of longfin smelt toward entrainment at the pumps. A subset of the juvenile and adult populations are counted at the pumping facilities. Larval longfin smelt (<20 mm) pass through the louvers and are not counted. Peak adult and juvenile longfin smelt salvage occurs in January and April to May, respectively. (Baxter *et al*. 2009.) Entrainment of larval smelt, although not counted, are likely greatest between March and April. (TBI/NRDC 4, p.16.) Adult and juvenile longfin smelt salvage is an inverse logarithmic function of net OMR flows. (Grimaldo *et al*. 2009.) Increasing OMR reverse flows results in an exponential increase in salvage loss. Juvenile longfin smelt salvage is a negative function of Delta outflow between March and May. (TBI/NRDC 4, p.17.) Higher outflow in these three months results in lower entrainment loss. This may result from the fact that during low outflow years spawning occurs higher in the system, placing adults and subsequent larvae and juveniles closer to the pumps. Also, negative net OMR flows can either passively draw fish to the pumps or at high levels mis-cue them as to the direction of higher salinity. A consequence is that juvenile longfin smelt are most in danger of entrainment at the CVP and SWP pumping facilities during low outflow years with high net negative OMR flows.

The OMR flow results discussed above are consistent with the findings of Baxter *et al* (2009). The authors used the Delta Simulation Model (DSM2, PTM subroutine) to predict the fate of larval longfin smelt. The PTM predicted that larval entrainment at the SWP might be substantial (2 to10%), particularly during the relatively low outflow conditions modeled. Baxter *et al*. (2009) also identified a significant negative relationship between spring (April to June) net negative OMR flows and the sum of combined SWP and CVP juvenile longfin smelt salvage. Juvenile longfin smelt salvage increased rapidly as OMR became more negative than -2,000 cfs. However, as winter-spring or just spring outflows increased, shifting the position of X2 downstream, the salvage of juvenile longfin smelt decreased significantly. Also, particle entrapment decreased, even with a high negative net OMR, when the flow of the Sacramento River at Rio Vista increased above 40,000 cfs. Entrainment of particles almost ceased at flows of 55,000 cfs.

TBI/NRDC (TBI/NRDC 2, pp. 15-19) conducted a generation to generation population abundance analysis for longfin smelt versus Delta outflow. The authors found that the probability of an increase in the FMWT longfin smelt index was greater than 50% in years when Delta outflow averaged 51,000 and 35,000-cfs between January to March and March to May, respectively. The analysis is important because it suggests a potential outflow trigger for growing the population.

There is also evidence that longfin smelt is food limited. (SFWC 1, p.59.) The FMWT index for longfin smelt is positively correlated in a multiple linear regression with the previous spring's *Eurytemora affinis* abundance (an important prey organism) after weighting the data by the proportion of smelt at each *Eurytemora* sampling station and normalizing by the previous years FMWT index. The spring population abundance of *Eurytemora* has itself been positively correlated with outflow between March and May since the introduction of *Corbula.* (Kimmerer, 2002a.) The positive correlation between *Eurytemora* abundance and spring outflow provides further support for a spring outflow criterion.

Longfin smelt populations are at an all time low. The average FMWT index for years 2001-2009 are only 3 percent of the average value for 1967 to 1987, a time period when pelagic fish did better in the estuary. The FMWT index for two of the last three years is the lowest on record.

Delta outflow recommendations to protect longfin smelt received from participants are summarized in Table 6. The DFG (DFG closing comments, p.7) recommended a Delta outflow between 12,400 and 28,000 cfs from January to June of all water year types to help transport larval/juvenile longfin smelt seaward in the estuary. TBI/NRDC (TBI/NRDC 2, pp. 19-26; TBI/NRDC Closing Comments, pp. 6-7) also made spring Delta outflow recommendations based on five sets of hydrologic conditions for the Central Valley. The TBI/NRDC recommendations range between 14,000 and 140,000 cfs for January through March and 10,000 to 110,000 cfs between April and May. The TBI/NRDC recommendations are based on their longfin smelt population abundance analysis which demonstrated positive growth in years with high spring outflow.

The four sets of OMR recommendations to protect longfin smelt received from participants are summarized in Table 7. TBI/NRDC (TBI/NRDC 4, pp. 21 and 30; TBI/NRDC closing comments, p. 11) recommended reducing entrainment losses of longfin smelt in dry years (March to May when outflow is less than 18,000 cfs) and population abundance is low (FMWT index less than 500) by maintaining positive net OMR flows in April and May. Alternatively, if the index is greater than 500 and Delta outflow is low, then net OMR flows should not be more negative than -1,500 cfs. The DOI (DOI 1, p.53) made a non-species specific recommendation that OMR flows should be positive in all months between January and June. CSPA/CWIN made a non-species specific recommendations that combined export rates equal zero from mid-March through June. (CSPA 1, p.8; CWIN 2, p. 26.) Finally, the DFG has issued an Incidental Take Permit for longfin smelt (2081-2009-001-03) that restricts net OMR flows in some years based on the recommendations of the Delta Smelt Workgroup. (Baxter *et al*. 2009.)

**Table 6. Participant Recommendations for Delta Outflow to Protect Longfin Smelt**

| Organization | Water Year | Jan | Feb | Mar | April | May | Jun |
|---|---|---|---|---|---|---|---|
| TBI/NRDC | 81-100% (driest years) | 14,000 – 21,000 | | | 10,000 – 17,500 | | 3000 – 4200 |
| | 61-80% | 21,000 – 35,200 | | | 17,500 – 29,000 | | 4200 – 5000 |
| | 41-60% | 35,200 – 55,000 | | | 29,000 – 42,000 | | 5000 – 8500 |
| | 21-40% | 55,000 – 87,500 | | | 42,000 – 62,500 | | 8500 – 25000 |
| | 0-20% (wettest years) | 87,500 – 140,000 | | | 62,500 – 110,000 | | 25000 – 50000 |
| DFG | all | 12,400 to 28,000 | | | | | |

### *Population Goal*

The immediate goal is to stabilize the longfin smelt population, as measured by the FMWT index, and to begin to grow the population. The long-term goal is to achieve the objective of the Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes (USFWS 1996). The plan states that longfin smelt will be considered recovered when its abundance is similar to the 1967 to 1984 period.

### *Species- Specific Recommendations*

Table 8 contains the species-specific flow criteria to protect longfin smelt. The purpose of the Delta outflow criteria is to stabilize and begin to grow the longfin smelt population; positive population growth is expected in half of all years with these flows. The net OMR flow criteria are intended to protect the longfin smelt population from entrainment in the CVP and SWP pumping facilities during years with limited Delta outflow (dry and critically dry years). As noted above, longfin smelt spawn in the Delta on both the Sacramento and San Joaquin rivers. Longfin smelt optimally need positive flow on both river systems to move buoyant larvae downstream and away from the influence of the pumps.

**Table 7. Participant Recommendations for Net OMR Reverse Flows to Protect Longfin Smelt**

| Organization | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2006 Bay-Delta Plan | all | Some restrictions, given in terms of E/I ratios | | | | | | | | | | | |
| DFG Take Permit | all | -1,250 to -5,000[1] | | | | | | | | | | | |
| TBI/NRDC | C/D | | | | >0[2] or -1,500[3] | | | | | | | | |
| DOI | all | >0 | | | | | | | | | | | |
| CSPA/CWIN | all | | | Combined export rates = 0 | | | | | | | | | |

[1] This condition is not likely to occur in many years and is based on requirements in the DFG Incidental Take Permit 2081-2009-001-03 and the advice of the Smelt Working Team. The condition is most likely to occur in dry or critical years when longfin smelt spawn higher in the Delta and hydrology does not rapidly transport hatched larvae from the central and south Delta.

[2] If FMWT index is less than 500

[3] If FMWT index is greater than 500

**Table 8. Delta Outflows to Protect Longfin Smelt**

| Flow Type | Water Year Type | Jan | Feb | Mar | April | May | Jun |
|---|---|---|---|---|---|---|---|
| Net Delta Outflow | C | 14,000 – 21,000 | | | 10,000 – 17,500 | | 3,000 – 4,200 |
| | D | 21,000 – 35,200 | | | 17,500 – 29,000 | | 4,200 – 5,000 |
| | BN | 35,200 – >50,000 | | | 29,000 – 42,000 | | 5,000 – 8,500 |
| | AN | >50,000 | | | >42,000 | | 8,500 – 25,000 |
| | W | >50,000 | | | >42,000 | | 25,000 – 50,000 |
| OMR | C/D | | | | >0[1] or -1,500[2] | | |

[1] If FMWT index is less than 500

[2] If FMWT index is greater than 500

## **Delta Smelt (*Hypomesus transpacificus*)**

### ***Status***

Delta smelt is listed as endangered under the CESA and threatened under the ESA. (DFG 2010.)

### ***Life History***

Delta smelt are endemic to the Delta. Delta smelt have an annual, one-year life cycle although some females may live and reproduce in their second year. (Bennett 2005.) Delta smelt complete their entire life cycle in the Delta and upper estuary. Delta smelt feed primarily on planktonic copepods, cladocerans, and amphipods. (Baxter *et al*. 2008.) In September or October delta smelt begin a slow upstream migration toward their freshwater spawning areas in the upper Delta, a process that may take several months. (Moyle 2002.) The upstream migration may be triggered by Sacramento River flows in excess of 25,000 cfs. (DSWG 2006.) Spawning can occur from late February to July, although most reproduction appears to take place between early April and mid-May. (Moyle 2002.) Spawning areas include the lower Sacramento, Mokelumne, and San Joaquin rivers, the west and south Delta, Suisun Bay, Suisun Marsh, and occasionally in wet years, the Napa River. (Wang 2007.) Eggs are negatively buoyant and adhesive with larvae hatching in about 13 days. (Wang, 1986; Mager 1996.) Upon hatching, the larvae are semi-buoyant staying near the bottom. Within a few weeks, larvae develop an air bladder and become pelagic, utilizing vertical water column movement to maintain their longitudinal position in the estuary. (Moyle 2002.)

Freshwater outflow during spring (March to June) affects the distribution of larvae by transporting them seaward toward the low salinity zone. (Dege and Brown 2004.) High Delta outflow during spring can carry some smelt downstream of their traditional rearing areas in the west Delta and Suisun Bay and into San Pablo Bay where long-term growth and survival may not be optimal. Conversely, periods of low outflow increase residence time in the Delta. Increasing residence time in the Delta probably prolongs the exposure of delta smelt to higher water temperatures and increased risk of entrainment at the State and Federal pumping facilities. (Moyle 2002.) Ideal rearing habitat conditions are believed to be shallow water areas most commonly found in Suisun Bay. (Bennett 2005.) When the mixing zone was located in Suisun Bay, it may in the past have provided optimal conditions for algal and zooplankton growth, an important food source for delta smelt. (Moyle 2002.) However, the quality of habitat in Suisun Bay appears to have deteriorated with the introduction of the clam *Corbula* which now consumes much of the phytoplankton that previously supported large populations of zooplankton. Since 2005, approximately 40% of the delta smelt population now remains in the Cache Slough complex north of the Delta. This may represent an alternative life history strategy in which the fish stay upstream of the low salinity zone (LSZ) through maturity. (Sommer et al., 2009.)

### ***Population Abundance and Relationship to Flow***

Delta smelt population abundance is measured in the summer tow net survey, the FMWT survey and the 20-mm spring-summer survey of juvenile fish. (Kimmerer et al. 2009.) All three indices indicate that delta smelt populations are at an all time low and may be in danger of extinction. The average FMWT index for 2001-2009 is only 20% of the value measured between 1967 and 1987, a time period when pelagic fish did better in the estuary. FMWT indices for the last six years (2004 to 2009) include all of the lowest values on record. The cause of the decline is unclear but likely includes some combination of flow, export pumping, food limitation, and introduced species.

Three types of flow have been hypothesized to affect delta smelt abundance. These are spring and fall Delta outflow and net OMR reverse flow. Testimony was received at the public proceeding recommending management changes to all three types of flow (Table 9 and Table 10). In the past, there has been a weak negative relationship between spring Delta outflow and delta smelt abundance as measured by the FMWT, however, the relationship has now disappeared. (Kimmerer *et al*. 2009.) The cause for the disappearance of the spring outflow-abundance relationship is not known but may result from the deterioration of rearing habitat in Suisun Bay because of colonization by the clam *Corbula.*

Several organizations recommend fall Delta outflow criteria for protection of delta smelt (Table 9). The primary purpose of a fall Delta outflow criterion is to increase the quality and quantity of rearing habitat for Delta smelt. (Nobriga et al. 2008; Feyrer et al. 2007; Feyrer et al., in review.) Rearing habitat is hypothesized to increase when the fall LSZ is downstream of the confluence of the Sacramento and San Joaquin rivers. This corresponds to Delta outflows greater than about 7,500 cfs between September and November, which would have to be achieved by release of water from upstream reservoirs in most years. Grimaldo et al. (2009) found that X2 was a predictor for salvage of adult delta smelt at the intra-annual scale when net OMR flows were negative. Moving X2 westward in the fall serves to increase the geographic and hydrologic distance of delta smelt from the influence of the export facilities and therefore likely reduces the risk of entrainment. (DOI 1, p. 34.) The USFWS (2008) recommended in their Opinion that the LSZ be maintained in the fall of above normal and wet water year types in Suisun Bay (Action 4). The action was restricted to above average water years to insure that sufficient cold water pool resources remained for steelhead and salmon and because these are the years in which SWP and CVP operations have most significantly affected fall conditions. (USFWS 2008.) The National Academy of Sciences (NAS) (2010) commented on this action in their review:

> ”The statistical relationship is complex. When the area of highly suitable habitat …is low, either high or low FMWT indices can occur. In other words, delta smelt can be successful even when habitat is restricted. More important, however, is that the lowest abundances all occurred when the habitat-area index was less than 6,000 ha. This could mean that reduced habitat area is a necessary condition for the worst population collapses, but it is not the only cause of the collapse… The … action is conceptually sound … to the degree that the amount of habitat available for smelt limits their abundance… however…the weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action difficult to understand.” The National Academy of Sciences noted approvingly that the U.S. Fish and Wildlife Service (2008) required “additional studies addressing elements of the habitat conceptual model to be formulated … and … implemented promptly.”

**Table 9. Participant Recommendations for Delta Outflows to Protect Delta Smelt**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2006 Bay-Delta Plan [1]** | C | 4500 [2] | 7100 – 29200 [3] | | | | | 4000 | 3000 | 3000 | 3000 | 3500 | |
| | D | 4500 | 7100 - 29200 | | | | | 5000 | 3500 | 3000 | 4000 | 4500 | |
| | BN | 4500 | 7100 - 29200 | | | | | 6500 | 4000 | 3000 | 4000 | 4500 | |
| | AN | 4500 | 7100 - 29200 | | | | | 8000 | 4000 | 3000 | 4000 | 4500 | |
| | W | 4500 | 7100 - 29200 | | | | | 8000 | 4000 | 3000 | 4000 | 4500 | |
| **USFWS Opinion[1]** | AN | | | | | | | | | 7000 [4] | | | |
| | W | | | | | | | | | 12400 | | | |
| **EDF/Stillwater Sciences** | C | | | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 4800 | 4800 | |
| | D | | | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 4800 | 4800 | |
| | BN | | | 26800 | 26800 | 26800 | 11500 | 7500 | 7500 | 7500 | 7500 | 7500 | |
| | AN | | | 26800 | 26800 | 26800 | 11500 | 11500 | 11500 | 11500 | 11500 | 11500 | |
| | W | | | 26800 | 26800 | 26800 | 17500 | 17500 | 17500 | 17500 | 17500 | 17500 | |
| **TBI/NRDC** | 81-100% | | | | | | | | | 5750 - 7500 | | | |
| | 61-80% | | | | | | | | | 7500 - 9000 | | | |
| | 41-60% | | | | | | | | | 9700 - 12400 | | | |
| | 21-40% | | | | | | | | | 12400 - 16100 | | | |
| | 0-20% | | | | | | | | | 16100 - 19000 | | | |

[1] 2006 Bay-Delta Plan and USFWS Opinion flows shown for comparative purposes.

[2] All water year types - Increase to 6000 if the December Eight River Index is > than 800 thousand acre-feet (TAF).

[3] Minimum Delta outflow calculated from a series of rules that are described in Tables 3 and 4 of the 2006 Bay-Delta Plan.

[4] USFWS Opinion (RPA concerning Fall X2 requirements [pp282-283] - improve fall habitat [quality and quantity] for delta smelt) (references USFWS 2008, Feyrer *et al* 2007, Feyrer *et al* in revision) - September-October in years when the preceding precipitation and runoff period was wet or above normal, as defined by the Sacramento Basin 40-30-30 Index, USBR and DWR shall provide sufficient Delta outflow to maintain monthly average X2 no greater than 74 km and 81 km in Wet and Above Normal years, respectively. During any November when the preceding water year was wet or above normal, as defined by Sacramento Basin 40-30-30 index, all inflow into the CVP/SWP reservoirs in the Sacramento Basin shall be added to reservoir releases in November to provide additional increment of outflow from Delta to augment Delta outflow up to the fall X2 of 74 km and 81 km for wet and above normal water years, respectively. In the event there is an increase in storage during any November this action applies, the increase in reservoir storage shall be released in December to augment the December outflow requirements in the 2006 Bay-Delta Plan.

**Table 10. Participant Recommendations for Net OMR Flows to Protect Delta Smelt**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2006 Bay-Delta Plan** | all | Some restrictions, given in terms of exports to inflow ratios | | | | | | | | | | | |
| **USFWS - Opinion** | all | Action 1: -2000 cfs for 14 days once turbidity or salvage trigger has been met; Action 2: range btw -1250 and -5000 cfs [1] | | | Range between -1,250 and -5,000 [2] | | | | | | | | See Jan-Mar |
| **USFWS** | all | >0 [3] | | | | | | | | | | | |
| **CSPA/ CWIN** | | | | Combined Export Rates = 0[3] | | | | | | | | | |
| **TBI/ NRDC** | all | >-1,500 cfs | | | | | | | | | | | >-1500 cfs |

[1] USFWS Opinion - RPA re: net OMR flows. Component 1 - Adults (December - March) - Action 1 (protect upmigrating delta smelt) - once turbidity or salvage trigger has been met, -2000 cfs OMR flow for 14 days to reduce flows towards the pumps. Action 2 (protect delta smelt after migration prior to spawning) – Net OMR flow range between -1250 and -5000 cfs determined using adaptive process until spawning detected. (pp.280-282.)

[2] USFWS Opinion - RPA re: net OMR flows. Component 2 - Larvae/juveniles - action starts once temperatures hit 12° C at three Delta monitoring stations or when spent female is caught. Net OMR flow range between -1250 and -5000 cfs determined using adaptive process. OMR flow restrictions continue until June 30 or when Delta water temperatures reach 25° C, whichever comes first. (pp. 280-282.)

[3] Recommendations by the USFWS and CSPA/CWIN were not species specific.

It should be reiterated that this measure should be implemented within an adaptive framework, including completing studies designed to clarify the mechanism(s) underlying the effects of fall habitat on the delta smelt population, and a comprehensive review of the outcomes of the action and its effectiveness. Until additional studies are conducted demonstrating the importance of fall X2 to the survival of delta smelt, additional fall flows, beyond those stipulated in the fall X2criteria, for the protection of delta smelt are not recommended if it will compete with preservation of cold water pool resources needed for the protection of salmonids.

Net negative OMR flows can affect delta smelt by pulling them into the central Delta where they are at risk of entrainment in the SWP and CVP pumps. Recent studies have shown that entrainment of delta smelt and other pelagic species increases as net OMR flows become more negative. (Grimaldo et al. 2009; Kimmerer 2008.) Delta smelt are at risk as juveniles in the spring during downstream migration to their rearing area, and as adults between the fall and early spring as they move upstream to spawn. Salvage of age-0 delta smelt at the SWP /CVP fish collection facilities at the intra-annual scale has been found to be related to the abundance of these fish in the Delta, while net OMR flows and turbidity were also strong predictors. (Grimaldo et al. 2009.) This suggests that within a given year, the mechanism influencing entrainment is probably a measure of the degree to which their habitat overlaps with the hydrodynamic “footprint” of net negative OMR flows. (Grimaldo et al. 2009.) PTM results suggest that entrainment is a function of both net OMR flows and river outflows. (Kimmerer and Nobriga 2008.) PTM results may be more applicable to neutrally buoyant larvae and poorly swimming juveniles than adult delta smelt. Particle entrainment increased as a logarithmic function of increasing net negative OMR flows and decreases in river outflows. The highest entrainment was observed at high net negative OMR flows and low outflows. PTM results suggest that entrainment losses might be as high as 40% of the total delta smelt population in some years. (Kimmerer 2008.) Similar results were obtained by Baxter et al. (2009) when evaluating entrainment of longfin smelt using PTM. Juvenile longfin smelt salvage increased rapidly as net OMR flows became more negative than -2,000 cfs. Also, particle entrapment decreased, even with high net negative OMR flows, when the flow of the Sacramento River at Rio Vista increased above 40,000 cfs. Entrainment of particles almost ceased at flows of 55,000 cfs.

Field population investigations support some of the spring PTM results. Gravid females and larvae are present in the Delta as early as March and April. (Bennett 2005.) However, analysis of otolith data on individuals collected later in the year by Bennett *et al*. (unpublished data) show that few of the early progeny survived if spawned prior to the VAMP time period (typically April 15 to May 15). The hydrodynamic data showed high net negative OMR flows in the months preceding and after the VAMP, leading the researchers to conclude that high winter and early spring net negative OMR flows were selectively entraining the early spawning and/or early hatching cohort of the delta smelt population. However, Baxter *et al*. (2008) stated that “under this hypothesis, the most important result of the loss of early spawning females would manifest itself in the year following the loss, and would therefore not necessarily be detected by analyses relating fall abundance indices to same-year predictors.” No statistical relationships have been found between either OMR flows or CVP and SWP pumping rates and Delta smelt population abundance. (Bennett 2005.)

Entrainment of adult delta smelt occurs following the first substantial precipitation event (“first flush”), characterized by sudden increases in river inflows and turbidity, in the estuary as they begin their migration into the tidal freshwater areas of the Delta. (Grimaldo *et al*. 2009.) Patterns of adult entrainment are distinctly unimodal, suggesting that migration is a large population-level event, as opposed to being intermittent or random. (DOI 1, p. 36.) Grimaldo *et al*. (2009) provided evidence suggesting that entrainment during these "first flush" periods could be reduced if export reductions were made at the onset of such periods.

The USFWS Opinion identifies turbidity criteria for which to trigger first flush export reductions, but total Delta outflow greater than 25,000 cfs could serve as an alternate or additional trigger since such flows are highly correlated with turbidity. (Grimaldo *et al*. 2009, DOI 1, p. 36.) Managing OMR flows to thresholds at which entrainment or populations losses increase rapidly, represents a strategy for providing additional protection for adult delta smelt in the winter period (Dec-Mar). (DOI 1, p.36.). The USFWS Opinion identified the lower net OMR flow threshold as - 5000 cfs based on observed OMR flow versus salvage relationships from a longer data period (USFWS 2008) and additional data summarized over a more recent period. (Grimaldo et al. 2009.) The -5000 cfs OMR flow threshold is appropriate because it is the level where population losses consistently exceed 10%. (USFWS 2008, DOI 1, p. 36.) Adult delta smelt entrainment varies according to their distribution in the Delta following their upstream migration. The population is at higher entrainment risk if the majority of the population migrates into the south Delta, which may require net OMR flows to be more positive than -5000 cfs to reduce high entrainment. Conversely, if the majority of the population migrates up the lower Sacramento River or north Delta, a smaller entrainment risk is presumed, which would allow for OMR flows to be more negative than -5000 cfs for an extended period of time, or until conditions warrant a more protective OMR flow. (DOI 1, p.36.)

The USFWS Opinion for delta smelt includes net negative OMR flow restrictions to protect both spawning adult and out-migrating young. Component 1 of the USFWS Opinion has two action items; both are to protect adult delta smelt. Action 1 restricts OMR flow in fall to -2,000 cfs for 14 days when a turbidity or salvage trigger has been met. Both triggers have previously been correlated with the upstream movement of spawning adult smelt. Action 2 commences immediately after Action 1. Action 2 is to protect adult delta smelt after migration, but prior to spawning, by restricting net OMR flows to between -1250 and -5,000 cfs based on the recommendations of the Delta Smelt Workgroup. Component 2 of the USFWS Opinion is to protect larval and juvenile fish. Component 2 actions start once water temperatures hit 12$^{o}$C at three monitoring stations in the Delta or when a spent female is caught. OMR flows during this phase are to be maintained more positive than -1,250 to -5000 cfs based on a 14-day running average. Component 2 actions are to continue until June 30 or when the 3-day-mean water temperature at Clifton Court Forebay is 25$^{o}$C. The Delta Smelt Working Group is to make recommendations on the specific OMR flow restrictions between -1250 and -5000 cfs.

The NAS (2010) reviewed the USFWS Opinion OMR flow restrictions and concluded:

> "…it is scientifically reasonable to conclude that high negative OMR flows in winter probably adversely affect smelt populations. Thus, the concept of reducing OMR negative flows to reduce mortality of smelt at the SWP and CVP facilities is scientifically justified … but the data do not permit a confident identification of the threshold values to use … and … do not

> permit a confident assessment of the benefits to the population…As a result, the implementation of this action needs to be accompanied by careful monitoring, adaptive management and additional analyses that permit regular review and adjustment of strategies as knowledge improves."

The negative impact of negative OMR flows on delta smelt, like on longfin smelt, is likely to be greatest during time periods with high negative OMR flows and low Sacramento River outflow. (Baxter *et al*. 2009; Kimmerer and Nobriga 2008.) The work of Grimaldo *et al*, (2009) suggests that impacts associated with the export facilities can be mitigated on a larger scale by altering the timing and magnitude of exports based on the biology of the fishes and changes in key physical and biological variables.

For the protection of longfin smelt, Delta outflow criteria between January and March range from 35,000 cfs in below normal water years to greater than 50,000 cfs in wet water years (Table 8). For the protection of longfin smelt, flow criteria between April and May range from 29,000 cfs to more than 42,000 cfs. These flows should also afford protection for larval delta smelt from excessive negative OMR flows and entrainment at the CVP and SWP pumping facilities. Under this criterion, lower outflows will still likely occur during critically dry and dry water year types (Table 6). These outflows may not be sufficient to prevent longfin and delta smelt entrainment at the pumping facilities. Therefore, the recommended criterion for longfin smelt specifies that net OMR flows should not be more negative than -1500 cfs in April and May of dry and critically dry water years to protect longfin smelt. The State Water Board determines that this criterion should be extended to include March and June of dry and critically dry water years to protect early and late spawning delta smelt (Table 11).

Minimizing net negative OMR flows during periods when adult delta smelt are migrating into the Delta could also substantially reduce mortality of the critical life stage. For example, one potential strategy is to reduce exports during the period immediately following the "first flush", based on a turbidity or flow trigger. (Grimaldo et al. 2009.) This supports a recommendation that net OMR flows be more positive than -5000 cfs during the period between December and March. Additional OMR flow restrictions may be warranted during periods when a significant portion of the adult delta smelt population migrates into the south or central Delta. In such instances, the determination of specific thresholds should be made through an adaptive approach that takes into account a variety of factors including relative risk (e.g., biology, distribution and abundance of fishes), hydrodynamics, water quality, and key physical and biological variables. The State Water Board agrees with the NAS (2010) that the data, as currently available, do not permit a confident assessment of the threshold OMR flow values nor of the overall benefit to the delta smelt population. Development of a comprehensive life-cycle model for delta smelt would be valuable in that it would allow for an assessment of population level impacts associated with entrainment. Such life-cycle models for delta smelt are currently under development. Therefore, net OMR flow criteria need to be accompanied by a strong monitoring program and adaptive management to adjust OMR flow criteria as more knowledge becomes available.

Delta smelt are food limited. Delta smelt survival is positively correlated with zooplankton abundance. (Feyrer et al., 2007; Kimmerer 2008; Grimaldo et al., 2009.) A new analysis by the SFWC (SFWC 1, p.60) also demonstrates a positive relationship between FMWT delta smelt indices and the previous spring and summer abundance of

*Eurytemora* and *Psuedodiaptomus.* There are several hypotheses for the cause of the decline in zooplankton abundance. First, zooplankton abundance in Suisun and Grizzly bays, prime habitat for delta smelt, declined after the introduction of the invasive clam *Corbula.* *Corbula* is thought to compete directly with zooplankton for phytoplankton food and lower phytoplankton levels may limit zooplankton abundance. A second hypothesis is that changes in nutrient loading and nutrient form in the Delta that result from the SRWTP discharge can have major impacts on food webs, from primary producers through secondary producers to fish. (Glibert, 2010.) Changes in nutrient concentrations and their ratios may have caused the documented shift in phytoplankton species composition from large diatoms to smaller, less nutritious algal forms for filter feeding organisms like zooplankton. If true, both of the above hypotheses could indirectly result in lower densities of delta smelt. Therefore, all recommended flow modifications should be accompanied by a strong monitoring and adaptive management process to determine whether changes in OMR flows result in an improvement in delta smelt population levels.

### *Population Abundance Goal*

The immediate goal is to stabilize delta smelt populations, as measured by the FMWT index, and begin to grow the population. The long term goal should be to achieve the objective of the Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes (USFWS 1996.)

### *Species-Specific Recommendations*

Although a positive correlation between Delta outflows and delta smelt is lacking, Delta outflows do have significant positive effects on several measures of delta smelt habitat. (Kimmerer *et al*. 2009), and spring outflow is positively correlated with spring abundance of *Eurytemora affinis* (Kimmerer 2002a), an important delta smelt prey item. No specific spring Delta outflow criteria are therefore recommended for delta smelt. Flow criteria to protect longfin smelt in the spring of wetter years (Table 8) may, however, afford some additional protection for the Delta smelt population.

The State Water Board advances the OMR flow criteria in Table 11 for dry and critically dry years to protect the delta smelt population from entrainment in the CVP and SWP pumping facilities during years with limited Delta outflow. The OMR flow restrictions are an extension of the criteria for longfin smelt. In addition, the State Water Board includes criteria for OMR flows to be more positive than -5,000 cfs between December and February of all water year types to protect upstream migrating adult delta smelt. The -5,000 cfs criteria may need to be made more protective in years when delta smelt move into the central Delta to spawn. The more restrictive OMR flows would be recommended after consultation with the USFWS's Delta Smelt Working Group. In the absence of any other specific information, the State Water Board determines that the existing 2006 Bay-Delta Plan Delta outflow objectives for July through December are needed to protect delta smelt.

**Table 11. Net OMR Flows for the Protection of Delta Smelt**

| Flow Type | Water Year Type | Dec | Jan | Feb | Mar - June |
|---|---|---|---|---|---|
| Net OMR flows | C/D | | | | > -1,500 cfs |
| Net OMR flows | All | > - 5000 cfs (thresholds determined through adaptive management) | | | |

## Sacramento Splittail (*Pogonichthys macrolepidotus*)

### Status

Sacramento splittail is currently recognized by the DFG as a species of special concern. Splittail was listed as a threatened species pursuant to the ESA in 1999; however, its status was remanded in 2003 on the premise of recent increases in abundance and population stability. This decision was subsequently challenged and the USFWS is revisiting the status of splittail and will make a new 12-month finding on whether listing is warranted by September 30, 2010.

### Life History

Sacramento splittail (*Pogonichthys macrolepidotus*) is a cyprinid native to California that can live seven to nine years and has a high tolerance to a wide variety of water quality parameters including moderate salinity levels. (Moyle 2002, Moyle et al. 2004.)

Adult splittail are found predominantly in Suisun Marsh, Suisun Bay, and the western Delta, but are also found in other brackish water marshes in the San Francisco Estuary as well as the fresher Delta. Splittail feed on detritus and a wide variety of invertebrates; non-detrital food starts with cladocerans and aquatic fly larvae on the floodplains, progresses to insects and copepods in the rivers, and to mysid shrimps, amphipods and clams for older juveniles and adults. (Daniels and Moyle 1983, Feyrer et al. 2003, Feyrer et al. 2007a, as cited in DFG 1, p. 13.) In winter and spring when California's Central Valley experiences increased runoff from rainfall and snowmelt, adult splittail move onto inundated floodplains to forage and spawn. (Meng and Moyle 1995; Sommer et al. 1997, Moyle et al. 2004, as cited in DFG 1, p. 13.) Spawning takes place primarily between late February and early July, and most frequently during March and April (Wang 1986, Moyle 2002) and occasionally as early as January. (Feyrer et al. 2006a.) Splittail eggs, laid on submerged vegetation, begin to hatch in a few days and the larval fish grow fast in the warm and food rich environment. (e.g., Moyle et al. 2004, Ribeiro et al. 2004.) After spawning, the adult fish move back downstream.

Once they have grown a few centimeters, the juvenile splittail begin moving off of the floodplain and downstream into similar habitats as the adults. These juveniles become mature in two to three years. In the Yolo Bypass, two flow components appear necessary for substantial splittail production (Feyrer et al. 2006a): (1) inundating flows in winter (January to February) to stimulate and attract migrating adults; and (2) sustained floodplain inundation for 30 or more days from March through May or June to allow successful incubation through hatching (3 to 7 days, see Moyle 2002), and extended rearing until larvae are competent swimmers (10 to 14 days; Sommer et al. 1997) and beyond to maximize recruitment. (DFG 1, p. 13.)

Large-scale spawning and juvenile recruitment occurs only in years with significant protracted (greater than or equal to 30 days) floodplain inundation, particularly in the

Sutter and Yolo bypasses. (Meng and Moyle 1995, Sommer et al. 1997, Feyrer et al. 2006a, as cited in DFG 1, p. 13.) Some spawning also occurs in perennial marshes and along the vegetated edges of the Sacramento and San Joaquin rivers. (Moyle et al. 2004.) During periods of low outflow, splittail appear to migrate farther upstream to find suitable spawning and rearing habitats. (Feyrer et al. 2005.) Moyle et al. (2004) noted that though modeling shows splittail to be resilient, managing floodplains to promote frequent successful spawning is needed to keep them abundant.

## Population Abundance and its Relationship to Flow

Age-0 splittail abundance has been significantly correlated to mean February through May Delta outflow and days of Yolo Bypass floodplain inundation, representing flow/inundation during the incubation and early rearing periods. (Meng and Moyle 1995, Sommer et al. 1997.) The flow-abundance relationship is characterized by increased abundance (measured by the FMWT) as mean February–May X2 decreases, indicating a significant positive relationship between FMWT abundance and flow entering the estuary during February–May. (Kimmerer 2002a.)

Feyrer et al. (2006a) proposed the following lines of evidence to suggest the mechanism supporting this relationship for splittail lies within the covarying relationship between X2 and flow patterns upstream entering the estuary: the vast majority of splittail spawning occurs upstream of the estuary in freshwater rivers and floodplains (Moyle et al. 2004); the averaging time frame (February–May) for X2 coincides with the primary spawning and upstream rearing period for splittail; the availability of floodplain habitat, as indexed by Yolo Bypass stage, is directly related to X2 during February–May ($y = 4.38 - 2.21x$; $p<0.001$; $r^2 = 0.97$); the center of age-0 splittail distribution does not reach the estuary until summer (Feyrer et al. 2005); and the splittail X2-abundance relationship has not been affected by dramatic food web changes (Kimmerer 2002a) that have significantly altered the diet of young splittail in the estuary. (Feyrer et al. 2003.)

### *Population Abundance Goal*

The immediate goal is to stabilize the Sacramento Splittail population, as measured by the FMWT index, and to begin to grow the population. The long-term goal is to maintain population abundance index as measured by FMWT in half of all years above the long term population index value.

### *Species- Specific Recommendations*

Delta Outflow - Upstream covariates of X2, such as the availability of suitable floodplain and off-channel spawning and nursery habitat, appear to be the attributes supporting the flow-abundance relationship for splittail. Therefore, the flow needs of this species, with respect to spawning and rearing habitat, are most effectively dealt with through establishment of flow criteria that address the timing, duration, and magnitude of floodplain inundation from a river inflow standpoint.

Delta Inflow - Information in the record on conditions conducive to successful spawning and recruitment of splittail shows that the species depends on inundation of off-channel areas. Sufficient flows are therefore needed to maintain continuous inundation for at least 30 consecutive days in the Yolo Bypass, once floodplain inundation has been achieved based on runoff and discharge for ten days between late-February and May, during above normal and wet years (Table 12). (DFG closing comments, p. 7.)

Opportunities to provide floodplain inundation in other locations (e.g., the San Joaquin River) warrant further examination.

Feyrer *et al* (2006a) noted that manipulating flows entering Yolo Bypass such that floodplain inundation is maximized during January through June will likely provide the greatest overall benefit for splittail, especially in relatively dry years when overall production is lowest. Within the Yolo Bypass, floodplain inundation of at least a month appears to be necessary for a strong year class of splittail (Sommer *et al*. 1997); however, abundance was highest when the period of inundation extended 50 days or more. (Meng and Moyle 1995.) Floodplain inundation during the months of March, April, and May appears to be most important. (Wang 1986, Moyle 2002.) Managing the frequency and duration of floodplain inundation during the winter and spring, followed by complete drainage by the end of the flooding season, could favor splittail and other native fish over non-natives. (Moyle et al. 2007, Grimaldo et al. 2004.) Duration and timing of inundation are important factors that influence ecological benefits of floodplains.

<u>Yolo Bypass Inundation</u> – The Fremont Weir is a passive facility that begins to spill into the Yolo Bypass when the Sacramento River flow at Verona exceeds 55,000 to 56,000 cfs. (AR/NHI 1, p. 21; EDF 1, p. 50; TBI/NRDC 3, p. 35; Sommer et al. 2001b.) Water also enters the bypass at the Sacramento Weir and from the west via high flow events in small west-side tributaries. (Feyrer et al. 2006b.) Each of these sources joins the Toe Drain, a perennial channel along the east side of the Yolo Bypass floodplain, and water spills onto the floodplain when the Toe Drain flow exceeds approximately 3,500 cfs. (Feyrer et al. 2006b.) The Yolo Bypass typically floods in winter and spring in about 60% of years (DOI 1, p. 54; Sommer et al. 2001a; Feyrer et al. 2006a), with inundation occurring as early as October and as late as June, with typical peak period of inundation during January-March. (Sommer et al. 2001b.) In addition, studies suggest phytoplankton, zooplankton, and other organic material transported from the Yolo Bypass enhances the food web of the San Francisco Estuary. (Jassby and Cloern 2000; Mueller-Solger et al. 2002; Sommer et al. 2004.) Much of the water diverted into the bypass drains back into the north Delta near Rio Vista. Besides the Yolo Bypass, the only other Delta region with substantial connectivity to portions of the historical floodplain is the Cosumnes River, a small undammed watershed. (Sommer et al. 2001b.)

Multiple participants provided recommendations concerning the magnitude and duration of floodplain inundation along the Sacramento River, lower San Joaquin River, and within the Yolo and Sutter bypasses. (AR/NHI 1, p. 32; DFG closing comments; DOI 1, p. 54, EDF 1, pp. 50-52, 53-55; SFWC closing comments; TBI/NRDC 3, p. 36.) In addition, the draft recovery plan for the Sacramento River winter-run Chinook salmon, Central Valley spring-run Chinook salmon, and Central Valley Steelhead (NMFS 2009) calls for the creation of annual spring inundation of at least 8,000 cfs to fully activate the Yolo Bypass floodplain. (NMFS 5, p.157.)

Overtopping the existing weirs and flooding the bypasses (e.g., Yolo and Sutter) to achieve prolonged periods (30 to 60 days) of floodplain inundation in below normal and dry water years would require excessive amounts flows given the typical runoff patterns during those year types. (AR/NHI 1, p. 29.) From a practical standpoint, it is probably only realistic to achieve prolonged inundation during drier water year types by notching the upstream weirs and possibly implementing other modifications to the existing system. (AR/NHI 1, p. 29.)

The BDCP is currently evaluating structural modifications to the Fremont Weir (e.g., notch the weir and install operable “inundation gates”), as a means of increasing the interannual frequency and duration of floodplain inundation in the Yolo Bypass. (BDCP 2009.) TBI/NRDC (TBI/NRDC 3, p. 36) and AR/NHI (AR/NHI 1, p. 32) provided floodplain inundation recommendations for the Yolo Bypass assuming structural modifications to the Fremont Weir were implemented. A potential negative impact of notching the Fremont Weir is that it will affect stage height and Sutter Bypass flooding, and the resulting spawning and rearing of splittail and spring-run Chinook salmon. (personal communication R. Baxter.)

The NMFS Opinion stipulates that USBR and DWR, in cooperation with DFG, USFWS, NMFS, and USACE, shall, to the maximum extent of their authorities (excluding condemnation authority), provide significantly increased acreage of seasonal floodplain rearing habitat, with biologically appropriate durations and magnitudes, from December through April, in the lower Sacramento River basin, on a return rate of approximately one to three years, depending on water year type. (NMFS 3, p.608.) USBR and DWR are to submit a plan to implement this action to NMFS by December 31, 2011. (NMFS 3, p. 608.) This plan is to include an evaluation of options to, among other things, increase inundation of publicly and privately owned suitable acreage within the Yolo Bypass and modify operations of the Sacramento Weir or Fremont Weir to increase rearing habitat. (NMFS 3, p. 608.) The NMFS Opinion specifies that in the event that this action conflicts with Shasta Operations Actions I.2.1 to I.2.3 (e.g., carryover storage requirements), the Shasta Operations Actions shall prevail. (NMFS 3, p. 608.)

<u>OMR Flows</u> - Entrainment of splittail at the SWP and CVP export facilities is highest during adult spawning migrations and periods of peak juvenile abundance in the Delta. (Meng and Moyle 1995, Sommer et al. 1997.) The incidence of age-0 splittail entrainment increased during wet years when abundance was also high (Sommer et al. 1997.) However, analyses conducted by Sommer et al. (1997) suggested that entrainment at the export facilities did not have an important population-level effect. However, Sommer et al. (1997) noted that their evidence does not demonstrate that entrainment never affects the species. For example, if the core of the population’s distribution were to shift toward the south Delta export facilities during a dry year, there could be substantial entrainment effects to a year-class. (Sommer et al. 1997.) Criteria for net OMR flows intended to protect salmon, delta smelt, and longfin smelt populations, as well as restrictions stipulated in the Opinions (NMFS 3, pp. 648-653; USFWS 2008) are likely to reduce the number of splittail entrained at the export facilities.

**Table 12. Floodplain Inundation Criteria for Sacramento Splittail**

| Mechanism | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spawning and Rearing Habitat | AN / W | -- | ≥ 30 day floodplain inundation | | | | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | | | | | | |

## **Starry Flounder (*Platichthys stellatus*)**

### ***Status***

Starry flounder is not listed pursuant to either the ESA or CESA.

### ***Life History***

Starry flounder is a native to the Bay-Delta Estuary. The geographic distribution of flounder is from Santa Barbara, California, to Alaska and in the western Pacific as far south as the Sea of Japan. (Miller and Lea 1972.) Starry flounder are important in both the recreational and commercial catch in both central and northern California. (Haugen 1992; Karpov et al. 1995.)

Starry flounder is an estuarine dependent species. (Emmett et al. 1991.) Spawning occurs in the Pacific Ocean near the entrance to estuaries and other freshwater sources between November and February. (Orcutt 1950.) Juveniles migrate from marine to fresh water between March and June and remain through at least their second year of life before returning to the ocean. (Baxter 1999.) Young individuals are found in Suisun Bay and Marsh and in the Delta. Older individuals range from Suisun to San Pablo bays. Maturity is reached by males at the end of their second year and by females in their third or fourth years. (Orcott 1950.)

Population abundance of young of the year and one year old starry flounder have been measured by the San Francisco Otter Trawl Study since 1980 and reported as an annual index. (Kimmerer et al. 2009.) The index declined between 2000 and 2002 but has since recovered to values in the 300 to 500 range. The median index value for the 29 years of record is 293.

### ***Population Abundance Relationship to Flow***

Starry flounder age-1 abundance in the San Francisco Bay otter trawl study is positively correlated with the March through June outflow of the previous year. (Kimmerer et al. 2009.) The mechanism underlying the abundance outflow relationship is not known but may be increased passive transport of juvenile flounder by strong bottom currents during high outflow years. (Moyle 2002.) There has been a decline in the abundance of flounder for any given outflow volume since 1987, presumably because of the invasion by the clam Corbula, however, the overall abundance-flow relationship is still statistically significant. (Kimmerer 2002a.)

### ***Population Abundance Goal***

The goal is to maintain the starry flounder population abundance index, as measured by the San Francisco Otter Trawl Study, in half of all years above the long term population median index value of 293.

### ***Species-Specific Recommendations***

Outflow recommendations were only received from the DFG. (DFG 1, p. 16.) DFG recommends maintaining X2 between 65 and 74 km between February and June. This corresponds to an average outflow of 11,400 to 26,815 cfs. Table 13 contains the criteria needed for protection of starry flounder. The purpose of this outflow criteria is to maintain population abundance near the long term median index value of 293. This net Delta outflow criteria is similar to those proposed for the protection of longfin smelt, delta smelt, and *Crangon sp*. The State Water Board's criteria for Delta outflow for the protection of both longfin and delta smelt and *Crangon* will also protect starry flounder. The proposed outflow is consistent with DFG's recommendation for starry flounder. There is no information in the record to support criteria for inflows or hydrodynamics to protect starry flounder.

**Table 13. Criteria for Delta Outflow to Protect Starry Flounder**

| Flow Type | Water Year Type | Jan | Feb | Mar | April | May | Jun |
|---|---|---|---|---|---|---|---|
| Net Delta Outflow | C | 14,000 – 21,000 | | | 10,000 – 17,500 | | |
| | D | 21,000 – 35,200 | | | 17,500 – 29,000 | | |
| | BN | 35,200 – >50,000 | | | 29,000 – 42,000 | | |
| | AN | >50,000 | | | >42,000 | | |
| | W | >50,000 | | | >42,000 | | |

## California Bay Shrimp (*Crangon franciscorum*)

### *Status*

The California bay shrimp is not listed pursuant to either ESA or CESA.

### *Life History*

There are three native species of Crangon, collectively known as bay shrimp or grass shrimp, common to the San Francisco Estuary: *Crangon franciscorum, C. nigricauda*, and *C. nigromaculata.* (Hieb 1999.) Bay shrimp are fished commercially in the lower estuary and sold as bait. (Reilly et al. 2001.) *C. franciscorum* species is targeted by the commercial fishery because of its larger size. Bay shrimp are also important prey organisms for many fish in the estuary. (Hatfield, 1995.)

The California bay shrimp (*Crangon franciscorum*) is an estuary dependent species that is distributed along the west coast of North America from Alaska to San Diego. Larvae hatch from eggs carried by females in winter in the lower estuary or offshore in the Pacific Ocean. Most late-stage larvae and juvenile *C. franciscorum* migrate into the estuary and upstream to nursery areas between April and June. Juvenile shrimp are common in San Pablo and Suisun bays in high outflow years. Their center of distribution moves upstream to Honker Bay and the lower Sacramento and San Joaquin rivers during low flow years. (Hieb 1999.) Mature shrimp migrate back down to higher salinity waters after a four to six month residence in the upper estuary. (Hatfield 1985.) *C. franciscornum* mature at one year and may live up to two years. Some females hatch more than one brood of eggs during a breeding season.

Population abundance of juvenile *C. franiscorum* is measured by DFG's San Francisco Bay Study and is reported as an annual index. (Jassby et al. 1995, Hieb 1999.) Indices over the 29 years of record have varied from 31 to 588 with a median value of about 103.

### *Population Abundance and Relationship to Flow*

There is a positive correlation between the abundance of *C. franciscorum* and net Delta outflow from March to May of the same year. (Jassby et al. 1995; Kimmerer et al. 2009.) The statistical relationship has remained constant since the early years of the San Francisco Bay Study, which began in 1980. The mechanism underlying the abundance relationship is not known but may be an increase in the passive transport of juvenile shrimp up-estuary by strong bottom currents during high outflows years. (Kimmerer et al. 2009, Moyle 2002, DFG 1992.) Other potential mechanisms include the effects of freshwater outflow on the amount and location of habitat, the abundance of food organisms and predators, and the timing of the downstream movement of mature shrimp. (DFG 1, p. 23.)

Delta outflow recommendations (Table 14) were received from both the DFG (DFG 1, p. 23) and TBI/NRDC. (TBI/NRDC 2, p. 17). TBI/NRDC analyzed the productivity of *C. franciscorum* as a function of net Delta outflow between March and May. The analysis suggests that estuary populations increased in about half of all years when flows between March and May were approximately 5 million acre-feet (MAF), or about 28,000 cfs per month. TBI/NRDC recommended that flow be maintained in most years above 28,000 cfs during these three months to insure population growth about half the time. The DFG recommended a net Delta outflow criterion of 11,400 to 26,800 cfs between February and June of all water years to aid immigration of late stage larvae and small juveniles.

**Table 14. Participant Recommendations for Delta Outflows to Protect Bay Shrimp**

| | Water Year | Feb | Mar | Apr | May | Jun |
|---|---|---|---|---|---|---|
| **TBI/NRDC Exhibit 2** | Most years | | 28,000 | | | |
| **Fish and Game Exhibit 1** | all | 11,400 to 26,815 | | | | |

### *Population Abundance Goal*

The goal is to maintain the juvenile C*. franciscorum* population abundance index, as measured by the San Francisco Bay Study otter trawl, in half of all years above a target value of 103. An index of 103 is the median longterm index value for this species in the San Francisco Estuary.

### *Species-Specific Recommendations*

The State Water Board determines the Delta outflow criteria in Table 15 are needed to protect C*rangon franciscorum*. The purpose of the outflow criteria is to maintain population abundance at a long term median index value of 103. Positive population growth is expected in half of all years under these flow conditions. The Delta outflow criteria are similar to those proposed for protection of both longfin smelt and delta smelt. The nursery area for C*. franciscorum* is usually downstream of the influence of the pumps, therefore no OMR flow recommendations were received and no review was conducted.

**Table 15. Criteria for Delta Outflows to Protect Bay Shrimp**

| **Flow Type** | **Water Year Type** | **Jan** | **Feb** | **Mar** | **April** | **May** |
|---|---|---|---|---|---|---|
| Net Delta Outflow | C | 14,000 – 21,000 | | | 10,000 – 17,500 | |
| | D | 21,000 – 35,200 | | | 17,500 – 29,000 | |
| | BN | 35,200 – >50,000 | | | 29,000 – 42,000 | |
| | AN | >50,000 | | | >42,000 | |
| | W | >50,000 | | | >42,000 | |

## Zooplankton (*E. affinis* and *N. mercedis*)

### *Status*

*Eurytemora affinis* is a non-native species that is not listed pursuant to either the ESA or CESA.  *Neomysis mercedis* is a native species that is not listed pursuant to either the ESA or CESA.

### *Life History*[14]

Zooplankton is a general term for small aquatic animals that constitute an essential food source for fish, especially young fish and all stages of pelagic fishes that mature at a small size, such as longfin smelt and delta smelt (DFG 1987b).  Although DFG follows trends of numerous zooplankton taxa (e.g., Hennessy 2009), two upper estuary zooplankton taxa of particular importance to pelagic fishes have exhibited abundance relationships to Delta outflow.  The first is the mysid shrimp *Neomysis mercedis*, which before its decline, beginning in the late 1980s, was an important food of most small fishes in the upper estuary (see Feyrer et al. 2003).  Prior to 1988, *N. mercedis* mean summer abundance (June through October) increased significantly as X2 moved downstream (mean March through November location, Kimmerer 2002a. Table 1).  After 1987, *N. mercedis* abundance declined rapidly and is currently barely detectable (Kimmerer 2002a, Hennessy 2009).  The second is a calanoid copepod, *Eurytemora affinis*, which also declined sharply after 1987, but more so in summer than in spring (Kimmerer 2002a).  Before 1987, *E. affinis* was abundant in the low salinity habitat (0.8-6.3 ‰) throughout the estuary (Orsi and Mecum 1986).  *E. affinis* is an important food for most small fishes, particularly those with winter and early spring larvae, such as longfin smelt, delta smelt and striped bass (Lott 1998, Nobriga 2002, Bryant and Arnold 2007, DFG unpublished).

### *Population Abundance and Relationship to Flow*

*E. affinis* was historically abundant throughout the year, particularly in spring and summer, but after 1987 abundance declined in all seasons, most notably in summer and fall. (Hennessy 2009, as cited in DFG 1, p. 26.)  After 1987, *E. affinis* spring abundance (March through May) has significantly increased as spring X2 has moved downstream. (Kimmerer 2002a. Table 1, as cited in DFG 1, p. 26.)  Relative abundance in recent years is highest in spring and persistence of abundance is related to spring outflow.  As flows decrease in late spring, abundance decreases to extremely low levels throughout the estuary. (Hennessey 2009, as cited in DFG 1, p. 26.)

[14] This section was largely extracted from DFG Exhibit 1, page 25.

The only outflow recommendation identified in the record specifically for *E. affinis* and *N. mercedis* was submitted by DFG, in their closing comments (Table 16). According to DFG, their current science-based conceptual model is that placement of X2 in Suisun Bay represents the best interaction of water quality and landscape for fisheries production given the current estuary geometry. (DFG 2, p. 6.) Maintaining X2 at 75 km and 64 km corresponds to net Delta outflows of approximately 11,400 cfs and 29,200 cfs, respectively. The Bay Institute provided flow recommendations for a suite of species, including *E. affinis (*Table 17*).*

**Table 16. DFG's Delta Outflow Recommendation to Protect *E. affinis* and *N. mercedis* (DFG Closing Comments)**

| Species | Parameter | Effect or Mechanism | Timing | Minimum | Maximum | Reference |
|---|---|---|---|---|---|---|
| Zooplankton | Flows | Habitat | February - June | X2 at 75 km | X2 at 64 km | DFG Exhibit 1, p.25-26; Exhibit 2, p.6 |

**Table 17. The Bay Institute's Delta Outflow Recommendations to Protect Zooplankton Species Including *E. affinis***

| Species | Mechanism | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Eurytemora affinis* | Habitat | 81-100% (driest years) | 14000-21000 cfs | | 10000-17500 cfs | | | 3000-4200 cfs | | | | | | |
| | | 61-80% | 21000-35000 cfs | | 17500-29000 cfs | | | 4200-5000 cfs | | | | | | |
| | | 41-60% | 35200-55000 cfs | | 29000-42500 cfs | | | 5000-8500 cfs | | | | | | |
| | | 21-40% | 55000-87500 cfs | | 42500-62500 cfs | | | 8500-25000 cfs | | | | | | |
| | | 0-20% (wettest years) | 87500-140000 cfs | | 62500-110000 cfs | | | 25000 - 50000 cfs | | | | | | |

### *Species-Specific Recommendations*

Table 18 shows the State Water Board's determination for Delta outflows needed to protect zooplankton. These recommendations are consistent with those submitted by DFG. (closing comments, p. 7.) The State Water Board concurs with DFG's current science-based conceptual model which concludes that placement of X2 in Suisun Bay represents the best interaction of water quality and landscape for fisheries production given the current estuary geometry. (DFG 2, p. 6.) Maintaining X2 at 75 km and 64 km corresponds to net Delta outflows of approximately 11,400 cfs and 29,200 cfs, respectively.  No explicit recommendations concerning zooplankton and inflow or hydrodynamic requirements were identified in the record.

**Table 18. Criteria for Delta Outflows to Protect Zooplankton**

| Effect or Mechanism | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Habitat | All | -- | X2[1] – 75 to 64 km (~11400 – 29200 cfs) | | | | | -- | -- | -- | -- | -- | -- |

## *4.3 Other Measures*

Information in the record for this proceeding broadly supports the five key points submitted by the DEFG of experts (DEFG 1):

1) Environmental flows are more than just volumes of inflows and outflows
2) Recent flow regimes both harm native species and encourage non-native species
3) Flow is a major determinant of habitat and transport
4) Recent Delta environmental flows are insufficient to support native Delta fishes for today's habitats
5) A strong science program and a flexible management regime are essential to improving flow criteria

These key points recognize that although adequate environmental flows are a necessary element to protect public trust resources in the Delta ecosystem, flows alone are not sufficient to provide this protection.  These key points and other information in the record warrant a brief summary discussion of other information in the record that should be considered in the development of flow criteria, consistent with the charge of SB1 that "the flow criteria include the volume, quality, and timing of water necessary for the Delta ecosystem. "  Based on review of the information in the record this charge is expanded to include specific consideration of:

- Variability, flow paths, and the hydrograph
- Floodplain activation and other habitat improvements
- Water quality and contaminants
- Cold water pool management
- Adaptive management

### 4.3.1 Variability, Flow Paths, and the Hydrograph

The first of the five key points submitted by the DEFG of experts stated, in part: "There is no one correct flow number. Seasonal, interannual, and spatial variability, to which our native species are adapted, are as important as quantity." Species and biological systems respond to combinations of quantity, timing, duration, frequency and how these inputs vary spatially. (DEFG 1.)  Based on their review of the literature in *Habitat Variability and Complexity in the Upper San Francisco Estuary*, Moyle *et al* (2010) find:

> "… unmodified estuaries are highly variable and complex systems, renowned for their high production of fish and other organisms (McClusky and Elliott 2004). The San Francisco Estuary, however, is one of the most highly modified and controlled estuaries in the world (Nichols et al. 1986).  As a consequence, the

estuarine ecosystem has lost much of its former variability and complexity and has recently suffered major declines of many of its fish resources (Sommer et al. 2007).

…the concept of the "natural flow regime" (Poff et al. 1997) is increasingly regarded as an important strategy for establishing flow regimes to benefit native species in regulated rivers (Postel and Richter 2003; Poff et al. 2007; Moyle and Mount 2007). For estuaries worldwide, the degree of environmental variability is regarded as fundamental in regulating biotic assemblages (McLusky and Elliott 2004). Many studies have shown that estuarine biotic assemblages are generally regulated by a combination of somewhat predictable changes (e.g., tidal cycles, seasonal freshwater inflows) and stochastic factors, such as recruitment variability and large-scale episodes of flood or drought (e.g., Thiel and Potter 2001). The persistence and resilience of estuarine assemblages is further decreased by various human alterations, ranging from diking of wetlands, to regulation of inflows, to invasions of alien species (McLusky and Elliott 2004, Peterson 2003).

…a key to returning the estuary to a state that supports more of the desirable organisms (e.g., Chinook salmon, striped bass, delta smelt) is increasing variability in physical habitat, tidal and riverine flows, and water chemistry, especially salinity, over multiple scales of time and space. It is also important that the stationary physical habitat be associated with the right physical-chemical conditions in the water at times when the fish can use the habitat most effectively (Peterson 2003)."

An example of a major change in the natural flow regime of the Delta is demonstrated by the increase in net OMR reverse flows just north of the SWP and CVP pumping facilities. Reverse flows are now a regular occurrence in the Delta channels because Sacramento River water enters on the northern side of the Delta while the two major pumping facilities, the SWP and CVP, are located in the south. This results in a net water movement across the Delta in a north-south direction along a web of channels including OMR instead of the more natural pattern from east to west or from land to sea. Positive net flows, connected flow paths, and salinity gradients are important features of an estuary. Natural net channel flows move water and some biota toward Suisun Bay and maintain downstream directed salinity gradients. Today, Delta gates and diversions can substantially redirect tidal flows creating net flow patterns and salinity and turbidity distributions that did not occur historically. These changes may influence migratory cues for some fishes. These cues are further scrambled by a reverse salinity gradient in the south Delta caused by higher salinity in agricultural runoff. (DEFG 1.)

Per the DEFG's paper, *Habitat Variability and Complexity in the Upper San Francisco Estuary* (Moyle et al., 2010), a more variable Delta has multiple benefits:

"Achieving a variable, more complex estuary requires establishing seaward gradients in salinity and other water quality variables, diverse habitats throughout the estuary, more floodplain habitat along inflowing rivers, and improved water quality. These goals in turn encourage policies which: (1) establish internal Delta flows that create a tidally-mixed, upstream-downstream gradient (without cross-Delta flows) in water quality; (2) create slough networks with more natural channel geometry and less diked rip-rapped channel habitat; (3) improve flows from the Sacramento and San Joaquin rivers; (4) increase tidal marsh habitat, including shallow (1-2 m) subtidal areas, in both fresh and brackish zones of the estuary; (5) create/allow large expanses of low salinity (1-4 ppt) open water habitat in the Delta; (6) create a hydrodynamic regime where salinities in parts of the Delta and Suisun Bay and Marsh range from near-fresh to 8-10 ppt periodically (does not have to be annual) to discourage alien species and favor desirable species; (7) take species-specific actions that reduce abundance of non-native species and increase abundance of desirable species; (8) establish abundant annual floodplain habitat, with additional large areas that flood in less frequent wet years; (9) reduce inflow of agricultural and urban pollutants; and (10) improve the temperature regime in large areas of the estuary so temperatures rarely exceed 20°C during summer and fall months."

Similarly, reliance upon water year classification as a trigger for flow volumes has contributed to reduced flow variability in the estuary. The information received during this proceeding supports the notion that reliance upon water year classification as a trigger for flow volumes is an imperfect means of varying flows. Any individual month or season might have a dramatically different hydrology than the overall hydrology for the year. A critically dry year, for example, can have one or two very wet months, just as a wet year may have several disproportionately dry months. Figure 10 demonstrates how this actually occurs. Unimpaired Delta outflow for the month of June from 1922 through 2003 has historically been highly variable. Many June months that occur in years classified as wet have had much lower flows than June flows in years classified as below normal. The opposite is also true; several June flows in years classified as critically dry are higher than some years classified as above normal. Depending on the direction of this divergence of monthly flows (higher or lower) relative to the water year, reliance upon water year classification can provide less than optimal protection of the ecosystem or more than needed water supply impacts. The figure also shows the actual June flows for various periods of years, demonstrating how much lower actual flows have been than unimpaired flows. The primary reason for the lower historical flows is consumption of water in the watershed. The three periods shown, however, are not directly comparable to the unimpaired flow record because the shorter time frame may have been wetter or drier than the full historical record.

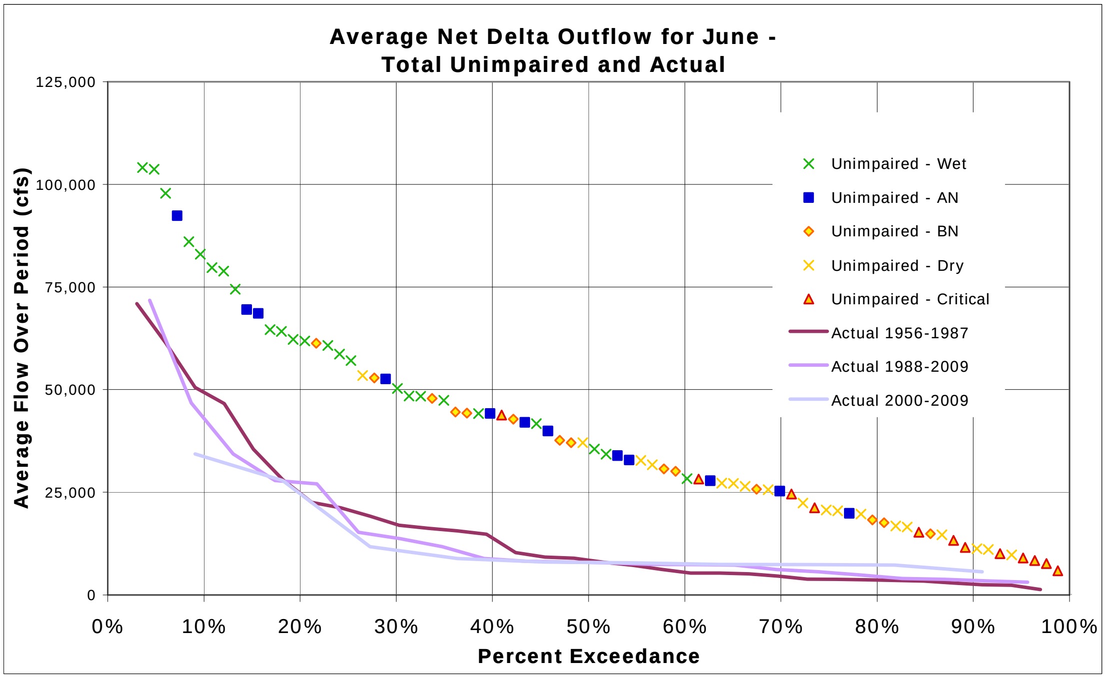



**Figure 10. Actual and Unimpaired June Delta Outflow**

Proportionality is one of the key attributes of restoring ecosystem functions by mimicking the natural hydrograph in tributaries to the Delta and providing for connectivity. Currently, inflows to the Delta are largely controlled by upstream water withdrawals and releases for water supply, power production, and flood control. As a result, inflows from tributaries frequently do not contribute flow to the Delta in the same proportions as they would have naturally, and to which native fish adapted. There is consensus in contemporary science that improving ecosystem function in the watershed, mainstem rivers, and the Delta is a means to improving productivity of migratory species. (e.g.,Williams 2005; NRC 1996, 2004a, 2004b as cited in NAS 2010, p. 42.) NAS found that, “Watershed actions would be pointless if mainstem passage conditions connecting the tributaries to, and through, the Delta were not made satisfactory.” (NAS 2010, p. 42.) “Propst and Gido (2004) support this hypothesis and suggest that manipulating spring discharge to mimic a natural flow regime enhances native fish recruitment (Propst and Gido, 2004 and Marchetti and Moyle, 2001).” (DOI, 1 p. 25.) Specifically, providing pulse flows to mimic the natural hydrograph could diversify ocean entry size and timing for anadromous fishes so that in many years at least some portion of the fish arrive in saltwater during periods favoring rapid growth and survival. (DOI 1, p. 30.) Food production may also be improved by maintaining the attributes of a natural hydrograph (EFG 1, p. 8.) Connectivity between natal streams and the Delta is critical for anadromous species that require sufficient flows to emigrate out of natal streams to the Delta and ocean, and sufficient flows upon returning, including flows necessary to achieve homing fidelity. Specifically, it is necessary for the scent of the river to enter the Bay in order for adult salmonids to find their way back to their natal river. (NMFS 2009, p.407 as cited in EDF 1, p. 48.) Further, insuring adequate flows from all of the tributaries that support native fish is important to maintain genetic diversity and species resilience in the face of catastrophic events.

### 4.3.2 Floodplain Activation and Other Habitat Improvements

Most floodplains in the Central Valley have been isolated from their rivers by levees. Due to the effects of levees and dams, side channel and floodplain inundating flows have been substantially reduced. At present, besides the Yolo Bypass, the only other Delta region with substantial connectivity to portions of the historical floodplain is the Cosumnes River, a small undammed watershed. (Sommer et al. 2001b.) Floodplains are capable of providing substantial benefits to numerous aquatic, terrestrial, and wetland species. (Sommer et al. 2001b.) Inundation of floodplains facilitates an exchange of organisms, nutrients, sediment, and organic material between the river and floodplain, and provides a medium in which biogeochemical processes and biotic activity (e.g., phytoplankton blooms, zooplankton and invertebrate growth and reproduction) can occur. (AR/NHI 1, p. 22.) This exchange of material can benefit downstream areas. For example, studies suggest phytoplankton, zooplankton, and other organic material transported from the Yolo Bypass enhances the food web of the San Francisco Estuary. (Jassby and Cloern 2000; Mueller-Solger et al. 2002; Sommer et al. 2004.)

Many fishes rear opportunistically on floodplains. (Moyle et al. 2007, as cited in Moyle et al. 2010), and juvenile salmon grow faster and become larger on floodplains than in the main-stem river channels. (Sommer et al. 2001a; Jeffres et al. 2008; DOI 1, p. 27; AR/NHI 1, p. 24.) Splittail require floodplains for spawning (Moyle et al. 2007), with large-scale juvenile recruitment occurring only in years with significant protracted (greater than or equal to 30 days) floodplain inundation, particularly in the Sutter and Yolo bypasses. (Meng and Moyle 1995, Sommer et al. 1997, Feyrer et al. 2006a.) Managing the frequency and duration of floodplain inundation during the winter and spring, followed by complete drainage by the end of the flooding season, could favor splittail and other native fish over non-natives. (Moyle et al. 2007, Grimaldo et al. 2004.) In addition, modeling conducted by Moyle et al. (2004) shows that while splittail are resilient, managing floodplains to promote frequent successful spawning is needed to keep them abundant. Improving management of the Yolo Bypass for fish, increasing floodplain areas along other rivers (e.g., Cosumnes and Mokelumne rivers), and developing floodplain habitat along the lower San Joaquin River, including a bypass in the Delta, represent opportunities to increase the frequency and extent of floodplain inundation. (Moyle et al. 2010.) The BDCP is currently evaluating structural modifications to the Fremont Weir (e.g., notch weir and install operable "inundation gates"), as a means of increasing the interannual frequency and duration of floodplain inundation in the Yolo Bypass. (BDCP 2009.)

The NMFS Opinion stipulates that USBR and DWR, in cooperation with DFG, USFWS, NMFS, and USACE, shall, to the maximum extent of their authorities (excluding condemnation authority), provide significantly increased acreage of seasonal floodplain rearing habitat, with biologically appropriate durations and magnitudes, from December through April, in the lower Sacramento River basin, on a return rate of approximately one to three years, depending on water year type. (NMFS 3, p. 608.) Per this NMFS Opinion, USBR and DWR are to submit a plan to implement this action to NMFS by December 31, 2011. (Id.) This plan is to include an evaluation of options to, among other things, increase inundation of publicly and privately owned suitable acreage within the Yolo Bypass, and modify operations of the Sacramento Weir or Fremont Weir to increase rearing habitat. (Id.)

Moyle et al. (2010) discuss the value of creating more slough networks with natural geometry and less diked, rip-rapped channel habitat, the value of tidal marsh habitat, and low salinity, open water habitat in the Delta:

> "Re-establishing the historical extensive dendritic sloughs and marshes is essential for re-establishing diverse habitats and gradients in salinity, depth and other environmental characteristics important to desirable fish and other organisms (e.g., Brown and May 2008). These shallow drainages are likely to increase overall estuarine productivity if they are near extensive areas of open water, because they can deliver nutrients and organic matter to the more open areas. Dendritic slough networks will develop naturally in Suisun Marsh after large areas become inundated following dike failures and they can be recreated fairly readily in the Cache Slough region by reconnecting existing networks. In the Delta, the present simplified habitat in the channels between islands needs to be made more suitable as habitat for desirable species. Many levees are maintained in a nearly vegetation-free state, providing little opportunity for complex habitat (e.g., marshes and fallen trees) to develop. Much of the low-value channel habitat in the western and central Delta will disappear as islands flood, but remaining levees in submerged areas should be managed to increase habitat complexity (e.g., through planting vegetation), especially in the cooler northern and eastern parts of the Delta.
>
> [Subtidal] habitat has been greatly depleted because marshes in the Delta and throughout the estuary have been diked and drained, mostly for farming and hunting (Figure 3). Unfortunately, most such habitat in shallow water today is dominated by alien fishes, including highly abundant species such as Mississippi silverside which are competitors with and predators on native fishes (Moyle and Bennett 1996; Brown 2003). Such habitat could become more favorable for native fishes with increased variability in water quality, especially salinity. In particular, increasing the amount of tidal and subtidal habitat in Suisun Marsh should favor native fishes, given the natural variability in salinity and temperature that occurs there. The few areas of the marsh with natural tidal channels tend to support the highest diversity of native fishes, as well as more striped bass (Matern et al. 2002; Moyle, unpublished data). With sea level rise, many diked areas of Suisun Marsh currently managed for waterfowl (mainly dabbling ducks and geese) will return to tidal marsh and will likely favor native fishes such as splittail and tule perch (Hysterocarpus traski), as well as (perhaps) migratory fishes such as juvenile Chinook salmon. Experimental (planned) conversions of some of these areas would be desirable for learning how to manage these inevitable changes to optimize habitat for desired fishes.
>
> Open water habitat is most likely to be created by the flooding of subsided islands in the Delta, as well as diked marshland 'islands' in Suisun Marsh (Lund et al. 2007, 2010; Moyle 2008). The depth and hydrodynamics of many of these islands when flooded should prevent establishment of alien aquatic plants while variable salinities in the western Delta should prevent establishment of dense populations of alien clams (Lund et al. 2007).

Although it is hard to predict the exact nature of these habitats, they are most likely to be better habitat for pelagic fishes than the rock-lined, steep-sided and often submerged vegetation-choked channels that run between islands today (Nobriga et al. 2005). Experiments with controlled flooding of islands should provide information to help to ensure that these changes will favor desired species. Controlled flooding also has the potential to allow for better management of hydrodynamics and other characteristics of flooded islands (through breach location and size) than would be possible with unplanned flooding."

### 4.3.3 Water Quality and Contaminants

Toxic effects are one of three general factors identified by scientists with the IEP in 2005 as contributing to the decline in pelagic productivity. The life history requirements and water quality sections above identify specific species sensitivities to water quality issues.

Though the information received in this proceeding supports the recommendation that modification to flow through the Delta is a necessary first step in improving the health of the ecosystem, it also supports the recommendation that flow alone is insufficient. The Delta and San Francisco Bay are listed under section 303(d) of the Federal Clean Water Act as impaired for a variety of toxic contaminants that may contribute to reduced population abundance of important fish and invertebrates. The contaminants include organophosphate and pyrethrin pesticides, mercury, selenium and unknown toxicity. In addition, low DO levels periodically develop in the San Joaquin River at the DWSC and in OMR. The low oxygen levels in the DWSC inhibit the upstream migration of adult fall-run Chinook salmon and adversely impact other resident aquatic organisms.

There is concern that a number of non-303(d) listed contaminants, such as ammonia, pharmaceuticals, endocrine disrupting compounds, and blue-green algal blooms could also limit biological productivity and impair beneficial uses. Sources of these contaminants include agricultural, municipal and industrial wastewater, urban storm water discharges, discharges from wetlands, and channel dredging activities. More work is needed to determine their impact on the aquatic community.

Ammonia has emerged as a contaminant of special concern in the Delta. Recent hypotheses are that ammonia is causing toxicity to delta smelt, other local fish, and zooplankton and is reducing primary production rates in the Sacramento River below the SRWTP and in Suisun Bay. A newer hypothesis is that ammonia and nitrogen to phosphorus ratios have altered phytoplankton species composition and these changes have had a detrimental effect on zooplankton and fish population abundance. (Glibert 2010.) More experiments are needed to evaluate the effect of nutrients, including ammonia, on primary production and species composition in the Sacramento River and Delta.

### 4.3.4 Cold Water Pool Management

As mentioned in the specific flow criteria, the criteria contained in this report should be tempered by the additional need to maintain cold water resources in reservoirs on tributaries to the Delta until improved passage and other measures are taken that would reduce the need for maintaining cold water reserves in reservoirs. As discussed in the Chinook salmon section, salmon have specific temperature tolerances during various portions of their life-cycle. Historically salmonids were able to take advantage of cooler upstream temperatures for parts of their life-cycle to avoid adverse temperature effects. Since construction of the various dams in the Central Valley, access to much of the cooler historic spawning and rearing habitat has been blocked. To mitigate for these impacts, reservoirs must be managed to preserve cold water resources for release during salmonid spawning and rearing periods. As reservoir levels drop, availability of cold water resources also diminishes. Accordingly, it may not be possible to attain all of the identified flow criteria in all years and meet the thermal needs of the various runs of Chinook salmon and other sensitive species. Thorough temperature and water supply modeling analyses should be conducted to adaptively manage any application of these flow criteria to suit real world conditions and to best manage the competing demands for water needed for the protection of public trust resources, especially in the face of future climate change.

Specifically, these criteria should not be construed as contradicting existing and future cold water management requirements that may be needed for the protection of public trust resources, including those for the Sacramento River needed to protect the only remaining population of winter-run Chinook salmon. (see NMFS 3, p. 590-603.)

### 4.3.5 Adaptive Management

Any environmental flow prescription for native species in the Delta will be imperfect. The problem is too complex, uncertainties are too large, and the situation in the Delta is changing too rapidly in too many ways for any single flow prescription to be correct, or correct for long. (Fleenor et al. 2010.) Some degree of certainty regarding future conditions in the Delta is needed before long term flow criteria can be developed. Since it is unlikely that certainty will be achieved before actions or responses are required by geologic, biological, and legal processes, it might be valuable to provide substantial financial and water reserve resources, along with responsible institutional wherewithal to respond to changes and undertake necessary experiments for more successfully transitioning into the largely unexplored new Delta. (Fleenor et al. 2010.) This confounding need for certainty of operations and water supply at the same time there is uncertainty underlying ecosystem needs, provides good rationale to rely upon adaptive management to address this uncertainty.

The Delta is continually changing. Flow criteria developed for the present Delta ecosystem will become less reflective of ecosystem needs with the passage of time. Accordingly, it is important that flow criteria be adaptive to future changes. Flows, habitat restoration, and measures to address other stressors should be managed adaptively. (AR/NHI Closing Comments.)

Adaptive management is “an iterative process, based on a scientific paradigm that treats management actions as experiments subject to modification, rather than as fixed and final rulings, and uses them to develop an enhanced scientific understanding about whether or not and how the ecosystem responds to specific management actions.” (NRC 1999 as cited in DOI Ex.1.) This notion of treating actions as experiments is key, because information received in this proceeding indicates that the mechanisms underlying the relationship between flows and the health of the Delta ecosystem are, at times, unclear. Adaptive management is the most suitable approach for managing with uncertainty. (DEFG 1.)

Murray and Marmorek (2004) describe an adaptive management approach as:

- exploring alternative ways to meet management objectives
- predicting the outcomes of alternatives based on the current state of knowledge
- implementing one or more of these alternatives
- monitoring to learn about the impacts of management actions
- using the results to update knowledge and adjust management actions

An adaptive approach provides a framework for making good decisions in the face of critical uncertainties, and a formal process for reducing uncertainties so that management performance can be improved over time. (Williams et al. 2007.)

Adaptive management does not postpone action until "enough" is known but acknowledges that time and resources are too short to defer *some* action, particularly actions to address urgent problems. (Lee 1999.) Adaptive management provides a means of informing planning and management decisions in spite of uncertainty. Key point number 5 of the DEFG states: “a strong science program and a flexible management regime are essential to improving flow criteria. (DEFG 1.)

Adaptive management can be used to manage uncertainty in two ways, over two time frames. Over the short-term, adaptive management could allow for a specific response to real time conditions so long as the response is otherwise consistent with the constraints of some overarching regulatory framework. Over the longer term, adaptive management could allow for the more nimble modification of regulatory constraints, so long as these modifications fell within the clearly defined parameters of the overarching regulatory framework.

<u>Short-term Adaptive Management</u>
Per the DEFG’s assessment regarding the role of uncertainty…

> “…despite [our] extensive scientific understanding substantial knowledge gaps remain about the ecosystem's likely response to flows. First, ecosystem processes in a turbid estuary are mostly invisible, and can be inferred only through sampling. Second, monitoring programs only scratch the surface of ecosystem function by estimating numbers of fish and other organisms, whereas the system’s dynamics depend on birth, growth, movement, and death rates which can rarely be monitored. Third, this system is highly variable in space (vertical, cross-channel, along-channel, and larger-scale), time (tidal, seasonal, and interannual), flow, salinity, temperature, physical habitat type, and species composition. Each of the hundreds of species has a different role in the system, and these differences can be subtle but important. As a result, we have little ability to predict how the ecosystem will respond to the numerous anticipated deliberate and uncontrolled changes.” (DEFG 1.)

Flexible management can be designed into a regulatory framework so that any requirements rely upon real time information and real time decisions to guide specific real-time action. A current example of this is the Delta Smelt Working Group that provides information and analyses used to guide real time operation of export facilities so that these facilities can be operated in a manner that conforms with the current NMFS and USFWS opinions.  Any such flexible management will need to consider the processes and governance structures required to make sound scienfically-based real-time decisions.  The Delta Smelt Working Group is a good example of how scientific assessment of real-time data, including the presence of fish, can better inform the real-time operation of export facilities.

Long-term Adaptive Management
Over the longer term, adaptive management can be used to more nimbly modify regulatory constraints so that fishery and water resource agencies are not locked into prescriptive constraints well past the time that current scientific understanding can support.  This longer term adaptive management has bearing on a number of the flow criteria being considered in this report because many of these criteria lack sufficiently robust information to support a specific numeric criterion.  Although the functional basis for a beneficial flow may be understood, the basis for a specific numeric criteria may not.  Some regulatory flows may therefore need to take the form of an informed experimental manipulation.  Such flows would need to be implemented… "as if they were experiments, with explicit conceptual and simulation models, predicting outcomes, and feedback loops so that the course of management and investigation can change as the system develops and knowledge is gained.  A talented group of people tasked to integrate, synthesize, and recommend actions based on the data being gathered are essential for making such a system work.  Failure to implement an effective adaptive management program will likely lead to a continued failure to learn from the actions, and a lack of responsiveness to changing conditions and increased understanding." (DEFG 1.)

The Delta Science Program, IEP, and other institutions could be relied upon to evaluate experimental flows and make recommendations to be considered for modifications of such flows.

## *4.4 Expression of Criteria as a Percentage of Unimpaired Flow*

In some cases, participants' recommendations were expressed as specific flows in specific months, to be applied during specific water year types or with specified probabilities of exceedance.  Review of unimpaired hydrology shows there is great variability in the quantity of unimpaired flow during these specified months when categorized by water year type.  Reliance upon monthly or seasonal flow prescriptions based on water year type would therefore result in widely ranging relative amounts of unimpaired flow depending upon the specific hydrology of the month or season.  Also, the rather coarse division of the hydrograph into five water year types can lead to abrupt step-wise changes in flow requirements.  In an attempt to more closely reflect the variation of the natural hydrograph, the State Water Board recommends that, when possible, the flow criteria be expressed as a percentage of unimpaired flow.

To develop criteria in this way, the unimpaired flow rate for a specified time period (e.g. average monthly flow over a range of months) was plotted on an exceedance probability graph (using the Weibull plotting position formula) along with the flow recommendations and desired return frequencies.  The unimpaired flow rates were also plotted such that the associated water year type can be identified and their percent exceedance estimated.  A percentage of unimpaired flow was selected by trial and error so that the desired flow rate and exceedance frequency was achieved.  A separate exceedance plot was produced for each time period being evaluated.

The unimpaired flow estimates used in the development of these flow criteria are based on those developed in the DWR May 2007 document: *"California Central Valley Unimpaired Flow Data" Fourth Edition Draft.* (DWR 2007.) This report contains estimates of the monthly flow for 24 sub-basins in the Central Valley. Each sub-basin uses a separate calculation dependant on conditions specific to that sub-basin, available gauge data, and relationships to other sub-basins. In many cases the methods change over the period of record to incorporate changes to infrastructure within the sub-basins that need to be accounted for. Estimates are provided for 83 water years from 1922 through 2003. A water year begins in October of the previous calendar year through September of the named water year. The following describes the unimpaired flow estimates that are the basis for flow criteria for the Sacramento River at Rio Vista, the San Joaquin River at Vernalis, and Net Delta Outflow.

## Sacramento Valley Unimpaired Total Outflow

Estimates of the unimpaired Sacramento Valley outflow were computed as the sum of estimates from 11 sub-basins in the watershed and are understood to represent the flow that would occur on the Sacramento River at approximately Freeport. These 11 sub-basins include the Sacramento Valley Floor, Putah Creek near Winters, Cache Creek above Rumsey, Stony Creek at Black Butte, Sacramento Valley West Side Minor Streams, Sacramento River near Red Bluff, Sacramento Valley East Side Minor Streams, Feather River near Oroville, Yuba River at Smartville, Bear River near Wheatland, and the American River at Fair Oaks.

The unimpaired Sacramento Valley outflow from DWR 2007 is used as the basis for flow criteria on the Sacramento River at Rio Vista, even though it is understood they are more representative of unimpaired flows expected at Freeport. This is a necessary simplification as such estimates do not exist at Rio Vista, but should be adequate for the purpose of these criteria. If future flow requirements are to be established at Rio Vista based on a percentage of unimpaired flow, it is recommended that new estimates of unimpaired flow be developed specific for this location.

## San Joaquin Valley Unimpaired Total Outflow

Estimates of the unimpaired San Joaquin Valley outflow were computed as the sum of estimates from nine sub-basins in the watershed and are understood to represent the flow that would occur on the San Joaquin River at Vernalis. These nine sub-basins include the Stanislaus River at Melones Reservoir, San Joaquin Valley Floor, Tuolumne River at Don Pedro Reservoir, Merced River at Exchequer Reservoir, Chowchilla River at Buchanan Reservoir, Fresno River near Daulton, San Joaquin River at Millerton Reservoir, Tulare Lake Basin Outflow, San Joaquin Valley West Side Minor Streams.

## Delta Unimpaired Total Outflow

Estimates of unimpaired Net Delta Outflow in DWR 2007 were computed generally as Delta Unimpaired Total Inflow minus unimpaired net use in the Delta, including both lowlands and uplands. Delta Unimpaired Total Inflows was calculated as the sum of the Sacramento Valley and San Joaquin Valley Unimpaired Total Outflows as described above and the East Side Streams Unimpaired Total Outflow. The later consists of four sub-basins including San Joaquin Valley East Side Minor Streams, Cosumnes River at Michigan Bar, Mokelumne River at Pardee Reservoir, and Calaveras River at Jenny Lind. Generally the unimpaired net use in the Delta is an estimate of the consumptive use from riparian and native vegetation (replacing historical irrigated agriculture and urban areas), plus evaporation from water surfaces, minus precipitation, and assumes that existing Delta levees and island remain intact. Unimpaired flow graphs in this report use the unimpaired flow record from 1922 to 2003.

# 5. Flow Criteria

Two types of criteria are provided in this report: numeric flow criteria, and other, non-numeric, measures that should be considered to complement the numeric criteria. Numeric criteria are subdivided into two categories: category “A” criteria have more and better scientific information, with less uncertainty, to support specific numeric criteria than do Category “B” criteria. Summary numeric criteria are provided for Delta outflow, as well as Sacramento River and San Joaquin River inflows, and Hydrodynamics (Old and Middle River, Inflow-Export Ratios, and Jersey Point flows) in Tables 19 through 22.

In addition to new criteria for Delta outflows, inflows, and hydrodynamics, some of the objectives for the protection of fish and wildlife from the 2006 Bay-Delta Plan are advanced as criteria in this report. While the State Water Board did not specifically reevaluate the methodology and basis for the Bay-Delta Plan objectives, the State Water Board recognizes that these flows provide some level of existing protection for fish and wildlife and, in the absence of more specific information, merit inclusion in these criteria. At the time the Bay-Delta Plan objectives were adopted, they were supported by substantial evidence, including scientific information. While the purpose of this report is to develop flow criteria using best available scientific information, water quality objectives are established taking into account scientific and other factors pursuant to Water Code section 1241.

## *5.1 Delta Outflows*

Following are Delta outflow criteria based on analysis of the species-specific flow criteria and other measures:

1) Net Delta Outflow: 75% of 14-day average unimpaired flow for January through June
2) Fall X2 for September through November
    - Wet years X2 less than 74 km (greater than approximately 12,400 cfs)
    - Above normal years X2 less than 81 km (greater than approximately 7,000 cfs)
3) 2006 Bay-Delta Plan Delta Outflow Objectives for July through December

Delta outflow criteria 1 is a Category A criterion because it is supported by more robust scientific information. Delta outflow criteria 2 and 3 are Category B criteria because there is less scientific information to support specific numeric criteria, but there is enough information to support the conceptual need for flows. Category A and B criteria are both equally important for protection of the public trust resource, but there is more uncertainty about the appropriate volume of flow required to implement Category B criteria. Following is discussion and rationale for these criteria.

The narrative objective of the flow criteria is to halt the population decline and increase populations of native species as well as species of commercial and recreational importance. The need to estimate the magnitude, duration, timing, and quality of Delta outflows necessary to support viable populations of these species is inherent to this objective. McElhany et al. (2000) proposed that four parameters are critical for evaluating population viability: abundance, population growth rate, population spatial structure, and diversity. Delta outflow may affect one, all, or some combination of these parameters for a number of resident and anadromous species. A species-specific analysis of flow needs for a suite of upper estuary species is included in section 4.2.4.

An analysis of generation to generation population abundance versus Delta outflows indicates that the "likelihood" of an increase in the longfin smelt FMWT abundance index in 50% of years corresponded with flow volumes of approximately 9.1 MAF (51,000 cfs) and 6.3 MAF (35,000 cfs) during January through March and March through May, respectively. (TBI/NRDC 2, pp. 17-19.) The provision of sufficient flows to achieve these flow volumes during January through March and March through May in approximately 45% and 47% of years, respectively, is intended to promote increased abundance and improved productivity for longfin smelt and other desirable estuarine species. Based on a comparison of the flows needs identified in section 4.2.4, it appears that winter-spring outflows designed to be protective of longfin smelt would benefit the other upper estuary species evaluated. The DFG recommended that spring outflows extend through June to fully protect a number of estuarine species. (DFG 1, pp. 2-5.) During June, sufficient outflow should be provided to maintain X2 in Suisun Bay (between 75 km and 64 km). (DFG closing comments, p. 7; DFG 2, p. 6.)

The State Water Board recognizes that the target flow volumes of 9.1 MAF (Jan-Mar, 51,000 cfs) and 6.3 MAF (Mar-May, 35,000 cfs) in greater than or equal to approximately 45% and 47% of years, respectively, and the positioning of X2 in Suisun Bay during the month of June are necessary in order to promote increased abundance and improved productivity for longfin smelt and other desirable estuarine species. An approach based on a percentage of unimpaired flows is intended as a means of distributing flows to meet the above-mentioned criteria in a manner that more closely resembles the natural hydrograph. Such an approach also recognizes the importance of preserving the general attributes of the flow regimes to which the native estuarine species are adapted.

Analyses of historic conditions (1921 to 2003), indicates that at 75% of unimpaired flows, average flows of 51,000 cfs occurred between January and March in approximately 35% of years, while average flows of 35,000 cfs happened between March and May in 70% of years. At 75% of unimpaired flow, X2 would be maintained west of Chipps Island more than 90% of the time between January and June (analyses not shown). Rather than advance multiple static flow criteria for the January through March, March through May, and June time periods, the State Water Board determines, as a Category A criterion, that 75% of 14-day average unimpaired flow is needed during the January through June time period to promote increased abundance and improved productivity for longfin smelt and other desirable estuarine species. It is important to note that this criterion is not a precise number; rather it reflects the general timing and magnitude of flows needed to protect public trust resources in the Delta ecosystem. However, this criterion could serve as the basis from which future analysis and adaptive management could proceed.

Given the extensive modifications to the system there may be a need to diverge from the natural hydrograph at certain times of the year to provide more flow than might have actually occurred to compensate for such changes. Fall outflow criteria, intended to improve conditions for Delta smelt by enhancing the quantity and quality of habitat in wet and above normal water years, represent such an instance. As a Category B criterion, the State Water Board determines that sufficient outflow is needed from September through November of wet and above normal water year types to position X2 at less than or equal to 74 km and 81 km, respectively (Fall X2 action). In addition, the Delta Outflow Objectives contained within the Bay-Delta Plan for July through December are advanced as a Category B criterion. The State Water Board does not recommend increasing fall flows beyond those stipulated in the Bay-Delta Plan and Fall X2 action at this time. The quantity and timing of fall outflows necessary to protect public trust resources warrants further evaluation.

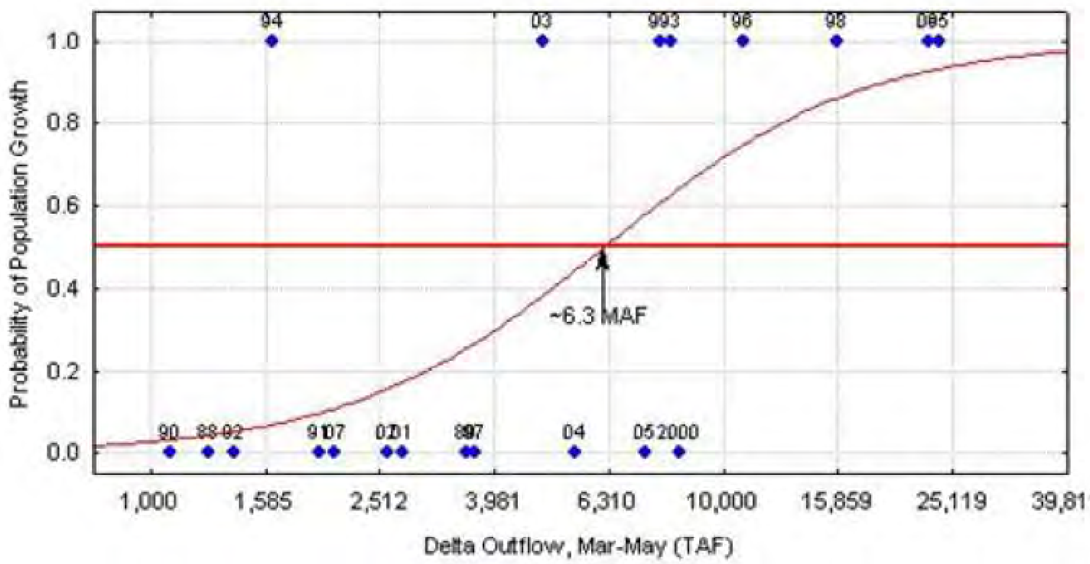
<u>Category A: Winter – Spring Net Delta Outflows</u>
The flow regime is important in determining physical habitat in aquatic ecosystems, which is in turn a major factor in determining biotic composition. (DEFG 1.) Bunn and Arthington (2002) highlight four principles by which the natural flow regime influences aquatic biodiversity: 1) developing channel form, habitat complexity, and patch disturbance, 2) influencing life-history patterns such as fish spawning, recruitment, and migration, 3) maintaining floodplain and longitudinal connectivity, and 4) discouraging non-native species. Altering flow regimes affects aquatic biodiversity and the structure and function of aquatic ecosystems. The risk of ecological change increases with greater flow regime alteration. (Poff and Zimmerman 2010.)

A suite of native, and recreationally or commercially important species were evaluated in an effort to assess the timing, volume, and quality of water necessary to protect public trust resources. Flow criteria were developed for each of the species identified by DFG as those that are priority concern and will benefit the most as a result of improved flow conditions. (DFG closing comments, p. 3.) For Delta outflow, this included longfin smelt, delta smelt, starry flounder, American shad, bay shrimp (*Crangon* sp.), mysid shrimp, and *Eurytemora affinis*. Through this process, data or information pertaining to life history attributes (e.g., timing of migration, spawning, rearing), relationships of species abundance or habitat to Delta outflow, season or time period when flow characteristics are most important, factors influencing and/or limiting populations, and other characteristics were assessed and summarized in the individual species write-ups.

Statistically significant relationships between annual abundance and X2 (or outflow) have been demonstrated for a diverse assemblage of species within the estuary. (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002a; Rosenfield and Baxter 2007; Kimmerer *et al*. 2009.) The causal mechanisms underlying the variation in annual abundance indices of pelagic species in the estuary are poorly understood, but likely vary across species and life stages.

Longfin smelt have the strongest X2-abundance relationship of those species for which such a relationship has been demonstrated. (Kimmerer et al. 2009.) Abundance indices for this species are inversely related to X2 during its winter-spring spawning and early rearing periods. (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002a; Rosenfield and Baxter 2007; Kimmerer et al. 2009.) However, a four-fold decline in the relationship, with no significant change in slope, occurred after 1987, coincident with the introduction and spread of the introduced clam *Corbula amurensis.* (Kimmerer 2002a.) Reduced prey availability due to clam grazing has been identified as a likely mechanism for the decline in the X2-abundance relationship. (Kimmerer 2002a.)

One of the key biological goals of the informational proceeding was to identify the flows needed to increase abundance of native and other desirable species. Logit regression (StatSoft 2010, as cited in TBI/NRDC 2, p.17) was used to address the question: What outflow corresponded to positive longfin smelt population growth 50% of the time in the past? Logit regression is used to find a regression solution when the response variable is binary. For the purpose of this analysis, the generation-over-generation changes in abundance indices were converted to a binary variable (increase = 1 or decrease = 0). The analysis was conducted using FMWT abundance indices for the period extending from 1988 to 2007 (post-*Corbula*). Two periods of the winter-spring seasons (January to March and March to May) were evaluated, as different life stages of longfin smelt are present in the Delta during those periods (spawning adults and larvae/juveniles, respectively) and the mechanisms underlying the flow-abundance relationship may occur and/or vary in some or all of the months during these periods. (TBI/NRDC 2, p. 13.) The results were statistically significant ($p < 0.015$) and revealed that the "likelihood" of an increase in FMWT abundance index in 50% of years corresponded with flows of approximately 9.1 MAF and 6.3 MAF during January through March and March through May, respectively. (Figure 11, TBI/NRDC 2, pp. 17-19.)




Logit regression showing relationship between March through May Delta outflow and generation-over-generation change in abundance of longfin smelt (measured as the difference between annual FMWT abundance indices). Positive changes in the abundance index were scored at "1" and declines were scored as "0". Arrow indicates flows above which growth occurred in more than 50% of years. Point labels indicate year of the FMWT index. (Source: TBI 2, Figure 15.)

**Figure 11. Logit Regression Showing Relationship Between March through May Delta Outflow and Generation-Over-Generation Change in Longfin Smelt Abundance**

A similar analysis was conducted for bay shrimp (*Crangon* sp.), a species whose flow-abundance relationship did not experience a "step decline" following the invasion of *Corbula.* (Kimmerer 2002a.) Results of the logit analysis indicate that abundance indices for this species increased in about 50% of years when flows during March through May were approximately 5 MAF. (TBI/NRDC 1, p. 17.) Therefore, flows associated with positive changes in the longfin smelt abundance index are anticipated to improve the likelihood of increases in bay shrimp abundance as well.

An analysis of historical longfin smelt flow-abundance relationships that corresponded to recovery targets in the Recovery Plan for the Sacramento/San Joaquin Delta Native Fishes (USFWS 1996) was also conducted. During the periods of January through March and March through May, cumulative Delta outflows of greater than 9.5 MAF and greater than 6.3 MAF, respectively, historically corresponded to abundance indices equal to or exceeding the recovery targets. (TBI/NRDC 2, p. 14.) These results are based on the intersection of the 1967 to1987 flow-abundance relationship and the recovery target. Use of the 1988 to 2007 flow-abundance relationship predicts lower abundance indices per any given flow, as compared to the historical relationship. Use of the pre-*Corbula* flow-abundance relationship underscores the need to address other stressors that may be affecting longfin smelt abundance concurrently with improved flow conditions. (TBI/NRDC 2, p. 14.) Applying this method and the logit regression produces very similar results.

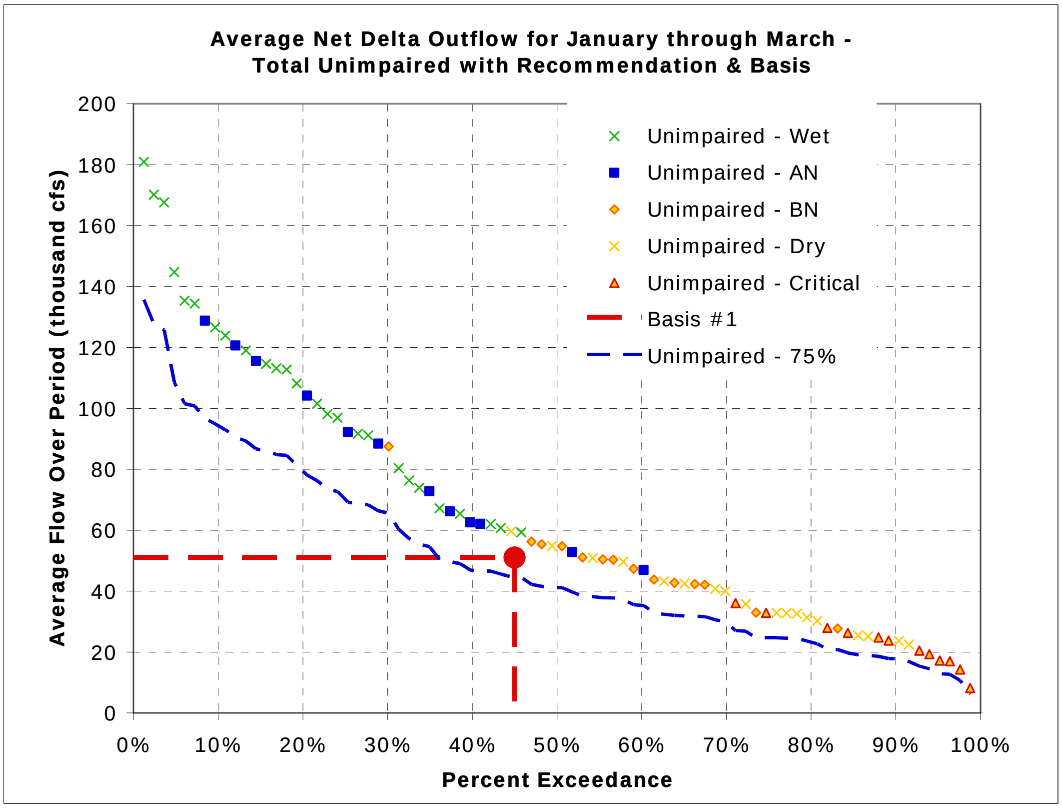
As noted above, the results of the logit analysis indicate that the "likelihood" of an increase in the longfin smelt FMWT abundance index in 50% of years corresponded with flows of approximately 9.1 MAF and 6.3 MAF during January through March and March through May, respectively. (TBI/NRDC 2, pp. 17-19.) Hereafter, these two flow volumes are reported in cubic feet per second, as 51,000 cfs and 35,000 cfs, respectively. Analyses indicate that under historic unimpaired conditions (1921 to 2003) average flows of 51,000 cfs occurred between January and March in approximately 50% of years (Figure 12a), while average flows of 35,000 cfs happened between March and May approximately 85% of the time (Figure 13a). The review of the historic record suggests that it is unrealistic to expect a 100% return frequency for the two magnitudes. A point of reference for determining a more realistic return frequency might be the actual (impaired) flows that occurred from 1956 to 1987. This was a time period when native fish were more abundant than today. Actual average flows between 1957 and 1987 of 51,000 cfs occurred between January and March in approximately 45% of years (Figure 12b). Similarly average flows of 35,000 cfs occurred between March and May 47% of the time (Figure 13b). However, since 2000, average flows of this magnitude only occurred about 27% and 33% of the time, respectively (Figures 12b and 13b). At 75% of unimpaired flow, average flows of 51,000 and 35,000 cfs would happen 35% and 70% of the time, respectively (Figure 12a and Figure 13a). Finally, the DFG has indicated that spring outflows should continue through June to fully protect a number of estuarine species (DFG 1, pp.2-5.)

A fixed 75% of unimpaired flow would extend the flow criteria to other years and distribute flows in a manner that more closely resembles the natural hydrograph. Expression of this criterion as a 14-day running average would better reflect the timing of actual flows (compared with a 30-day running average) while still allowing for a time-step to which reservoirs could be operated. The appropriateness of the 14 day averaging period warrants further evaluation. The unimpaired flows from which the 75% criterion is calculated are monthly values. Estimates of 14-day average unimpaired flows have not been published, but a cursory analysis indicates that they are likely to generate an exceedance curve similar to one generated with monthly values.

The State Water Board therefore determines that the Net Delta Outflow criterion be 75% of the 14-day average unimpaired flow between January and June (Figure 14a, Table

20). Consistent with the DFG recommendation (closing comments, p. 7) that X2 be maintained between 65 and 74 km (Chipps Island and Port Chicago) from January through June, a criterion of 75% of unimpaired flow, would maintain X2 west of Chipps Island more than 90% of the time, between January and June, based on monthly averages (analyses not shown). The return frequency for all months combined is about 98% of the time (Figure 14a). This compares with about a 90% percent return frequency between 2000 and 2009 (Figure 14b).

a)




b)

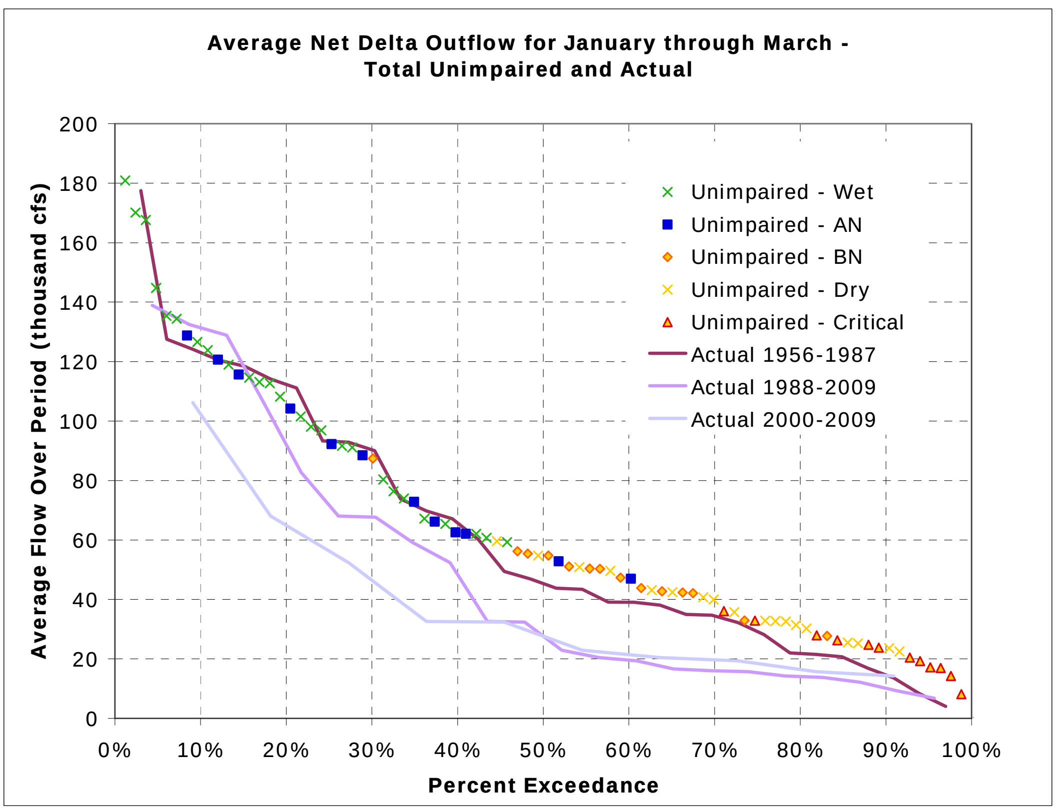
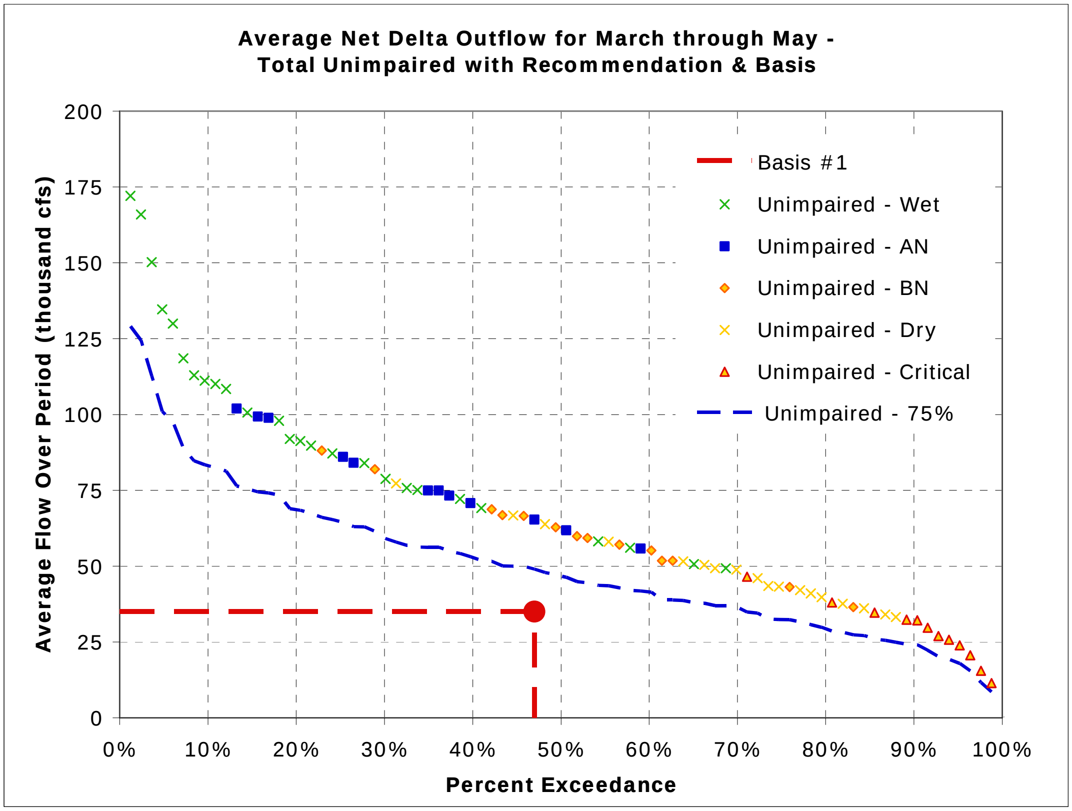



**Figure 12. Net Delta Outflow Flow Exceedance Plot - January through March**

a)




b)

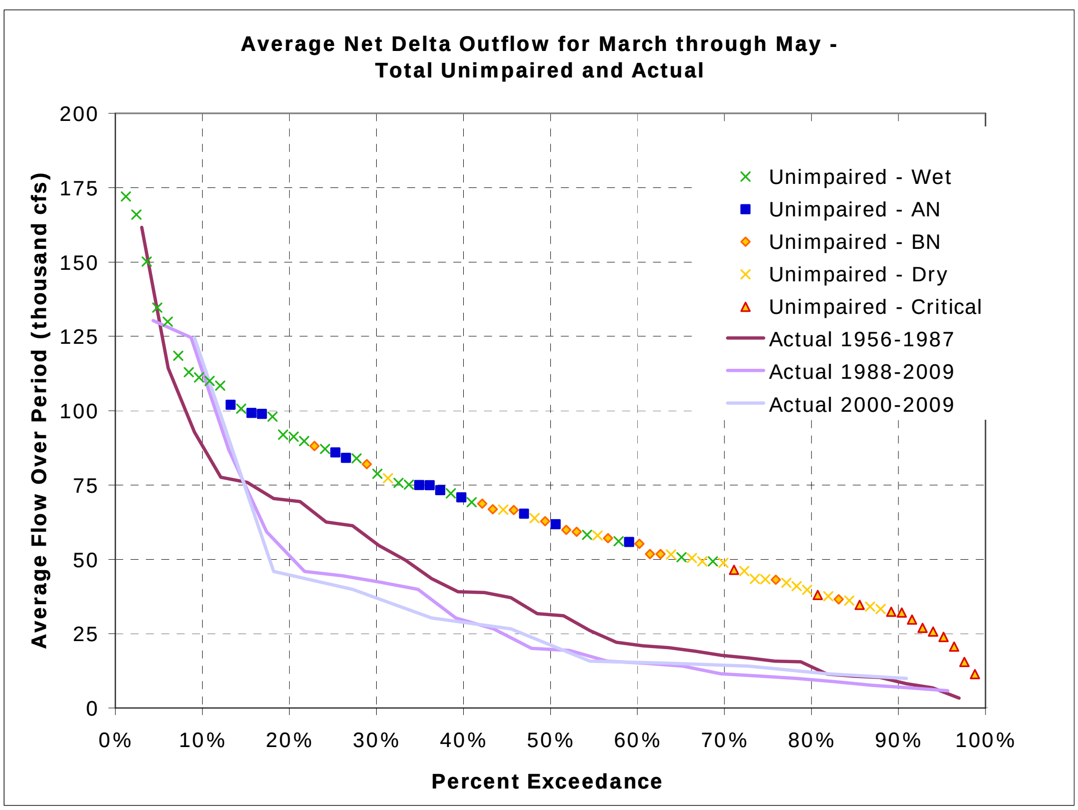
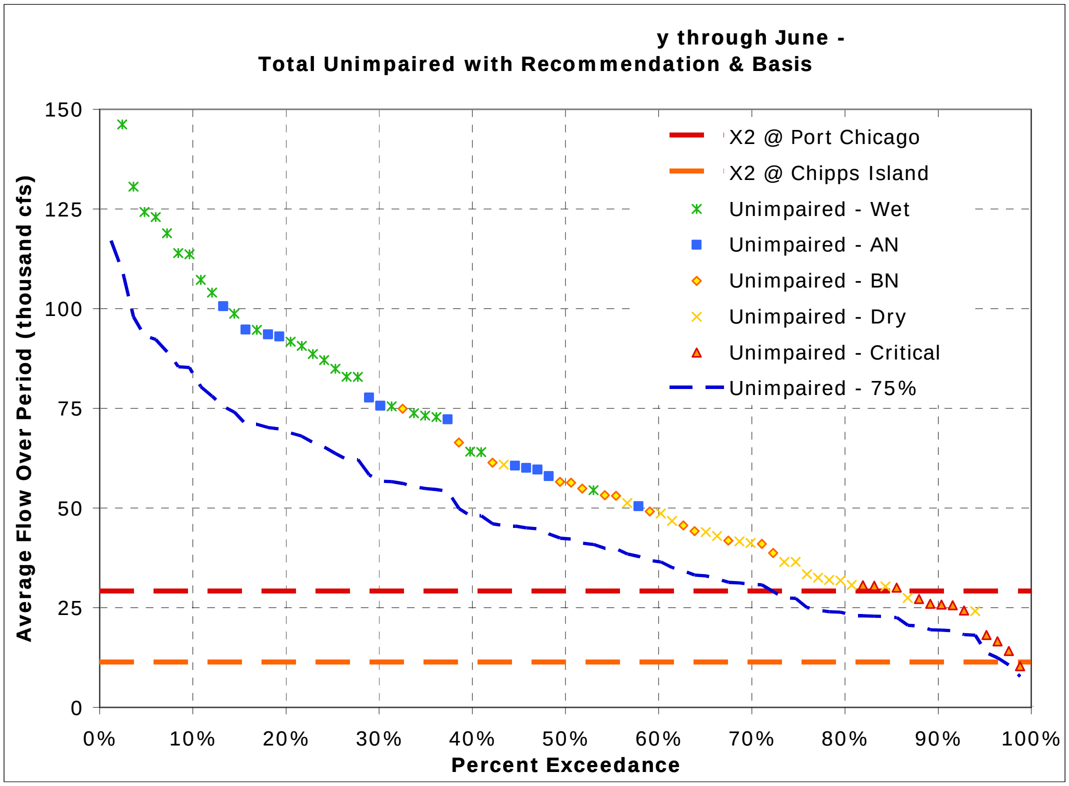



**Figure 13. Net Delta Outflow Flow Exceedance Plot - March through May**

a)




b)

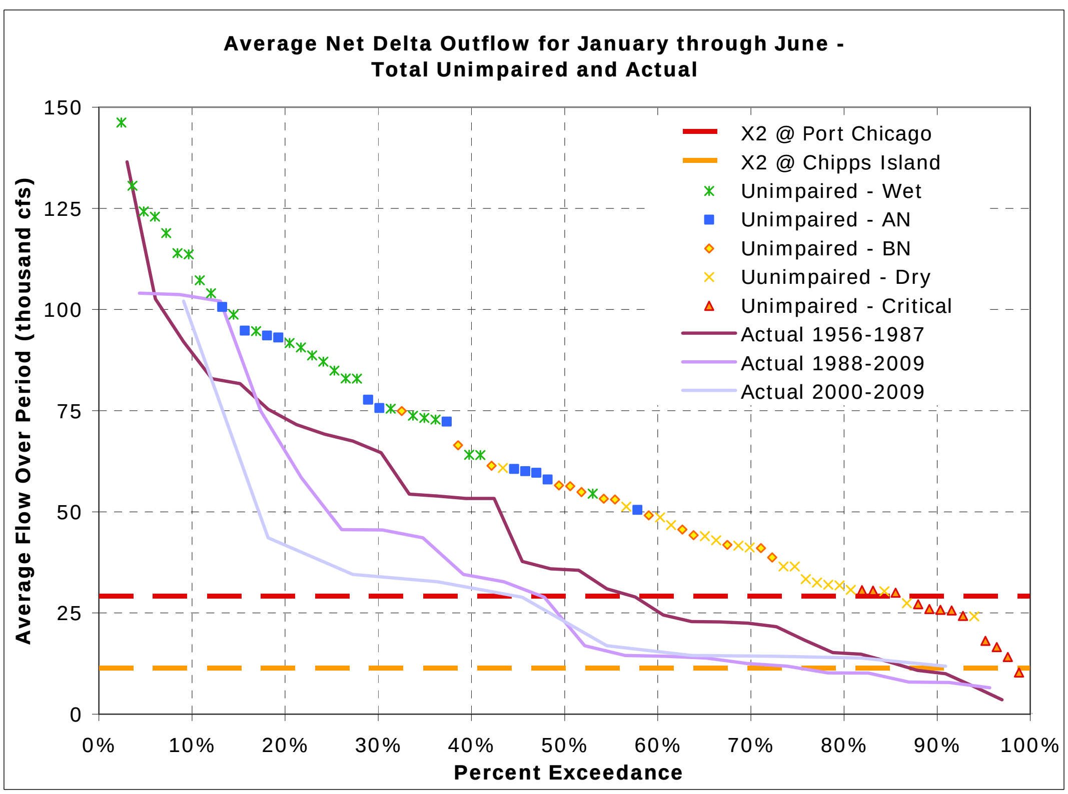



**Figure 14. Net Delta Outflow Flow Exceedance Plot - January through June**

The net Delta outflow criterion of 75% of unimpaired flows from January through June is anticipated to increase the likelihood of positive population growth for a number of other public trust species, notably those for which abundance-X2 relationships have been demonstrated, including American shad, striped bass, starry flounder, bay shrimp (*Crangon franciscorum*), and *Eurytemora affinis* (spring abundance). For example, the spring (March through May) abundance of *Eurytemora affinis* has been positively related to flow, following the invasion of *Corbula.* (Kimmerer 2002a.) This species represents an important prey item for most small fishes, particularly those with winter and early spring larvae, such as longfin smelt, delta smelt and striped bass. (Lott 1998, Nobriga 2002, Bryant and Arnold 2007, DFG unpublished.) Increases in the abundance of prey species, such as *E. affinis* and bay shrimp, has the potential to improve productivity of the estuarine food web and benefit a number of fishes, especially given that food limitation has been identified as a potential contributing factor in the POD. (Baxter *et al*. 2008.) Additional information concerning the relationship of population abundance to flow for these species is provided in the species life history section of this report.

Delta smelt abundance does not respond to freshwater outflow in a predictable manner similar to that of other numerous estuarine species. (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002a.) However, freshwater outflow during spring (March to June) does affect the distribution of delta smelt larvae by transporting them seaward toward the low salinity zone. (Dege and Brown 2004.) Ideal rearing habitat conditions for this species are believed to be shallow water areas most commonly found in Suisun Bay. (Bennett 2005.) Outflows that locate X2 in Suisun Bay (mean April through July location) produce the highest delta smelt abundance levels; however, low abundances have also been observed under the same conditions, which indicates several mechanisms must be operating. (Jassby et al. 1995; DFG 1, p. 15.) A criterion of 75% of unimpaired flow is expected to place X2 in Suisun Bay from March through June in nearly all years.

The DFG's current science-based conceptual model is that placement of X2 in Suisun Bay represents the best interaction of water quality and landscape for fisheries production given the current estuary geometry. (DFG 2, p. 6.) The DFG (closing comments, p. 7) provided recommended flow criteria for the Delta based on the placement of X2, for January through June (exact period varied by species), for longfin smelt, starry flounder, bay shrimp, zooplankton, and American shad. For each of these species, the DFG (*Id*.) recommends that sufficient outflow be provided to position X2 between 75 km and 64 km. These criteria are generally consistent with spring X2 requirements in the 2006 Bay-Delta Plan, which requires salinity at one compliance point (81 km) not to exceed 2 psu continuously, and at two other compliance points (64 km [Port Chicago] and 75 km [Chipps Island]) not to exceed 2 psu for a set number of days during February through June. Positioning X2 at 75 km and 64 km is equivalent to a 3-day running average Net Delta Outflow Index of 11,400 cfs and 29,200 cfs, respectively. Implementation of the 75% of unimpaired flow criteria would be largely consistent with the intent of the DFG's recommendations by placing X2 between Chipps Island and Port Chicago, or further to the west, in nearly all years during the January through June period.

The step-decline in the abundance-X2 relationship that occurred after 1987 for many of these species in combination with the lack of understanding concerning the causal mechanisms underlying those relationships leads to uncertainty regarding the future response of these species to elevated flows. In addition, a number of major changes to the Delta landscape, including levee failure and island flooding, are likely to occur over the next several decades. (Lund et al. 2007, 2008.) Flow regimes needed to maintain desired environmental conditions will change through time, in response to changes in the geometry of waterways, climate, and other factors. A number of “stressors” are currently being evaluated as potential contributors to the POD, including attributes of physical and chemical fish habitat. (Sommer et al. 2007; Baxter et al. 2008.) Increasing flows, without concurrent improvements to habitat and water quality, would decrease the extent of expected improvements in native species abundances and habitats. (DOI 1, p. 40.) However, the scientific information received during this proceeding supports the conclusion that flow, though not sufficient in and of itself, is necessary to protect public trust resources and that the current flow regime has harmed native species and benefited non-native species. Each of these issues adds further support to the need for a strong adaptive management program.

The specific flow criteria may need to be tempered by the need to maintain water in reservoirs to provide adequate cold water resources to support egg incubation, juvenile rearing, and holding in the Sacramento River, San Joaquin River, and associated tributary basins. It may not be possible to attain the outflow criteria and meet the thermal needs of the various runs of Chinook salmon and other sensitive species in certain years. Water supply modeling and temperature analyses should be conducted to identify conflicting requirements to achieve both outflow and cold water temperature goals.

<u>Category B: Fall X2</u>

Abiotic habitat parameters for delta smelt have been described for both the summer and fall seasons as combinations of salinity, temperature, and turbidity. (Nobriga et al. 2008; Feyrer et al. 2007; Feyrer et al. in review.) During fall, delta smelt typically occur in low salinity rearing habitats located around the confluence of the Sacramento and San Joaquin Rivers. Suitable abiotic habitat for delta smelt during fall has been defined as relatively turbid water (Secchi depths < 1.0 m) with a salinity of approximately 0.6-3.0 psu. (Feyrer et al. 2007.) Long-term trend analysis has shown that environmental quality, as defined by salinity and turbidity, has declined across a broad geographical range, most notably within the south-eastern and western regions of the Delta, leaving a relatively restricted area in the lower Sacramento River and around the confluence of the Sacramento and San Joaquin rivers with the least habitat alteration, compared to the rest of the upper estuary. (Feyrer et al. 2007, DOI 1, p.34.)

The amount of habitat available to delta smelt is controlled by freshwater flow and how that flow affects the position of X2, geographically, in the estuary (Figure 15). (Feyrer et al. in review.) Through the use of a 3D hydrodynamic model, Kimmerer et al. (2009) showed that the extent of delta smelt habitat, as defined by salinity, increases as X2 moves seaward. When X2 is located downstream of the confluence of the Sacramento and San Joaquin rivers, suitable abiotic habitat extends into Suisun and Grizzly bays, resulting in a large increase in the total area of suitable abiotic habitat. (Feyrer et al. in review.) The average position of X2 during fall has moved upstream, resulting in a corresponding reduction in the amount and location of suitable abiotic habitat. (Feyrer et al. 2007; Feyrer et al. in review.)

Average Net Delta Outflow for September, October, and November are presented in Figure 16, Figure 17, and Figure 18. Historically, unimpaired flows in fall were independent of water year type. Interestingly, actual outflow was greater than unimpaired flow between 1956 and 1987. However, fall outflows have fallen since then and since 2000 are almost always less than unimpaired flow. This is consistent with the observations of Feyrer et al. (2007) that fall X2 has moved upstream and this has reduced the amount of available habitat for smelt in fall.

Fall conditions may be very important for delta smelt, since this period of time coincides with the pre-spawning period for adult delta smelt. (Feyrer et al. 2007.) In general, reductions in habitat constrict the range of these fishes, which combined with an altered food web, may affect their health and survival. (Feyrer et al. 2007.) There is a statistically significant stock-recruitment relationship for delta smelt in which pre-adult abundance measured by the FMWT positively affects the abundance of juveniles the following year in the Summer Townet survey. (Bennett 2005; Feyrer et al. 2007, as cited in USFWS 2008.) Incorporating the combined effects of specific conductance and Secchi depth improved the stock-recruitment relationship. (Feyrer et al. 2007.)

Feyrer et al. (In Review) demonstrated that delta smelt are more abundant when a large amount of habitat is available. However, the relationship between habitat area and FMWT abundance is complex and not strong. (NAS 2010.) When the area of highly suitable habitat is low, either high or low FMWT indices can occur (Figure 15). Therefore, delta smelt can be successful in instances where habitat is limited. More important, however, is that the lowest abundances all occurred when the habitat-area index was less than 6,000 ha. (Feyrer et al. in review; NAS 2010.) This potentially suggests that while reduced habitat area may be an important factor associated with the worst population collapses, it is not likely the only cause of the collapse. (NAS 2010.)

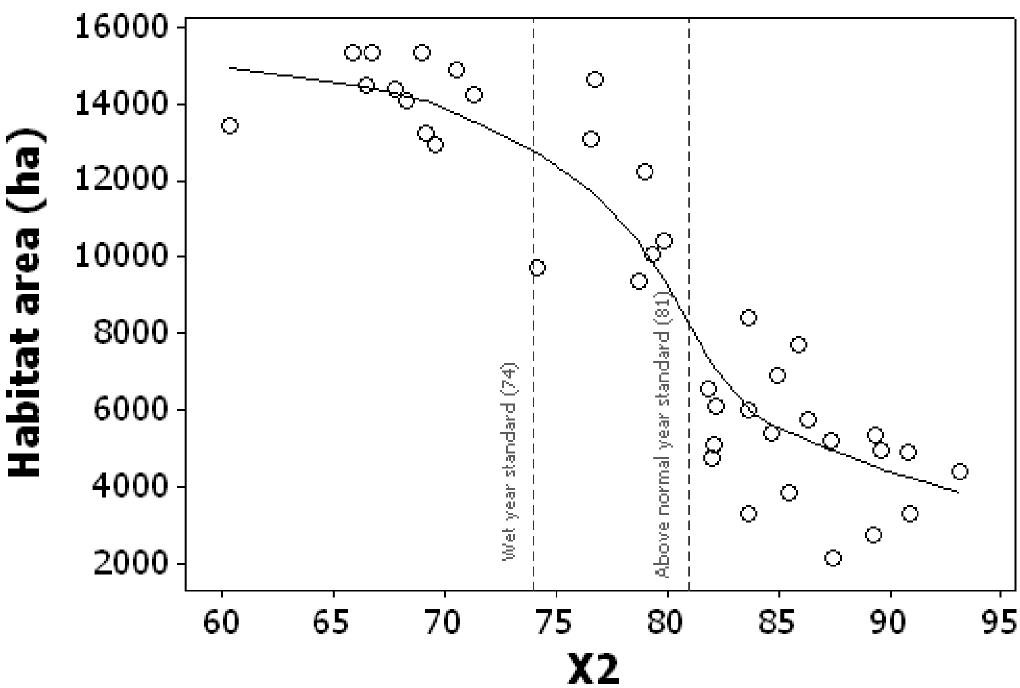
The fall X2 action described in the USFWS Opinion is focused on wet and above normal years because these are the years in which project operations have most significantly affected fall outflows. Actions in these years are more likely to benefit delta smelt. (USFWS 2008.) The action calls for maintaining X2 in the fall of wet years and above-normal years at 74 km and 81 km, respectively. (Figures 14, 15, and 16; USFWS 2008.) In addition to increasing the quality and quantity of habitat for delta smelt, moving X2 westward in the fall may also reduce the risk of entrainment by increasing the geographic and hydrologic distance of delta smelt from the influence of the Project export facilities. (DOI 1, p. 34.)

The NAS (2010) commented on this action in their review of the USFWS Opinion and concluded:

> “The X2 action is conceptually sound in that to the degree that habitat for smelt limits their abundance, the provision of more or better habitat would be helpful. However, the examination of uncertainty in the derivation of the details of this action lacks rigor. The action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance), with each step being uncertain. The relationships are correlative with substantial variance being left unexplained at each step. The action also may have high water requirements and may adversely affect salmon and steelhead under some conditions (memorandum from USFWS and NMFS, January 15, 2010). As a result, how specific X2

targets were chosen and their likely beneficial effects need further clarification."

The State Water Board determines that inclusion of the delta smelt fall X2 action as a Category B flow criterion, consistent with requirements stipulated in the USFWS Opinion will likely improve habitat conditions for delta smelt. However, in light of the uncertainty about specific X2 targets and the overall effectiveness of the fall X2 action, the State Water Board recommends this action be implemented within the context of an adaptive management program. The program should include studies designed to clarify the mechanisms underlying the effects of fall habitat on the delta smelt populations, the establishment and peer review of performance measures and performance evaluation related to the action, and a comprehensive review of the outcomes of the action and effectiveness of the adaptive management program. (USFWS 2008.) Absent study results demonstrating the importance of fall X2 to the survival of delta smelt, fall flows beyond those stipulated in the fall X2 action for the protection of delta smelt are not recommended at this time.




Relationship between X2 and habitat area for delta smelt during fall, with standard shown for wet and above normal years. (Source: USFWS 2008, Figure B17).

**Figure 15. X2 Versus Habitat Area for Delta Smelt During Fall**

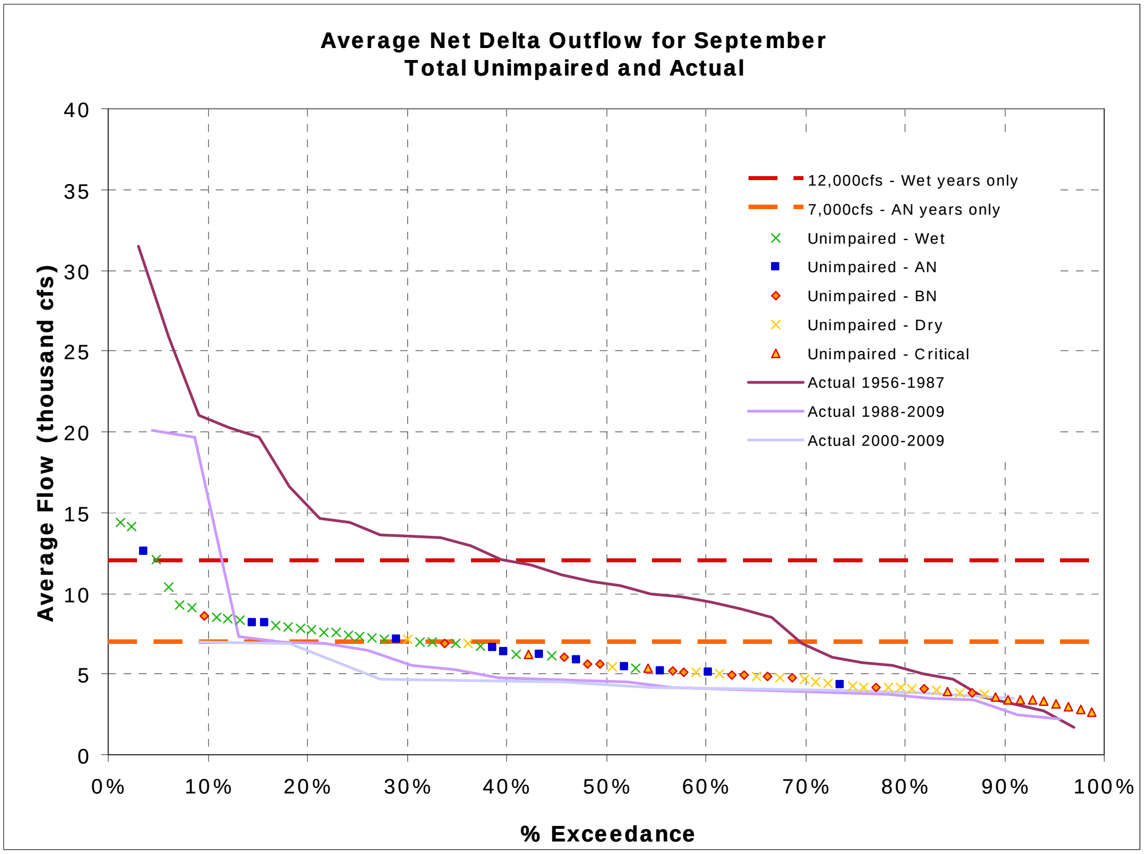



**Figure 16. Net Delta Outflow Flow Exceedance Plot - September**

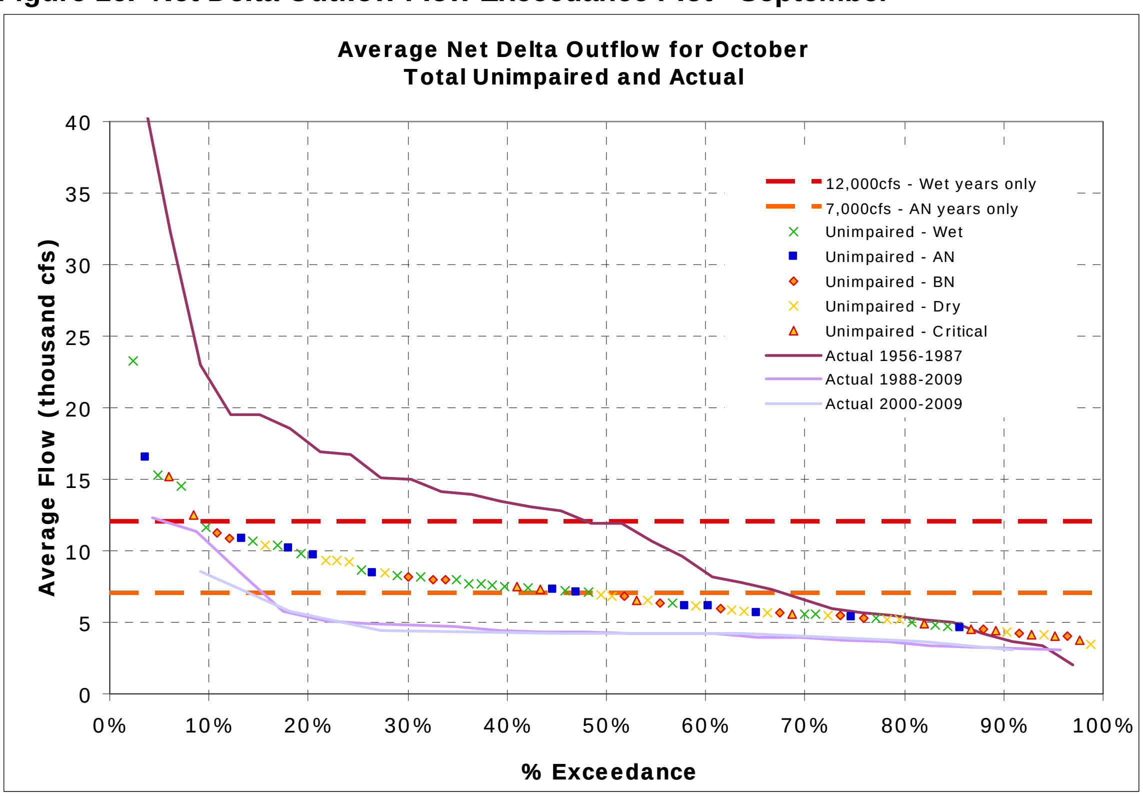



**Figure 17. Net Delta Outflow Flow Exceedance Plot - October**

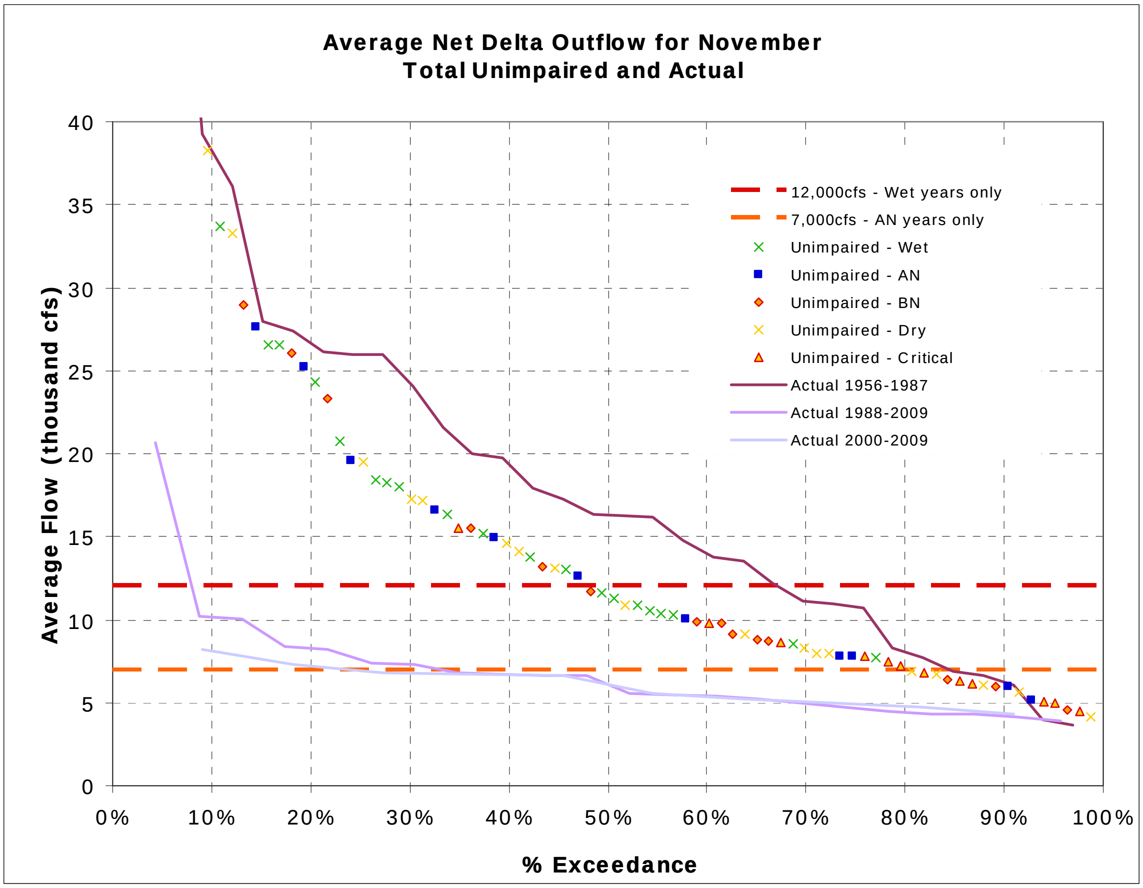



**Figure 18. Net Delta Outflow Flow Exceedance Plot - November**

The specific Delta outflow criteria may need to be tempered by the need to maintain water in reservoirs to provide adequate cold water and tributary specific flows on tributaries to the Delta. It may not be possible to attain both the flow criteria and meet the thermal and tributary specific flow needs of all of the sensitive species in the Delta Watershed. Water supply modeling and temperature analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals.

<u>Category B: 2006 Bay-Delta Plan</u> <u>Summer – Fall Delta Outflow</u>
Resident estuarine species, such as delta smelt, require flows sufficient to provide adequate habitat throughout the year. Delta outflow criteria for January through June are discussed above. In addition to providing flows to support resident species, sufficient flows must also be provided in the fall to provide attraction cues and a homing mechanism for returning adult salmon. Criteria for fall salmon attraction flows on the Sacramento and San Joaquin rivers are discussed in Sections 5.2 and 5.3. The 2006 Bay-Delta Plan contains summer – fall Delta outflow water quality objectives for fish and wildlife beneficial uses, which are summarized below in Table 19.

**Table 19. 2006 Bay-Delta Plan Delta Outflow Objectives for July through December**

| Water Year | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|
| Critical | 4000 | 3000 | 3000 | 3000 | 3500 | 3500 |
| Dry | 5000 | 3500 | 3000 | 4000 | 4500 | 4500 |
| Below Normal | 6500 | 4000 | 3000 | 4000 | 4500 | 4500 |
| Above Normal | 8000 | 4000 | 3000 | 4000 | 4500 | 4500 |
| Wet | 8000 | 4000 | 3000 | 4000 | 4500 | 4500 |

Multiple participants submitted testimony concerning the need for additional flows in the fall to benefit delta smelt, striped bass, and other resident species (CSPA 1, p. 7; CWIN 2, p. 29; DOI 1, pp. 46-48; EDF 1, pp. 49-50; TBI/NRDC 2, pp. 27-37), and as a means to potentially control the spread of harmful invasive species (e.g., *Corbula* and toxic algae). (TBI/NRDC 2, pp. 27-37.) The recommendations were based largely on recent research conducted by Feyrer *et al*. (2007 and In Review) and the fall X2 action in the USFWS's Opinion. The Fall X2 action in the USFWS Opinion requires that sufficient outflow be provided in September through November of Above Normal and Wet water year types to position X2 at 81 km and 74 km, respectively. This action was restricted to Above Normal and Wet years because these are the years in which project operations have most significantly affected fall outflows and to limit potential conflicts with cold water pool storage. (USFWS 2008.)

Following its review of the USFWS Opinion, the NAS (2010) noted that:

> "[a]lthough there is evidence that the position of X2 affects the distribution of smelt, the weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action difficult to understand… The X2 action is conceptually sound in that to the degree that the amount of habitat available for smelt limits their abundance, the provision of more or better habitat would be helpful… the committee concludes that how specific X2 targets were chosen and their likely beneficial effects need further clarification."

The USFWS Opinion also recognized uncertainty concerning the position of fall X2 and subsequent abundance of delta smelt and requires that the action be implemented with an adaptive management program to provide for learning and improvement of the action over time.

However, some participants provided flow recommendations that called for increased fall outflows during all water year types, as compared to the objectives in the 2006 Bay-Delta Plan, and in certain instances in excess of those required by the USFWS Opinion. Given the need for improved understanding concerning the fall X2 criterion, including the mechanisms underlying the effects of fall habitat on delta smelt populations, determination of specific X2 targets, potential conflicts with cold water pool storage, and the likely effectiveness of the action, the State Water Board is not advancing criteria for increased fall flows in Critical, Dry, and Below Normal water year types beyond those required in the 2006 Bay-Delta Plan and in Above Normal and Wet water year types beyond those stipulated in the fall X2 action (Category B). The quantity and timing of fall outflows necessary to protect public trust resources warrants further evaluation and underscores the need for a well-designed adaptive management program. The potential to use variability in flows during summer and fall months as a means of controlling the distribution and abundance of invasive species should also be evaluated.

## *5.2 Sacramento River*

Following are the Sacramento River inflow criteria based on analysis of the species-specific flow criteria and other measures:

1) Sacramento River Flow at Rio Vista: 75 percent of 14-day average unimpaired flow from April through June to increases juvenile salmon outmigration survival for fall-run Chinook salmon
2) Sacramento River Flow at Rio Vista: 75 percent of 14-day average unimpaired flow from November through March to increases juvenile salmon outmigration survival for other runs of Chinook salmon
3) Sacramento River at Wilkins Slough: Provide pulse flows of 20,000 cfs for 7 days starting in November coincident with fall/early winter storm events; the timing, magnitude, duration, and number of pulses should be determined on an adaptive management basis informed by unimpaired flow conditions and monitoring of juvenile salmon migration to promote juvenile salmon emigration
4) Sacramento River Flow at Freeport: Provide flows of 13,000 to 17,000 cfs in the Sacramento River downstream of confluence with Georgiana Slough when salmon are migrating through the Delta from November through June to increase juvenile salmon outmigration survival by reducing straying into Georgiana Slough and the central Delta
5) Sacramento River at Rio Vista: 2006 Bay-Delta Plan flow objectives for September and October to provide Fall adult Chinook salmon attraction flows

The magnitude, duration, timing, and source of Sacramento River inflows are important to all runs of Chinook salmon migrating through the Bay-Delta and several different aspects of their life history. Inflows are needed to provide appropriate conditions to cue upstream adult migration to the Sacramento River and its tributaries, adult holding, egg incubation, juvenile rearing, emigration from the Sacramento River and its tributaries, and other functions. Sacramento River inflows are important throughout the year to support various life stages of the different Chinook salmon runs inhabiting the Sacramento River. However, given the focus of this proceeding on inflows to the Delta and the importance of the juvenile salmon emigration period, the Sacramento River inflow criteria included in this report focus primarily on flows needed to support emigrating juvenile Chinook salmon from natal streams through the Delta. Following is a brief summary of the Sacramento River inflow criteria that were developed based on the species-specific flow needs analyses for salmon included in section 4.2.3 followed by a detailed discussion.

Available scientific information indicates that average April through June flows of 20,000 to 30,000 cfs on the Sacramento River at Rio Vista represent a flow threshold at which survival of juveniles and subsequent adult abundance is substantially improved for fall-run Chinook salmon. Less information is available for the other runs of Chinook salmon on the Sacramento River. However, outmigration flows needed to protect other races are assumed to be generally the same since factors that affect fall-run survival are generally applicable to other runs with some exceptions. In addition, analyses indicate that providing pulse flows of 20,000 cfs at Wilkins Slough on the Sacramento River beginning in November and extending through the first of the year provides for earlier migration timing and increased survival of juvenile winter, spring, and late-fall run Chinook salmon. In addition, information indicates that flows of 13,000 cfs to 17,000 cfs may be needed on the Sacramento River at Freeport to prevent salmon from migrating through Georgiana Slough and the interior Delta where survival is substantially lower.

Continuity of flows from natal stream through the Delta and flow variability are also important so rather than static April through June threshold flows of 20,000 to 30,000 cfs, the State Water Board determines, as a Category A criterion, that 75% of unimpaired flow is needed to achieve a threshold flow of 25,000 cfs (average of 20,000 and 30,000 cfs) approximately 50% of the time. The same percentage of unimpaired flow for the November through March period is also advanced as a Category B criterion due to the lack of information upon which this criterion was based. In addition, as Category B criteria, the State Water Board determines that shorter pulse flows of 20,000 cfs for 7 days at Wilkins Slough are needed starting in November and extending through the first of the year and flows of 13,000 cfs to 17,000 cfs at Freeport are needed from November through June to provide additional protection for Sacramento River Chinook salmon. The State Water Board also advances the Sacramento River flow objectives from the Bay-Delta Plan during September and October to provide a minimal level of protection during these months pending development of additional information concerning flow needs during this period. All of the Sacramento River flow criteria are not precise; rather they reflect the general timing and magnitude of flows needed to protect public trust resources, but could serve as a reasonable basis from which future analysis and adaptive management could proceed. The criteria also do not consider other Sacramento River flow needs.

<u>Sacramento River Inflow as a Percentage of Unimpaired Flows</u>
It appears to be important to preserve the general attributes of the natural hydrograph to which the various salmon runs adapted over time. Information indicates that Chinook salmon respond to variations in flows and need some continuity of flow between natal streams and the Delta for transport and homing fidelity. As such, the historic practice of developing monthly flow criteria to be met from limited sources may be less than optimal for protecting Chinook salmon runs. At the same time, given the impediments to fish passage into historic spawning and rearing areas, there may also be a need to diverge from the natural hydrograph at certain times of year to provide more flow than might have naturally occurred or less flow such that those flows are available at other times of year to mitigate for passage and habitat issues (e.g. cold water pool management).

Based on the above, the State Water Board developed Sacramento River inflow criteria, intended to mimic the natural hydrograph during the peak emigration period, to protect emigrating juvenile Chinook salmon. While emigration of some runs may occur outside of this period, peak emigration is generally believed to occur between November through June. As such, the criteria are recommended to apply to this time period. To achieve the attributes of a natural hydrograph, the criteria are recommended as a percentage of unimpaired flow on a 14-day average, to be provided generally on a proportional basis from the tributaries to the Sacramento River. The 14-day average is intended to better capture the peaks of actual flows compared to a 30-day average time-step, while still allowing for a time-step at which facilities can be operated. The appropriateness of this time-step for protecting public trust resources should be further evaluated.

*Spring Sacramento River Inflows at Rio Vista*
The species-specific flow needs analyses for salmon in section 4.2.3 indicates that average April through June flows of 20,000 to 30,000 cfs on the Sacramento River at Rio Vista provide for improved survival and abundance of juvenile fall-run Chinook salmon on the Sacramento River.

Flow exceedance graphs were used to determine the percentage of flow needed to achieve various flows needed to protect Chinook salmon. Analysis of unimpaired flows at Freeport (Figure 19) shows that under historic unimpaired conditions, average April through June flows of 30,000 cfs or more would occur in approximately 60% of years. Flows of 25,000 cfs or more would occur is approximately 72% of years, and flows of 20,000 cfs or more would occur in roughly 85% of years. At 75% of unimpaired flows, average flows of 30,000 cfs would be achieved between April and June in roughly 37% of years, flows of 25,000 cfs would be achieved in roughly 50% of years, and flows of 20,000 cfs would be achieved in approximately 70% of years. At 50% of unimpaired flows, flows of 30,000 cfs would be achieved in approximately 15% of years, flows of 25,000 cfs in roughly 25% of years, and flows of 20,000 cfs in roughly 35% of years. Actual flows of 30,000, 25,000, and 20,000 cfs were met in 26, 32, and 39% of years, respectively between 1986 and 2005. It is important to note, however, that unimpaired flows between 1986 through 2005 are not necessarily representative of the longer term unimpaired flow record. Flow criteria equal to 75% of unimpaired flows during the April through June period, on average, would therefore provide favorable conditions for fall-run juvenile Chinook salmon in at least 50% of years (assuming 25,000 cfs flows). As a result, the State Water Board advances 75% of unimpaired flows on a 14-day average from April through June as a potential means to achieve the 20,000 to 30,000 cfs Sacramento River flow threshold discussed above while maintaining variability and the attributes of the natural hydrograph. This criterion is included as criterion 1) for Sacramento River flows and is a Category A criterion.

The unimpaired estimates from which the 75% criterion is calculated are monthly estimates. Estimates of 14-day unimpaired flow have not been published, but are expected to generate an exceedance curve similar to one generated with monthly estimates. This specific percent of unimpaired flow and the averaging period should be adaptively managed. More information and analyses should be conducted to determine if there are maximum flows above which no, or significantly diminishing, additional biological or geomorphological benefits are obtained. This criterion would allow for flows to vary over time coincident with precipitation events reflecting the natural hydrograph. Climate change, however, and its associated effect on flow patterns will likely change how effective such flows are in protecting Chinook salmon. As such, these flow criteria would need to be adaptively managed in the future to ensure the protection of Chinook salmon.

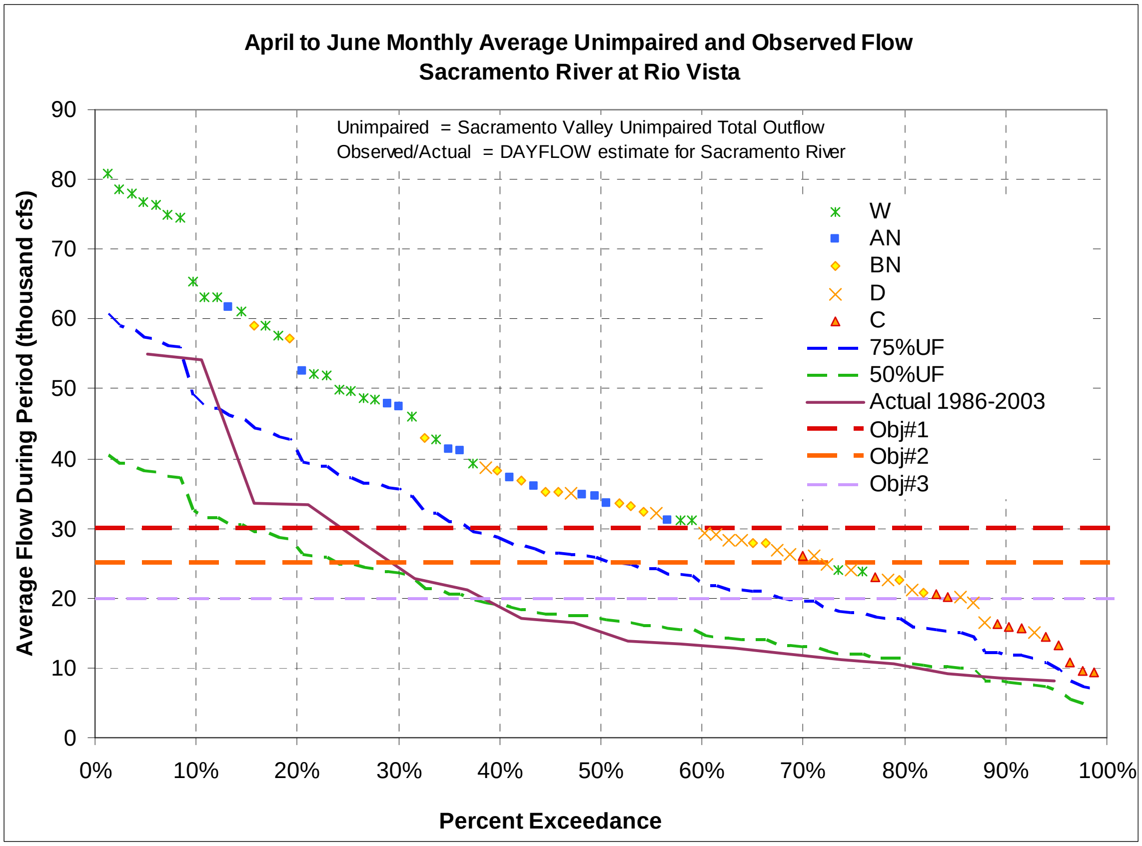



**Figure 19. Sacramento River Flow Exceedance Plot - April through June**

*Fall and Winter Sacramento River Inflows at Rio Vista*
Available data and analysis focus primarily on juvenile fall-run Chinook salmon outmigration. Outmigration flows to protect other races and life stages are assumed to be generally the same since factors that affect fall-run survival are generally applicable to other runs, with some exceptions including temperature, which may not be a concern in the winter months. (USFWS 1992, p. 8.) In the absence of sufficient data and analyses regarding flows needed for other Chinook salmon runs, however, the State Water Board advances 75% of unimpaired flows between November and March as an initial criterion from which future analysis and adaptive management could proceed. There is, however, no specific information that indicates that 75% is the correct percent of unimpaired flow. Additional quantitative analyses should be conducted to determine the specific flow needs of winter, spring, and late-fall run Chinook salmon.

<u>Sacramento River Flow at Freeport</u>
Analyses show that Chinook salmon survival is significantly lower for fish migrating through Georgiana Slough. Reverse flows in the vicinity of Georgiana Slough increase the occurrence of salmon migrating through Georgiana Slough. The available data show that flows of 13,000 to 17,000 cfs on the Sacramento River at Freeport provide adequate flow conditions to prevent reverse flows in Georgiana Slough. Flow criteria of 13,000 to 17,000 cfs on the Sacramento River at Freeport when salmon are migrating through the Delta during the November through June period is advanced as a Category B criterion. Additional analyses should be conducted to verify that flows of this magnitude are

needed to achieve the desired outcome of significantly reducing straying of outmigrating juvenile Chinook salmon. These flows are also expected to benefit adult Chinook salmon returning to the Sacramento River basin to spawn during this period. However, additional analyses regarding the relationship of adult Chinook salmon and reverse flows in Georgiana Slough should also be conducted.

Sacramento River Flow at Wilkins Slough

Information discussed in the species-specific flow needs analyses for salmon in section 4.2.3 indicates that significant precipitation in the Sacramento River in the fall facilitates emigration of juvenile Chinook salmon. When this flow is delayed, emigration of salmon is also delayed resulting in reduced survival to the Delta. The available data show that juvenile salmon require flows of 15,000 cfs to 20,000 cfs at Wilkins Slough by November continuing through the first of the year to facilitate emigration. These flows are needed to provide ecological continuity from natal streams to the Delta. Information supports a range of pulse flows of 15,000 cfs to 20,000 cfs at Wilkins Slough to be provided coincident with fall and early winter storm events. This range should be adaptively managed and further evaluated. Absent additional information, flows of 20,000 cfs for seven days are advanced. Such an approach will retain the attributes of the natural hydrograph and provide for ecological continuity. The timing, magnitude, duration, and number of pulses should be determined through adaptive management, informed by unimpaired flow conditions and monitoring of juvenile salmon migration. Additional analyses should be conducted regarding this flow relationship to refine these criteria and inform adaptive management.

Sacramento River at Rio Vista: 2006 Bay-Delta Plan Objectives

The above criteria cover flows on the Sacramento River from the November through June time period. In addition, the Bay-Delta Plan provides minimum flows from September through December. Aside from what is discussed above, there was no new information submitted in the record for this proceeding on fall flows and the Sacramento River fall flow objectives were not specifically reviewed. In the absence of any new information, the State Water Board advances the 2006 Bay Delta Plan Sacramento River inflow objectives for September and October as a Category B criterion. Given that Chinook salmon may also be present in the Sacramento River during July and August, it is likely warranted that some minimal flows be provided during those months as well. However, adequate information on which to base such flows was not readily available for this proceeding. Further, adequate minimal flows during this time period may be provided by temperature and other requirements and reservoir releases for power production and export operations.

The specific Sacramento River flow criteria may need to be tempered by the need to maintain water in reservoirs to provide adequate cold water and tributary specific flows in the Sacramento River basin. It may not be possible to attain both the flow criteria and meet the thermal and tributary specific flow needs of the various runs of Chinook salmon and other sensitive species in the Sacramento River basin. Water supply modeling and temperature analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals.

## 5.3 San Joaquin River

Following are the San Joaquin River inflow criteria based on analysis of the species-specific flow criteria and other measures:

1) San Joaquin River at Vernalis: 60%of 14-day average unimpaired flow from February through June
2) San Joaquin River at Vernalis: 10 day minimum pulse of 3,600 cfs in late October
3) San Joaquin River at Vernalis: 2006 Bay-Delta Plan flow objective for October

San Joaquin River inflow criterion 1 and 2 are Category A criteria because they are supported by sufficiently robust scientific information. The 2006 Bay-Delta Plan San Joaquin River inflow objective for October is included as a Category B criterion because it is not clear that eliminating this criterion in lieu of criteria 2 would provide adequate protection to migrating adult Chinook salmon. Following is discussion and rationale for these criteria. Category A and B criteria are both equally important for protection of the public trust resource, but there is more uncertainty about the appropriate volume of flow required to achieve the goals of the Category B criterion. Following is discussion and rationale for these criteria.

As discussed in the Sacramento River inflow section, the magnitude, duration, timing, and source of San Joaquin River inflows are important to Chinook salmon migrating through the Bay-Delta and several different aspects of their life history. Inflows are needed to provide appropriate conditions to cue upstream adult migration to the San Joaquin River and its tributaries, adult holding, egg incubation, juvenile rearing, emigration from the San Joaquin River and its tributaries, and other functions. San Joaquin River inflows are important for much of the year to support various life stages of San Joaquin basin fall-run Chinook salmon (and spring-run when they are reintroduced). However, given the focus of this proceeding on inflows to the Delta and the lack of information received concerning spring-run flow needs on the San Joaquin River, the San Joaquin River inflow criteria included in this report focus on flows needed to support migrating fall-run Chinook salmon from and to natal streams through the Delta. Following is a brief summary of the San Joaquin River inflow criteria that were developed based on the species-specific flow needs analyses for salmon included in section 4.2.3 followed by a detailed discussion.

Available scientific information indicates that average March through June flows of 5,000 cfs on the San Joaquin River at Vernalis represent a flow threshold at which survival of juveniles and subsequent adult abundance is substantially improved for fall-run Chinook salmon and that average flows of 10,000 cfs during this period may provide conditions necessary to achieve doubling of San Joaquin basin fall-run. Both the AFRP and DFG flow recommendations to achieve doubling also seem to support these general levels of flow, though the time periods are somewhat different (AFRP is for February through May and DFG is for March 15 through June 15). Available information also indicates that flows of 3,000 to 3,600 cfs for 10 to 14 days are needed during mid to late October to reduce straying, improve olfactory homing fidelity, and improve gamete viability for San Joaquin basin returning adult Chinook salmon.

Continuity of flows from natal stream through the Delta and flow variability are also important, so rather than advancing static flow criteria for the spring period to support emigration of juvenile San Joaquin basin fall-run Chinook salmon, the State Water Board determines, as a Category A criterion, that 60% of unimpaired flow from February through June is needed in order to achieve a threshold flow of 5,000 cfs or more in most years (over 85% of years) and flows of 10,000 cfs slightly less than half of the time (45% of years). Given that the focus of this proceeding is on protection of public trust resources, the State Water Board determines that the time period for these flows should be extended to cover all three periods supported by the DFG, AFRP, and TBI/NRDC analyses concerning flow needs. In addition, the State Water Board determines, as a Category A criterion, that flows of 3,600 cfs are needed for 10 days in late October. These flows could also be provided in a manner that better reflects the natural hydrograph to coincide with natural storm events. Until additional information is developed, maintaining the October pulse flow called for in the 2006 Bay-Delta Plan is also determined to be a Category B criterion to assure that the existing protection provided during this period is not diminished. All of the San Joaquin River flow criteria are not precise; rather they reflect the general timing and magnitude of flows needed to protect public trust resources, but could serve as a reasonable basis from which future analysis and adaptive management could proceed. The criteria also do not consider other San Joaquin River flow needs.

<u>San Joaquin River Inflows as a Percentage of Unimpaired Flow During the Spring</u>
As discussed in the Sacramento River inflow section, it is important to preserve the general attributes of the natural hydrograph to which the various salmon runs adapted to over time, including variations in flows and continuity of flows. Accordingly, as with the Sacramento River flow criteria, the State Water Board developed flow criteria for San Joaquin River inflows to protect emigrating juvenile Chinook salmon intended to mimic the natural hydrograph during the peak emigration period of February through June. This period may also cover a portion of the rearing period for juveniles as well. As with the Sacramento River flow criteria, to achieve the attributes of a natural hydrograph, the criteria are advanced as a percentage of unimpaired flow on a 14-day average, to be achieved on a proportional basis from the tributaries to the San Joaquin River. The unimpaired estimates from which the 60% criterion is calculated are monthly estimates. Estimates of 14-day unimpaired flow have not been published, but the exceedance curve is likely similar to one generated with monthly estimates. The appropriateness of this time-step and the percentage of unimpaired flows should be further evaluated.

To determine the percentage of unimpaired flow needed to protect Chinook salmon, the State Water Board reviewed flow exceedance information to determine what percentage of flow would be needed to achieve various flows. The analysis in section 4.2.3 indicates that increasing spring flows on the San Joaquin River and its tributaries is needed to protect Chinook salmon in the San Joaquin River basin. The TBI/NRDC analyses of temperatures and population growth indicate that there is a threshold response for fall-run Chinook salmon survival to flows above 5,000 cfs during the spring period and that average flows of 10,000 cfs during this same period may provide adequate flows to achieve doubling. Both the AFRP and DFG modeling analyses also seem to support these flows. However, the time periods for the AFRP recommended flows is from February through May and the time period for the DFG recommended flows is from March 15 through June 15. AFRP, DFG, and TBI/NRDC provide different recommendations for how to distribute flows during the spring period in different years, with increasing flows in increasingly wet years. All are generally consistent with an approach that mimics the natural flow regime to which these fish were adapted. Other analyses speak to the validity of this approach. (Propst and Gido, 2004 and Marchetti and Moyle, 2001, as cited in DOI 1, p. 25.) San Joaquin River flow criteria for the

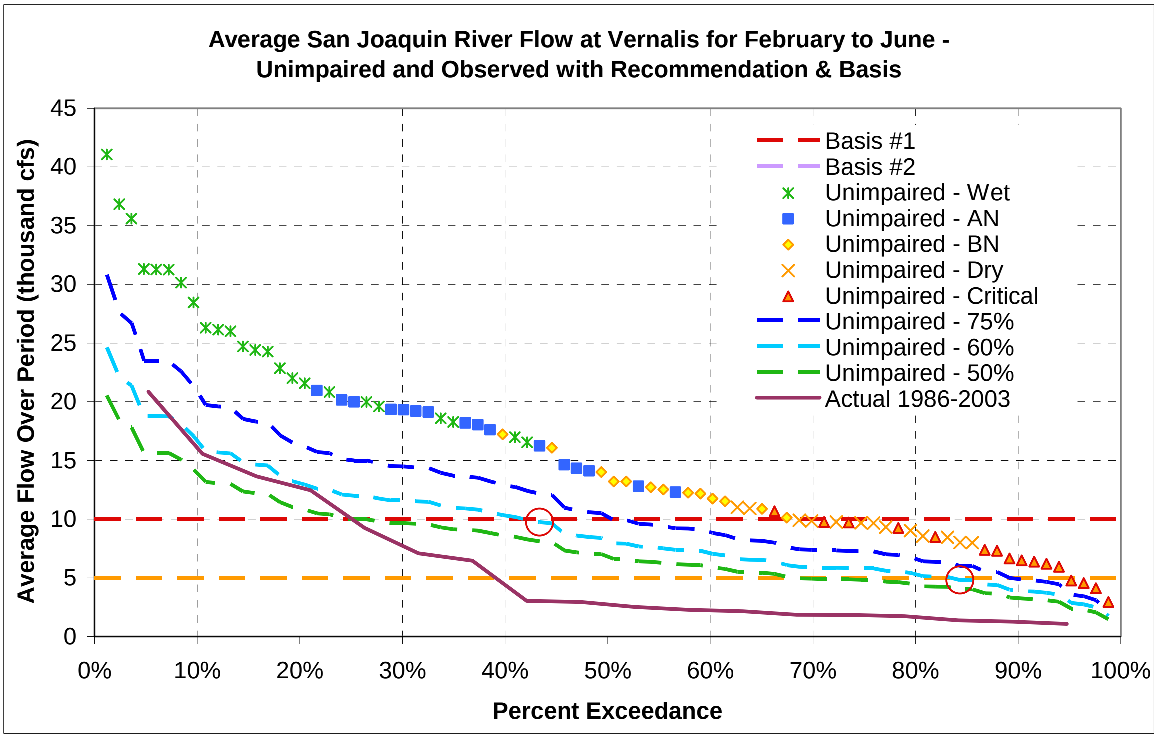
February through June period are determined to be 60% of unimpaired flows. Figure 20b shows that if 60% of unimpaired San Joaquin River flow at Vernalis were provided, average March through June flows would meet or exceed 5,000 cfs in over 85% of years (shown by red circle). An unimpaired flow of 60% during this period would also meet or exceed 10,000 cfs during the March through June time period in approximately 45% of years. The exceedance rates are not significantly different if applied to the February through June period as shown in Figure 20a. Additional information should be developed to determine whether these flows could be lower or higher and still meet the Chinook salmon doubling goal in the long term.

San Joaquin River Fall Flows

In addition to spring flows, fall pulse flows on the San Joaquin River are needed to provide adequate temperature and DO conditions for adult salmon upstream migration, to reduce straying, improve gamete viability, and improve olfactory homing fidelity for San Joaquin basin salmon. Analyses support a range of flows from 3,000 to 3,600 cfs for 10 to 14 days during mid to late October. Absent additional information, the State Water Board determines flow criteria for late fall to be 3,600 cfs for a minimum of 10 days in mid to late October. Providing these flows from the tributaries to the San Joaquin River that support fall-run Chinook salmon appears to be a critical factor to achieve homing fidelity and continuity of flows from the tributaries to the mainstem and Delta. Until additional information is developed regarding the need to maintain the 2006 Bay-Delta Plan October flow objective, these flows supplement and do not replace the 2006 Bay-Delta Plan October flow requirements such that flows do not drop below historic conditions during the remainder of October when the pulse flow criteria would not apply. Additional analyses should be conducted to determine the need to expand the pulse flow time period and modify the criteria to better mimic the natural hydrograph by coinciding pulse flows with natural storm events in order to potentially improve protection by mimicking the natural hydrograph.

Given that salmon and steelhead may be present in the San Joaquin River and its tributaries for all or most of the year (including spring-run in the future) and that the Bay-Delta plan does not currently include any flow requirements from July through September and November through January, additional flow criteria for the remainder of the year may be needed to protect Chinook salmon and their habitat. Specifically, additional criteria for spawning, egg incubation, rearing and riparian vegetation recruitment may be needed. However, adequate information is not available in the record for this proceeding upon which to base such criteria at this time. Additional information, building on the AFRP and other analyses, should be developed to determine needed flows for the remainder of the year.

a)




b)

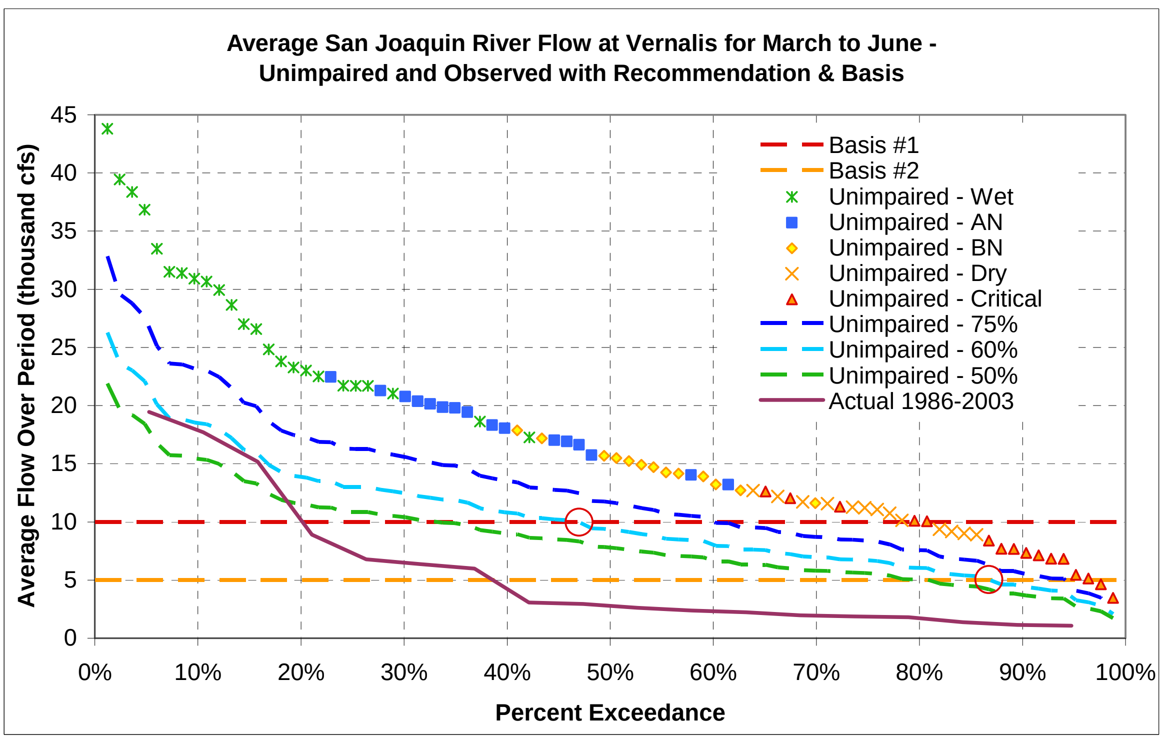



**Figure 20. San Joaquin River Flow Exceedance Plot - February through June**

The specific San Joaquin River flow criteria may need to be tempered by the need to maintain water in reservoirs to provide adequate cold water and tributary specific flows in the San Joaquin River basin.  It may not be possible to attain both the flow criteria and meet the thermal and tributary specific flow needs of steelhead, fall-run Chinook salmon, and other sensitive species in the San Joaquin River basin.  Water supply modeling and temperature analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals.

## *5.4 Hydrodynamics*

The following hydrodynamic related criteria have been developed based on analysis of the species-specific flow criteria and other measures discussed above:

1) San Joaquin River Flow to Export Ratio: Vernalis flows to exports great than .33 during the 10 day San Joaquin River pulse flow in October
2) Old and Middle River Flows: greater than -1,500 cfs in March and June of Critical and Dry water years
3) Old and Middle River Flows: greater than 0 or -1,500 cfs in April and May of Critical and Dry water years, when FMWT index for longfin smelt is less than 500, or greater than 500, respectively
4) Old and Middle River Flows: greater than -5,000 cfs from December through February in all water year types
5) Old and Middle River Flows:  greater than -2,500 when salmon smolts are determined to be present in the Delta from November through June
6) San Joaquin River Flow to export Ratio:  Vernalis flow to exports greater than 4.0 when juvenile San Joaquin River salmon are migrating in the mainstem San Joaquin River from March through June
7) San Joaquin River at Jersey Point Flows:  Positive flows when salmon are present in the Delta from November through June
8) 2006 Bay-Delta Plan Exports to Delta Inflow Limits for the Entire Year

Hydrodynamic criteria 1 is a Category A criterion because it is supported by more robust scientific information.  Hydrodynamic criteria 2-7 are Category B criteria because there is less scientific information, with more uncertainty, to support the specific numeric criteria.  The 2006 Bay-Delta Plan exports to Delta inflow objective (criteria 8) is offered as a Category B criterion as a minimal level of protection when the other criteria above do not apply.  However, the validity of the specific export restrictions included in the 2006 Bay-Delta Plan were not specifically reevaluated.  Category A and B criteria are both equally important for protection of the public trust resource, but there is more uncertainty about the appropriate volume of flow required to achieve the goals of the Category B criteria.  Following is discussion and rationale for these criteria.

<u>Pelagic Species Criteria</u>

Net OMR reverse flows have increased in both magnitude and frequency with the development of the California water projects (Figure 8) and are having a detrimental effect on biotic resources in the Delta. (Brown et al. 1996.)  It is also clear that the negative impact of net OMR reverse flows increases as Sacramento River inflows and net Delta outflow decreases. (Grimaldo et al. 2009; Kimmerer 2008; USFWS 2008; NMFS, 2009.)  Net OMR flow restrictions for the protection of longfin and Delta smelt are only recommended for dry and critically dry water years when less Delta outflow may be available (Table 23, criteria 2 and 3).  No spring restrictions for the protection of longfin and delta smelt are proposed for other water year types if the higher net Delta outflow criteria are met. If higher outflows are not provided in wetter years, then restrictions on OMR may be needed in these years as well. The State Water Board determines that net OMR flow criteria of greater than -5,000 cfs, from December through February in all water year types, to protect upstream migrating adult smelt are needed. The -5,000 cfs criterion may need to be made more protective if a large portion of the smelt population moves into the central Delta. The additional restrictions would be recommended after consultation with the USFWS (2008) Smelt Working Group. Spring and winter net OMR flow criteria for the protection of longfin and Delta smelt are classified as Category B because, as noted by the NAS (2010),

> "… the data do not permit a confident identification of the threshold [OMR] values to use … and … do not permit a confident assessment of the benefits to the population… As a result, the implementation of this action needs to be accompanied by careful monitoring, adaptive management and additional analyses that permit regular review and adjustment of strategies as knowledge improves…"

Chinook Salmon Criteria

Salmon must migrate through the Delta past the effects of the south Delta export facilities and the associated inhospitable conditions in the central Delta, first as juveniles on their way to the ocean, and later as adults returning to spawn. Exports change the hydrodynamic patterns in the Delta, drawing water across the Delta rather than allowing water to flow out of the Delta in a natural pattern. Over the years, different criteria have been developed to attempt to protect migrating salmon from the adverse hydrodynamic conditions caused by the south Delta export facilities in order to preserve the functional flows needed for migration that could be used to protect public trust resources. Net OMR flows, Jersey Point flows, and Vernalis flow to export ratios are all criteria that can be used to protect migrating salmon. The State Water Board advances a combination of these criteria to protect migrating salmon from export effects.

Increasingly negative net OMR flows have been shown to increase particle entrainment, particularly beginning at flows between -2,500 and -3,500 cfs. While juvenile salmon do not necessarily behave like particles, the particle entrainment estimates are a useful guide until additional information can be developed using evolving acoustic tracking methods and other appropriate techniques. Reduced negative net OMR flows should also provide some level of protection from the indirect reverse flow effects related to fish entering the central Delta where predation and other sources of mortality are higher. Based on the above, the State Water Board determines criteria for net OMR flows should be for greater than -2,500 cfs when salmon are present in the Delta during the peak juvenile outmigration period of November through June, for the protection of Chinook salmon. This is a Category B criterion because there is limited information upon which to base a specific numeric criteria at this time. Such information should be developed to better understand the relationship between salmon survival and net OMR flows to determine more specific criteria that would protect against entrainment and other factors leading to indirect mortality.

Increased reverse flows at Jersey Point have also been shown to decrease survival of salmon smolts migrating through the lower San Joaquin River. However, the precise Jersey Point flow that is necessary to protect migrating salmon is unclear. In addition, it is unclear whether the same functions of such a flow could be better met using different criteria such as net OMR flows or San Joaquin River flow to export ratios.  The State Water Board therefore advances positive Jersey Point flows when salmon are present in the Delta during the peak juvenile salmon outmigration period of November through June.  Again, this is a Category B criterion because there is limited information upon which to base a specific numeric criteria at this time.

Increased San Joaquin River flow to export ratios appear to improve survival for San Joaquin River salmon, though the exact ratio that is needed to protect public trust resources is not well understood.  A San Joaquin River flow to export ratio of greater than 4.0 is recommended as a Category B criterion when San Joaquin River juvenile salmon are outmigrating from the San Joaquin River from March through June.  There is, however, sufficient information in the record to support a Category A criterion for exports to be kept to less than 300% of San Joaquin River flows (equal to a San Joaquin River flow to export ratio of more than 0.33) at the same time that the recommended San Joaquin River pulse flows are provided.  Additional analyses should be conducted to determine if this time frame should be extended to capture more of the San Joaquin River adult Chinook salmon return period between October and January.

The NAS review concerning OMR restrictions for salmon concluded that:

> "…the strategy of limiting net tidal flows toward the pump facilities is sound, but the support for the specific flows targets is less certain.  In the near-term telemetry-based smolt migration and survival studies (e.g, Perry and Skalski, 2009) should be used to improve our understanding of smolt responses to OMR flow levels." (NAS 2010, p. 44.)

Much additional work is needed to better understand the magnitude and timing of the recommended criteria and how net OMR flow criteria should be integrated with other criteria for San Joaquin River flows, San Joaquin River flows to export ratios, Sacramento River flows, and net OMR flow restrictions for the protection of pelagic species.  For all of the OMR, Jersey Point, and Vernalis flows to export ratiocriteria, further analysis and consideration is needed to determine: 1) how salmon presence should be measured and the information used to temper the criteria; 2) an appropriate averaging period; and 3) how to adaptively manage to assure that flows are sufficiently, but not overly, protective.

The October San Joaquin River flow to export ratio criteria is a Category A criterion since the basis for this minimum criterion is sufficiently understood to develop a quantitative criteria.  Additional analyses should still, however, be conducted to determine if this criteria could be refined to provide better protection for migrating adult San Joaquin River Chinook salmon.  All of the other hydrodynamic criteria for the protection of Chinook salmon are Category B criteria.

The San Joaquin River flow to export criterion during the spring is also a Category B criterion due to a lack of certainty regarding the needed protection level.  Regarding this issue, the NAS concluded that:

> "…the rationale for increasing San Joaquin River flows has a stronger foundation than the prescribed action of concurrently managing inflows and exports.  We further conclude that the implementation of the 6-year steelhead smolt survival study (action IV.2.2) could provide useful insight

as to the actual effectiveness of the proposed flow management actions as a long-term solution." (NAS 2010, p. 45.)

In addition, based on similar uncertainty regarding needed protection levels and interaction between net OMR flows and San Joaquin River flows to export ratios, the San Joaquin River at Jersey Point criterion is also a Category B criterion. More work is needed to develop a suite of operational tools and an operational strategy for applying those tools to protect public trust resources in the Delta from the adverse hydrodynamic effects of water diversions, channel configurations, reduced flows, and other effects.

<u>2006 Bay-Delta Plan</u> <u>Export Objectives</u>
The 2006 Bay-Delta Plan includes export limitations for the entire year. From February through June exports are limited to 35-45% of Delta inflow. (State Water Board 2006a, pp. 184-187.) From July through January, exports are limited to 65% of Delta inflow. (*Id.)* The export to Delta inflow restrictions are intended to protect the habitat of estuarine-dependent species. (State Water Board 2006b, pp. 46-47.) These export restrictions provide a minimum level of protection for public trust uses and should be maintained to the extent that the other recommended criteria do not override them.

For all of the hydrodynamic criteria, biologically appropriate averaging periods need to be developed. Averaging periods may need to include a two-step approach whereby a shorter averaging period is included that allows for some divergence from the criteria and a longer averaging period is included that does not.

## *5.5 Other Inflows - Eastside Rivers and Streams*

The Cosumnes and Mokelumne rivers, and smaller streams such as the Calaveras River, Bear Creek, Dry Creek, Stockton Diversion Channel, French Camp Slough, Marsh Creek, and Morrison Creek are all tributary to the Delta. Flows should generally be provided from tributaries in proportion to their contribution to unimpaired flow.

## *5.6 Other Measures*

### 5.6.1 Variability, Flow Paths, and the Hydrograph

Criteria should reflect the frequency, duration, timing, and rate of change of flows, and not just volumes or magnitudes. Accordingly, whenever possible, the criteria specified herein are expressed as a percentage of the unimpaired flow rather than as a single number or range of numbers that vary by water year type. Additional efforts should focus on restoring habitat complexity. Inflows should generally be provided from tributaries to the Delta watershed in proportion to their contribution to unimpaired flow in order to assure connection between Delta flows and upstream tributaries, to the extent that such connections are beneficial to protecting public trust resources. Flows should be at levels that maintain flow paths and positive salinity gradients through the Delta. This concept is reflected in the specific determinations made above. More study is needed to determine to which tributaries such criteria should apply. For example, since the percent of unimpaired flow criteria determined to protect public trust uses for San Joaquin River inflows is at times lower than the criteria determined for Delta outflow, more study is needed to determine the appropriate source of such flows to protect public trust resources. All determined flow criteria must also be tempered by the need to protect health and safety. No flow criteria, for example, should be in excess of flows that would lead to flooding. For all of the flow criteria, there may be a need to reshape the specified flows to better protect public trust resources based on real-time considerations. All of the criteria should be implemented adaptively to allow for such appropriate reshaping to improve biological and geomorphological processes.

Moyle *et al* (2010) concluded, however, that there is a fundamental conflict between restoring variability and maintaining the current Delta:

> “restoring environmental variability in the Delta is fundamentally inconsistent with continuing to move large volumes of water through the Delta for export. The drinking and agricultural water quality requirements of through-Delta exports, and perhaps even some current in-Delta uses, are at odds with the water quality and variability needs of desirable Delta species.”

### 5.6.2 Floodplain Activation and Other Habitat Improvements

Activated floodplains stimulate food web activity and provide spawning and rearing habitat for floodplain adapted fish. The frequency of low-magnitude floods that occurred historically has been reduced, primarily by low water control levees. The record supports the conclusion that topography changes associated with future floodplain restoration will provide improved ecosystem function with less water. Studies and demonstration projects for, and implementation of, floodplain restoration projects should therefore proceed to allow for the possible reduction of flows required to protect public trust resources in the Delta.

<u>Floodplain Flow Determinations for Protection of Salmon and Splittail</u>:
Floodplain and off-channel inundation are required for splittail spawning and appear to be important in protecting Chinook salmon. At the same time, it is also important how and when such inundation occurs. Due to the effects of levees and dams, natural side channel and floodplain inundating flows have been substantially reduced. As a result, modification to weirs and other changes may be needed to substantially improve floodplain inundation conditions on the Sacramento and San Joaquin rivers. Based on the above, the State Water Board determines that an effort be made to provide appropriate additional seasonal floodplain habitat for salmon, splittail, and other species in the Central Valley. The various recommendations the State Water Board received for floodplain inundation are included in Appendix A.1. The State Water Board has no specific flow determinations for floodplain inundation. The State Water Board recommends that BDCP, the Council, and others continue to explore the various issues concerning flood protection, weir modifications, and property rights related to floodplain inundation.

Other future habitat improvements will likely change the response of native fishes to flow and allow flow criteria to be modified. Habitat restoration should proceed to allow for the possible reduction of flows required to protect public trust resources in the Delta. Other future habitat restoration that should be reviewed and implemented include:

- Development of slough networks with natural channel geometry and less diked and rip-rapped channel habitat
- Increased tidal marsh habitat, including shallow (one to two meters) subtidal areas in both fresh and brackish zones of the estuary (in Suisun Marsh, for example)

- Create large expanses of low salinity open water habitat in the Delta

### 5.6.3 Water Quality and Contaminants

Any set of flow criteria should include the capacity to readily adjust the flows to adapt to changing future conditions and improved understanding. (DEFG 1.) As our understanding of the effect of contaminants on primary production and species composition in the Sacramento River and Delta improves, flow criteria may need to be revisited.

The Central Valley and San Francisco Regional Water Boards should continue developing Total Maximum Daily Loads (TMDLs) for all listed pollutants and adopting programs to implement control actions. Specifically, the Central Valley Regional Board should require additional studies and incorporate discharge limits and other controls into permits, as appropriate, for the control of nutrients, including ammonia.

### 5.6.4 Coldwater Pool Resources and Instream Flow Needs on Tributaries

The flow criteria contained in this report should be tempered by the need to maintain cold water resources and meet tributary specific flow needs in the Delta watershed. It may not be possible to attain all of the identified flow criteria in all years and meet the tributary flow needs and thermal needs of the various runs of Chinook salmon, steelhead, and other sensitive species. Temperature and water supply modeling analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals. In addition, these flow determinations do not consider the needs of other non-fish species and terrestrial species which should be considered before any implementation of these criteria.

### 5.6.5 Adaptive Management

The numeric criteria are all short term criteria that are only appropriate for the current physical system and climate. There is uncertainty in these criteria even for the current physical system and climate, and therefore for the short term. Long term numeric criteria, beyond five years, for example, and assuming a modified physical system, are highly speculative. Only the underlying principles for the proposed numeric criteria and the other measures are advanced as long term determinations.

The information received in this proceeding suggests that the relationships between hydrology, hydrodynamics, water quality, and the abundance of desirable species are often unclear. In preparing for the long term, resources should be directed toward better understanding these relationships. In particular, there is significant uncertainty associated with Category B numeric criteria advcanced in this report. Category B criteria should therefore be high priority candidates for grant funded research.

A strong science program and a flexible management regime are critical to improving flow criteria. The relationship between flow, habitat, and abundance is not well enough understood to recommend flows in the Delta ecosystem without some reliance on adaptive management to better manage these flows. The State Water Board intends to work with the Council, the Delta Science Program, IEP, and others to develop the framework for adaptive management that could be relied upon for the management and regulation of flows in the Delta. The State Water Board will consider supporting and incorporating into its regulations greater reliance upon adaptive management in its flow regulations.

## 5.7 Summary Determinations

Table 20 through Table 23 provide summary determinations for Delta outflows, Sacramento inflows, San Joaquin River inflows, and hydrodynamics, respectively. Each table shows various numbered criteria, applicable to the shaded range of months. Criteria fall into two categories. Category “A” criteria have more robust scientific information to support specific numeric criteria than do Category “B” criteria. Both categories of criteria are considered equally important for protection of public trust resources in the Delta ecosystem, and are supported by scientific information on function-based species or ecosystem needs. The basis and explanation for each criterion is provided. Each table is appended with the following notes to explain the limitations and constraints of how the criteria should be considered:

- All flows are subject to appropriate ramping rates to avoid ramping impacts to public trust resources
- These flow criteria should be tempered by tributary specific flow needs and the need to manage cold-water resources for the protection of public trust resources
- Criteria for percentages of unimpaired flows apply only up to a specified maximum cap; appropriate maximum flow caps still need to be determined based on public trust needs and to avoid flooding.
- Additional flows may be needed for the protection of public trust resources for periods of time for which no flow criteria have been determined or where Bay-Delta Plan flow objectives are advanced, but adequate information is not available at this time to determine such flows

These criteria are made specifically to achieve the stated goal of halting the population decline and increase populations of native species as well as species of commercial and recreational importance. Additionally, positive changes in the Delta ecosystem resulting from improved flow or flow patterns will benefit humans as well as fish and wildlife, especially when accompanied by large-scale habitat restoration and pollution reduction. (Moyle *et al*, 2010.)

In addition, Table 24 contains a summary of other issues and concepts that should be considered in conjunction with the numeric criteria. These other measures are also based on a synthesis of the best scientific information submitted by participants in the State Water Board’s Informational Proceeding. These criteria and other measures, however, must be further qualified as to their limitations. The limitations of this and any other flow prescription are described at the end of the Fleenor *et al*. (2010) “flow prescriptions” report as a “further note of caution”:

> “How much water do fish need?” has been a common refrain in Delta water management for many years… it is highly unlikely that any fixed or predetermined prescription will be a "silver bullet". The performance of native and desirable fish populations in the Delta requires much more than fresh water flows. Fish need enough water of appropriate quality over the temporal and spatial extent of habitats to which they adapted their life history strategies. Typically, this requires habitat having a particular range of physical characteristics, appropriate variability, adequate food supply and a diminished set of invasive species. While folks ask “How much water do fish need?” they might well also ask, “How much habitat of different types and locations, suitable water quality,

> improved food supply and fewer invasive species that is maintained by better governance institutions, competent implementation and directed research do fish need?" The answers to these questions are interdependent. We cannot know all of this now, perhaps ever, but we do know things that should help us move in a better direction, especially the urgency for being proactive. We do know that current policies have been disastrous for desirable fish. It took over a century to change the Delta's ecosystem to a less desirable state; it will take many decades to put it back together again with a different physical, biological, economic, and institutional environment."

The State Water Board concurs with this cautionary note and recommends the flow criteria and other conclusions advanced in this report be used to inform the planning efforts for the Delta Plan and BDCP and as a report that can be used to guide needed research by the Delta Science Program and other research institutions.

**Table 20. Delta Outflow Summary Criteria**

| Delta Outflows | |
|---|---|
| | **Category A** |
| **Water Year** O N D J F M A M J J A S | **Criteria** |
| | 1) Net Delta Outflows: 75% of 14-day average unimpaired flow |
| | **Category B** |
| **Water Year** O N D J F M A M J J A S | **Criteria** |
| | 2) Fall X2<br>a. Wet years: X2 less than 74 km (greater than approximately 12,400 cfs)<br>b. Above normal years: X2 less than 81 km (greater than approximately 7,100 cfs) |
| | 3) Net Delta Outflows: 2006 Bay-Delta Plan Delta Outflow Objectives - applies during critical, dry, and below normal years |
| | **Basis for Criteria and Explanation** |

1) Promote increased abundance and improved productivity (positive population growth) for longfin smelt and other desirable estuarine species
2) Increase quantity and quality of habitat for delta smelt; fall X2 requirement limited to above normal and wet years to reduce potential conflicts with cold water pool storage, while promoting variability with respect to fall flows and habitat conditions in above normal and wet water year types; expected to result in improved conditions for delta smelt, however, the statistical relationship between fall X2 and abundance is not strong; note 2) above regarding need for improved understanding concerning the fall X2 action also applies
3) Fish and wildlife beneficial use protection

Notes:

- These flow criteria do not consider any balancing of public trust resource protection with public interest needs for water.
- All flows are subject to appropriate ramping rates to avoid ramping impacts to public trust resources.
- These flow criteria should be tempered by tributary specific flow needs and the need to manage cold-water resources for the protection of public trust resources.
- Criteria for percentages of unimpaired flows apply only up to a specified maximum cap; appropriate maximum flow caps still need to be determined based on public trust needs and to avoid flooding.
- Additional flows may be needed for the protection of public trust resources for periods of time for which no flow criteria are recommended or where 2006 Bay-Delta Plan flow objectives are recommended, but adequate information is not available at this time to recommend such flows.

**Table 21. Sacramento River Inflow Summary Criteria**

| Sacramento River Inflows | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Category A** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 1) Rio Vista: 75% of 14-day average unimpaired flow[1] |
| **Category B** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 2) Rio Vista: 75% of 14-day average unimpaired flow to support same functions as #1 for other runs of Chinook salmon |
| | | | | | | | | | | | | 3) Wilkins Slough: Provide pulse flows of 20,000 cfs for 7 days starting in November coinciding with storm events producing unimpaired flows at Wilkins Slough above 20,000 cfs until monitoring indicates that majority of smolts have moved downstream[2] |
| | | | | | | | | | | | | 4) Freeport: Positive flows in Sacramento River downstream of confluence with Georgiana Slough while juvenile salmon are present (approximately 13,000 to 17,000 cfs) |
| | | | | | | | | | | | | 5) Rio Vista: 2006 Bay-Delta Plan flow objectives |

**Basis for Criteria and Explanation, and Notes**

1) Increase juvenile salmon outmigration survival and abundance for fall-run Chinook salmon
2) Promote juvenile salmon emigration for other runs of Chinook salmon
3) Increase juvenile salmon outmigration survival by reducing diversion into Georgiana Slough and the central Delta
4) Increases juvenile salmon outmigration survival
5) Fall adult Chinook salmon attraction flows

Notes:

- These flow criteria do not consider any balancing of public trust resource protection with public interest needs for water.
- All flows are subject to appropriate ramping rates to avoid ramping impacts to public trust resources.
- These flow critiera should be tempered by tributary specific flow needs and the need to manage cold-water resources for the protection of public trust resources.
- Criteria for percentages of unimpaired flows apply only up to a specified maximum cap; appropriate maximum flow caps still need to be determined based on public trust needs and to avoid flooding.
- Additional flows may be needed for the protection of public trust resources for periods of time for which no flow criteria are recommended or where 2006 Bay-Delta Plan flow objectives are recommended, but adequate information is not available at this time to recommend such flows.

[1] 75% of unimpaired flow at Freeport applied to Rio Vista

[2] Definition of storm, number of storms, and how to determine when the majority of juveniles have outmigrated needs to be determined.

**Table 22. San Joaquin River Inflow Summary Criteria**

| San Joaquin River Inflows | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Category A** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 1) Vernalis: 60% of 14-day average unimpaired flow |
| | | | | | | | | | | | | 2) Vernalis: 10 day minimum pulse flow of 3,600 cfs in late October (e.g., October 15 to 26) |
| **Category B** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 3) Vernaisl: 2006 Bay-Delta Plan October flows |
| **Basis for Criteria and Explanation, and Notes** | | | | | | | | | | | | |

1) Increase juvenile Chinook salmon outmigration survival and abundance and provide conditions that will generally produce positive population growth in most years and achieve the doubling goal in more than half of years
2) Minimum adult Chinook salmon attraction flows to decrease straying, increase DO, reduce temperatures, and improve olfactory homing fidelity
3) Adult Chinook salmon attraction flows

Notes:

- These flow criteria do not consider any balancing of public trust resource protection with public interest needs for water.
- All flows are subject to appropriate ramping rates to avoid ramping impacts to public trust resources.
- These flow criteria should be tempered by tributary specific flow needs and the need to manage cold-water resources for the protection of public trust resources.
- Criteria for percentages of unimpaired flows apply only up to a specified maximum cap; appropriate maximum flow caps still need to be determined based on public trust needs and to avoid flooding.
- Additional flows may be needed for the protection of public trust resources for periods of time for which no flow criteria are recommended or where 2006 Bay-Delta Plan flow objectives are recommended, but adequate information is not available at this time to recommend such flows.

**Table 23. Hydrodynamics Summary Criteria**

| Hydrodynamics: Net OMR, Inflow-Export Ratios, and Jersey Point | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Category A** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 1) San Joaquin River Flow to Export Ratio: Vernalis flows to exports greater than 0.33 during fall pulse flow (e.g., October 15 – 26); complementary action to San Joaquin River inflow critieria #2 |
| **Category B** | | | | | | | | | | | | |
| **Water Year** | | | | | | | | | | | | **Criteria** |
| O | N | D | J | F | M | A | M | J | J | A | S | |
| | | | | | | | | | | | | 2) Net OMR Flows: greater than -1,500 cfs in Critical and Dry water years |
| | | | | | | | | | | | | 3) Net OMR Flows: greater than 0 or -1,500 cfs in Critical and Dry water years, when FMWT index for longfin smelt is less than 500, or greater than 500, respectively |
| | | | | | | | | | | | | 4) Net OMR Flows: greater than -5,000 cfs in all water year types |
| | | | | | | | | | | | | 5) Net OMR Flows: greater than -2,500 cfs when salmon smolts are determined to be present in the Delta |
| | | | | | | | | | | | | 6) San Joaquin River Flow to Export Ratio: Vernalis flows to exports greater than 4.0 when juvenile San Joaquin River salmon are migrating in mainstem San Joaquin River |
| | | | | | | | | | | | | 7) Jersey Point: Positive flows when salmon present in the Delta |
| | | | | | | | | | | | | 8) Exports to Delta Inflows: 2006 Bay-Delta Plan exports to inflows restrictions |

**Basis for Criteria and Explanation**

1) Reduce straying and improve homing fidelity for San Joaquin basin adult salmon
2) Reduce entrainment of larval / juvenile delta smelt, longfin smelt, and provide benefits to other desirable species
3) Same as number 2), but if the previous FMWT index for longfin smelt is less than 500, then OMR must be greater than 0 (to reduce entrainment losses when abundance is low), or greater than -1,500 if the previous FMWT index for longfin smelt is greater than 500
4) Reduce entrainment of adult delta smelt, longfin smelt, and other species; less negative flows may be warranted during periods when significant portions of the adult smelt population migrate into the south or central Delta; thresholds for such flows need to be determined
5) Reduce risk of juvenile salmon entrainment and straying to central Delta at times when juveniles are present in the Delta; will also provide associated benefits for adult migration
6) Improve survival of San Joaquin River juvenile salmon emigrating down the San Joaquin River and improve subsequent escapement 2.5 years later
7) Increase survival of outmigrating smolts, decrease diversion of smolts into central Delta where survival is low, and provide attraction flows for adult returns
8) Protection of estuarine dependent species

(cont.)

Notes:

- These flow criteria do not consider any balancing of public trust resource protection with public interest needs for water.
- All flows are subject to appropriate ramping rates to avoid ramping impacts to public trust resources.
- These flow critieria should be tempered by tributary specific flow needs and the need to manage cold-water resources for the protection of public trust resources.
- Criteria for percentages of unimpaired flows apply only up to a specified maximum cap; appropriate maximum flow caps still need to be determined based on public trust needs and to avoid flooding.
- Additional flows may be needed for the protection of public trust resources for periods of time for which no flow criteria are recommended or where 2006 Bay-Delta Plan flow objectives are recommended, but adequate information is not available at this time to recommend such flows.

**Table 24. Other Summary Determinations**

**Variability and the Natural Hydrograph:**

- Criteria should reflect the frequency, duration, timing, and rate of change of flows, and not just volumes or magnitudes. Accordingly, whenever possible, the criteria specified above are expressed as a percentage of the unimpaired hydrograph.
- Inflows should generally be provided from tributaries to the Delta watershed in proportion to their contribution to unimpaired flow unless otherwise indicated. This concept is reflected in the specific criteria above.

**Floodplain Activation and Other Habitat Improvements:**

- Studies and demonstration projects for, and implementation of, floodplain restoration, improved connectivity and passage, and other habitat improvements should proceed to provide additional protection of public trust uses and potentially allow for the reduction of flows otherwise needed to protect public trust resources in the Delta.

**Water Quality and Contaminants:**

- The Central Valley and San Francisco Regional Water Boards should continue developing TMDLs for all listed pollutants and adopting programs to implement control actions.
- The Central Valley Regional Board should require additional studies and incorporate discharge limits and other controls into permits, as appropriate, for the control of nutrients and ammonia.

**Coldwater Pool Resources and Instream Flow Needs on Tributaries:**

- Temperature and water supply modeling and analyses should be conducted to identify conflicting requirements to achieve both flow and cold water temperature goals.

**Adaptive Management:**

- A strong science program and a flexible management regime are critical to improving flow criteria. The State Water Board should work with the Council, the Delta Science Program, IEP, and others to develop the framework for adaptive management that could be relied upon for the management and regulation of Delta flows.
- The numeric criteria in this report are all short term criteria that are only appropriate for the current physical system and climate; actual flows should be informed by adaptive management
- Only the underlying principles for the numeric criteria and these other measures are advanced as long termcriteria.

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# 7. Appendices

## *Appendix A: Summary of Participant Recommendations*

**Appendix A, Table 1. Delta outflow recommendations summary table (cfs unless otherwise noted).**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unimpaired Flow 1956-2003 | C | 16092 | 23292 | 31045 | 29103 | 27552 | 15301 | 5974 | 3880 | 4096 | 8167 | 8372 | 12531 | |
| | D | 24670 | 37460 | 52907 | 45810 | 39512 | 18994 | 6801 | 4759 | 5180 | 7221 | 16635 | 19339 | |
| | BN | 32402 | 63985 | 52056 | 53471 | 49644 | 25325 | 9091 | 5683 | 6004 | 7027 | 12842 | 16911 | |
| | AN | 88051 | 99722 | 86990 | 69589 | 78076 | 50019 | 18214 | 7932 | 7862 | 8162 | 13980 | 26763 | |
| | W | 113261 | 114512 | 103250 | 92975 | 96911 | 68197 | 27987 | 11354 | 8717 | 11804 | 30357 | 77204 | |
| Historical Flow 1956-2003 | C / D | 14117 | 17916 | 17597 | 9193 | 7367 | 4504 | 3952 | 3334 | 4285 | 6896 | 9663 | 12734 | 87 |
| | BN | 27274 | 48832 | 32673 | 14991 | 10100 | 4336 | 3952 | 5025 | 7798 | 12116 | 15192 | 18996 | |
| | AN | 61801 | 70133 | 70404 | 32283 | 27876 | 13444 | 7172 | 5985 | 7865 | 6766 | 10940 | 17093 | |
| | W | 94930 | 111565 | 87497 | 67642 | 46530 | 29897 | 14279 | 10588 | 15545 | 13385 | 23024 | 60061 | |
| D1641 | C | 4500 ([1]) | 7100 - 29200 ([2]) | | | | | 4000 | 3000 | 3000 | 3000 | 3500 | | 1, 2 |
| | D | 4500 | 7100 - 29200 | | | | | 5000 | 3500 | 3000 | 4000 | 4500 | | |
| | BN | 4500 | 7100 - 29200 | | | | | 6500 | 4000 | 3000 | 4000 | 4500 | | |
| | AN | 4500 | 7100 - 29200 | | | | | 8000 | 4000 | 3000 | 4000 | 4500 | | |
| | W | 4500 | 7100 - 29200 | | | | | 8000 | 4000 | 3000 | 4000 | 4500 | | |
| Draft D1630 | All | | | | 6700 | | | | | | | | | 3 |
| | C | | | | | 3300 | 3100 | 2900 | | | | | | 4 |
| | D | | | | | 4300 | 3600 | 3200 | | | | | | |
| | BN | | | | | 11400 | 9500 | 6500 | | | | | | |
| | AN | | | | | 14000 | 10700 | 7700 | | | | | | |
| | W | | | | | 14000 | 14000 | 10000 | | | | | | |
| | W | | 10000 | | | | | | | | | | | 5 |
| | BN & AN | 12000 | | | | | | | | | | | | 6 |
| | All | 6600 (if > flow not required by other standards) | | | | | | | | | | | | 7 |
| TBI / NRDC / AR / NHI / EDF | 81-100% (driest years) | 14000 - 21000 | | | 10000 - 17500 | | 3000 - 4200 | | | 5750 - 7500 | | | | 8 |
| | 61-80% | 21000 - 35000 | | | 17500 - 29000 | | 4200 - 5000 | | | 7500 - 9000 | | | | |
| | 41-60% | 35200 - 55000 | | | 29000 - 42500 | | 5000 - 8500 | | | 9700 - 12400 | | | | |
| | 21-40% | 55000 - 87500 | | | 42500 - 62500 | | 8500 - 25000 | | | 12400 - 16100 | | | | |
| | 0-20% (wettest years) | 87500 - 140000 | | | 62500 - 110000 | | 25000 - 50000 | | | 16100 - 19000 | | | | |
| CSPA / C-WIN | C | 4100 | 9100 | | 6700 | | | | 4100 | | | | | 9 |
| | D | 9200 | 23500 | | 10800 | | | | 9200 | | | | | |
| | BN | 12100 | 41000 | | 14400 | | | | 12100 | | | | | |
| | AN | 14600 | 90800 | | 23000 | | | | 14600 | | | | | |
| | W | 29000 | 91800 | | 43000 | | | | 29000 | | | | | |
| EDF / Stillwater (monthly average) | C | 11500 | 26800 | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 6500 | 5300 | 7500 | 10, 11, 12 |
| | D | 11500 | 26800 | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 6500 | 5300 | 7500 | |
| | BN | 26800 | 26800 | 26800 | 26800 | 26800 | 11500 | 7500 | 7500 | 7500 | 7500 | 7500 | 11500 | |
| | AN | 26800 | 26800 | 26800 | 26800 | 26800 | 11500 | 11500 | 11500 | 11500 | 11500 | 11500 | 17500 | |
| | W | 26800 | 26800 | 26800 | 26800 | 26800 | 17500 | 17500 | 17500 | 17500 | 17500 | 17500 | 26800 | |
| EDF / Stillwater (peak flows) | C | 11500 | 26800 | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 6500 | 5300 | 7500 | 13 |
| | D | 11500 | 26800 | 26800 | 17500 | 17500 | 7500 | 4800 | 4800 | 4800 | 6500 | 5300 | 7500 | |
| | BN | 26800 | 90800 ([14]) | 90800 ([15]) | 26800 | 26800 | 11500 | 7500 | 7500 | 7500 | 7500 | 7500 | 11500 | 14, 15 |
| | AN | 26800 | 105600 ([16]) | 105600 ([17]) | 26800 | 26800 | 11500 | 11500 | 11500 | 11500 | 11500 | 11500 | 17500 | 16, 17 |
| | W | 26800 | 105600 ([18]) | 105600 ([19]) | 26800 | 26800 | 17500 | 17500 | 17500 | 17500 | 17500 | 17500 | 26800 | 18, 19 |
| USFWS - OCAP Bio Op | AN | | | | | | | | | X2 $\leq$ 81 km (approx. 7000) | | X2 $\leq$ 81 km | | 20 |
| | W | | | | | | | | | X2 $\leq$ 74 km (approx. 12400) | | X2 $\leq$ 74 km | | |

Appendix A, Table 1. Delta outflow recommendations summary table - con't. (p. 2 of 2)

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| CDFG | All | Recommendation in X2 format: 64 - 75 km (approx. 29200 - 11400 cfs) | | | | | | | | | | | | 21 |
| | | | | | | | | | | | | | | |
| DWR / SFWC | All | Recommendation to maintain requirements stipulated in D-1641 | | | | | | | | | | | | 22 |
| | | | | | | | | | | | | | | |
| The following is from Fleenor et al. 2010 (Preliminary Draft) - Functional flow approach with exports occurring via a peripheral canal, tunnel, or other alternative form of conveyance. | | | | | | | | | | | | | | |
| Delta Solutions Group | 5 of 10 yrs | | | 48000 | | | | | | | | | | 23 |

**Appendix A, Table 2. Sacramento River inflow recommendations (cfs unless noted otherwise).**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D1641 | C | | | | | | | | | 3000 | | 3500 | | |
| | D | | | | | | | | | 3000 | 4000 | 4500 | | |
| | BN | | | | | | | | | 3000 | 4000 | 4500 | | |
| | AN | | | | | | | | | 3000 | 4000 | 4500 | | |
| | W | | | | | | | | | 3000 | 4000 | 4500 | | |
| Draft D1630 | All | | | | $\geq$18000 | | | | | | | | | 24 |
| | All | | | | $\geq$13000 (14-day running average) and $\geq$9000 (min mean daily flow) | | | | | | | | | 25 |
| | C | 1500 | 2500 | 2000 | | | | 1000 | 1000 | 1500 | | | | 26 |
| | D | 1500 | 2500 | 2500 | | | | 1000 | 1000 | 1500 | | | | |
| | BN | 2500 | 2500 | 3000 | | | | 2000 | 1000 | 2500 | | | | |
| | AN | 2500 | 2500 | 3000 | | | | 2000 | 1000 | 2500 | | | | |
| | W | 2500 | 3000 | 5000 | | | | 3000 | 1000 | 5000 | | | | |
| CDFG | All | | 6000 (base flows) | | | | | | | | | | | 27 |
| | All | | | | 20000 - 30000 (pulse flows @ Rio Vista) | | | | | | | | | |
| C-WIN / CSPA | All | | 6000 (minimum base flows, measured @ Rio Vista) | | | | | | | | | | | 28 |
| | All | | | | 30000 (Freeport to Chipps Island) | | | | | | | | | 29 |
| PCFFA | All | | | | 25000 (Hood to Chipps Island) | | | | | | | | | 30 |
| USFWS | | | | | The catch of juvenile salmon at Chipps Island between April and June is correlated to flow at Rio Vista. The highest abundance leaving the Delta has been observed when flows at Rio Vista between April and June averaged above 20000 cfs..." | | | | | | | | | 31 |
| AR / NHI | All | Sac Riv at Bend Bridge - Pulse flows continuously exceed 8000, periodically exceed 12000, for a duration exceeding 2 weeks | | | | | | | | | | See Jan - May | | 32 |
| | All | Sac Riv at Wilkins Slough and Freeport - Pulse flows of 15000 at Wilkins Slough, and up to 20000 at Freeport, should occur for a duration of 7 days or longer. There should be at least 5 such events in dry years and more in wet years | | | | | | | | | | | See Jan - May | 33 |
| TBI / NRDC / AR / NHI | C (0-20 percentile) | | | 27500 for 15 cont days | | | | | | | | | | 34 |
| | D (20-40 percentile) | | | 27500 for 30 cont days | | | | | | | | | | |
| | BN | | 30000 for 60 cont days | | | | | | | | | | | |
| | AN | | 32500 for 90 continous days | | | | | | | | | | | |
| | W | 35000 for 120 continuous days | | | | | | | | | | | | |
| NMFS | AN & W | | $\geq$ 17700 (at Grimes RM125) | | | | | | | | | | | 35 |
| | AN & W | | $\geq$ 31100 (at Verona RM80) | | | | | | | | | | | |
| | All | Provide pulse flows $\geq$ 20000 cfs, measured at Freeport periodically during winter-run emigration season to facilitate outmigration past Chipps Island (ie, Dec-Apr) | | | | | | | | | | | See Jan-Apr | 36 |

**Appendix A, Table 2. Sacramento River inflow recommendations - con't. (p. 2 of 2)**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EDF / Stillwater | C | 3500 | | 10000 | | | Determined based on Delta outflows ([38]) | | | 3000 - 3500 ([39]) | | | 3500 | 37, 38, 39 |
| | D | 4500 | | 10000 | | | | | | 3000 - 4500 | | | 4500 | |
| | BN | 4500 | | 10000 | | | | | | 3000 - 4500 | | | 4500 | |
| | | 64000 (pulse flow, 21 consecutive days) | | | | | | | | | | | | |
| | AN | 4500 | | 10000 | | | | | | 3000 - 4500 | | | 4500 | |
| | | 64000 (pulse flow, 35 consecutive days) | | | | | | | | | | | | |
| | W | 4500 | | 10000 | | | | | | 3000 - 4500 | | | 4500 | |
| | | 64000 (pulse flow, 49 consecutive days) | | | | | | | | | | | | |
| DWR / SFWC | All | Recommendation to maintain requirements stipulated in D-1641 | | | | | | | | | | | | 22 |
| The following is from Fleenor et al. 2010 (Preliminary Draft) - Functional flow approach with exports occurring via a peripheral canal, tunnel, or other alternative form of conveyance. | | | | | | | | | | | | | | |
| Delta Solutions Group | 6 of 10 yrs | 10000 | | | | | | | | | 10000 | | | 40 |
| | 6 of 10 yrs | | | 25000 | | | | | | | | | | |
| | 1 of 10 yrs | 70000 | | | | | | | | | | | | 41 |
| | 8 of 10 yrs | | Yolo Bypass 2500 (Sac Riv ~45750) | | | | | | | | | | | 42 |
| | 6 of 10 yrs | | | Yolo Bypass 4000 (pulse) (Sac Riv ~ 50150) | | | | | | | | | | |

**Appendix A, Table 3. San Joaquin River inflow recommendations summary table (cfs unless noted otherwise).**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D1641 | C | | 710 or 1140 (43) | | 3110 or 3540 (44) | 710 or 1140 (43) | | | | | 1000 (45) | | | 43, 44, 45 |
| | D | | 1420 or 2280 | | 4020 or 4880 | 1420 or 2280 | | | | | 1000 | | | |
| | BN | | 1420 or 2280 | | 4620 or 5480 | 1420 or 2280 | | | | | 1000 | | | |
| | AN | | 2130 or 3420 | | 5730 or 7020 | 2130 or 3420 | | | | | 1000 | | | |
| | W | | 2130 or 3420 | | 7330 or 8620 | 2130 or 3420 | | | | | 1000 | | | |
| Draft D1630 | C | | | | 2000 (46) | | | | | | ≥2000 (47) | | | 46, 47 |
| | D | | | | 4000 | | | | | | ≥2000 | | | |
| | BN | | | | 6000 | | | | | | ≥2000 | | | |
| | AN | | | | 8000 | | | | | | ≥2000 | | | |
| | W | | | | 10000 | | | | | | ≥2000 | | | |
| CDFG | C | | | 1500 (Base) | 5500 (Pulse) (4/15-5/15) (Total 7000) | | | | | | | | | 48 |
| | D | | | 2125 (Base) | 4875 (Pulse) (4/11-5/20) (Total 7000) | | | | | | | | | |
| | BN | | | 2258 (Base) | 6242 (Pulse) (4/6-5/25) (Total 8500) | | | | | | | | | |
| | AN | | | 4339 (Base) | 5661 (Pulse) (4/1-5/30) (Total 10000) | | | | | | | | | |
| | W | | | 6315 (Base) | 8685 (Pulse) (3/27-6/4) (Total 15000) | | | | | | | | | |
| C-WIN / CSPA | C | | 13400 | 4500 | 6700 / 8900 | 1200 | | | | | 5400 | | | 49 |
| | D | | 13400 (2 days) | 4500 | 6700 / 8900 | 1200 | | | | | 5400 | | | |
| | BN | | 13400 (16 days), 26800 (2 days) | 4500 | 6700 / 8900 | 11200 | 1200 | | | | 5400 | | | |
| | AN | | 13400 (13 days), 26800 (5 days) | 4500 | 6700 / 8900 | 11200 | 1200 | | | | 5400 | | | |
| | W | | 13400 (17 days), 26800 (5 days) | 13400 | | | 14900 | | | | 5400 | | | |
| TBI / NRDC | 100% of years (all yrs) | 2000 | | | 5000 | | 2000 | | | | | | | 50 |
| | 80% (D yrs) | 2000 | | | 5000 / 10000 | 7000 / 5000 | 2000 | | | | | | | |
| | 60% (BN yrs) | 2000 | | | 20000 / 10000 | 7000 / 5000 | 2000 | | | | | | | |
| | 40% (AN yrs) | 2000 | | 5000 | 20000 | 7000 | 2000 | | | | | | | |
| | 20% (W yrs) | 2000 | | 5000 | 20000 | | 7000 | 2000 | | | | | | |

**Appendix A, Table 3. San Joaquin River inflow recommendations summary table - con't. (p. 2 of 3)**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AR / NHI | 100% of years (all yrs) | | | 3000; 4000 | 5000 | | 2000 | | | | | | | 51 |
| | 80% (D yrs) | | | 3000; 4000 | 5000; 10000 | 7000; 5000 | 2000 | | | | | | | |
| | 60% (BN yrs) | | | 3000; 5000 | 20000; 10000 | 7000; 5000 | 2000 | | | | | | | |
| | 40% (AN yrs) | | | 3000; 5000 | 20000 | 7000 | 2000 | | | | | | | |
| | 20% (W yrs) | | | 3000; 5000 | 20000 | 7000 | 2000 | | | | | | | |
| | All | | | Flows of approx. 10000 cfs should occur at Vernalis for ≥5 days. There should be at least 2 such events in dry years, and more in wetter years. | | | | | | | | | | |
| EDF / Stillwater | All | | | | | | | | | > 1800 in DWSC | | | | 52 |
| | All | | | Discuss USFWS (1995) and D-1641, no clear recommendation ([55]) | | | Determined based on Delta outflows ([38]) | | | | 3500 (10-14 days) ([54]) | FERC ([53]) | | 38, 53, 54, 55 |
| | C & D | 1000 (positive flows at Jersey Pt) | | | | | | | | | | | See Jan-Feb | 56 |
| | BN & AN | 2000 (positive flows at Jersey Pt) | | | | | | | | | | | See Jan-Feb | |
| | W | 3000 (positive flows at Jersey Pt) | | | | | | | | | | | See Jan-Feb | |
| | AN | 14800 (pulse flow, ≥ 21 consecutive days) | | | | | | | | | | | | 57 |
| | W | 14800 (pulse flow, ≥ 35 consecutive days) | | | | | | | | | | | | |
| USFWS | | | "...the Board should consider the Vernalis flows contained in USFWS (2005) [AFRP] and DFG's San Joaquin Escapement Model as a starting point for establishing flow for the protection of salmon and steelhead migrating from the San Joaquin basin" | | | | | | | | | | | 58 |
| AFRP (salmon doubling) | C | | 1744 | 2832 | 4912 | 5665 | | | | | | | | 59 |
| | D | | 1784 | 3146 | 5883 | 7787 | | | | | | | | |
| | BN | | 1809 | 3481 | 6721 | 9912 | | | | | | | | |
| | AN | | 2581 | 5162 | 8151 | 13732 | | | | | | | | |
| | W | | 4433 | 8866 | 10487 | 17369 | | | | | | | | |
| AFRP (53% Increase in Salmon Production) | C | | 1250 | 1665 | 2888 | 3331 | | | | | | | | 60 |
| | D | | 1350 | 1850 | 3459 | 4579 | | | | | | | | |
| | BN | | 1450 | 1933 | 3733 | 5505 | | | | | | | | |
| | AN | | 1638 | 2703 | 4266 | 7194 | | | | | | | | |
| | W | | 2333 | 4667 | 5520 | 9142 | | | | | | | | |
| NMFS OCAP Bio Op | | | | | Interim Operations in 2010-2011, min flows at Vernalis ranging from 1500 - 6000 based on New Melones Index | | | | | | | | | 61 |
| | | In addition, USBR/DWR shall seek supplemental agreement with SJRGA as soon as possible to achieve the min flows listed below at Vernalis | | | | | | | | | | | | |
| | C | | | | 1500 | | | | | | | | | |
| | D | | | | 3000 | | | | | | | | | |
| | BN | | | | 4500 | | | | | | | | | |
| | AN | | | | 6000 | | | | | | | | | |
| | W | | | | 6000 | | | | | | | | | |

**Appendix A, Table 3. San Joaquin River inflow recommendations summary table - con't. (p. 3 of 3)**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | |
| NMFS | AN & W<br>AN & W | | ≥ 14000 (at Vernalis)<br>≥ 7000 (at Newman) | | | | | | | | | | | 62 |
| | | | | | | | | | | | | | | |
| DWR / SFWC | All | Recommendation to maintain requirements stipulated in D-1641 | | | | | | | | | | | | 22 |
| | | | | | | | | | | | | | | |
| The following is from Fleenor et al. 2010 (Preliminary Draft) - Functional flow approach with exports occurring via a peripheral canal, tunnel, or other alternative form of conveyance. | | | | | | | | | | | | | | |
| Delta Solutions Group | C | 2000 | | | 5000 | 2000 | | | | | | | | 63 |
| | D | 2000 | | | 7000 | 2000 | | | | | | | | |
| | BN | 2000 | | | 10000 | | 2000 | | | | | | | |
| | AN | 2000 | | | 15000 | | 2000 | | | | | | | |
| | W | 2000 | | | 20000 | | | 2000 | | | | | | |
| | | | | | | | | | | | | | | |

**Appendix A, Table 4. Old and Middle River flow, export restriction, San Joaquin River flows at Jersey Point (e.g., QWEST) recommendations summary table (cfs unless noted otherwise).**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D1641 | All | See Jul-Dec | Export/Inflow Ratio: 35% of Delta Inflow ([64]) | | | | | Export/Inflow Ratio: 65% of Delta Inflow | | | | | | 64 |
| D1641 | All | | | | Export Limit: > of 1500 or 100% of 3-day avg. Vernalis flow | | | | | | | | | 65 |
| Draft D1630 | All | QWEST > -2000 | No reverse flow for all year types on a 14-day running average in the Western Delta (QWEST > 0 cfs, as calculated in Dayflow) | | | | | QWEST > -1000 | QWEST > -2000 | | | | | 66 |
| Draft D1630 | C & D | | | | 14-day running average combined export rate for Tracy, Banks, and Contra Costa pumping plants shall be ≤ 4000 cfs | | | | | | | | | |
| Draft D1630 | BN, AN, W | | | | 14-day running average combined export rate for Tracy, Banks, and Contra Costa pumping plants shall be ≤ 6000 cfs | | | | | | | | | |
| CSPA / C-WIN | All | | | Combined Export Rates = 0 | | | | | | | | | | 67 |
| CSPA / C-WIN | All | | | 2000 cfs daily flow in Old and Middle Rivers | | | | | | | | | | 68 |
| CSPA / C-WIN | C | 1000 (positive 14-day mean flows at SJ Riv at Jersey Pt) | | | | | | | | | See Jan-June | | | 69 |
| CSPA / C-WIN | D | 1500 (positive 14-day mean flows at SJ Riv at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| CSPA / C-WIN | BN | 2000 (positive 14-day mean flows at SJ Riv at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| CSPA / C-WIN | AN | 2500 (positive 14-day mean flows at SJ Riv at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| CSPA / C-WIN | W | 3000 (positive 14-day mean flows at SJ Riv at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| TBI / NRDC | | Sac Salmonids, Delta Smelt, Longfin Smelt* | | Sac & SJR Salmonids, D. Smelt, L. Smelt* | Sac & SJR Salmonids, D. Smelt, L. Smelt (C & D yrs) | | Sac & SJR Salmonids, D. Smelt | | | | Sac Basin Salmon | | Sac Salmon, D. Smelt | 70 |
| TBI / NRDC | C | -1500 or >0* | -1500 or >0* | -1500 or >0* | >0 | >0 | -1500 | | | | -2000 | -2000 | -1500 | |
| TBI / NRDC | D | -1500 or >0* | -1500 or >0* | >0 | >0 | >0 | -1500 | | | | -2000 | -2000 | -1500 | |
| TBI / NRDC | BN | -1500 or >0* | -1500 or >0* | >0 | >0 | >0 | -1500 | | | | -2000 | -2000 | -1500 | |
| TBI / NRDC | AN | -1500 or >0* | -1500 or >0* | >0 | >0 | >0 | -1500 | | | | -2000 | -2000 | -1500 | |
| TBI / NRDC | W | -1500 or >0* | -1500 or >0* | >0 | >0 | >0 | -1500 | | | | -2000 | -2000 | -1500 | |
| AFRP | C / D | 1000 (net seaward flows at Jersey Pt) | | | | | | | | | See Jan-June | | | 71 |
| AFRP | BN / AN | 2000 (net seaward flows at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| AFRP | W | 3000 (net seaward flows at Jersey Pt) | | | | | | | | | See Jan-June | | | |
| NMFS - OCAP Bio Op | All | Limit negative flows to -2000 to -5000 cfs in Old and Middle Rivers, depending on the presence of salmonids (see decision tree upon which the negative flow objective w/in the range shall be determined) | | | | | | | | | | | | 72 |
| NMFS - OCAP Bio Op | All | | | | Export restrictions based on Vernalis flow: <6000 cfs = 1500 cfs export limit 6000-21750 cfs = 4:1 (Vernalis flow:export ratio) >21750 = Unrestricted | | | | | | | | | |

Appendix A, Table 4. Old and Middle River flow, export restriction, San Joaquin River flows at Jersey Point (e.g., QWEST) recommendations summary table - con't. (p. 2 of 2)

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| USFWS | All | Board should develop reverse flow criteria that would maintain Old and Middle River flow positive during key months (Jan - Jun) | | | | | | | | | | | | 73 |
| USFWS | All | "...the AFRP Working Paper (USFWS, 1995) Restoration Action #3 calls for maintaining positive QWEST flows, or an equivalent measure of net seaward flows at Jersey Point... Higher flow at Jersey Point has been provided during the VAMP period (mid-April to mid-May) with the adoption of VAMP flows and exports. We encourage the Board to retain or expand this type of action to assure the contribution of downstream flow from the San Joaquin Basin to Delta outflow..." | | | | | | | | | See Jan - June | | | 74 |
| USFWS - OCAP Bio Op | All | Action 1: -2000 cfs for 14 days once turbidity or salvage trigger has been met. Action 2: range btw -1250 and -5000 cfs ([75]) | | | Range between -1250 and -5000 ([76]) | | | | | | | | See Jan-Mar | 75, 76 |
| CDFG Longfin Smelt Incidental Take Permit | All | Condition 5.1 (Dec - Feb): >-5000 ([77])<br>Condition 5.2 (Jan - June): OMR flow between -1250 and -5000 cfs ([78]) | | | | | | | | | | | Condition 5.1 (Dec-Feb) | 77, 78 |
| DWR / SFWC | All | Recommendation to maintain requirements stipulated in D-1641 | | | | | | | | | | | | 22 |

**Appendix A, Table 5. Floodplain inundation flow recommendations summary table.**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDFG | AN & W | ≥ 30 day floodplain inundation | | | | | | | | | | | | 79 |
| EDF / Stillwater | BN | 64000 (pulse flow, 21 consecutive days) | | | | | | | | | | | | 37 |
| | AN | 64000 (pulse flow, 35 consecutive days) | | | | | | | | | | | | Sacr Riv - |
| | W | 64000 (pulse flow, 49 consecutive days) | | | | | | | | | | | | Yolo Byp |
| TBI / NRDC / AR / NHI | C (0-20 percentile) | | | 27500 for 15 cont days | | | | | | | | | | 34 |
| | D (20-40 percentile) | | | 27500 for 30 cont days | | | | | | | | | | Sac Riv - Yolo Byp |
| | BN | | 30000 for 60 cont days | | | | | | | | | | | |
| | AN | | 32500 for 90 continous days | | | | | | | | | | | |
| | W | 35000 for 120 continuous days | | | | | | | | | | | | |
| AR / NHI | All | Sac Riv at Bend Bridge - Pulse flows continuously exceed 8000, periodically exceed 12000, for a duration exceeding 2 weeks | | | | | | | | | | See Jan - May | | 32 |
| USFWS | 6 of 10 yrs | "The Board should consider the importance of more frequent floodplain inundation (especially Yolo Bypass flows) when determining the Delta outflows..." | | | | | | | | | | | | 80 |
| NMFS - OCAP Bio Op | All | "...Reclamation and DWR shall, to the maximum extent of their authorities, provide significantly increased acreage of seasonal floodplain rearing habitat, with biologically appropriate durations and magnitudes, from December through April, in the lower Sacramento River basin, on a return rate of approximately one to three years, depending on water year type." | | | | | | | | | | | See Jan-Apr | 81 |
| NMFS - Recovery Plan | All | "Enhance the Yolo Bypass by re-configuring Fremont and Sacramento weirs to: ... and (6) create annual spring inundation of at least 8000 cfs to fully activate the Yolo Bypass floodplain." | | | | | | | | | | | | 82 |
| Delta Solutions Group | 8 of 10 yrs | | Yolo Bypass 2500 (Sac Riv ~ 45750) | | | | | | | | | | | 42 |
| | 6 of 10 yrs | | | Yolo Bypass 4000 (pulse) (Sac Riv ~ 50150) | | | | | | | | | | |
| **San Joaquin River** | | | | | | | | | | | | | | |
| EDF / Stillwater | AN | 14800 (pulse flow, ≥ 21 consecutive days) | | | | | | | | | | | | 57 |
| | W | 14800 (pulse flow, ≥ 35 consecutive days) | | | | | | | | | | | | |

See TBI / NRDC and AR / NHI SJ River Inflow recommendations, flows >20000 cfs to trigger floodplain inundation

**Appendix A, Table 6. Delta Cross Channel closures summary table.**

| | Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Source / Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D-1641 | | see Nov | Gates Closed | | | Close for 14 days ([83]) | | | | | | Nov-Jan - gates may be closed for up to total of 45 days | | 83 |
| Draft D-1630 | All | Closed if daily DOI >12000 | Operated based on results of real-time monitoring | | | | | | | | | | | 84 |
| CSPA / C-WIN | All | | Gates Closed | | | | | | | | | | | 85 |
| | All | | Acoustic Barrier at head of Georgiana Slough at Sacramento River | | | | | | | | | | | |
| NMFS - OCAP Bio Op | All | Dec 15 - Jan 31 Gates closed | Gates Closed per D1641 | | | Gates closed up to 14 days per D1641 | | | | | Gates closed if fish are present | | Gates closed except for experiments/water quality<br>Dec 15 - Jan 31 Gates closed | 86 |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 1 | D1641 | Outflow | All water year types - Increase to 6000 if the Dec 8RI is > than 800 TAF |
| 2 | D1641 | Outflow | Habitat Protection Flows, minimum Delta outflow calculated from a series of rules that are described in Tables 3 and 4 of D1641 |
| 3 | Draft D1630 | Outflow | Striped Bass, Antioch spawning - Delta outflow index, Sac Riv at Chipps Island, average for the period not less than value shown (cfs). |
| 4 | Draft D1630 | Outflow | Striped Bass, general - Delta outflow index, Sac River at Chipps Island - average for period not less than value shown (cfs), May period = May 6-31 |
| 5 | Draft D1630 | Outflow | Suisun Marsh - Delta outflow index at Sac River at Chipps Island - average of daily DOI for each month, not less than value shown (cfs) |
| 6 | Draft D1630 | Outflow | Suisun Marsh - Delta outlflow index, Sac River at Chipps Island - minimum daily DOI for 60 consecutive days in the period |
| 7 | Draft D1630 | Outflow | Suisun Marsh - Delta outflow index, Sac River at Chipps Island - average of daily DOI for each month, not less than value shown, in cfs: applies whenever storage is at or above minimum level in flood control reservation envelope at two of the following - Shasta Reservoir, Oroville Reservoir, and CVP storage on the American River |
| 8 | TBI et al | Outflow | Water year categories represent exceedance frequencies for the 8-river index, they are not equivalent to the DWR "water year types" (which account for storage and other conditions). TBI_Exhibit 2 (Outlfow). References for correlation btw winter-spring outlfow and abundance of numerous species on p.3. Winter-spring Delta outflow criteria approximate the frequence distribution of outflow levels, i.e., the relationship btw outflow and the 8 River Index, for the 1956-1987 period. Winter and spring outlfow recommendations to benefit public trust uses of pelagic species (as represented by abundance and productivity of longfin smelt, Crangon shrimp, and starry flounder and spatial distribution of longfin smelt) (see TBI Exhibit 2, pp 21-25). Two methods were used to develop outflow criteria: an analysis of historical flow-abundance relationships that corresponded to recovery targets for longfin smelt abundance (Native Fishes Recovery Plan, USFWS 1995), and an analysis of population growth response to outflows in order to identify outflows that produced population growth more than 50% of the time. Applying these |
| 8 cont | TBI et al | Outflow | two methods produces very similar results regarding desirable outflow levels. Break in summary table at mid-Mar is artificial, original table included Mar under both Winter and Spring, so for simplicity, it was split at 15 Mar. Fall outflows (TBI Exhibit 2, p. 35, Table 1 and Fig 27) - analyzed emerging statistical evidence of relationship btw outlfow and abundance and distribution of delta smelt and striped bass (Feyrer et al 2007; Feyrer et al In Review; DSWG notes, Aug 21, 2006), in order to develop recommendations. Recommendations occassionaly exceed unimpaired outflow in limited cases (would require reservoir releases in fall independent of antecedent conditions). |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 9 | CSPA / C-WIN | Outflow | Net Delta Outflow, as a 14-day running average - Source WRINT-DFG Exh 8 (1992). Feb-Mar - flows correspond to Table 8 (p.23), Alternative C (Estuarine species - target mean monthly flows based on data from DWR's 1995 Level of Development + 50% increase). Orig. recommendations by month, C-WIN/CSPA took average of Feb and Mar, and reported as such. Apr-July - flows correspond to Table 2 (p16), Alternative C (mean Delta outflows required to maintain populations of 1.7 million adult striped bass). Aug-Jan - based on Alt C (discussed above), in combination with flow recommendations developed by C-WIN for Jan. DFG identified flows for all months except Jan, C-WIN developed a method for Jan flows from DayFlow information (C-WIN extracted monthly average Delta outflows from DayFlow, sorted them, and then allocated them to water years based on unimpaired runoff data from the California Data Exchange Center. The medians of the water year types were then used as January flows in developing our optimal conditions recommendations for mean Delta outflows in the August 1 through January 31 period). |
| 10 | EDF / Stillwater | Outflow | Stillwater Focal Species Approach - Source - EDF closing comments (Table 1), Supporting Info - EDF Exhibit 1 (Winter [Dec-Feb] outflows - p.52-53). A primary objective was to provide enough Delta outflow to maintain X2 westward of 65 km, w/ variations to allow eastward excursion of X2 as far as 80 km in drier water year types. Proximate function is to increasethe westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions. "This will serve to increase the availability of food resources to larval fish species in late winter as well as improve access to low salinity habitat in the shallows of Grizzly and Honker bays (Feyrer et al 2009)." Flows also designed to limit the eastward distribution and density of overbite clam. "...low salinity may inhibit spawning and subsequent adult recruitment, thereby reducing grazing pressures on phytoplankton and the pelagic food web. Improvements in food resources to the western Delta will serve to increase populations of Delta smelt, striped bass, and other pelagic species that are currently in decline." |
| 11 | EDF / Stillwater | Outflow | Stillwater Focal Species Approach - Source - EDF closing comments (Table 1), Supporting Info - EDF Exhibit 1 (Spring [Mar-May] Outlfows - p.55-56). Spring flows primarily based on delta outflows needed to maintain X2 in locations that are beneficial to delta pelagic fish populations as well as the provision of floodplain inundation in the Yolo Bypass during March Primary objective was to provide enough Delta outflow to maintain X2 westward of 65 km, w/ variations to allow eastward excursion of X2 as far as 70 km in drier water year types. References in justification: Feyrer et al. In Revision, Bennett et al 2005. Herbold 1994, Hobbs et al 2004, Bennett et al. 2008, and others). Secondary goal is to provide sufficient flows to maintain inundated season floodplain habitat in Yolo Bypass and lower SJ Riv for varying periods in March based on water year type. These floodplain inundation flows should be coordinated with flows in late winter to provide prolonged periods of inundation. |
| 12 | EDF / Stillwater | Outflow | Stillwater Focal Species Approach - Source - EDF closing comments (Table 1), Supporting Info - EDF Exhibit 1 (Fall [Sept-Nov] - pp.49-50; Summer - pp.57-58) Summer (Jun-Aug) and Fall flows based primarily on Delta outflows needed to maintain X2 in the shallow-water habitats of Suisun Bay. Secondary objective for Fall outflows from the Delta were to provide attraction flows for upstream-migrating salmonids and to maintain adequate DO concentrations for fall-run chinook salmon within the lower SJ River system. Summer and Fall - in some months and water year types, depending on water year type and month, the projected monthly outflows are higher than the unimpaired and/or current flow ranges. Thus some modification of upstream reservoir release schedules may be required to meet these flows. Fall - references in justification - Feyrer et al 2007; Feyrer et al In revision; Bennet et al 2002; Jassby et al 1995; and others |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 13 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Peak flows required to provide floodplain inundation are assumed to be concurrent between the Sac and SJ River basins as well as the east side tributaries.  However, the duration of the peak flows varies by water year (see notes 69-74) |
| 14 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 14 days of floodplain inundation flow of 64000 cfs in the Sac River |
| 15 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 7 days of floodplain inundation flow of 64000 cfs in the Sac River |
| 16 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 21 days of floodplain inundation flow of 64000 cfs in the Sac River and 14 days of floodplain inundation flow of 14800 cfs in the SJ River |
| 17 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 14 days of floodplain inundation flow of 64000 cfs in the Sac River and 7 days of floodplain inundation flow of 14800 cfs in the SJ River. |
| 18 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 28 days of floodplain inundation flow of 64000 cfs in the Sac River and 21 days of floodplain inundation flow if 14800 cfs in the SJ River |
| 19 | EDF / Stillwater | Outflow | EDF_Closing Comments (Table 1) - Includes 21 days of floodplain inundation flow of 64000 cfs in the Sac River and 14 days of floodplain inundation flow of 14800 cfs in the SJ River |
| 20 | USFWS | Outflow | Delta smelt biological opinion (RPA concerning Fall X2 requirements [pp. 282-283] - improve fall habitat [quality and quantity] for DS) (references USFWS 2008, Feyrer et al 2007, Feyrer et al in revision) - Sept-Oct in years when the preceeding precipitation and runoff period was wet or above normal, as defined by the Sacramento Basin 40-30-30 Index, USBR and DWR shall provide sufficient Delta outflow to maintain monthly average X2 no greater than 74 km and 81 km in Wet and Above Normal yrs, respectively.  During any November when the preceding water yr was W or AN, as defined by Sac Basin 40-30-30 index, all inflow into the CVP/SWP reservoirs in the Sac Basin shall be added to reservoir releases in Nov to provide additional increment of outflow from Delta to augment Delta outflow up to the fall X2 of 74 km and 81 km for W and AN water yrs, respectively.  In the event there is an increase in storage during any Nov this action applies, the increase in reservoir storage shall be released in December to augment the Dec outflow requirements in SWRCB D-1641. |
| 21 | CDFG | Outflow | Outflow recommendations from closing comments.  Originally provided as X2 recommendations - Source - DFG Exhibit 1 and Exhibit 2 - Consolidates recommendations for American Shad, Longfin Smelt, Starry Flounder, Bay Shrimp, Zooplankton (consistent with D1641 requirements to maintain X2 at one of two compliance points in Suisun Bay [64 km or 75 km] from Feb-June).  Longfin smelt = Jan - June; Starry flounder, Bay shrimp, zooplankton = Feb - Jun; and American Shad = April - June. |
| 22 | DWR / SFWC | Outflow, SJ Riv Inflow, Sac Riv Inflow, OMR | DWR_closing comments, in response to request for a table identifing recommended flows, DWR submitted summary of D-1641 objectives. |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 23 | UCDavis - Delta Solutions Group | Outflow | Functional Flow 5a - Delta Smelt flows, 48000 cfs, from March through May (5 out of 10 years, every other year). Maintain freshwater to low salinity habitat in the northeastern Delta to Napa River, facilitating a broad spatial and temporal range in spawning and rearing habitat (Bennett 2005, Hobbs et al 2005). Flow recommendation not based on water year type, but rather number of years out of 10. Based on exports through an alternative form of conveyance (e.g., peripheral canal or tunnel). |
| 24 | Draft D1630 | Sac River Inflow | Function = Chinook salmon. Sac River at Freeport. Average flow at Freeport >18000 cfs for a 14-day continuous period corresponding to release of salmon smolts from Coleman Nat Fish Hatchery. Anticipate to occur in late April or early May. If no fish are released from the hatchery, the Executive Director shall determine the appropriate timing of this pulse flow with advice from CDFG. |
| 25 | Draft D1630 | Sac River Inflow | Function = striped bass, general; Sac River at Freeport - 14-day running average at Freeport >13000 cfs for a 42-day continuous period, with minimum mean daily flow >9000 cfs. Requirement initiated when real-time monitoring indicates the presence of striped bass eggs and larvae in Sac River below Colusa. This period should begin in late April or early May in most years. |
| 26 | Draft D1630 | Sac River Inflow | Function = chinook salmon. Sac River at Rio Vista - 14-day running average of minimum daily flow. |
| 27 | CDFG | Sac River Inflow | Chinook salmon, smolt outmigration. (1) Feb - Oct base flows. Source - DFG Exhibit 14 (WRINT-DFG-8, p.11). (2) Apr - Jun pulse flows. Source - DFG Exhibit 1, page 1, 6, and USFWS Exhibit 31 (Kjelson). |
| 28 | CSPA | Sac River Inflow | CSPA Closing Comments. Source - CDFG_1992_WRINT-DFG-Exhibit #8, p.11. Minimum base flow, measured at Rio Vista. 14-day average flow. |
| 29 | CSPA / C-WIN | Sac River Inflow | Sacramento River from Freeport to Chipps Island - Pulse flows - flows needed to sustain viable migration corridor for optimal smolt passage and survival. Source - USFWS Exhibit 31 (Kjelson) |
| 30 | PCFFA | Sac River Inflow | Function = salmonid juvenile outmigration. PCFFA closing comments, Source - USFWS Exhibit 31 (Kjelson). Kjelson and Brandes research - found that flows of 20000 to 30000 cfs yield the greatest survival of juvenile salmon during out-migration from Sac River to San Francisco Bay (PCFFA recommends splitting the difference and setting standard at 25000 cfs). Set from Hood to Chipps Island. |
| 31 | USFWS | Sac River Inflow | USFWS testimony concerning scientific information used to determine flow criteria. Source: U.S. Department Of the Interior - Comments Regarding the California State Water Resources Control Board's Notice of Public Informational Proceeding to Develop Delta Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources, Sections II and III, pages 25, 54, and 57. "The catch of juvenile salmon at Chipps Island between April and June is correlated to flow at Rio Vista (USFWS, 1987; Brandes and McLain, 2001; Brandes et al., 2006). The highest abundance leaving the Delta has been observed when flows at Rio Vista between April and June averaged above 20,000 cfs which is also the level where we have observed maximum survival in the past (USFWS, 1987)" (p.25). |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 32 | AR / NHI | Sac River Inflow | AR_NHI_Exh1 (testimony of Cain, Opperman, and Tompkins) and AR_NHI_closing comments. Purpose - interconnect side channels with main channel, contribute to foodweb productivity and rearing habitat for salmon. Inundated off-channel habitat such as high flow channels can also provide rearing habitat for salmon (Peterson and Reid 1984), but regulated spring flows are generally insufficient to inundate these habitats for prolonged periods (30-60 days), A recent study of these habitats in the Sac River determined that a large proportion of secondary channels between Red Bluff and Colusa become fully connected to the river at flows above 12000 cfs (Kondolf 2007). (from AR_NHI_Exh1 p.28) |
| 33 | AR / NHI | Sac River Inflow | AR_NHI_Exh1 (Testimony of Cain, Opperman, and Tompkins) and AR_NHI_closing comments - aid migration of winter-run chinook, in later months aid migration of spring and fall-run. Recent analyses indicate that the onset of emigration of winter-run fish to the Delta at Knights Landing is triggered by flow pulses of 15000 cfs at Wilkins Slough, and emigration from the Sac River to Chipps Island follows pulse flows of 20000 cfs at Freeport (del Rosario 2009). Previous studies found that smolt survival increased with increasing Sac River flow at Rio Vista, with maximum survival observed at or above about 20000 and 30000 cfs (USFWS 1987, Exhibit 31). Despite uncertainty about the exact magnitude of flow necessary to initiate substantial bank erosion, there is growing evidence that flows between 20000 and 25000 cfs will erode some banks while flows above 50000 to 60000 cfs are likely to cause widespread bank erosion (Stillwater 2007). |
| 34 | TBI / NRDC / AR / NHI | Sac River Inflow | TBI_Exh3 (Inflows - Table 3), TBI_closing comments (Table 3), AR/NHI_Exh1 (Testimony of Cain, Opperman, and Tompkins), AR/NHI closing comments - Table 3. Flows recommended for floodplain inundation (Sutter and Yolo Bypasses) - salmonid rearing, splittail spawning and early rearing. Flows measured at Verona. Flow magnitudes assume structural modifications to the weir to allow inundation at lower flow rates than is currently possible. Reservoir releases should be timed to coincide with and extend duration of high flows that occur naturally on less regulated rivers and creeks. The duration target is fixed for each year type, but actual timing of inundation should vary across the optimal window depending on hydrology and to maintain life history diversity. |
| 35 | NMFS | Sac River Inflow | NMFS_Exh9 (from ARFP 1995), Sturgeon (Grn and Wht) - adult migration to spawning and downstream larval transport |
| 36 | NMFS | Sac River Inflow | Public Draft Recovery Plan for Central Valley Salmon and Steelhead (October 2009). NMFS_Exhibit_5. Section 6.1.1 Recovery Action Narrative, Action 1.5.9, p.158. |
| 37 | EDF / Stillwater | Sac River Inflow | Source: EDF_Exh1 (Stillwater Sciences - Focal Species Approach). Spring flows - Establishing base flows of at least 10000 cfs in the Sac Riv in spring would improve transport of eggs and larval striped bass and other young anadromous fish and to reduce egg settling and mortality at low flows (USFWS 2001, EDF_Exh1, p.53). Proximate function of Delta inflows is to maintain net transport of passively swimming fishes (juv salmonids, larval delta smelt, and striped bass) and nutrients towards Suisun and San Francisco bays (USFWS 2008). Goal of winter and spring floodplain activation flows (managed pulse flows of approx 64000 cfs at Verona) is to maintain inundated seasonal floodplain habitat conditions in much of Yolo Bypass during January and April for a minimum of 21, 35, and 49 days in Below Normal, Above Normal, and Wet water year types, respectively. The NMFS (2009) draft recovery plan for Sac winter-run chinook, CV spring-run chinook, and CV steelhead ESUs calls for an annual spring flow of 8000 cfs (approx 64000 cfs at Verona) above the initial spill level "to fully activate the Yolo Bypass floodplain." For the |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 37 cont | EDF / Stillwater | Sac River Inflow | purposes of this assessment, Stillwater allocated the Delta inflows for floodplain inundation to February and March. Summer Delta inflows to be determined by Delta outflows.  Fall Inflows - Maintenance of D1641 flow standards in necessary to provide attraction flows for Chinook salmon, although these levels would potentially need to be increased to provide adequate Delta outflows.  Winter Inflows - Winter flows primarily designed to provide upstream migration passage for salmonids and striped bass during Dec and Jan, as well as to inundate floodplains such as Yolo Bypass for benefit of rearing juv salmonids and other floodplain associated species (p.50-51).  See Spring for discussion of goal of combined winter-spring floodplain activation flows. |
| 38 | EDF / Stillwater | Sac Riv Inflow / SJ Riv Inflow | Inflows determined based on Delta outflows (EDF_Exh1 - Stillwater Focal Species) |
| 39 | EDF / Stillwater | Sac River Inflow | These levels may need to be increased to provide adequate Delta outflows (EDF_Exh1 - Stillwater Focal Species) |
| 40 | UCDavis - Delta Solutions Group | Sac River Inflow | Functional Flow 2a - Sac River adult salmon - 10000 cfs to to occur from Oct - June during 6 out of 10 years (references Newman and Rice 2002, Williams 2006, Harrell et al. 2009, USFWS Exhibit 31 1987, Kjelson and Brandes 1989). Functional Flow 2b - Sac River juvenile salmon migration - 25000 cfs from Mar - June during 6 out of 10 years (references Newman and Rice 2002, Williams 2006, Harrell et al. 2009, USFWS Exhibit 31 1987, Kjelson and Brandes 1989).  Flows not based on water year type, but rather number of years out of ten. |
| 41 | UCDavis - Delta Solutions Group | Sac River Inflow | Functional Flow 2c - Sacr River adult sturgeon flows - 70000 cfs to occur between Jan and May during 1 out of 10 years (flows for salmon -2a, 2b, and 1a,1b) (Kohlhorst et al 1991 [flow rate], Harrell and Sommer 2003 [passage problems at Fremont Weir]).  Flows not based on water year type, but rather number of years out of ten. |
| 42 | UCDavis - Delta Solutions Group | Sac River Inflow | Functional Flow 1a - yolo bypass inundation - salmon and splittail (area inundated based on recommended flows BDCP draft rpt 2008) (other references related to flow and corresponding extent of habitat in Yolo Bypass Moyle et al. 2004, Sommer et al. 2004, Harrell and Sommer 2003, Harrell et al. 2009).  Functional Flow 1b - yolo bypass pulse - salmon and splittail (area inundated based on recommended flows BDCP draft rpt 2008) (other references related to flow and corresponding extent of habitat in Yolo Bypass Moyle et al. 2004, Sommer et al. 2004, Harrell and Sommer 2003, Harrell et al. 2009).  Functional Flows 1a and 1b require flows at Freeport of approx. 45750 and 50150 cfs, respectively, based on regressions of historical data. |
| 43 | D1641 | SJ River Inflow | Base Vernalis minimum monthly average flow rate in cfs (the 7-day running average shall not be less than 20% below the objective).  Take the higher objective if X2 is required to be west of Chipps Island |
| 44 | D1641 | SJ River Inflow | Pulse Vernalis minimum monthly average flow rate in cfs.  Take the higher objective if X2 is required to be west of Chipps Island |
| 45 | D1641 | SJ River Inflow | Pulse - up to an additional 28 TAF pulse/attraction flow to bring flows up to a monthly average of 2000 cfs except for a critical year following a critical year.  Time period based on real-time monitoring and determined by CalFed Op's group |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 46 | Draft D1630 | SJ River Inflow | SJ River at Vernalis. Function = chinook salmon.  Minimum daily flow, in cfs, for 21-day continuous period.  Start date depends on beginning of chinook salmon smolt out-migration from SJ basin.  During this time, water right holders on Mokelumne and Calaveras rivers shall bypass all inflows for 5 consecutive days.  Daily mean combined pumping at Tracy, Banks, and Contra Costa pumping plants shall be ≤1500 cfs.  All pumping restrictions are to be split equally between CVP and SWP.  Total annual maximum of 150 TAF for the two salmon flows (these and fall attraction flows) from the SJ Basin reservoirs |
| 47 | Draft D1630 | SJ River Inflow | SJ River at Vernalis. Function = chinook salmon.  Minimum daily flow, for 14-day continuous period.  Start date depends upon beginning of chinook salmon adult spawning migration.  Attraction flow shall be provided only if water is avaiable from the 150 TAF alloted for the two salmon flows. During this time, water right holders on Mokelumne and Calaveras rivers shall bypass all inflows for 5 consecutive days. |
| 48 | CDFG | SJ River Inflow | Source: SJR Salmon Model V.1.6 (CDFG 2009), DFG Exhibit 3 (Flows needed in the Delta to restore anadromous salmonid passage from the SJ River at Vernalis to Chipps Island) - Table 10 - South Delta (Vernalis) flows needed to double smolt production at Chipps Island (by water year type), and CDFG closing comments.  Flows to support smolt outmigration. |
| 49 | CSPA / C-WIN | SJ River Inflow | CSPA and C-WIN Closing Comments - CSPA Table 2.  Based on WRINT-DFG Exhibit 8 (1992) and C. Mesick 2010 (C-Win Exh 19).  Pulse flows in all years to attract adult spawning salmonids, Oct 20-29, SJR at Vernalis. To the tributary flows (each measured at their confluence with SJ Riv mainstem (see Mesick 2010), C-WIN / CSPA added in a flow of the SJ Riv below Millerton Lake reflecting that river's fair share unimpaired flow, as well as accretions and other inflows.  Combined valley flows at Vernalis assumes tributaries (Mer, Stan, Tuol) are 67.06% of total SJ River flow at Vernalis.  Spring - pulse flows for temperature regulation, migration cues, habitat inundation. Oct - pulse flows to attract adult salmonids. |
| 50 | TBI / NRDC | SJ River Inflow | TBI Exhibit 3 - Delta Inflows (Table 1, p.28), TBI / NRDC closing comments (Table 3b).  Flows >5000 cfs to maintain minimum temperature (≤ 65F) for migrating salmonids in April and May.  Flows >20000 to trigger floodplain inundation.  Year-round flows should exceed 2000 cfs to alleviate potential for DO problems in DWSC. |
| 51 | AR / NHI | SJ River Inflow | AR_NHI_Exh1 (testimony of Cain, Opperman, and Tompkins) and AR_NHI_closing comments (Table 2).  SJ River flows to benefit salmon rearing habitat and smolt out-migration (increase flow velocities and turbidity), with focus on temperature (maintain temp at or below 65F) and floodplain inundation.  Criteria recommended to be in addition to those stipulated in D1641. |
| 52 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.47-49).  Based upon investigations for the SJ River DO TMDL, minimum instream flows at the Stockton DWSC should be maintained in excess of 1,800 cfs during Sept and Oct of each year. Low DO in the lower SJ River has been found to impede upstream salmon migration (NMFS 2009, p.74).  Studies by Hallock (1970) indicate that low DO at Stockton delay upmigration and straying rates. |
| 53 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.47-49).  Flows during November should correspond to current minimum Federal Energy Regulatory Commission (FERC) spawning flow requirements from the Stanislaus, Tuolumne, Merced, and upper San Joaquin rivers. |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 54 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.47-49). Salmonid spawning attraction flows in excess if 3500 cfs at Vernalis should be provided for 10-14 days during October, using coordinated releases from the SJ River and tributaries. For remainder of fall, Delta inflows would be determined by the minimum instream flow requirements of the SJ River basin and east side tributaries. Upstream flow levels would likely be increased to meet the Delta outflow recommendations. |
| 55 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.54). "Although USFWS (1995) previously recommended spring Delta inflows ranging from 4,050 cfs to 15,750 cfs at Vernalis based upon of regression models of Chinook salmon smolt survival. The current D-1641 flow minimums range from 3,110 cfs to 8,620 cfs (Table 1-5), depending upon water year type, have never been fully implemented. In addition to baseline flows, for the benefit of rearing Chinook salmon and other native fishes, floodplain activation flows should be provided..." |
| 56 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.51-52). Winter Inflows - Minimum flows at Vernalis and the eastside tributaries should be coordinated to maintain net seaward flows at Jersey Point of 1000 cfs in Critical and Dry years, 2000 cfs in Below and Above Normal years, and 3000 cfs in Wet years (USFWS 1995 3-Xe-19). Net seaward flows for benefit of outmigrating juvenile salmon. |
| 57 | EDF / Stillwater | SJ River Inflow | EDF / Stillwater Exh 1 (focal species approach, pp.54-55). For the benefit of rearing chinook salmon and other native fishes, floodplain activation flows should be provided of 14800 cfs in the lower SJ River in Above Normal and Wet water year types. A series of pulse flows instead of a single extended high flow event might also be used to achieve the desired target of continuous days of inundated floodplain. Goal for combined winter and spring floodplain activation flows is to maintain inundated seasonal floodplain habitat conditions (or the potential for such conditions in sites where floodplain restoration actions may be undertaken in the future) in the lower SJ River during Jan through Apr for a minimum of 21 and 35 consecutive days in Above Normal and Wet water year types, respectively. For the purposes of this assessment, Stillwater allocated the Delta inflows for floodplain inundation to February and March. Also discusses inundation of Cosumnes River floodplain. |
| 58 | USFWS | SJ River Inflow | USFWS testimony concerning scientific information used to determine flow criteria. Source: U.S. Department Of the Interior - Comments Regarding the California State Water Resources Control Board's Notice of Public Informational Proceeding to Develop Delta Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources, Sections II and III, pages 56-57 and 25. Quote in table from p.56-57. "The Anadromous Fish Restoration Program has developed estimates of flow levels needed at Vernalis to achieve a 53% increase (page 9) and a doubling (page 10) in predicted Chinook salmon production for the basin (USFWS, 2005). These Vernalis flow criteria vary by water year type and by month between February and May. We recommend these flows as starting point for establishing minimum and maximum volume of flow for increasing juvenile salmon and steelhead survival in the San Joaquin basin." (p.25). |
| 59 | AFRP | SJ River Inflow | Anadromous Fish Restoration Program (ARFP). Recommended streamflow schedules to meet the AFRP Doubling Goal in the San Joaquin River Basin (USFWS, 27 Sept 2005). Salmon doubling - total average flow (Stanislaus, Tuolumne, Merced) that would be expected to double the total predicted Chinook salmon production for the basin. |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 60 | AFRP | SJ River Inflow | Anadromous Fish Restoration Program (ARFP) - Recommended streamflow schedules to meet the AFRP Doubling Goal in the San Joaquin River Basin (USFWS, 27 Sept 2005). Total average flow (Stanislaus, Tuolumne, Merced) that would be expected to achieve a 53% increase in total predicted Chinook salmon production for the basin. |
| 61 | NMFS | SJ River Inflow | NMFS OCAP Bio Opinion, Action IV.2.1 (pp.641-644) San Joaquin River Inflow to Export Ratio - both interim (2010-2011) and long-term (beginning in 2012) requirements are stipulated. Interim flows are based on maintaining a minimum status quo for SJ River basin salmonid populations. Long term flow schedules for the SJ River are expected to result from SWRCB proceedings on SJ River flows. Export limitations and flows are also described on pp. 642-644 |
| 62 | NMFS | SJ River Inflow | NMFS_Exh9 (from AFRP 1995) - Sturgeon (Green and White), mean monthly flows - ensure suitable conditions for sturgeon to migrate and spawn and for progeny to survive. |
| 63 | UCDavis - Delta Solutions Group | SJ River Inflow | Functional Flows 3a - transport juvenile salmon (references USFWS Exhibit 31, 1987; Newman and Rice 2002; Williams 2006) - wet years - 20000 cfs, Apr-Jun (2 out of 10 years); AN years - 15000 cfs, April - Jun 15 (4 out of 10 years); BN years - 10000 cfs, Apr-May (6 out of 10 years); Dry years - 7000 cfs, Apr-May 15 (8 out of 10 years); and Critical years - 5000 cfs, Apr (10 out of 10 years). Functional Flows 3c - adult salmon recruitment (reference USFWS Exhibit 31, 1987) - 2000 cfs year round (10 out of 10 years) (flows were not experienced in unimpaired conditions, but likely result from the disturbed conditions). Functional Flows 3b - Improve DO conditions in DWSC (2000 cfs, July-Oct, all years) (Lehman et al 2004, Jassby and VanNieuwenhuyse 2005). |
| 64 | D1641 | OMR | Export/Inflow ratio - the maximum percent Delta inflow diverted for Feb may vary depending on the Jan 8RI (see D1641) |
| 65 | D1641 | OMR | SWP/CVP Export Limit - All water year types, Apr 15 - May 15, the greater of 1500 cfs or 100% of 3-day avg. Vernalis flow. Maximum 3-day average of combined export rate (cfs), which includes Tracy Pumping Plant and Clifton Court Forebay Inflow less Byron-Bethany pumping. The time period may need to be adjusted to coincide with fish migration. Maximum export rate may be varied by CalFed Ops Group. |
| 66 | Draft D1630 | OMR | Reverse flow restrictions for all year types are relaxed when combined CVP and SWP exports are < 2000 cfs. Export pumping restriction is relaxed for all year types when Delta outflow > 50000 cfs, except for the export pumping restriction during the SJ River pulse period. July 1 - Jan 31 - 14-day running average flow (as calculated in DAYFLOW), these restrictions do not apply whenever the EC at the Mallard Slough monitoring station is < 3 mmhos/cm. QWEST standards in 1630 discussed in DOI submittal, p.53, section concerning reverse flows. |
| 67 | CSPA / C-WIN | OMR | CSPA closing comments, C-WIN closing comments, CSPA_Exh1_Jennings. Combined export rates would be 0 cfs in all years from March 16 through June 30. Prevent entrainment and keep migration corridors open to maximize salmon juvenile and smolt survival. Facilitate SJ River salmonid migration down Old River. |
| 68 | CSPA / C-WIN | OMR | CSPA and C-WIN closing comments - flow direction, entrainment protection and provision of migration corridors |

**Appendix A, Table 7. Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 69 | CSPA / C-WIN | OMR | SJ River at Jersey Point flow recommendations (positive 14-day mean flows). Source: CSPA_exh1_Jennings_test; CDFG_1992_WRINT-DFG-Exhibit #8, Alt C (p.11, flows at Jersey Pt from Apr 1 through June 30, salmon); AFRP Working Paper, 1995, p. 3-Xe-19 (salmon). Function maintain positive flow for salmonid smolt outmigration and protect Delta smelt, originally two separate recommendations. DS - Feb 1 - Jun 30, Salmon - Oct 1 - Jun 30, only difference between flow recommendations where overlap occurred was DS in AN years = 2500 cfs, salmon in AN years = 2000. For this table, recommendations merged and 2500 cfs used for AN years (+DFG Exh 8 recommends 2500 cfs in AN years) |
| 70 | TBI / NRDC | OMR | TBI/NRDC closing comments (Table 4). The hydrodynamic recommendations expressed as Vernalis flow and/or export to inflow ratios in TBI/NRDC Exh4 (Delta Hydrodynamics, p.30) were converted to OMR flows, using the San Joaquin flow recommendations as described in TBI/NRDC Exh 3 (Delta Inflows), for inclusion in Table 4. Note: recommended OMR flows assume SJ River flows recommended in TBI Exhibit 3 are also implemented. (*) - when the previous longin smelt FMWT index <500, OMR flows in Jan-Mar are >0. This corrects a typographical error in the table on p.30 of TBI Exhibit 4 |
| 71 | AFRP | OMR | Anadromous Fish Restoration Program (ARFP) (Working Paper on Restoration Needs, Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California, Volume 3, 1995, p. 3-Xe-19). Action 3 - Maintain positive QWEST flows, or an equivalent measure of net seaward flows at Jersey Point, of 1000 cfs in Critical and Dry years, 2000 cfs in below- and above normal years, and 3000 cfs in wet years from Oct 1 through June 30. Objective - Increase survival of smolts migrating down the mainstem rivers, decrease the number of smolts diverted into the central Delta, increase the survival of smolts diverted into the central Delta, and provide attraction flows for San Joaquin Basin adults (Oct - Dec). |
| 72 | NMFS | OMR | NMFS OCAP Bio Opinion, Action IV.2.3 - Old and Middle River Flow Management (pp. 648-652). See action triggers on pp. 648-650. Actions will be taken in coordination with USFWS RPA for Delta Smelt and State-listed longfin smelt 2081 incidental take permit. During the Jan 1 - Jun 15 period, the most restrictive export reduction shall be implemented. |
| 73 | USFWS | OMR | USFWS testimony concerning scientific information used to determine flow criteria. Source: U.S. Department Of the Interior - Comments Regarding the California State Water Resources Control Board's Notice of Public Informational Proceeding to Develop Delta Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources, Sections II and III, pages 50, 53, and 24-25 (references USFWS 1992; AFRP Working Paper p.3-Xe-19, USFWS 2005, Restoration Action #3; D-1630, pp44-47). "Based on the scientific information we reviewed, the Board should develop reverse flow criteria that would maintain the Old and Middle river flow positive during key months (January through June) of the year to protect important public trust resources in the Delta" (p.53). |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 74 | USFWS | OMR | USFWS testimony concerning scientific information used to determine flow criteria.  Source: U.S. Department Of the Interior - Comments Regarding the California State Water Resources Control Board's Notice of Public Informational Proceeding to Develop Delta Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources, Sections II and III, pages 24,25, and 53. "In a previous Board exhibit (USFWS, 1992), we showed a positive relationship between temperature corrected juvenile survival indices and flow at Jersey Point for marked fish released at Jersey Point (QWEST) (USFWS, 1992, p.21).  In addition, the AFRP Working Paper (USFWS, 1995) Restoration Action #3 calls for maintaining positive QWEST flows, or an equivalent measure of net seaward flows at Jersey Point, of 1000 cfs in critical and dry years, 2000 cfs in below- and above-normal years, and 3000 cfs in wet years from Oct 1 through June 30.  Higher flow at Jersey Point has been provided during the VAMP period (mid-April to mid-May) with the adoption of VAMP flows and exports.  We encourage the Board to retain or expand this |
| 74 cont | USFWS | OMR | type of action to assure the contribution of downstream flow from the San Joaquin Basin to Delta outflow for the protection of juvenile and adult salmonids migrating from the San Joaquin basin." |
| 75 | USFWS | OMR | USFWS OCAP Bio Opinion - RPA re: OMR flows.  Component 1 - Adults (Dec - Mar) - Action 1 (protect upmigrating delta smelt) - once turbidity or salvage trigger has been met, -2000 cfs OMR for 14 days to reduce flows towards the pumps.  Action 2 (protect delta smelt after migration prior to spawning) - OMR range between -1250 and -5000 cfs determined using adaptive process until spawning detected.  pp.280-282 |
| 76 | USFWS | OMR | USFWS OCAP Bio Opinion - RPA re: OMR flows.  Component 2 - Larvae/Juveniles - action starts once temperatures hit 12 degrees C at three delta monitoring stations or when spent female is caught.  OMR range between -1250 and -5000 cfs determined using adaptive process.  OMR flows continue until June 30 or when Delta water temperatures reach 25 degrees C, whichever comes first.  pp. 280-282 |
| 77 | CDFG | OMR | Longfin Smelt Incidental Take Permit (2009), p. 9-10, Condition 5.1.  This Condition is not likely to occur in many years.  To protect adult longfin smelt migration and spawning during December through February period, the Smelt Working Group (SWG) or DFG SWG personnel staff shall provide OMR flow advice to the Water Operations Management Team (WOMT) and to Director of DFG weekly.  The SWG will provide the advice when either: 1) the cumulative salvage index (defined as the total longfin smelt salvage at the CVP and SWP in the December through February period divided by the immediately previous FMWT longfin smelt annual abundance index) exceeds five (5); or 2) when a review of all abundance and distribution survey data and other pertinent biological factors that influence the entrainment risk of adult longfin smelt indicate OMR flow advise is warranted.  Permittee shall ensure the OMR flow requirement is met by maintaining the OMR flow 14-day running average is no more negative than -5000 cfs and the initial 5-day running average is not more negative than -6250 cfs.  During any time OMR flow restrictions for |
| 77 cont | CDFG | OMR | the FWS's 2008 Biological Opinion for delta smelt are being implemented, this condition (5.1) shall not result in additional OMR flow requirements for protection of adult longfin smelt.  Once spawning has been detected in the system, this Condition terminates and 5.2 begins.  Condition 5.1 is not required or would cease if previously required when river flows are 1) > 55000 cfs in the Sac River at Rio Vista; or 2) > 8000 cfs in the SJ River at Vernalis.  If flows go below 40000 cfs in the Sac River at Rio Vista or 5000 cfs in the SJ River at Vernalis, the OMR flow in Condition 5.1 shall resume if triggered previously.  Review of survey data and other pertinent biological factors that influence the entrainment risk of adult longfin smelt may result in a recommendation to relax or cease an OMR flow requirement. |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 78 | CDFG | OMR | Longfin Smelt Incidental Take Permit (2009), p. 10-11, Condition 5.2.  To protect larval and juvenile longfin smelt during Jan-June period, the SWG or DFG SWG personnel shall provide OMR flow advice to the WOMT and the DFG Director weekly.  The OMR flow advice shall be an OMR flow between -1250 and -5000 cfs and be based on review of survey data, including all of the distributional and abundance data, and other pertinent biological factors that influence the entrainment risk of larval and juvenile longfin smelt.  When a single Smelt Larval Survey (SLS) or 20 mm Survey sampling period results in: 1) longfin smelt larvae or juveniles found in 8 or more of the 12 SLS or 20mm stations in the central and south Delta (Stations 809, 812, 901, 910, 912, 918, 919) or, 2) catch per tow exceeds 15 longfin smelt larvae or juveniles in 4 or more of the 12 survey stations listed above, OMR flow advice shall be warranted.  Permittee shall ensure the OMR flow requirement is met by maintaining the OMR flow 14-day running average no more negative than the required OMR flow and the 5-day running average is within 25% of the |
| 78 cont | CDFG | OMR | required OMR.  This Conditions OMR flow requirement is likely to vary throughout Jan through June.  Based on prior analysis, DFG has identified three likely scenarios that illustrate the typical entrainment risk level and protective measures for larval smelt over the period: High Entrainment Risk Period: Jan - Mar OMR range from -1250 to -5000 cfs; Medium Entrainment Risk Period: April and May OMR range from -2000 to -5000 cfs, and Low Entrainment Risk Period: June OMR -5000 cfs.  When river flows are: 1) greater than 55000 cfs in the Sac River at Rio Vista; or 2) greater than 8000 cfs in the SJ River at Vernalis, the Condition would not trigger or would be relaxed if triggered previously.  Should flows go below 40000 cfs in Sac River at Rio Vista or 5000 cfs in the SJ River at Vernalis, the Condition shall resume if triggered previously.  In addition to river flows, the SWG or DFG SWG personnel review of all abundance and distribution survey data and other pertinent biological factors that influence the entrainment risk of longfin smelt may result in a recommendation by DFG to WOMT to relax or cease an OMR flow requirement. |
| 79 | CDFG | Floodplain | DFG_Closing: DFG Exhibit 1, Page 13.  Sacramento Splittail - floodplain inundation (habitat) - incubation, early rearing, egg and larval habitat and survival |
| 80 | USFWS | Floodplain | USFWS testimony concerning scientific information used to determine flow criteria.  Source: U.S. Department Of the Interior - Comments Regarding the California State Water Resources Control Board's Notice of Public Informational Proceeding to Develop Delta Flow Criteria for the Delta Ecosystem Necessary to Protect Public Trust Resources, Sections II and III, pages 28 and 54. "The Board should consider the importance of more frequent floodplain inundation (especially Yolo Bypass flows) when determining the Delta outflows needed to restore the Delta ecosystem pursuant to the Board’s public trust responsibilities" (p.28).  "The Yolo Bypass floods via the Fremont Weir when flows on the Sacramento River exceed approximately 70,000 cfs, which it currently does in about 60% of years (Feyrer, et al. 2006). Flows on the Sacramento River should therefore exceed 70,000 cfs in at least six out of ten years. Recent historical floodplain inundation events are shown in Figure 4 (Sommer et al., 2001)" (p.54). |

**Appendix A, Table 7.  Notes for Tables 1 through 6.**

| No. | Entity | Type | Notes (excerpts from source documents) |
|---|---|---|---|
| 81 | NMFS | Floodplain | NMFS OCAP Bio Opinion, Action I.6.1 - Restoration of Floodplain Rearing Habitat. p.608. " Objective: To restore floodplain rearing habitat for juvenile winter-run, spring-run, and CV steelhead in the lower Sacramento River basin. This objective may be achieved at the Yolo Bypass, and/or through actions in other suitable areas of the lower Sacramento River. Action: In cooperation with CDFG, USFWS, NMFS, and Corps, Reclamation and DWR shall, to the maximum extent of their authorities, provide significantly increased acreage of seasonal floodplain rearing habitat, with biologically appropriate durations and magnitudes, from December through April, in the lower Sacramento River basin, on a return rate of approximately one to three years, depending on water year type.  In the event this action conflicts with Shasta Operations Actions I.2.1 to I.2.3., the Shasta Operations Actions shall prevail."  By December 31, 2011, Reclamation and DWR shall submit to NMFS a plan to implement this action. |
| 82 | NMFS | Floodplain | NMFS - Public Draft Recovery Plan for the ESUs of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the DPS of Central Valley Steelhead (October 2009), Section 1.5.5, p.157. "Enhance the Yolo Bypass by re-configuring Fremont and Sacramento weirs to:  (1) all for fish passage through Fremont Weir for multiple species; (2) enhance lower Putah Creek floodplain habitat; (3) improve fish passage along the toe drain/Lisbon weir; (4) enhance floodplain habitat along the toe drain; and (5) eliminate stranding events;and (6) create annual spring inundation of at least 8000 cfs to fully activate the Yolo Bypass floodplain." |
| 83 | D1641 | DCC | For the May 21 - June 15 period, close the Delta Cross Channel gates for a total of 14 days per CALFED Ops Group. During the period the DCC gates may close 4 consecutive days each week, excluding weekends |
| 84 | Draft D1630 | DCC | When monitoring indicates that significant numbers of salmon smolts or striped bass eggs and larvae are present or suspected to be present, the Executive Director (ED) or his designee shall order USBR to close the gates.  The ED, with advice from other agencies, will develop specific monitoring and density criteria for closing and opening the gates. |
| 85 | CSPA / C-WIN | DCC | CSPA_Exh1_Jennings, C-WIN closing comments.  Source CDFG_1992_WRINT-DFG-Exhibit #8, Alt C (p10).  Function: reduce entrainment of Sacramento salmon smolts into the interior Delta |
| 86 | NMFS | DCC | NMFS OCAP Bio Opinion, Action Suite IV.1 (pp. 631-640) |
| 87 | EDF / Stillwater | Ouflow | EDF_Closing Comments (Table 1) - Mean Historical Delta Outflow Volumes (TAF) for 1956-2003 by month and water year type.  Historical and unimpaired flow values are based on Water Years 1956-2003 using California Central Valley Unimpaired Flow Data, 4th ed. (CDWR 2007).  In instances where there was a difference between Dry and Critically Dry years, the value for Critically Dry years was selected.  Originally reported as volume (TAF).  Conversion calculated as follows: (TAF/month)(1000 AF/TAF)(43560 ft3/AF)(month/X days)(day/86400 sec) |

## *Appendix B: Enacting Legislation*

California Water Code, Division 35 (Sacramento-San Joaquin Delta Reform Act of 2009), Part 2 (Early Actions), Section 85086

(a) The board shall establish an effective system of Delta watershed diversion data collection and public reporting by December 31, 2010.

(b) It is the intent of the Legislature to establish an accelerated process to determine instream flow needs of the Delta for the purposes of facilitating the planning decisions that are required to achieve the objectives of the Delta Plan.

(c)

(1) For the purpose of informing planning decisions for the Delta Plan and the Bay Delta Conservation Plan, the board shall, pursuant to its public trust obligations, develop new flow criteria for the Delta ecosystem necessary to protect public trust resources. In carrying out this section, the board shall review existing water quality objectives and use the best available scientific information. The flow criteria for the Delta ecosystem shall include the volume, quality, and timing of water necessary for the Delta ecosystem under different conditions. The flow criteria shall be developed in a public process by the board within nine months of the enactment of this division. The public process shall be in the form of an informational proceeding conducted pursuant to Article 3 (commencing with Section 649) of Chapter 1.5 of Division 3 of Title 23 of the California Code of Regulations, and shall provide an opportunity for all interested persons to participate. The flow criteria shall not be considered predecisional with regard to any subsequent board consideration of a permit, including any permit in connection with a final BDCP.

(2) Any order approving a change in the point of diversion of the State Water Project or the federal Central Valley Project from the southern Delta to a point on the Sacramento River shall include appropriate Delta flow criteria and shall be informed by the analysis conducted pursuant to this section. The flow criteria shall be subject to modification over time based on a science-based adaptive management program that integrates scientific and monitoring results, including the contribution of habitat and other conservation measures, into ongoing Delta water management.

(3) Nothing in this section amends or otherwise affects the application of the board's authority under Part 2 (commencing with Section 1200) of Division 2 to include terms and conditions in permits that in its judgment will best develop, conserve, and utilize in the public interest the water sought to be appropriated.

(d) The board shall enter into an agreement with the State Water Project contractors and the federal Central Valley Project contractors, who rely on water exported from the Sacramento River watershed, or a joint powers authority comprised of those contractors, for reimbursement of the costs of the analysis conducted pursuant to this section.

(e) The board shall submit its flow criteria determinations pursuant to this section to the council for its information within 30 days of completing the determinations.