Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability

I. INTRODUCTION

In 2008, the US Fish and Wildlife Service (Service) issued a Biological Opinion (BiOp) on Central Valley Project (CVP)/State Water Project (SWP) operations that concluded that aspects of those operations jeopardize the continued existence of delta smelt and adversely modify delta smelt critical habitat. Among other requirements, the Reasonable and Prudent Alternative (RPA) that was issued with the BiOp calls for the adaptive management of fall Delta outflow (hereafter "Fall outflow") following "wet" and "above normal" water-years. The Service determined that the Fall outflow element of the RPA is required to alleviate both jeopardy to delta smelt and adverse modification of delta smelt critical habitat. The Fall outflow action is expected to improve habitat suitability and contribute to a higher average population growth rate of delta smelt.

The RPA prescription is expressed in terms of X2, the nominal location of the 2 ppt isohaline (Jassby et al. 1995). The RPA calls for Delta outflow to be managed such that fall X2 must average either 74 km or 81 km upstream from the Golden Gate during each of September and October, respectively, if the water year containing the preceding spring was classified as wet or above normal. There is an additional storage-related requirement to enhance outflow in November that does not have a specific X2 target. The RPA states that the performance of the action shall be investigated with a research and monitoring program containing a feedback loop allowing it to be adjusted from learned information (i.e., adaptive management).

At the time the BiOp was issued, the Bureau of Reclamation (Reclamation) responded with a "provisional acceptance" letter. In 2009-10, Reclamation and the Service developed and initiated a package of studies designed to increase understanding about Fall X2 and support a passive form of adaptive management.

Reclamation has further reviewed the science underlying the Fall outflow requirement in order to better understand the uncertainties and to consider how efficient adaptive management might proceed. Based on those considerations, and because the costs of implementing the Fall outflow action are high, Reclamation has drafted a framework for active adaptive management. By adopting a more aggressive, active approach, Reclamation hopes to achieve more rapid learning – thereby finding the best and most efficient action faster – while alleviating adverse modification of delta smelt critical habitat and avoiding jeopardy.

The adaptive management plan includes a description of how adaptive management works and how an aggressive scientific studies element can responsibly be incorporated into it, a statement of management goals, and a draft of the set-up elements. Since a starting point for the management is logically required, Reclamation has reviewed the rationale for the action and considered initial management alternatives.

This plan implements critical recommendations made by the National Academies of Science panel in its March 2010 report (available at http://www.nap.edu/catalog.php?record_id=12881). By laying out a framework for rigorous, science-based adaptive management, we hope the plan will enable us to learn what we need to know about the effects of Fall outflow, so that the most appropriate conservation action can be identified and implemented at lowest possible water cost.

We have addressed a number of questions, issues, and recommendations made by various stakeholders and the California Department of Water Resources. Their advice was solicited in order to help improve the quality and implementability of this plan. Reclamation appreciates the constructive input that was received.

This plan is designed to formalize and strengthen the adaptive management process that was begun with the 2010 draft studies plan. It will require ongoing development during implementation. The plan presented here provides a framework for work that is to follow. We are completing plans for augmented monitoring first, in order to place crews in the field annually beginning this year. We expect development and implementation of the more difficult modeling components to occur on an ongoing basis.

This plan deals with only one aspect of the broad issue of Delta outflow. As one of the primary determinants of the characteristics of the ecosystem, Delta outflow patterns are important year-round, and affect many species. Delta outflow is a topic of discussion in several ongoing public processes, including the Bay-Delta Conservation Plan development, the Delta Stewardship Council's Delta Plan development, the State Water Resources Control Board's Delta Flow Criteria proceedings, and the Environmental Protection Agency's advance notice of proposed rulemaking for water quality issues in the Bay-Delta. We expect that as these processes move forward, linkages and interactions that arise between fall outflow management for delta smelt and other aspects of outflow management will be addressed as circumstances and Reclamation's regulatory obligations require.

II. Background

A. Delta smelt

Delta smelt is undoubtedly the most estuary-dependent native fish species that lives in the San Francisco Estuary (Moyle et al. 1992; Bennett 2005). Most delta smelt complete the majority of their annual life cycle in the low salinity zone (LSZ) of the estuary and use the freshwater portion of the estuary only for spawning and juvenile rearing (Figure 1; Dege and Brown 2004, Bennett 2005). Because it is endemic to the San Francisco Estuary, the continued existence of the species is dependent upon its ability to successfully grow, develop, and survive in the LSZ.

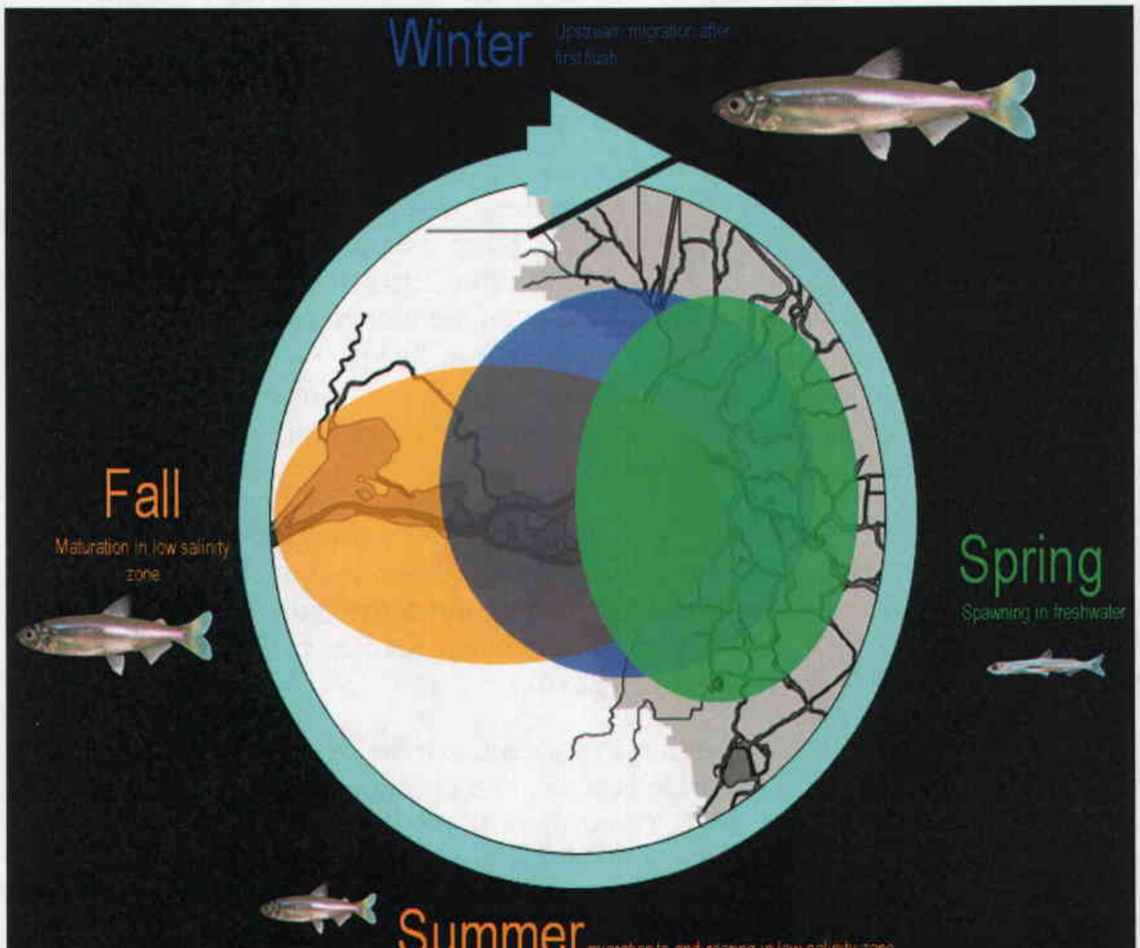


Figure 1. Simple conceptual diagram of the delta smelt life cycle (modified from Bennett 2005).

Delta smelt distribution and life history was first described by Moyle et al. (1992). A number of recent studies have examined delta smelt habitat use in more detail.

Bennett (2005) described general patterns of delta smelt habitat use by life stage. Dege and Brown (2004) described the effects of outflow on the distribution of larval and young juvenile delta smelt and noted the initial upstream and eventual close association between young delta smelt distribution and X2. Feyrer et al (2007, 2010) described the habitat associations of delta smelt during fall months (September-December) based on forty years of sampling data collected by the Fall Midwater Trawl Survey. Nobriga et al. (2008) described habitat associations during summer months (June-July) based on the forty plus years of sampling data collected by the Summer Townet Survey. Kimmerer et al. (2009) expanded on these studies by examining the habitat associations of delta smelt for each of the major IEP fish monitoring surveys. Finally, Sommer et al. (2011) examined delta smelt distribution shifts from fall through the spring months. Together, these studies demonstrate that most delta smelt reside in the low salinity zone in the summer and fall, with a center of distribution at approximately the 2 psu isohaline, but move upstream during winter and spring months when spawning and early development occur in freshwater.

Sommer et al. (2011) also noted the year-round presence of delta smelt in an upstream freshwater region of the system in the general Cache Slough/Sacramento Deep Water Shipping Channel, suggesting that there is a portion of the delta smelt population that may not utilize the low salinity zone. Historically, delta smelt were also present in the south Delta in the summer, but are now found there only in the winter and spring (Nobriga et al. 2008, Sommer et al. 2011). Fisch (2011) determined that individuals collected from this region were not genetically unique relative to delta smelt captured from other regions of the system; rather, there is a single, panmictic delta smelt population in the estuary.

Against a background of highly variable abundance, delta smelt have suffered a long-term abundance decline (Figure 2; USFWS 2008, Sommer et al. 2007; Thomson et al. 2010). The decline spans the post-1966 portion of the "post-reservoir period" described in Baxter et al. (2010) and was particularly marked in the "POD [Pelagic Organism Decline] period" (Baxter et al. 2010).

Long term trend analyses confirm that a step decline in pelagic fish abundance marks the transition to the POD period (Manly and Chotkowski 2006, Moyle and Bennett 2008, Mac Nally et al. 2010, Thomson et al. 2010, Moyle et al. 2010) and may signal a rapid ecological regime shift in the upper estuary (Moyle et al. 2010, Baxter et al. 2010).

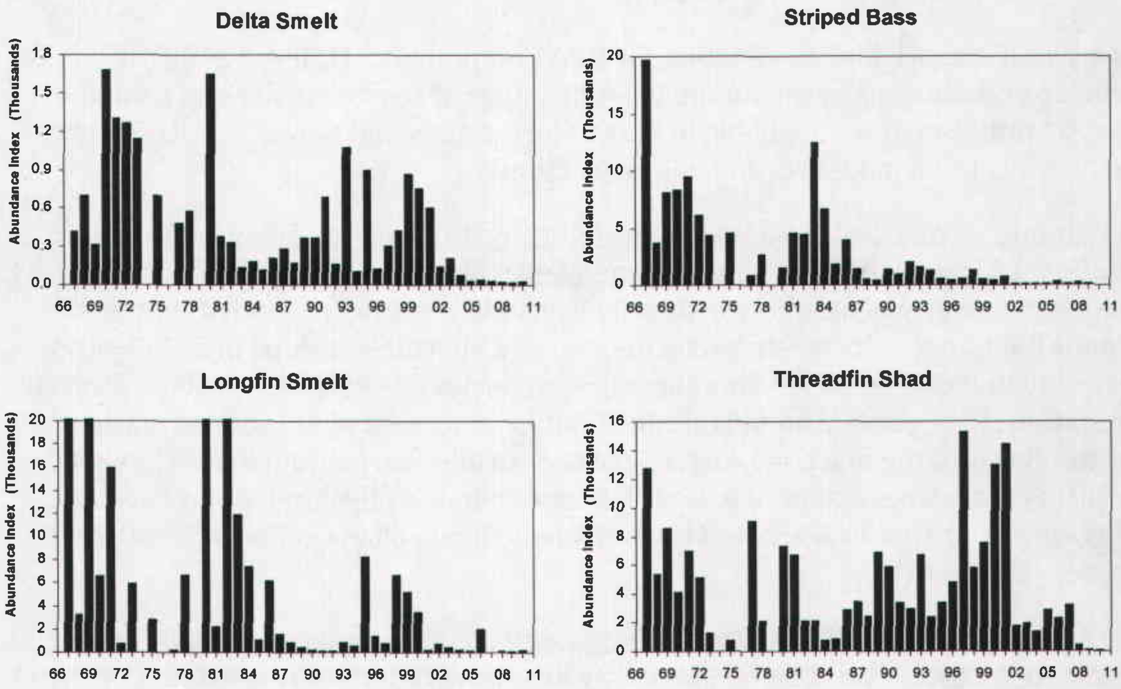


Figure 2. Trends in abundance indices for four pelagic fishes from 1967 to 2010 based on the Fall Midwater Trawl, a California Department of Fish and Game survey that samples the upper San Francisco Estuary. No sampling occurred in 1974 or 1979 and no index was calculated for 1976. Note that the y-axis for longfin smelt represents only the lower 25% of its abundance range to more clearly portray the lower abundance range.

The decline of delta smelt has been intensively studied as part of the POD investigation (Baxter et al. 2010; Sommer et al. 2007). The POD investigators have concluded that among several causes habitat degradation predominates.

> "We hypothesize that degradation of habitat is the fundamental cause of delta smelt decline and that it affects the species mainly through effects on growth and subsequent reproductive potential rather than immediate mortality. Both abiotic and biotic aspects of habitat suitability have declined over time. This has led to smaller, less healthy adults, which have lower per capita fecundity. These ecosystem challenges have probably been exacerbated by periodic high entrainment loss. We hypothesize that habitat degradation has reduced carrying capacity. Thus, entrainment losses at historical levels could have increased in importance because the population is smaller. Large-scale water diversion may also influence delta smelt carrying capacity through seasonal effects on Delta outflow" (Baxter et al. 2010, p. 54).

B. The 2008 Outflow RPA Action

As we read the original explanation for RPA Component 3 (USFWS 2008), it develops conclusions based on the following lines of reasoning derived from the best scientific analyses available in 2008. More details and newer results are given in the conceptual model section below (Section 4).

(1) Abiotic, or physical habitat used by delta smelt during the fall months has diminished in availability because of changes in water project operations. An analysis of historical monitoring data by Feyrer et al. (2007) revealed that the abiotic habitat of delta smelt can be defined as a specific envelope of salinity and turbidity that changes over the course of the species' life cycle. Over time, project operations have pushed and maintained fall X2 upstream of the wide expanse of Suisun Bay into the much narrower Sacramento and San Joaquin River channels, reducing the spatial extent of habitat falling within the physical habitat envelope. This may be further exacerbated by predicted climate change effects (USBR 2008; Feyrer et al. 2011).

(2) There is a discernible effect of good-quality abiotic habitat availability and delta smelt abundance. Fall habitat suitability has shown a long-term decline (Feyrer et al. 2007). Variation in abiotic habitat variables in the fall explained about 20% of the variance in subsequent juvenile abundance.

(3) The BiOp also asserted that restricted habitat area is likely to increase the probability that stochastic, localized, catastrophic events might affect a large fraction of the population.

The BiOp concluded that an outflow action was needed to (1) alleviate adverse modification of delta smelt critical habitat, and (2) avoid jeopardizing the continued existence of delta smelt. Based on the analysis contained in the BiOp and RPA, Component 3 of the RPA set requirements that X2 average 74 km in each of September and October following wet years and 81 km in the same months following above normal years "to mitigate the effects of X2 encroachment upstream in current and proposed action operations, and provide suitable habitat area for delta smelt" (BiOp page 373). Component 3 also includes a storage pass-through requirement in November. The effect of the November requirement is to enhance outflow above what the projects would normally provide when there is early precipitation, but does not require that a specific X2 objective be met.

The RPA also called for the adaptive management of the fall action, and prescribed that a team be convened to develop and implement a plan. The team, which became known as the Habitat Study Group (HSG), first convened in 2009. The HSG developed a package of studies to support fall outflow management, and completed a draft report of its activities in 2010. With Reclamation funding, the HSG studies were begun in 2010 under the administration of the Interagency Ecological Program (IEP) as part of the IEP POD investigation (Baxter et al. 2010).

C. Review of RPA Action

We have reviewed the basic rationale provided in the BiOp, bringing to bear information that has become available since the BiOp was completed. New information includes the 2010 POD synthesis (Baxter et al 2010), some newly published studies bearing directly on outflow effects and other issues, preliminary results from ongoing studies, commentaries from several review panels, complaints about the RPA that were raised by the State and Federal water contractors in letters and in litigation, and commentaries by DWR and NRDC that were provided to us in May 2011.

The main questions Reclamation asks in this review are the following. What kind of action seems appropriate, given the present array of available information? What are the most important specific uncertainties that affect management decisions pertaining to Fall Outflow?

We consider the available information in five sections, each of the last four building on those before it: (1) delta smelt habitat; (2) X2 as a surrogate for delta smelt habitat; (3) evidence for associations between habitat and abundance; (4) Delta hydrology, X2 and delta smelt habitat in the fall; and (5) the specific X2 action prescribed in the BiOp. Additional details are provided in the conceptual model section below (Section 4).

(1) Delta smelt habitat

As described above, seasonal movements and use of habitat by delta smelt have been captured by IEP long-term monitoring studies and reported in multiple studies (Moyle et al. 1992, Dege and Brown 2004, Bennett 2005, Feyrer 2007, Nobriga et al. 2008, Sommer et al. 2011). Two studies (Feyrer et al. 2007; 2011) have characterized the abiotic habitat of delta smelt using the Fall Midwater Trawl (FMWT) data set. Since 1967, the FMWT has trawled at 100+ fixed stations across the estuary each month from September through December. We have assumed, as Feyrer and colleagues did, that what constitutes suitable abiotic habitat in the POD period is the same as what constituted abiotic habitat during the post-reservoir period. Feyrer et al. (2007; 2010) found that delta smelt inhabit a wide range of salinity and turbidity levels, but the probability of observing a delta smelt is greatest at low salinities, centering on about 2 psu, and at relatively high turbidity levels. They analyzed the FMWT data using a generalized additive modeling approach, which is a commonly-used tool in ascertaining the habitat associations of fishes and other organisms. Generally, the method is a semi-parametric extension of a generalized linear model and is effective for describing non-linear relationships between predictor and response variables. The same method was used by Nobriga et al. (2008) and Kimmerer et al. (2009) in their studies of delta smelt habitat.

Sommer et al. (2011) found that one measure of smelt distribution, the center of distribution, is strongly correlated with X2 (Figure 3. see also Dege and Brown 2004) during the fall months (Figure 3). These relationships appear surprisingly robust even though the FMWT survey has been criticized for not sampling with respect to the tide (see conceptual model (Section 4) below for more details about implications).

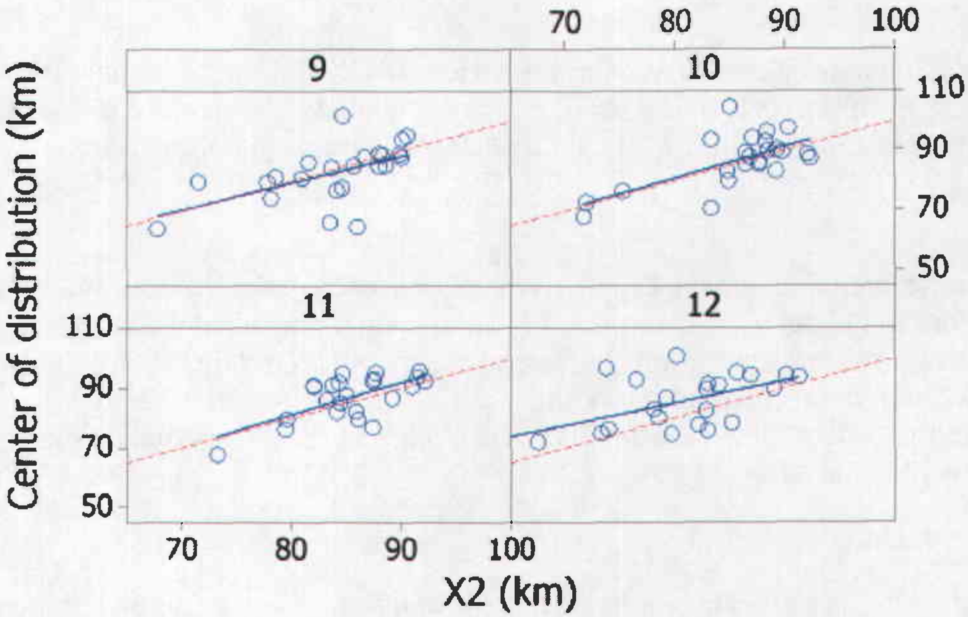


Figure 3. Center of delta smelt distribution during the fall months plotted against X2. Figure is from Sommer et al. (2011, their Figure 3) which has the following caption: "Monthly distribution of adult delta smelt in relation to salinity for the FMWT survey. The fish distribution data represent the centroid of the distribution from the FMWT (Dege and Brown 2004). Salinity is based on X2, the location of the 2-psu isohaline (Jassby and others 1995). The units for each data series represent the distance in kilometers from the Golden Gate Bridge. Hence, smaller values represent a seaward location and larger values represent a landward location. The red dotted lines show when the centroid and X2 values are equal. Centroid values above the red line represent fish distributions upstream of X2: centroid values below the line represent distributions downstream of X2. The blue lines show the fitted lines for the data, based on GLMs."

One issue that we cannot tackle in time to inform this document, but will be addressing as we proceed, arises from the fact that the FMWT samples at fixed geographical points without reference to the phase of the tides. The FMWT sampling plan thus represents an Eulerian approach that is being applied to what might be thought of as a Lagrangian problem, to the extent that delta smelt position themselves with respect to the moving body of water rather than fixed landmarks in order to stay in preferred physical habitat. The reality is probably nuanced. Because delta smelt are pelagic and tend to hold position with respect to a particular water mass over time, we have long thought that they must be "tidally surfing" in the presence of residual downstream flow. That is, they presumably ride the flood tide upstream, then seek refuge in the boundary layer near the bottom, or in littoral areas, during the ebb tide to avoid being swept too far downstream by the combination of net delta outflow and the ebb tide. However, summer/fall net flows are on the order of 1 cm per second downstream (Kimmerer pers com. 2011), a rate which delta smelt can easily overcome by swimming upstream, so tidal surfing is not necessary to maintain position. Recent work by Burau and Bennett (unpublished) may confirm the expectation that delta smelt strongly tidally surf upstream on the flood tide during periods of high net outflow.

Feyrer et al.'s (2007, 2011) approach has been criticized for being able to explain only approximately one quarter of the variance in presence-absence of delta smelt within the overall data set. The critics have asserted that this means that salinity and water clarity are unimportant, because other factors that were not considered in the analysis must explain the remaining three quarters of the variance in the data set.

We agree that adding pertinent additional factors might improve the model, but it is incorrect to interpret the percentage of variance explained as an indication that salinity and turbidity are unimportant (e.g. Abelson 1985, D'Andrade and Dart 1990, Bridgeman et al. 2009). Feyrer et al. (2011) demonstrated that the strong association between delta smelt occurrence and these factors was consistent over the history of the FMWT survey. Kimmerer et al. (2009) demonstrated that the result was also robust whether the response variable was occurrence or abundance. Moreover, in general, this degree of variance explanation is extremely common in studies on other species and in other systems where similarly strongly predictive habitat features have been identified (e.g. Kupshus 2003; Maravelias 1999; Stoner et al. 2001).

(2) X2 as a surrogate for delta smelt habitat

Feyrer et al. (2010) used the FMWT series to develop an abiotic habitat index, which incorporated both quantity and quality of habitat as defined by salinity and water clarity. The annual abiotic habitat index is a unitless quantity that can be thought of as the surface area of the estuary standardized for salinity and water clarity conditions preferred by delta smelt. This annual index exhibits a stepped relationship with X2 (Figure 4). The steep, stepped portion of the curve occurs over X2 ranging between about 85 km and 74 km, with less change outside this range.

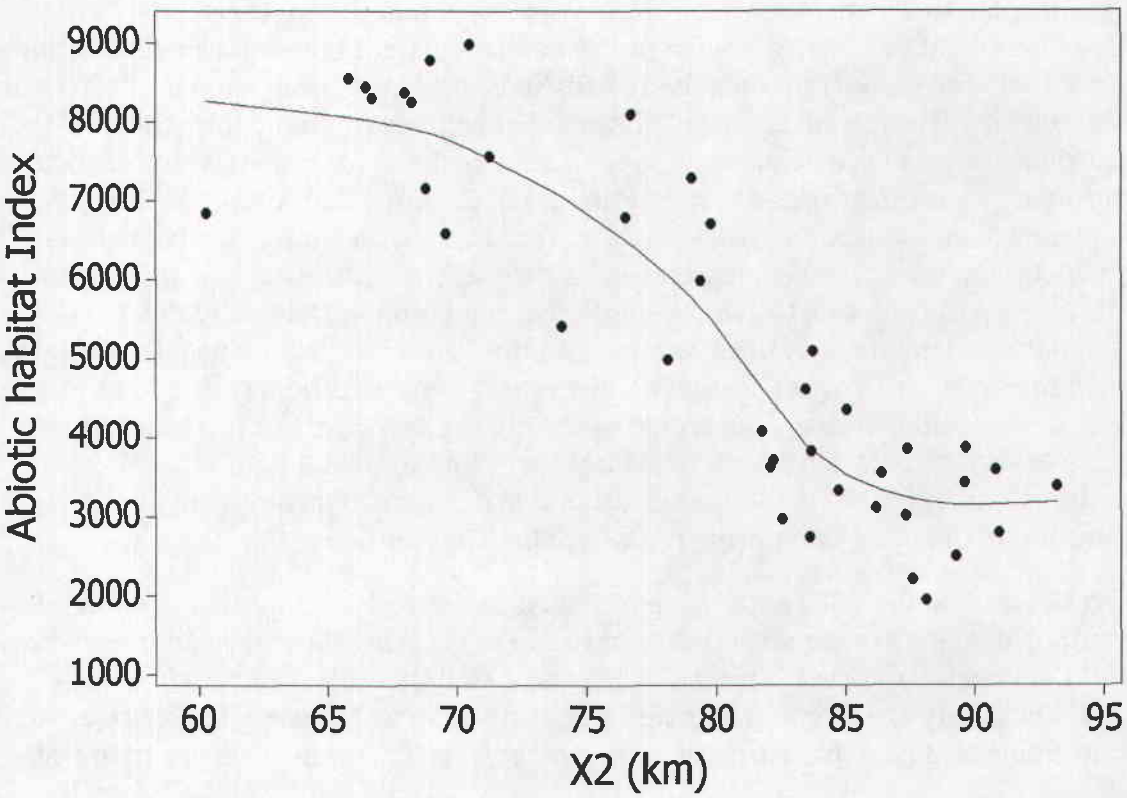


Figure 4. Delta smelt abiotic habitat index plotted against X2. Figure re-drawn from Feyrer et al. (2010). Curve is a LOESS smooth.

Across this 12-km range of X2, the habitat index increases approximately 2-fold. The habitat change is due to geography, in particular to change in the water surface area along the axis of the estuary. This range in X2 corresponds to a geographic area that straddles the confluence of the Sacramento and San Joaquin rivers, which is located at approximately 80km. When X2 is located downstream of the confluence there is a larger area of suitable habitat because the low salinity zone encompasses the expansive Suisun and Grizzly Bays and Suisun Marsh, which results in a dramatic increase in the habitat index (Figure 5). Newer hydrodynamic modeling results using the 3-dimensional UnTRIM Bay-Delta model show that the area occupied by the low salinity zone (defined as average daily salinity conditions of 1-6 ppt) is almost 5,000 hectares (12,000 acres) larger when X2 is 74 km than when it is 85 km (Figure 6, M. MacWilliams, unpublished) and varies in concert with the annual fall habitat index. X2 can thus be used to predict the annual habitat index defined by Feyrer et al (2010).

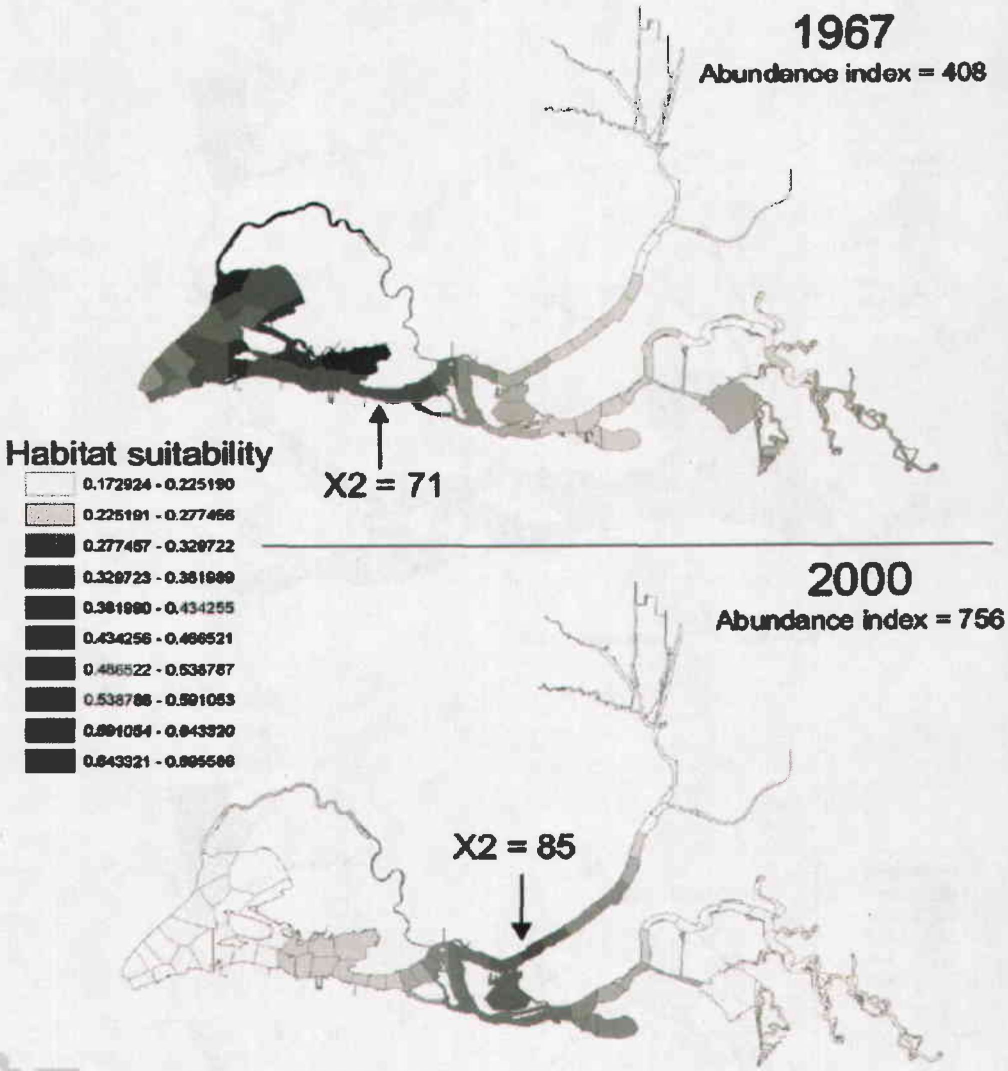
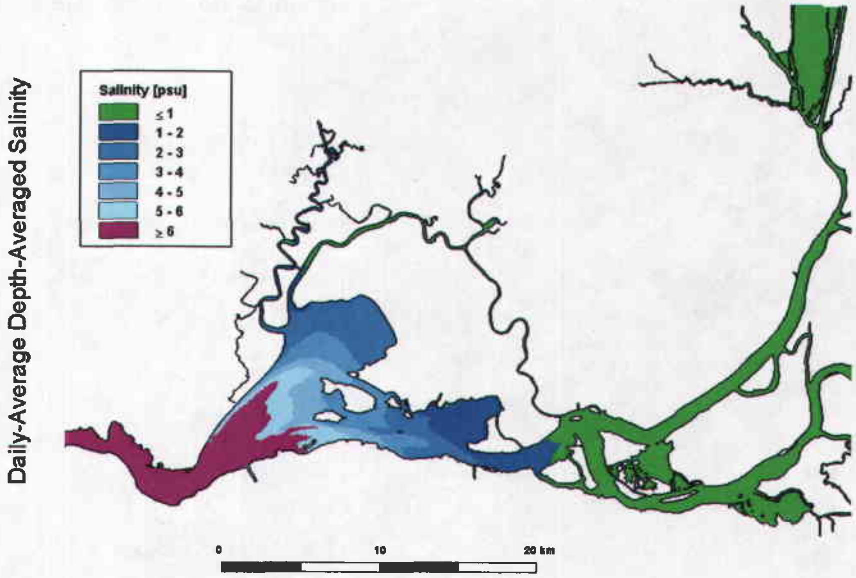


Figure 5. Spatial distribution of habitat suitability for delta smelt under different X2 conditions. Figure taken from Feyrer et al. (2010).



a) a) b)

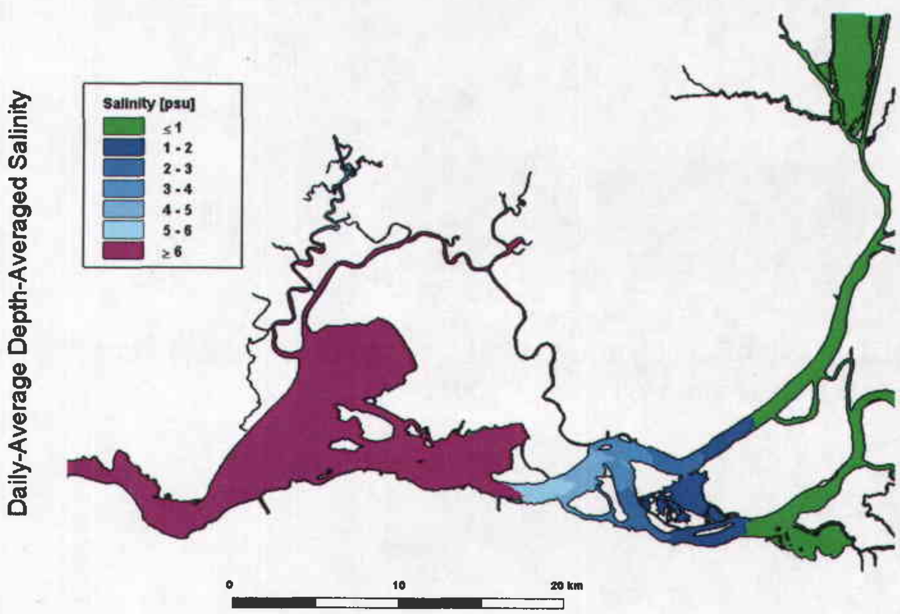


Figure 6. Spatial distribution of the low salinity zone (blue shades) under different X2 conditions: a) when X2=74 km (low salinity area = 9139 ha) and b) when X2=85 km (4262 ha) (Source: M. MacWilliams, unpublished).

This X2-habitat curve has been criticized for not considering biological features of habitat. According to this criticism, the habitat index does not represent the true realized habitat occupied by delta smelt. While it is true that a complete description of habitat includes physical, chemical, and relevant biological characteristics, physical and chemical characteristics are necessary preconditions for suitability. The ability of salinity and turbidity to reliably predict where delta smelt will be found during the fall months indicates that these variables are useful descriptors of habitat. Biotic factors, including food supply, that characterize an area become an important issue only after abiotic conditions are such that smelt can reside in the area without incurring excessive physiological costs or other detrimental effects.

(3) Evidence for a link between habitat and abundance

Two key papers demonstrate lines of evidence of an association between delta smelt abundance and summer and fall habitat conditions. After identifying long-term declines in habitat suitability, Feyrer et al. (2007) hypothesized that habitat changes might affect recruitment. Their analysis revealed a significant long-term decline in delta smelt abiotic habitat suitability and a substantial spatial constriction of habitat space. Incorporating abiotic habitat covariates into a basic stock-recruit model linking the abundance of sub adult delta smelt (FMWT) to juvenile production (TNS) improved the fit of the model. Models that included the abiotic habitat variables accounted for approximately 20% more of the variance in the data set than those without the abiotic habitat variables (r-squared values improved from 0.39 to 0.59). Model selection with AIC indicated that the models with the abiotic habitat variables were superior to the models without them. The salinity variable had the strongest effect.

(4) Delta hydrology, X2, and delta smelt habitat

Average X2 is largely determined by water project operations before winter storms begin in the fall. Since 1967, average fall X2 has moved upstream (Figure 7). In the last decade of the post-reservoir period there was substantial interannual variation in fall conditions. After wetter springs, there were often flood control releases in the fall months that moved X2 downstream for weeks. In the POD period very little interannual variation has been observed in the fall, and fall outflow conditions resemble what formerly occurred after drier springs regardless of actual spring hydrology (Figure 7).

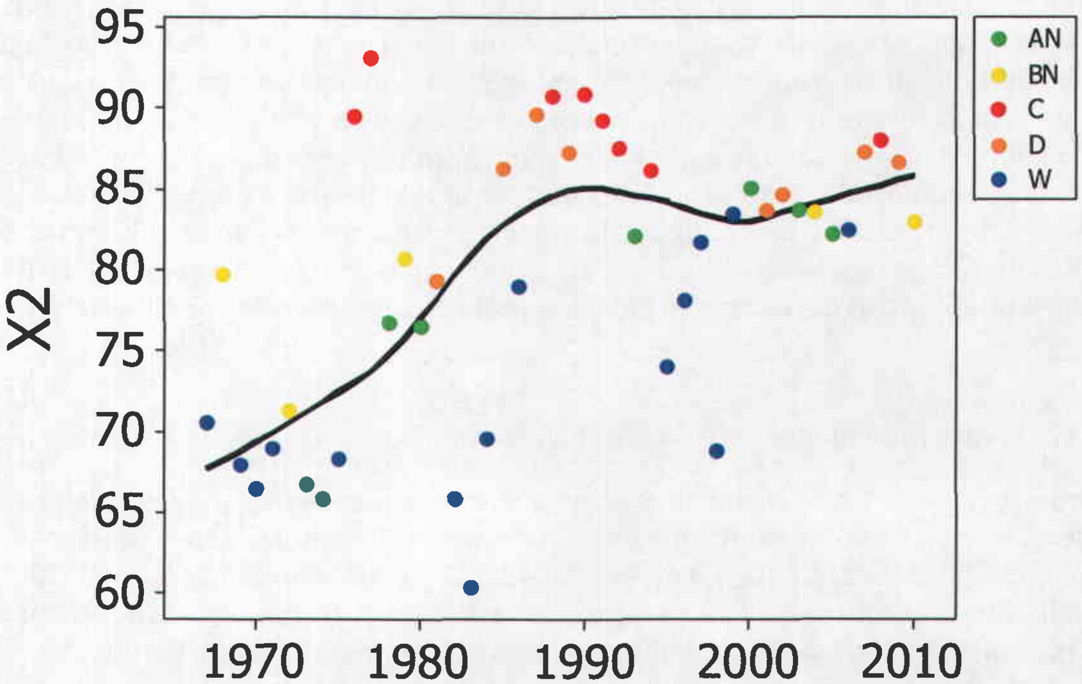


Figure 7. Time series of average fall X2 (km, September – December) since 1967. Symbols: water year type of the preceding spring for the Sacramento valley (W: wet, AN: above normal, BN: below normal, D: Dry, C: critically dry). A LOESS smooth is fitted to the data. (Source: F. Feyrer, unpublished. See also Figure 3 in Winder and Jassby 2010 and Figure 26 in Baxter et al 2010.).

Since 1967, the upstream shift in X2 has resulted in a decline in the average delta smelt abiotic habitat index, with the effect most pronounced in wet or above normal years (Figure 8; Feyrer et al. (2011) calculates a 78% decline from 1967 to 2008). This decline in delta smelt habitat has coincided with the long-term decline in delta smelt abundance (Feyrer et al. 2010). Operations modeling to evaluate the effects of project operations indicated that reduced and homogeneous fall outflow conditions will persist into the future (USBR 2008). Feyrer et al. (2011) concluded that the effects of future project operations in combination with climate change are likely to lead to further declines in delta smelt habitat in all water year types.

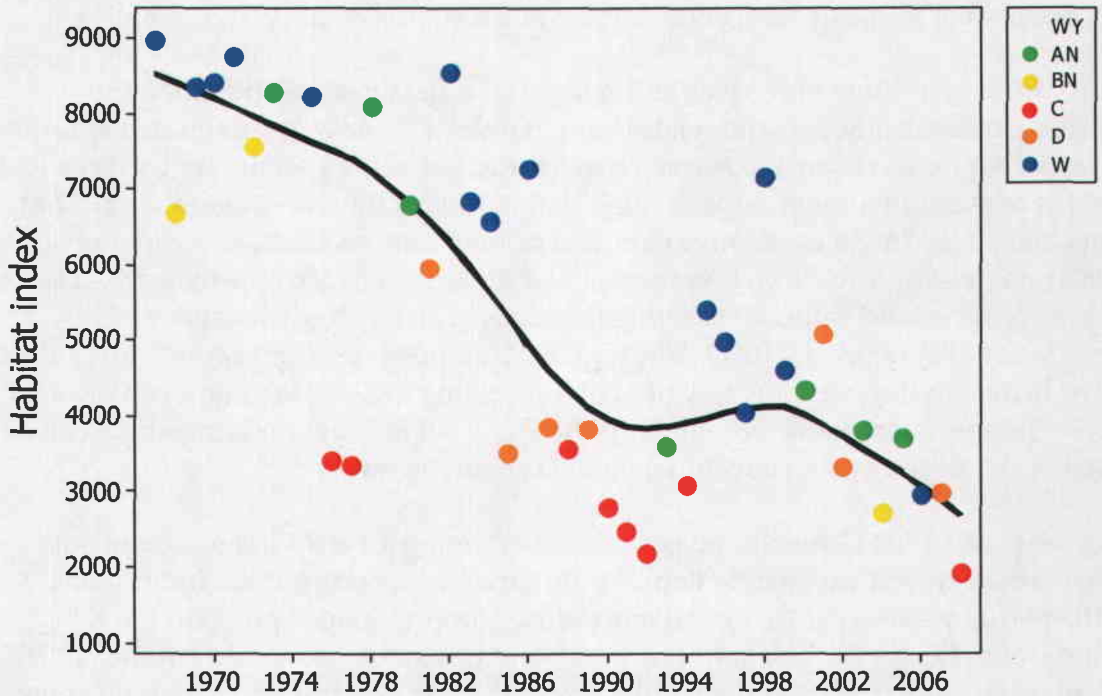


Figure 8. Delta smelt habitat index time series. A LOESS smooth is fitted to the data.

(5) Specific X2 prescription

The justification provided in the 2008 BiOp was to "mitigate the effects of X2 encroachment upstream in current and proposed action operations, and provide suitable habitat area for delta smelt" (BiOp page 373). The basic question is: how to achieve mitigation? It has been demonstrated in both the BiOp and the discussion above that project operations have affected average X2 during the fall (September-December). A closer examination of the data using Kendall trend tests reveals that there are significant positive trends in X2 for September, October, and November but not December in wet and above normal years.

Late fall and winter precipitation often drives X2 downstream in December, and to a lesser extent November (USBR 2008). Moreover, delta smelt may start moving into fresher water in December (Figure 3). For this reason, December has not been considered further. November has some frequency of both early precipitation and flood control releases (USBR 2008). While November has seen significant average reduction in outflow since the post-reservoir period, average outflow in November is still more frequently elevated than in either September or October. September and October have exhibited little variability in X2 in the POD period, and have seen larger changes in monthly average X2 compared with the post-reservoir period.

Consequently, limiting the fall outflow action to the first two fall months appears to be reasonable for protecting delta smelt while also protecting water supplies.

The choice of outflow objectives and related X2 objectives in September and October is constrained by the relationship between outflow and habitat. Feyrer et al.'s habitat index (Figure 4) reveals two habitat index tiers separated by threshold values containing a steep slope: a "high" habitat index tier corresponding to X2 at approximately 74 km or downstream, and a "low" tier for X2 at approximately 86 km or upstream. The curve is empirical and these figures are approximate. That there are threshold values separating these tiers is likely a consequence of geography (Feyrer et al. 2011). The high habitat index tier corresponds to X2 close to or in Suisun Bay, with the low tier corresponding to X2 in the more constrained river channels upstream. Potential mechanisms behind these relationships will be further discussed in the conceptual model section below.

Feyrer et al.'s (2011) results suggest that positioning X2 at 74 km or less in falls after wet years approximately doubles the expected abiotic habitat index above POD-period values (Figure 4) and more closely approximates pre-POD fall X2 conditions (Figure 7). The shift to a persistent upstream positioning of the fall LSZ in all water year types and the resulting reduction in delta smelt fall habitat is one of the most striking changes in the system during the POD years. Reestablishing X2 at 74 km or less is expected to restore delta smelt habitat and produce subsequent abundance benefits.

The use of an 81 km target for falls after above-normal years provides about 50% more of the abiotic habitat benefits than maintaining X2 at 86 km, and at present represents a reasonable intermediate action to restore late post-reservoir period salinity conditions in the fall.

D. Conclusions

It seems clear that outflow affects the quality and extent of abiotic smelt habitat. It also seems clear that restoring lost abiotic habitat availability is likely to produce subsequent-abundance benefits to delta smelt, probably by raising the carrying capacity. We are also left with important unanswered questions that bear on the management of fall outflow. What are the key underlying ecological mechanisms that link outflow to delta smelt abundance, and how important and manageable is each link? How does fall outflow fit in with other drivers of delta smelt abundance? Are there more water-efficient ways to provide the necessary benefits?

Answering these questions is important to good management. In the succeeding sections of this document, we address how to reduce these uncertainties while implementing the outflow action using an adaptive management approach.

III. ADAPTIVE MANAGEMENT OF FALL OUTFLOW

A. BASIC MANAGEMENT FRAMEWORK

Adaptive management is management undertaken in the face of uncertainty. Because large uncertainties about outcomes are a common feature of most natural resource management action, this management approach is strongly embraced by the Delta Plan under development by the State's Delta Stewardship Council as well as by the Bay Delta Conservation Plan under development by Reclamation and other Federal and State agencies. The plan for adaptive management of fall outflow presented here follows the Department of Interior (DOI) Technical Guide for adaptive management strategies (http://www.doi.gov/initiatives/AdaptiveManagement/) fairly closely. The DOI Guide defines the general adaptive management approach as a looped process with six steps (Figure 9).

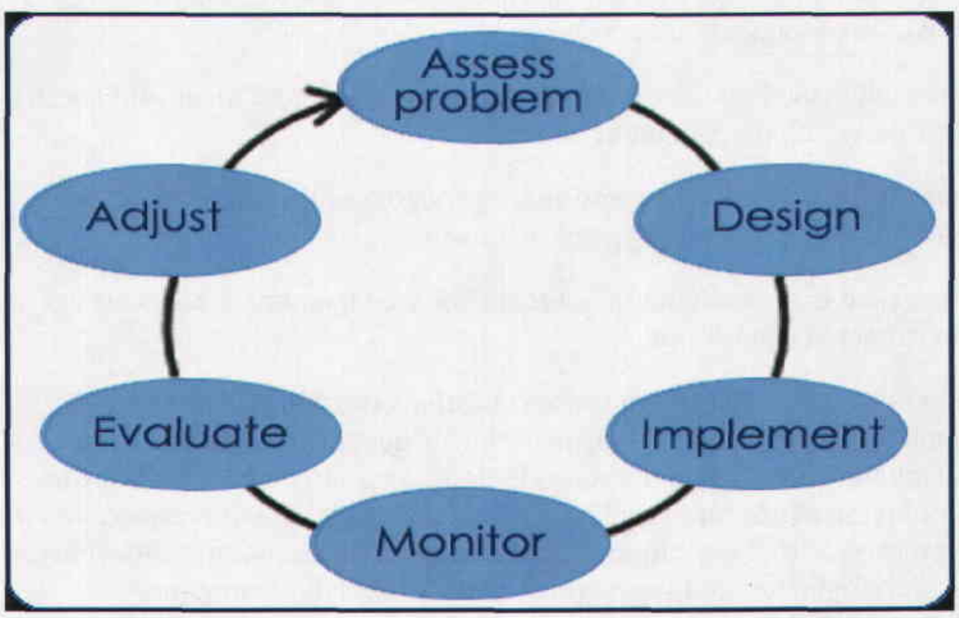


Figure 9. Adaptive management cycle (reproduced from DOI Adaptive Management Technical Guide).

The loop is initially entered in a "set-up phase" at the "assess problem" step. The set-up phase establishes key components of the adaptive management process including management goals and objectives, potential management actions, predictive conceptual and numerical models, and monitoring and research plans. The set-up phase is followed by the iterative phase which uses these components in an ongoing cycle of "learning and doing," with the "doing" based on what is learned and the "learning" aimed at improving the doing. Because of its critical management relevance, the fall outflow adaptive management strategy is based on a fast-paced annual cycle which closes the feedback loop every year and corresponds to the annual delta smelt life cycle. This implies that field and possibly laboratory data would be collected annually, regardless of water-year type and whether fall outflows were augmented. After each year's experience, a workshop and expert panel review would be used to assess what had been learned to date and what adjustments to the action and investigation should be considered.

While the steps in this loop are intuitively obvious, implementing a workable system to achieve learning can be a major challenge. In particular, the key to successfully navigating the sequence DESIGN → IMPLEMENT → MONITOR → EVALUATE lies in establishing management objectives that have the following features. Objectives must be "SMART":

1. Specific and unambiguous, with clear metrics and target conditions;
2. Measurable, with elements that can be readily observed, to promote evaluation of the management action;
3. Achievable, and based on the capabilities of the physical, political, and social system within which management occurs;
4. Results-oriented, with resource end-points and/or conditions, such as habitat conditions, representing their achievement;
5. Time-fixed, such that resolving the outcome of management choices occurs within an expected time-frame.

Defining objectives that satisfy all of these conditions is difficult in most real-world adaptive management situations. One of the hardest problems raised by consideration of fall outflow management lies in defining a satisfactory population-level delta smelt objective that can be reliably measured. Delta smelt are rare, and a simple calculation reveals that we cannot expect to detect an abundance difference in the FMWT after a single year of flow augmentation unless the abundance difference is very large. Other biologically important differences might not be detectable without many observations. To help overcome this difficulty, it is necessary to consider using every investigational tool that can responsibly be applied.

The term 'active adaptive management' (e.g. Walters 1986) has been used to describe the use of experimental manipulation embedded in management action as a learning tool. The advantage of an active approach is potentially much more rapid learning quickly leading to more effective management, but it also requires a much greater level of involvement and commitment by managers, scientists, and stakeholders. The potentially high water costs of implementing fall outflow actions and concomitant need to learn about the effectiveness of outflow management alternatives as quickly as possible strongly recommend the active approach. Lack of control and replicate "treatments" preclude true "experiments," but carefully designed flow adjustments and temporal and spatial comparisons as described below offer a greater likelihood of rapid learning and management adjustments than the previously envisioned more passive approach.

This document is a successor to the 2010 HSG Adaptive Management Plan (USFWS 2010). The HSG approach fell firmly in the 'passive' adaptive management category. The first package of HSG studies, which mostly focused on bottom-up questions related to outflow, was funded in 2010 and brief study descriptions are included in the 2010 POD work plan (Baxter et al. 2010).

This plan incorporates the investigations laid out in the 2010 plan. The new plan relies on both investigation of relevant ecological processes and on direct experimental manipulation of Delta outflow within the confines of the management action. It also includes a comparison with an upstream area (Cache Slough Complex, CSC) that is inhabited year-round by delta smelt (Sommer et al. 2011) and targeted for restoration in the draft Delta Plan and draft Bay Delta Conservation Plan. In combination, the use of these approaches provides a more efficient means than was available in 2010 to improve the conceptual model and test predictions about the consequences of management choices.

B. Elements of the 2011 Adaptive Management Plan

The preceding discussion reviewed the background for Fall outflow management and the basic adaptive management framework.

The succeeding sections of this document lay out plan elements that observe the conventions of adaptive management as described in the DOI Guide for the initial "set-up" phase. It is expected that these elements will be refined over the coming years during annual iterative cycles.

(1) SET-UP ELEMENT: GOALS AND OBJECTIVES

The goals of the fall outflow adaptive management plan are as follows.

I. To manage fall outflow for conservation benefits to delta smelt while minimizing water supply impacts.

II. To increase understanding about the effects of adjusting Fall outflow on the physical and biological environment, how those effects propagate through the ecosystem to affect delta smelt, and how to provide conservation benefits to delta smelt at least water cost.

As described above, objectives provide specific intermediate targets to aid in achieving the goals of the plan. The initial objectives of the fall outflow adaptive management plan emphasize achievement of conservation benefits to delta smelt, improved water efficiency, and improvement in understanding of the underlying basis for the action.

1) Use enhanced Delta outflow in wetter falls to increase the geographic area of the low-salinity zone, increasing the availability of high-quality LSZ physical habitat for delta smelt.

2) Restore LSZ connectivity to Suisun Bay in wetter falls, especially including Grizzly Bay and Honker Bay, to provide delta smelt access to the channel and shoal habitats in that area and allow access to Suisun Marsh sloughs.

3) Ensure higher annual and seasonal variability in salinity regimes in eastern Suisun Bay to reduce density of *Corbula* adults, thereby reducing the impacts of *Corbula* grazing on phytoplankton biomass and capture of selenium into the food chain year-round.

4) Use practical experience of managing enhanced fall outflow during wetter falls to improve efficiency of fall outflow water operations, including exploring utility of spring-neap outflow throttling and other possible methods to improve water efficiency of the action.

5) Improve understanding of turbidity dynamics by completing field studies of Delta sediment suspension and transport processes, and improve numerical modeling of hydrodynamics and sediment transport.

6) Improve understanding of delta smelt growth, health, and fecundity in order to evaluate the roles of delta outflow and other processes occurring through the summer and fall in determining the state of delta smelt at the onset of the spawning migration.

7) Improve understanding of plankton and benthos dynamics in Suisun Bay and the western Delta to support investigation of physical processes that may affect the abundance and accessibility of food for delta smelt and other species during the summer and fall.

8) Improve understanding of nutrient and contaminant dynamics that may be affected by outflow variability and the location of the LSZ during summer and fall, to support investigation of their potential influences on delta smelt growth, health, and fecundity.

(2) SET-UP ELEMENT: INITIAL MANAGEMENT ACTION AND ALTERNATIVES

The starting point for management includes the initial action and its alternatives. The choice depends on two main considerations. First, the management approach, including the manner in which the alternatives are deployed for study, must provide necessary conservation benefits to delta smelt. The second is that the management alternatives and the approach to deploying them must provide opportunities for learning. Both considerations limit the universe of possibilities.

We have relied on the analysis, discussion, and literature cited earlier in this document to conclude that although there are important uncertainties associated with the outflow prescription in the RPA, it is almost certain to provide improved fall habitat conditions for delta smelt and likely to result in better recruitment. Hence, the initial conservation action adopted in this plan is to have the projects operate to meet the targets identified in the 2008 RPA.

2011 Operations

Water year 2011 was quite wet, with precipitation falling throughout the winter and spring, even into June. The year has been officially classified as "Wet" by the State of California. On July 21, 2011, Reclamation transmitted a memorandum describing its proposed operations for fall 2011. Those operations implemented the 74 km fall outflow action as described for falls after hydrologically "wet" years in the 2008 RPA. The Service responded on July 22 that the proposal was consistent with Component 3 of the RPA.

The letter summarizes Reclamation's relevant features of operations that affect outflow and X2, including total Delta inflow, combined exports, expected Delta outflow, and expected X2. The proposal is premised on additional assumptions about consumptive use within the Delta that are based on historical demand patterns, with consumptive use declining through October to a point where they can be neglected in November. Moreover, the proposal was prepared without full feedback from DWR, so assumptions were made about DWR actions during the fall that may have to be revisited later. Because of the unusually wet hydrology, Reclamation expects that X2 will be close to the target of 74 km at the end of August, making the transition from August to September seamless.

August:

"In order to meet that average through the month of September, Reclamation anticipates the CVP and SWP will begin to modify combined operations for the second half of August. Based on a 50 percent exceedance hydrology, in the second half of August, Reclamation anticipates average daily combined inflows to the Delta of 25,000 cubic feet per second (cfs), combined exports of about 11,400 cfs and net Delta outflow of 11,800 cfs that will move X2 near the 74 km target. Because of the high level of exports and reservoir releases for multiple purposes during this period, Reclamation has forecasted no water cost to either the CVP or SWP during the month of August."

September:

"Reclamation intends that the CVP and SWP will operate in September to maintain monthly average X2 no greater than 74 kilometers (km). In order to meet that average through the month of September, Reclamation anticipates the CVP and SWP will begin to modify combined operations for the second half of August. Based on a 50 percent exceedance hydrology, in the second half of August, Reclamation anticipates average daily combined inflows to the Delta of 25,000 cubic feet per second (cfs), combined exports of about 11,400 cfs and net Delta outflow of 11,800 cfs that will move X2 near the 74 km target. Because of the high level of exports and reservoir releases for multiple purposes during this period, Reclamation has forecasted no water cost to either the CVP or SWP during the month of August.

Reclamation's current forecast projects an average outflow of 11,400 cfs to maintain X2 at 74 km. Reclamation is forecasting a continued average inflow to the Delta of about 25,000 cfs based on the 50 percent exceedance hydrology. Under these conditions, combined exports will be maintained near 11,000 cfs. Because of the high level of exports and reservoir releases for multiple purposes during this period, Reclamation has forecasted no water cost to either the CVP or SWP during the month of September."

October:

"Reclamation intends that the CVP and SWP will also operate in October to maintain a monthly average X2 position no greater than 74 km. In October, Reclamation is forecasting an average daily inflow of 18,200 cfs into the Delta. Combined average exports are expected to be reduced to approximately 6,300 cfs. The main reason for this reduction in total exports as compared to September is that the SWP has indicated that they will likely reduce reservoir releases on the Feather River from 7,000 cfs to 1,750 cfs in mid-October to avoid triggering a requirement to maintain those higher releases through the winter to prevent the dewatering of salmon redds in the Feather River. With the reduced reservoir releases, combined exports will be correspondingly reduced to maintain average X2 at 74 km. Reclamation believes Delta outflow required to maintain X2 at 74 km in October could be less than 11,400 cfs and that the initial calculation of outflow required is only an estimate. Assuming Delta outflow of 11,400 cfs is required to maintain average X2 at 74 km, and that DWR will reduce its Feather River releases to 1,750 cfs, then Reclamation estimates reduced exports of up to 300,000 acre-feet (AF) by the SWP. If Delta outflow of 10,000 cfs proves to be sufficient to maintain average X2 at 74 km in October, the SWP would incur an estimated reduction of exports of about 210,000 AF for October. In addition, if DWR's river releases at Oroville Dam were to be set above 1,750 cfs, the SWP could increase exports while maintaining X2 at 74 km. Based on the 50 percent exceedance forecast and an outflow requirement of between 11,400 and 10,000 cfs, Reclamation estimates little or no water supply impact to the CVP for October." [Footnote describing Kimmerer-Monismith X2 estimator omitted.]

November:

"Specific November Operations:

A. Any accumulated CVP and SWP Sacramento Basin reservoir storage attributable to November runoff will be added to reservoir releases. To the extent possible, Reservoir releases will be adjusted as necessary to achieve no net increase of storage in the month of November. The total amount of runoff passed-through for release may be apportioned among the Sacramento River Basin CVP and SWP reservoirs in any combination, irrespective of the source of the reservoir inflow, as long as the combined total of releases equals the volume of November inflow into these reservoirs.

B. For purposes of calculating the average November outflow required under these proposed operations, the average required outflow will be set at one half the computed Delta inflow in November, but will be no less than an average of 5,700 cfs. Delta inflow will be calculated in a manner consistent with the technique used in the State Water Resources Control Board's water right decision D-1641. At the beginning of the month of November, outflow will be based on one half the then current 14-day running average Delta inflow and will be adjusted through the month to achieve an average monthly outflow that is one half the computed average inflow for November.

C. In the event there is a net increase in Sacramento Basin CVP and SWP storage during November, [excepting storage accrued while X2 is maintained at 74 km]*, the increase in reservoir storage shall be released in December in a manner consistent with the RPA as quoted above. If this situation should arise, Reclamation will notify the Service to discuss project operations into the month.

D. Nothing in this proposal should be construed to override potential flood operations at CVP and SWP reservoirs and facilities that operators judge to be required for health, safety, and protection of property. Reclamation will notify the Service if operations deviate from those outlined in this proposal due to any of these reasons.

[T]hese operations are intended to result in November Delta outflow that will vary in accordance with runoff from the Sacramento and San Joaquin River Basins. In the absence of significant November precipitation, this proposal would impose no additional reservoir releases at the CVP and SWP reservoirs beyond those needed to pass through projected November reservoir inflows, not requiring pumping reductions beyond those necessary to maintain a minimum Delta outflow of at least 5700 cfs, or other modifications to coordinated CVP and SWP operations beyond what is needed to meet any other relevant obligations, both upstream and in the Delta. With increasing November runoff, the proposed operations for this year would result in Delta outflow to increase until the 74 km X2 value required for September and October under the RPA is achieved. Runoff exceeding what is needed to achieve 74 km X2 could be retained in upstream reservoirs or exported consistent with D-1641 at the discretion of the CVP and SWP, as it would not be needed to achieve the outflow objectives of the action.

Reclamation intends that the CVP and SWP will operate in November to maintain a monthly average Delta outflow consistent with the methods described above. Applying these methods in November, Reclamation is forecasting that average Delta outflow for the month would be 8,500 cfs based on the 50 percent exceedance hydrology forecast. In a 90 percent exceedance hydrology forecast, Delta outflow is estimated to be around 7,000 cfs for the month of November. Reclamation would anticipate that a Delta outflow sufficient to maintain X2 at 74 km (11,400 cfs) would occur at about a 40 percent exceedance hydrology this fall."

The asterisk marks text not in the original memorandum. The bracketed text was added for clarification.

There are no operations planned for December. However, under one contingency of November operations described above, the inadvertent retention of runoff that should have been passed through, the excess water would be released in early December to complete the fall action. There is some uncertainty how much runoff might remain unspent at the end of November; experience will likely help refine implementation of the action.

Under the operations described above, the projects will achieve the X2 target in September and the first half of October at no cost, simply by augmenting Delta inflow with reservoir releases that are expected to be required to evacuate flood space by November 1. During the second half of October, Reclamation expects that the SWP will reduce Oroville releases to set Feather River flow at a low level when permit restrictions are in force, with a corresponding reduction in SWP exports following in order to maintain Delta outflow at a level sufficient to keep average X2 at 74 km for the month. November operations will depend on precipitation, and the exact mix of tributary flows that might contribute to Delta inflow in November is hard to predict at present.

San Joaquin River contribution to Delta outflow

The San Joaquin River is shallower and has higher nutrient concentrations than the Sacramento River (Ball and Arthur 1979; Jassby 2008). The San Joaquin River thus generally supports higher levels of phytoplankton biomass. There are several reasons, however, for assuming that very little of this biomass is likely to make its way to the western Delta and Suisun Bay during Fall 2011. First, the flows in the San Joaquin are likely to remain relatively high, so the standing stock of phytoplankton will be relatively low (Jassby 2005). Second, owing to the absence of a barrier at the head of Old River, a portion of the phytoplankton load will be diverted directly to the CVP/SWP export facilities before it can reach the Delta (Jassby 2005). Depending on flow, most of the remaining phytoplankton load will settle out and die once it reaches the Stockton Deepwater Ship Channel (Jassby 2005). Finally, during most of the two-month period during which X2 will be fixed at 74 km, total export pumping will be set at 6000 cfs or higher. This is likely to mean that the total south Delta export rate will be similar to or higher than San Joaquin flow. Under these circumstances, only a small fraction of the San Joaquin's water reaches the western Delta, and then only because of tidal mixing processes rather than net flow. We plan to carry out water "fingerprinting" studies of several scenarios during the next month to more thoroughly explore this question.

Considerations for Future Operations

This plan does not establish a specific sequence of management treatments beyond 2011. In keeping with the premises of adaptive management, we have considered the kinds of information that will be needed to make informed management decisions and how best to learn from experience this year, but the actual choice of future management actions will depend on both management imperatives and the findings of this year's investigation.

That said, we believe some key questions will be most efficiently answered by implementing the action in very different ways (within the boundaries of prudence) in otherwise similar years and contrasting the results. To establish this idea for the future, we propose that there should be one initial management alternative to the RPA prescription, and that it should produce the highest practicable contrast with the RPA. The best choice from a learning point of view would be an alternative in which the action is not taken at all, with X2 instead managed so that it remains in the 84-86 km range during the period in which the RPA targets would otherwise be in force. This would provide a 10-12 km X2 contrast that covers the steepest portion of Feyrer et al.'s curve. We realize, however, that this approach creates some additional unmitigable risk to the species. If this approach is unavailable, we will consult with USFWS to determine what lower-outflow alternative is acceptable.

Because we have observed an almost unbroken string of low-outflow Falls since 2000, it is clear that the most informative Fall outflow action in 2011 would be a high-outflow action. With 2011 now officially designated as a "wet" year, we recommend that the Fall 2011 action should be the 74 km "wet"-year action described in the 2008 RPA.

While a number of key variables has been historically monitored, new forms of monitoring have been identified as key elements of the plan. Both high-outflow and low-outflow management alternatives will have to be observed with the full monitoring system in place. As the adaptive management process evolves, therefore, we expect that it will be necessary to observe both high- and low-flow actions in otherwise similar years to resolve key management questions and achieve the first goal of this plan.

(3) SET-UP ELEMENT: LEADERSHIP AND COLLABORATIONS

Successful implementation of this plan requires effective leadership. After review of a large number of case studies, Walters (2007) concluded that (a) adaptive management plans have succeeded less often than they have failed, and (b) a common feature of those that have succeeded is that they were led by strong, single-minded individuals who had been granted the time and resources to ensure success. Citing Walters, the outside panel that reviewed an earlier version of this plan recommended the identification of a single, highly empowered leader to oversee implementation of the plan. "The fall outflow plan leadership team should include one individual who is given the freedom to ensure that the implementation and monitoring of the plan is her/his top priority and principal responsibility for the next year starting July 1, 2011." (Page 25)

We agree with this recommendation and are working to identify a full-time leader with the right qualities to act as a lead scientist for the plan. In the meantime, a "core group" of scientists and managers representing several State and Federal agencies has offered its services to lead further development of the plan and implementation of the fall 2011 studies.

The core group, eventually led by the lead scientist, will work to implement the studies associated with this plan under the management of the Interagency Ecological Program (IEP). The IEP has established scientific and monitoring expertise in the Delta and has for six years conducted the similarly complex and cross-cutting Pelagic Organism Decline (POD) investigation. The IEP represents an established cooperative endeavor of the State and Federal agencies with interests here. It provides a management superstructure within which the studies and decision-support system needed for this adaptive management plan can be developed under the supervision, and with the support, of agency policymakers.

We plan to release this plan to the public in the near future, and hope to foster cooperative participation among the agency and stakeholder entities that are interested in the plan. Ongoing litigation bearing on the subject of this plan has made it difficult to obtain cooperative participation from the water users, who are plaintiffs. However, we will continue to invite their participation, as we strongly agree with the review panel's recommendation that stakeholder participation be enlisted.

> "The Panel hopes that the research community, water users and NGOs may conduct supplemental monitoring to further our understanding of the ecosystem services provided by the Fall outflow manipulation. This has also been expressed as moving toward a 'single version of the truth' where the best-available science with a quantification of the inherent uncertainties is developed and separated from the difficult policy decisions that must be made (Nunes, 2011). The Panel expects that the 2011 manipulation will be significant enough to address some of the fundamental questions posed by Reclamation in the Draft AM Plan and presents an opportunity to invest in monitoring to draw defensible scientific conclusions. Whatever Fall action is adopted, the decision is likely to be criticized and contested. Previous attempts at these major manipulations have been scaled back or inadequate monitoring programs were implemented to deduce findings. This opportunity should not be lost." (page 13)

(4) SET-UP ELEMENT: MODELS ABOUT SYSTEM DYNAMICS AND DELTA SMELT RESPONSES TO FALL OUTFLOW MANAGEMENT

This plan relies on a Bay-Delta pelagic fishes conceptual framework developed by the IEP that identifies and interrelates fish abundance and key drivers that help to explain the pelagic organism decline (POD) (Sommer et al. 2007, Baxter et al. 2010). It also uses the subsequent adaptation of the POD conceptual models described in the 2010 HSG Adaptive Management Plan (USFWS 2010) as well as an ecosystem-based view of estuarine habitats that was presented by an expert group to the SWRCB in their proceedings to develop flow recommendations and which was reflected in the SWRCB's final report (SWRCB 2010). In the following sections we first briefly review the existing conceptual models and then provide a new conceptual model specifically designed for adaptive management of fall outflows in 2011. Results from monitoring and studies in 2011 will inform conceptual model refinement for future years.

a) Role of Quantitative Models

Numerical models quantifying and integrating many aspects of the conceptual models are currently under development (see monitoring and study plan section, and Appendix 2) and are expected to deliver results that will help guide fall outflow management in the coming years. Results from these models will, however, not be available for some time, and fall flow management in 2011 along with associated studies and monitoring will thus necessarily rely to a large degree on conceptual models. Development of quantitative models, and their integration with the Newman et al. life cycle model currently under development, will proceed on a parallel track with an expectation that one to several years will be required before products of sufficient quality and management applicability are available for use. The quantitative modeling framework included with a previous draft of this plan is provided as Appendix 2.

b) Existing Conceptual Models

Basic POD model - The basic POD conceptual model (Figure 10) focuses on the four POD fish species and is rooted in classical food web and fisheries ecology. It contains four major components: (1) prior fish abundance, in which abundance history affects current recruitment (i.e., stock-recruitment effects); (2) habitat, in which the amount of water (volume or surface area) with suitable conditions for a species has changed because changes in estuarine water quality variables, disease, and toxic algal blooms in the estuary affect survival and reproduction; (3) top-down effects, in which predation and water project entrainment affect mortality rates; and (4) bottom-up effects, in which consumable resources and food web interactions affect growth and thereby survival and reproduction. Each model component contains one or more potential drivers affecting the POD fishes.

Although the IEP framework recognizes bottom-up, top-down, and prior-abundance driver categories, it treats habitat-related drivers differently.

> "For the habitat component of the model, a key point is that habitat suitability affects all other components of the model. This is indicated by the overlap of habitat with all other components in [Figure 2]. Hence, changes in habitat not only affect pelagic fishes, but also their predators and prey, which, in turn, can also have effects on the habitat they occupy." (Baxter et al. 2010, p. 23)

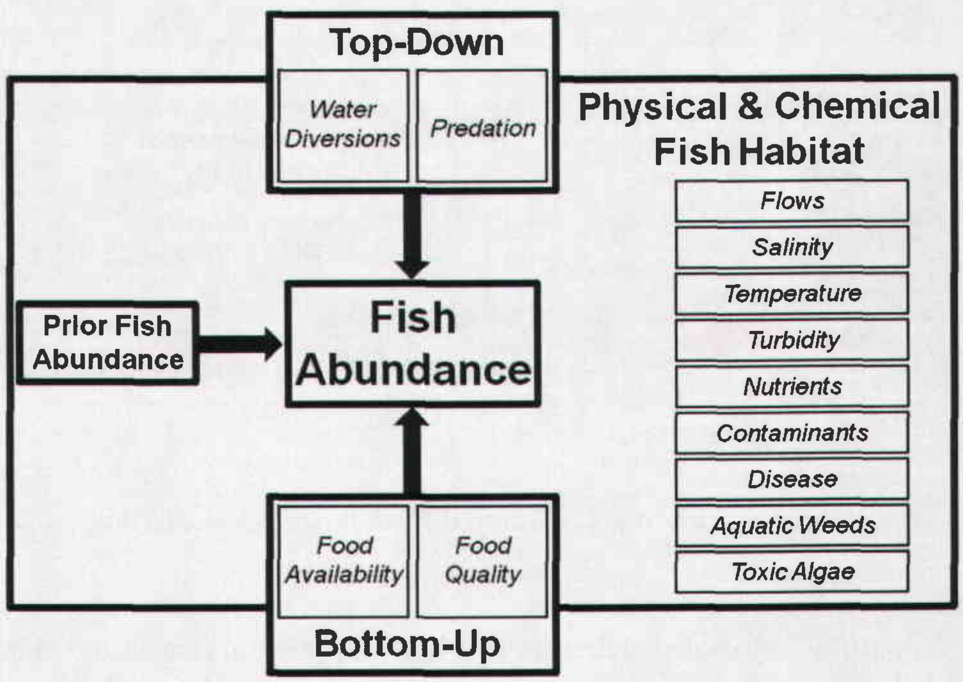


Figure 10. The basic conceptual model for the pelagic organism decline (updated from Sommer et al. 2007). Adapted from Baxter et al. 2010.

This treatment recognizes that habitat features may affect each of the other categories of drivers additively, antagonistically, or synergistically, producing outcomes that are not always easily predictable.

Delta smelt species model - We also rely on the delta smelt species model developed by the POD investigators which focuses on delta smelt (Figure 11; Baxter et al. 2010).

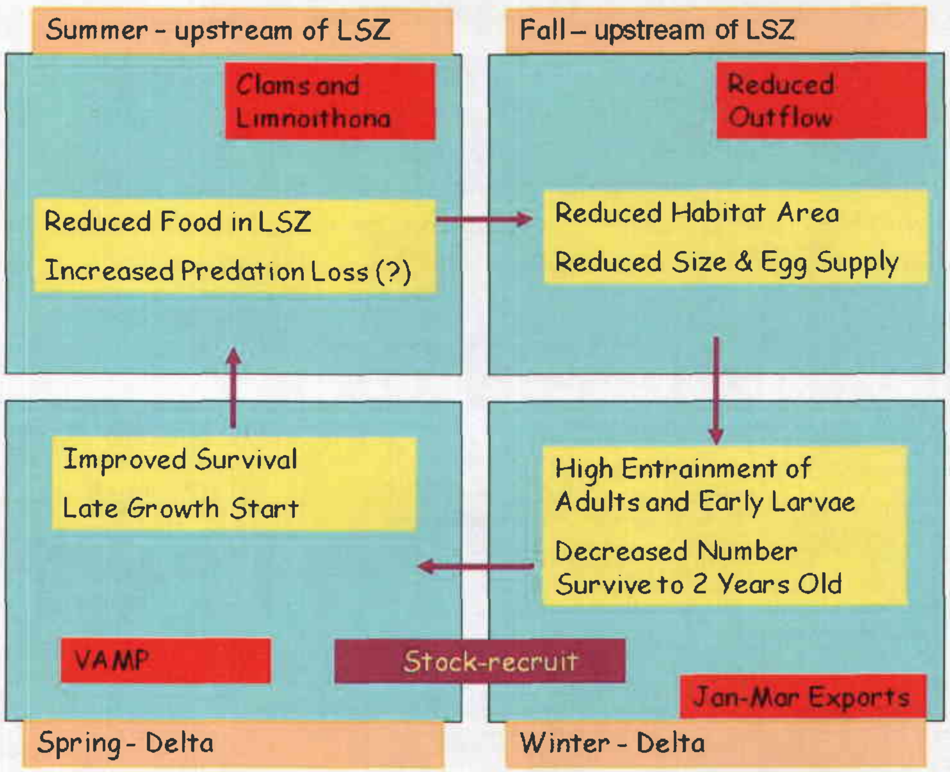


Figure 11. Delta smelt species model. Adapted from Baxter et al. 2010.

The model identifies key seasonal drivers in red, with proximal causes and effects in yellow. In fall, reduced habitat area is posited to affect the population through reduced growth and restricted egg supply rather than direct mortality. Fall effects therefore manifest themselves in potential limits on subsequent abundance, with the outcome depending on a variety of other seasonal factors.

Regime Shift Model – This more recently developed conceptual model focuses on the ecosystem of the upper estuary and posits that the POD is a manifestation of a rapid and comprehensive ecological regime shift that followed a longer-term erosion of ecological resilience in the estuary (Figure 12, see also Manly and Chotkowski 2006, Moyle and Bennett 2008, Baxter et al. 2010, Mac Nally et al. 2010, Thomson et al. 2010, Moyle et al. 2010). This conceptual model serves as a working hypothesis for future ecosystem investigations. Outflow, salinity, and turbidity are considered among the key "slow" environmental drivers in this conceptual model. The model posits that a more westward and variable salinity gradient favors native species (such as delta smelt), while a more eastward, constricted, and stable salinity gradient favors non-native and nuisance species (such as invasive jelly fish) and contributes to the erosion of the resilience of the original ecological regime. In this context, the fall outflow action would help restore resilience. This conceptual model also recognizes the step decline in turbidity in Suisun Bay that occurred after the sediment-flushing El Niño event of 1997–1998 (Schoellhamer 2011). Along with persistent high fall salinity in Suisun bay during the POD period, this sudden clearing may have also contributed to the POD regime shift and affected delta smelt fall habitat.

Old Regime	Environmental Drivers	New Regime
Variable, High	Outflow	*Variable, Lower*
To the west, Variable	Salinity gradient	*To the east, Constricted*
Complex, Variable	Landscape	*Simplified, Rigid*
Low, Variable	Temperature	*High, Uniform*
High, Variable	Turbidity	*Low, Less variable*
High P, low N	Nutrients	*Low P, High N (NH_4+)*
Few, Low	Contaminants	*Many, High*
Predation, Fishing	"Harvest"	*Predation and Entrainment*

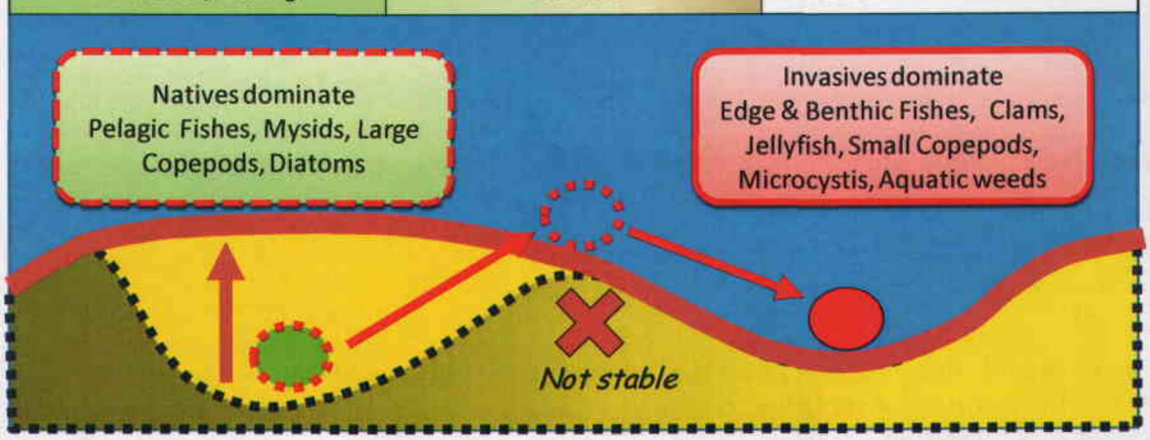


Figure 12. Regime shift model. From Baxter et al. (2010, their Figure 8 which has the following caption: "The ecological regime shift in the Delta results from changes in (slow) environmental drivers that lead to profoundly altered biological communities and, as soon as an unstable threshold region is passed, a new relatively stable ecosystem regime."

HSG Model - The 2010 HSG Adaptive Management Plan adapted the POD models to address key processes associated with habitat quality and quantity for delta smelt in the fall. This model represents habitat, bottom-up, and top-down drivers affecting delta smelt abundance, distribution, and health (Figure 13). Fall X2 is envisioned as a "filter" modifying the drivers and subsequent delta smelt responses. It implies that most of the potential effects of fall outflow are expected to occur through the processes that affect the growth and survival of juvenile and fecundity of adult delta smelt.

Figure 13. HSG model of effects of fall outflow on delta smelt through changes in habitat quantity and quality. Fall outflow affects (either directly or indirectly) the quantities on the left.

Estuarine Habitats Model - Peterson (2003) proposed an ecosystem-based view of estuarine habitats. A modified version of this view was presented by the Environmental Flows Group to the SWRCB in their recent proceedings to develop flow recommendations for the Delta. This group included regional technical experts including several members of the IEP POD team and others. Their view of estuarine habitats was reflected in the SWRCB's final report (SWRCB 2010) and provides the final piece for a new conceptual model for fall outflow adaptive management. In this view, the environment of an estuary consists of two integral parts:

(1) a stationary topography with distinct physical features that produce different levels of support and stress for organisms in the estuary, and

(2) a dynamic regime of flows and salinities. Organisms passively transported by flow or actively searching for a suitable salinity will be exposed to the different levels of support and stress that are fixed in space in the stationary topography.

Together these stationary and dynamic habitat features control the survival, health, growth and fecundity of estuarine pelagic species and ultimately their reproductive success (Figure 14).

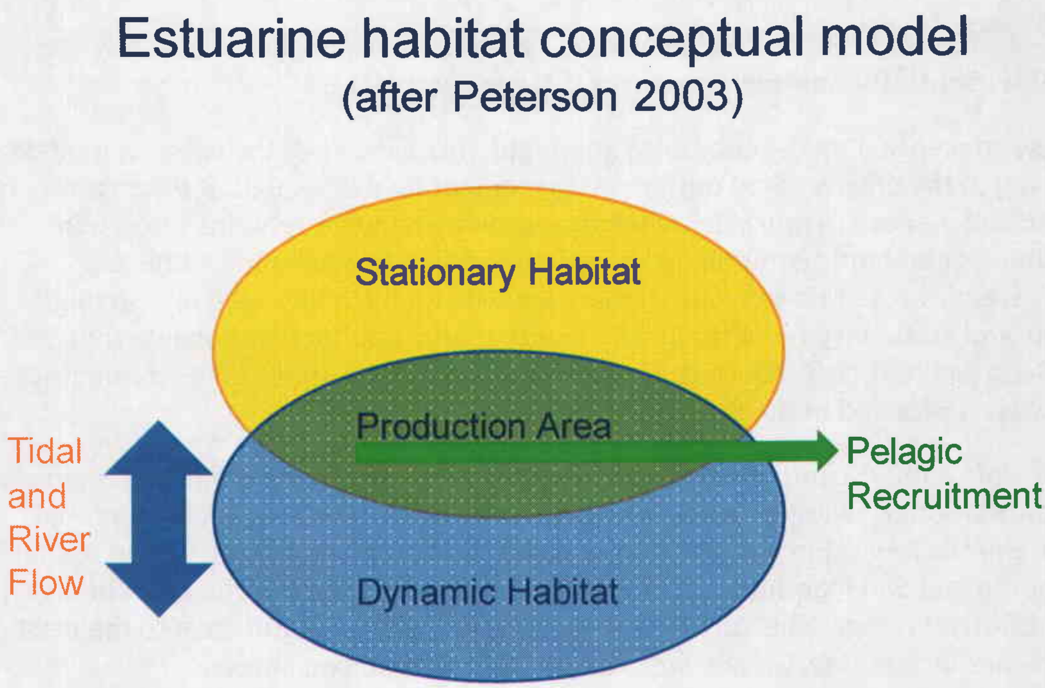


Figure 14. Estuarine habitat conceptual model presented to the SWRCB by the Environmental Flows Group (the full presentation is available at http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/defg_presentation.shtml).

For the Delta, this dynamic and interacting view of estuarine ecology is reflected in the comments of UC Davis scientists to the SWRCB: "A vast ecological literature documents the significant roles of habitat complexity and variability in promoting abundance, diversity, and persistence of species in a wide array of ecosystems. This literature stresses the importance of both predictable and stochastic physical disturbances, timing and extent of resource availability, as well as the degree of connectivity among habitat patches, relative to the abilities of species to move between them. However, landscapes are not stable in their configurations through time and environmental fluctuations generally increase the duration and frequency of connections among patches of different kinds of habitat. This can increase turnover of resources, making the resources available to a shifting array of species. The variability implies that different processes interact at various scales in space and time, with the result that more species are present than would be characteristic of a hypothetical stable landscape (e.g., an agricultural landscape). Therefore, ecological theory strongly supports the idea that an estuarine landscape that is heterogeneous in salinity and geometry (depth, the configuration of flooded islands, tidal sloughs, floodplains, etc.) is most likely to have high overall productivity, high species richness, and high abundances of desired species." (Moyle et al. 2010).

c) A New, Spatially Explicit Conceptual Model For 2011

This new conceptual model combines and highlights aspects of the existing models pertaining to the effects of fall outflow management on delta smelt. It offers a way to describe and explore in more detail what is known and what remains uncertain about abiotic and biotic components of delta smelt fall habitat under different outflow scenarios. In this conceptual model, we distinguish between interacting dynamic and stationary (geographically fixed) abiotic habitat components that affect delta smelt, their predators, and their food resources in the river channels of the western Delta and in the Suisun region in the fall.

The dynamic habitat components are associated with different fall outflow regimes, while the stationary habitat components are associated with the specific physical structure of the low salinity zone when it is located in the confluence region of the Sacramento and San Joaquin Rivers (hereafter referred to as the "river confluence") or in the Suisun region. The Suisun region borders the river confluence to the west and includes Suisun Bay, Grizzly Bay, Honker Bay, and Suisun Marsh.

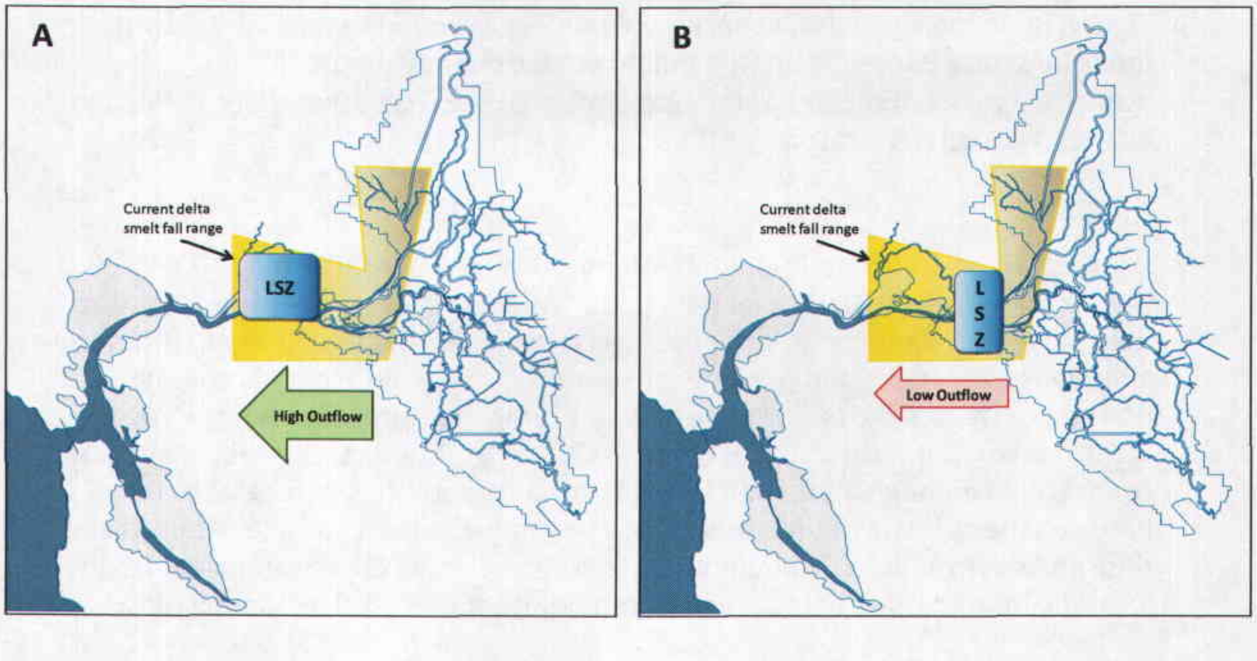


Figure 15: In the fall, delta smelt are currently found in a small geographic range (yellow shading) that includes the Suisun region, the river confluence, and the northern Delta, but most are found in or near the LSZ. **A:** The LSZ overlaps the Suisun region under high outflow conditions. **B:** The LSZ overlaps the river confluence under low outflow conditions.

The small current range of delta smelt (Figure 15) encompasses the Cache Slough complex and the lower portion of the Sacramento ship channel in the northern Delta, the river confluence in the western Delta, and the Suisun region. Historically, delta smelt also occurred in the central and southern Delta (Erkkila et al. 1950), but they are no longer found there in the summer and fall months (Bennett 2005, Nobriga et al. 2008, Sommer et al. 2011). Juvenile and sub-adult delta smelt occur mostly in the low salinity zone in the fall (LSZ, here defined as 1-6 psu) and are most abundant at 1-2 psu (Swanson et al. 1996, Bennett 2005, Sommer et al. 2011). While delta smelt can survive year-round in fresh water, the salinity levels in the LSZ seem best suited to the physiology of juvenile and sub-adult delta smelt. Delta smelt are generally not found at salinity levels above 14 psu and cannot survive at salinity levels above about 20 psu (Swanson et al. 2000).

In our conceptual model, the LSZ is a dynamic abiotic habitat component. Its size (surface area) and location varies with net freshwater outflow from the Delta. Under high outflow conditions, a broad LSZ overlaps a large part of the Suisun region (Figure 15 A) and the potential production area (see Figure 14) for delta smelt is relatively large and spread out across the deep and shallow areas of the Suisun region. Under low outflow conditions, a narrower LSZ overlaps the river confluence (Figure 15 B) and the potential production area for delta smelt is smaller and mostly confined to deep river channels.

Delta smelt and other organisms that seek the salinity levels of the LSZ or are transported by flow into this zone encounter and respond differently to different dynamic and stationary habitat features under high and low fall outflow conditions that place the LSZ in either the river confluence or in the Suisun region (Figure 16). This conceptual model focuses on the western part of the current delta smelt range. After describing this model, we will also briefly consider delta smelt habitat in the northern delta. This region has lower salinity levels, but resembles the LSZ in some of its other habitat features and, like the Suisun region, is an important target for habitat restoration (ERP 2011).

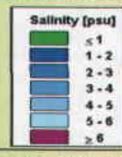
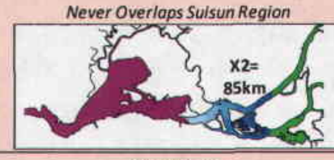
Suisun Region	**Stationary Abiotic Habitat Components**	*River Confluence*
Higher	Bathymetric Complexity	*Lower*
Higher	Erodible Sediment Supply	*Lower*
Many in South, Fewer in North	Contaminant Sources	*Many*
Fewer	Entrainment Sites	*More*
Variable Fall Outflow Regime	**Dynamic Abiotic Habitat Components**	***Static Fall Outflow Regime***
Higher After Wet Springs	Net Total Delta Fall Outflow	*Always Low*
Higher After Wet Springs	San Joaquin River Contribution to Fall Outflow	*Always Low*
After Wet Springs, Broad Fall LSZ Overlaps Suisun Region 	Location and Extent of the Fall LSZ (1-6 psu) 	*Narrow Fall LSZ In River Channels, Never Overlaps Suisun Region* 
Higher After Wet Springs	Hydrodynamic Complexity in the Fall LSZ	*Always Lower*
Higher After Wet Springs	Wind speed in the Fall LSZ	*Always Lower*
More Variable, Higher After Wet Springs	Turbidity in the Fall LSZ	*Always Less Variable, Lower*
More Variable, Maybe Lower After Wet Springs	Contaminant Concentrations in the Fall LSZ	*Less Variable, Maybe Higher*
LSZ Overlaps Suisun Region	**Dynamic Biotic Habitat Components**	***LSZ Overlaps River Confluence***
Higher	Food Availability and Quality	*Lower*
Variable	Predator Abundance	*Higher*
LSZ Overlaps Suisun Region	**Delta Smelt Responses**	***LSZ Overlaps River Confluence***
Broad, Westward	Distribution	*Constricted, Eastward*
Higher	Growth, Survival, Fecundity	*Lower*
Better	Health and Condition	*Worse*
May be Higher	Recruitment in the next Spring	*Lower*

Figure 16. Spatially explicit conceptual model for the western reach of the modern delta smelt range in the fall: interacting stationary and dynamic habitat features drive delta smelt responses.

Here, we are primarily concerned with delta smelt responses to the fall X2 flow manipulation described in the OCAP Biological Opinion and the opportunities for learning offered by the very favorable hydrology of 2011, but this conceptual model can also be used to explore effects of dynamic and stationary drivers on other species and to inform and refine the other conceptual models summarized above. Further, by applying this model to the San Francisco Estuary and in particular to the dynamics of the low salinity zone and delta smelt responses in its entire fall habitat including the northern Delta, we capture the effects of all likely drivers not only on delta smelt, but on much of the ecosystem as a whole. This will contribute not only to a refinement of the delta smelt species model, but also to a better understanding of the ecological "regime shift" conceptualized by Baxter et al. (2010).

Stationary abiotic habitat components: The POD and HSG models suggest four key stationary habitat components that differ between the river confluence and Suisun regions and may affect habitat quality and availability for delta smelt. Each of the four stationary habitat components is described below. It is important to note that while these features differ between the two regions, they are not uniform or static within each region – all vary within each region, and all change over time in response to dynamic drivers, albeit much more slowly than the dynamic habitat components. For example, bathymetry and erodible sediment supply can change as more sediment is transported into the region and deposited or eroded and flushed out to the ocean. Contaminant sources and entrainment sites are added or eliminated with changes in land and water use. Here we briefly summarize some of what is known and what remains uncertain about the four stationary habitat components in the river confluence and Suisun region.

- *Bathymetric complexity:* Differences in bathymetry and spatial configuration between the Suisun region and the river confluence affect nearly all other habitat features and interact strongly with the prevailing dynamic tidal and river flows to produce regionally distinct hydrodynamics. Overall, the Suisun region is more bathymetrically complex than the river confluence. The Suisun region includes deep and wide channel areas to the south, the large, shallow (less than 3–4 m), and open Suisun, Grizzly, and Honker bays in its center, and Suisun Marsh, the largest remaining tidal marsh in the estuary, to the north. In contrast, the only substantial shallow embayment in the river confluence is Sherman Lake which connects the mostly steep-sided and deep Sacramento and San Joaquin rivers near their mouths and there is only a very small amount of tidal marsh in this area.

- *Erodible Sediment Supply:* The amount and composition of the erodible sediment supply is an important factor in the regulation of dynamic suspended sediment concentrations and turbidity levels and quality in the water column. Suisun Bay features extensive shallow water areas such as Grizzly and Honker Bays that are subject to wind waves that resuspend bottom sediment and increase turbidity relative to the confluence (Ruhl and Schoellhamer 2004). Moreover, the bottom sediments in the shallow areas of Suisun Bay are composed mostly of easily erodible silts and clays, while the bottom sediments in the deep channels of the Suisun region and river confluence consist of silts and heavier sands (Schoellhamer 2011).The contribution of organic materials to the erodible sediment supply in Suisun region and the river confluence and its role are uncertain. It seems likely, however, that the large wetlands in the Suisun region and the shallow regions along its margins likely have higher benthic algal and aquatic plant productivity than deeper areas and thus likely contribute organic materials to the sediment supply that further affects the amount and source of turbidity in this region. Organic materials in the erodible sediments of the river confluence are likely of upstream riverine origin.

- *Contaminant Sources:* The large urban areas surrounding the estuary and the intensive agricultural land use in the Central Valley watershed and the Delta have resulted in pollution of the estuary with many chemical contaminants. Many of these pollutants (e.g. heavy metals, pesticides, etc.) are toxic to aquatic organisms and degrade the habitats of the estuary. Urban and industrial contaminant sources are located in the urban zones that surround the Delta and Suisun regions on all sides (Stoms 2010). Most wastewater treatment plants in and upstream of the Delta and Suisun regions have been upgraded to tertiary treatment which removes most inorganic nutrients and pathogens in addition to organic materials and also eliminates many pesticides and endocrine disrupting chemicals. However, the largest wastewater treatment plant in the Delta, the Sacramento Regional Wastewater Treatment Plant (SRWTP), continues to discharge effluent with high amounts of ammonium, pyrethroid pesticides, and other pollutants into the Sacramento River near the northern Delta border. The large Contra Costa wastewater treatment plant also discharges substantial amounts of ammonium and other pollutants into the western Suisun Bay near Carquinez Straight. Ammonium is converted to un-ionized ammonia at higher pH levels; un-ionized ammonia is toxic to animals. Ammonium has been found to suppress nitrate uptake and growth of phytoplankton in the Delta and Suisun Bay (Dugdale et al. 2007). In addition to man-made chemical pollution, blooms of the toxic cyanobacteria *Microcystis aeruginosa* have become a common summer occurrence in the central and southern parts of the Delta, including the river confluence and the eastern edge of the Suisun region. *Microcystis* produces chemicals that are toxic to many animals.

- *Entrainment sites:* Entrainment sites include agricultural water diversions and urban water intakes throughout the Delta and Suisun regions of the estuary, the state and federal water project pumps near Tracy, and two power plant cooling water intakes in the southern Suisun region (in Pittsburg and Antioch). Entrainment can cause direct mortality in fish screens, pumps, or pipes, or it can cause indirect mortality due to enhanced predation or unsuitable water quality associated with diversion structures and operations. Direct entrainment of delta smelt in the fall months is likely rare, although studies of entrainment effects of the power plants are ongoing. The plants are used mainly to satisfy peak electricity demands in the summer and fall months and could thus entrain delta smelt from the Suisun region, but the plants are not used very often and one of the plants will soon no longer use cooling water from Suisun Bay.

The starting distribution of delta smelt before winter migration is strongly influenced by salinity (Sommer et al. 2011). The winter spawning migration, which begins at the starting distribution and proceeds to points upstream, is typically initiated by "first flush" turbid river flows (Grimaldo et al. 2009; Sommer et al. 2011). A more eastward starting location may increase the risk of entrainment at the State and Federal water projects when "first flush" conditions trigger widespread upstream movement, but the extent of this risk is not known, and is under study.

Dynamic abiotic habitat components: In addition to stationary abiotic habitat components, the POD and HSG models also contain a number of dynamic components that change in magnitude and spatial configuration at daily, tidal, seasonal, and interannual time scales. Their interactions with each other and with stationary habitat components determine the extent and location of production areas for estuarine species. Chief among the dynamic components in this conceptual model is freshwater outflow that is the primary driver responsible for the location and extent of the dynamic LSZ in the fall. Other dynamic components are hydrodynamic complexity, wind speed, turbidity, and contaminant concentrations.

- *Total Delta outflow and San Joaquin River contribution in the fall:* The interaction of ocean tides with inflows from tributary rivers is the main dynamic driving force in estuaries and determines outflow to the ocean. Here, we briefly summarize the natural setting and the flow manipulations and landscape alterations that affect current outflow dynamics in the San Francisco estuary.

  The San Francisco estuary experiences twice-daily ebb and flood tides and strong fortnightly spring and neap tidal cycles. The estuary is located in a Mediterranean climate zone with highly variable precipitation and river flow patterns (Dettinger 2011). Winters are generally wet and summers are dry, but there is a large amount of interannual variability and California water managers distinguish between five different water year types (wet, above normal, below normal, dry, and critically dry). Historically, freshwater was "stored" as groundwater and in large seasonal and tidal wetlands along the rivers and in the estuary which buffered the seasonal inflow variation into the estuary to some degree. High flows during wet winters and springs recharged these natural freshwater reservoirs and their slow draining into the rivers allowed the Delta and the landward side of the Suisun region to remain fresh during summers and falls following wet springs (Enright and Culberson 2010).

  Large-scale disconnection of floodplains from river channels, draining of wetlands, filling of rivers with mining debris, and the beginning of groundwater depletion by pumping reduced the natural freshwater storage capacity of the system and increased seasonal and interannual flow variability in the late 1800s and early 1900s. Beginning in the first half of the 20th century, large dams were built on nearly all tributaries to the estuary to store water in large, artificial reservoirs for release during the dry season. Also, more and more water was diverted from the tributaries and the Delta itself and groundwater depletion became substantial. As a result, inflows into the Delta are now less variable within and between years than they would be under unimpaired conditions without reservoirs, flow diversions, and groundwater pumping. In general, late fall, winter, and spring inflows into the Delta are lower than under unimpaired conditions, while summer and early fall inflows are higher (Moyle et al. 2010). On an annual basis, San Joaquin River flows are reduced to a much greater extent than Sacramento River flows, and only a small amount of San Joaquin River water is actually discharged to the ocean in all but the wettest years. This is especially true in the fall months, when only a very small fraction of the entire water volume at Chipps Island is contributed by water from the San Joaquin River. According to hydrodynamic modeling using the Delta Simulation Model 2 (DSM2, see http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm), water from the Sacramento River and water intruding from San Francisco Bay via Carquinez Straight are by far the dominant water sources during these months and throughout most of the year (Figure 17). Even with greater wet year fall outflows, the San Joaquin River contribution to total outflow will likely remain small.

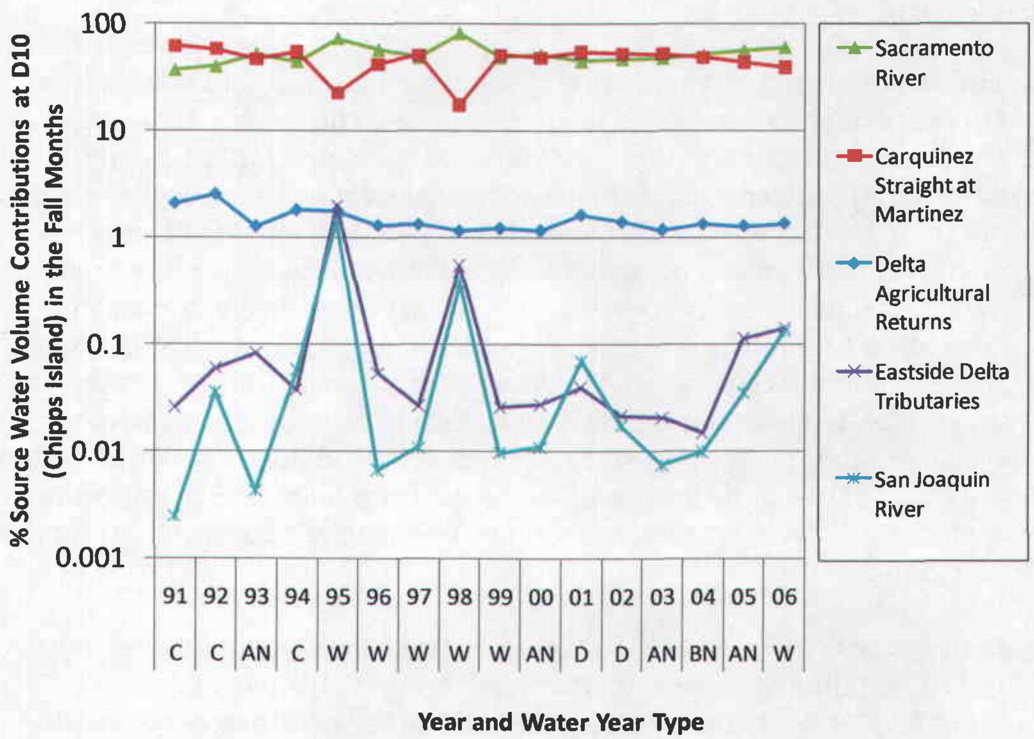


Figure 17. 1995-2006 times series of average seasonal water contributions from different sources to the total water volume at IEP-EMP station D10 at Chipps Island. Data: Volumetric water source "fingerprint" data for this station generated with the Delta Simulation Model 2 (DSM2, http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.c

fm). These data were provided to Anke Mueller-Solger by Bob Suits, DWR, in late 2006.

Annual net Delta outflows past Chipps Island increased in the first half of the 20th century due to increasing precipitation and less natural freshwater storage capacity, but declined in the second half due to water storage in reservoirs and increasing water diversions (Enright and Culberson 2009). Consistent with greater summer inflows due to reservoir releases and in contrast to outflows in all other months, summer outflows increased significantly over time (Enright and Culberson 2009). Long-term trends in early fall (September and October) outflows, on the other hand, do not follow the increasing trends in early fall inflows over the last eight decades (Enright and Culberson 2009). Fall (September through October) outflows increased until the mid-1970s, but decreased thereafter due to increasing inflow diversion through the Delta to the State and Federal Water Project pumps (Enright and Culberson 2009, Lund et al. 2008, Cloern and Jassby in prep.). Similarly low fall outflow levels never occurred after wet and above normal springs in the available data record from 1930 to 1990. In the POD period, fall outflows have been uniformly low, including in the fall months following the wet spring of 2006 (Figure 18, shaded period). This extreme level of disconnection of fall outflows from the interannual hydrological variability in the watershed is unprecedented in the entire historical data record.

The fall outflow management prescribed in the BiOp increases average fall outflows from the POD period average of about 5,200 cfs (95% confidence interval: 5,004 to 5,407 cfs) to approximately 11,400 cfs in September and October and 7,000 to 8,500 cfs in November following the wet spring of 2011 (see section I B). Approximately similar fall outflows would likely be required in other falls following wet and above normal springs in order to achieve the BiOp X2 objectives. While more than twice as high as during the POD years, the higher outflow levels in September and October 2011 would remain well below the average daily fall outflows during wet and above normal years from 1930-2009, even after excluding the extreme outflow years of 1982 and 1983 (Figure 17).

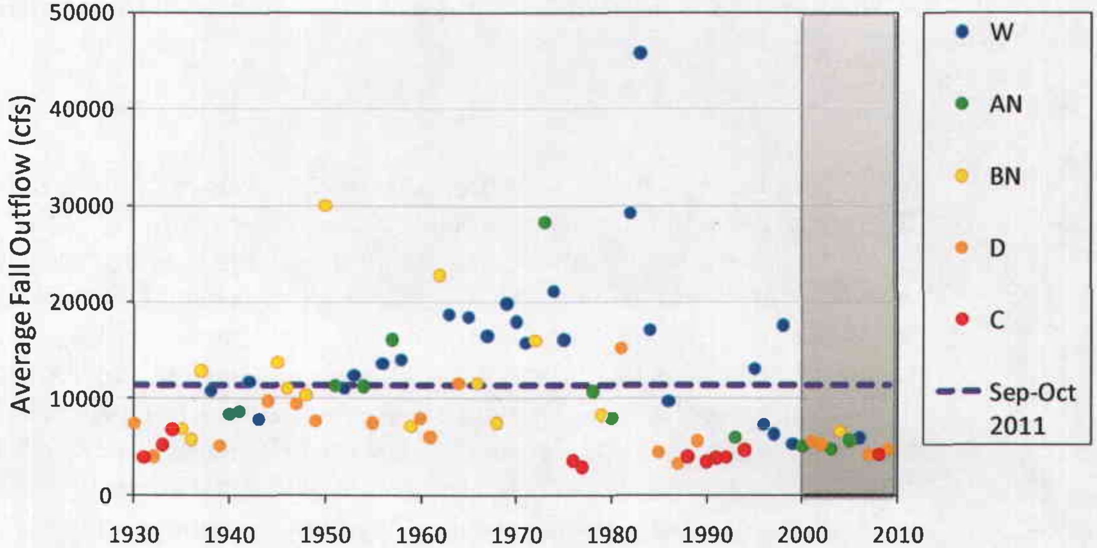


Figure 18. Time series of average daily net Delta outflow index in the fall (cfs, September – November) from 1930 to 2009. The shaded area shows the POD period. Symbols: water year type of the preceding spring for the Sacramento valley (W: wet, AN: above normal, BN: below normal, D: Dry, C: critically dry). Dashed purple line: projected average daily net Delta outflow level for September and October 2011. (Data source: Dayflow (http://www.water.ca.gov/dayflow/). Graphic: A. Mueller-Solger, unpublished.)

- *Location and extent of the fall LSZ:* Under the static fall outflow regime that has been typical for the POD period, outflows throughout much of the fall are always low and salinity intrudes far to the east (X2>80km, Figure XX, see also Figure 7), causing the LSZ to be constricted into a narrow band that overlaps the confluence of the deep Sacramento and San Joaquin river channels (Figure 6b). Prior to the POD period, a more variable fall outflow regime meant that high outflows in the spring were often followed by relatively high outflows in the fall of the same year (Figure 7 and Figure XX). Higher fall freshwater outflows do not allow salinity from the ocean to intrude into the river confluence. Instead, the LSZ is more westward (X2<80km) and much more spatially extensive than in low outflow falls (Figure 6a). In high outflow falls, it broadly overlaps the large shallow embayments of Suisun, Honker, and Grizzly Bays and reaches substantially into Suisun Marsh sloughs and wetlands. On an annual basis, the difference between X2 calculated for actual and unimpaired flows increased by 1.4% per year from 1932 to 2009 due to water management that resulted in a decline in outflow and allowed increasingly more salinity intrusion. The difference has been especially pronounced during the post-1960 droughts, with substantially greater salinity intrusions than the estuary experienced historically, including during the Dust Bowl drought of the 1930s (Winder et al. 2011).

- *Hydrodynamic complexity in the fall LSZ*: Hydrodynamics are driven by the interaction of dynamic river flows, ocean tides, and wind with the stationary bathymetry and spatial configuration. Hydrodynamics in the estuary are generally fairly well understood and have been modeled with a variety of modeling tools (see, for example, DSM2; CDWR 2008; CDWR 2005; Close et al., 2003)There remains much uncertainty, however, about the interaction of hydrodynamics with the stationary habitat components in the Suisun and river confluence regions and their combined effect on other dynamic habitat components including turbidity, contaminants, and biota. The diverse channel configurations and variable depths of the shallow regions and marshes in the Suisun region produce complex hydrodynamic features such as floodtide pulses in Grizzly Bay (Warner et al. 2004), tidal asymmetry (Stacey et al. 2010), lateral density fronts in Suisun cutoff (Lacy et al. 2003), and multiple null zones and turbidity maxima (Schoellhamer and Burau 1998, Schoellhamer 2001)see, for example, Wolanski 2007; Fischer et al., 1979).In contrast, the river confluence area has simpler bathymetry that lacks adjacent shallow embayments. . The greater hydrodynamic complexity in the Suisun region enables suspension and concentration of sediment particles (Ruhl and Schoellhamer 2004, Schoellhamer 2001), including inorganic sediment particles, organic detritus, and planktonic organisms, but detailed studies about these interactions are currently lacking. Greater residence times in the Suisun region may allow for the nitrification and uptake of river-borne ammonium to a degree that allows for more efficient algal nitrate uptake and growth. Greater mixing of the water column in these shallow areas and lateral exchange of water between deep and shallow areas may also prevent low dissolved oxygen conditions that can occur at the bottom of deep channels. Low dissolved oxygen conditions have been documented for the San Joaquin ship channel near Stockton and in some Suisun Marsh sloughs, but there have not been any thorough investigations of dissolved oxygen levels and dynamics in the Suisun region or the river confluence.

- Wind speed in the fall LSZ: The Suisun and river confluence regions of the San Francisco estuary often experience strong winds from the north and west. On average, wind speeds are high throughout most of the year including early fall, but lower in mid to late fall. The interaction of wind with river and tidal flows and the erodible sediment supply drives the resuspension of erodible bed sediments. Wind-wave resuspension is substantial in the shallow bays of the Suisun region and helps maintain generally high suspended sediment concentration and turbidity levels in these bays (Ruhl and Schoellhamer 2004). In contrast, wind likely plays a less important role in suspending sediments in the deep channels of the river confluence.

- Turbidity in the fall LSZ: In the San Francisco Estuary, turbidity is largely determined by the amount of suspended inorganic sediments in the water (Cloern 1987, Ganju et al. 2007, Schoellhamer et al. in press), although organic components likely also play an important role (USGS 2008). Sediment particles are constantly deposited, eroded, and resuspended, and are transported into, within, and out of the estuary. The amount of sediment that is suspended in the water column depends on the available hydrodynamic energy, which determines transport capacity, and on the supply of erodible sediment. In the late 1800s, enormous amounts of sediments were washed into the rivers in the estuary's watershed by hydraulic gold mining. A substantial portion of these sediments was deposited in the rivers and bays of the estuary because the transport capacity was not enough to wash them out to the ocean. In the 1900s, river-borne sediment supplies started to decline due to the end of hydraulic mining, sediment trapping behind newly constructed dams, and rip-rapping of river banks for flood protection. This meant that the eroding sediment pool was no longer rapidly replenished from upstream and started to wash out to the ocean, leaving behind thinning bed sediments and slowly declining turbidity levels. High flushing flows associated with two recent, strong El Niño-Southern Oscillation (ENSO) events led to the sudden and permanent clearing of the river confluence in 1983 (Jassby et al 2005) and the bays of the San Francisco estuary in 1999 (Schoellhamer 2011). In the western estuary, the onset of this clearing coincided with the onset of the POD period. It appears that turbidity from suspended sediments is now regulated by the bed supply of sediments, not by the transport capacity of the estuary, a situation that was not experienced in the estuary since before the gold rush.

  In spite of the depletion in erodible sediments, strong turbulent hydrodynamics in the Suisun region that are caused by strongly interacting tidal and riverine flows, bathymetric complexity, and high wind speeds continue to constantly resuspend large amounts of the remaining erodible sediments in the large and open shallow bays of the Suisun region. The Suisun region thus remains one of the most turbid regions of the estuary. Turbidity dynamics in the deep channels of the river confluence are driven more by riverine and tidal processes while high wind and associated sediment resuspension has little if any effect (Ruhl and Schoellhamer 2004). In Fall, fine erodible sediment has been somewhat winnowed from the bed and wind speed is less than spring and summer, so wind wave resuspension and suspended-sediment concentrations typically are low compared to other seasons. While generally lower than in the last century, turbidity in the river confluence can still increase dramatically during high flow events ("first flush") that bring in large amounts of suspended sediments from the watershed. In the fall, however, turbidity is usually lower in the river confluence than in the Suisun region (Bennett and Burau 2011). This is also consistent with preliminary analyses by W. Kimmerer (SFSU, pers. com.) that suggest that turbidity in the LSZ is higher when fall X2 is further downstream and the LSZ overlaps the Suisun region.

- *Contaminant Concentrations in the fall LSZ:* Chemical contaminants from agricultural and urban sources that are present in the estuary include pyrethroid pesticides, endocrine disruptors, and many traditional contaminants of concern. The estuary is also overly enriched with the nutrient ammonium (Johnson 2010). In the late summer and early fall, blooms of the cyanobacteria *Microcystis aeruginosa* can release toxic microcystins (Lehman et al. 2009). Agricultural contaminants are delivered into the LSZ from winter to summer in storm-water run-off, rice field discharge, and irrigation return water (Kuivila and Hladik 2008). The amount and types of agricultural contaminants that reach the LSZ vary seasonally, with more inputs from winter to summer than in the fall (Kuivila and Hladik 2008). Urban and industrial pollution from wastewater treatment plants and industrial discharges occurs more steadily throughout the year, although the amount of contaminant-containing urban storm-water run-off is largest in the winter and spring. In the fall, pollutant loading from stormwater is generally negligible and lower river flows mobilize fewer sediment bound contaminants than in other seasons. However, low flows also produce higher residence times and therefore enhance the possibility of accumulation and acute and chronic effects of contaminants from agricultural and urban sources. For example, the percentage of samples collected from the Delta and Suisun regions of the estuary that were acutely toxic to the amphipod *Hyalella azteca* was much higher in 2007, a relatively dry year (8.5 % of 340 samples), than in the wet year 2006 (1.7% of 353 samples) (Werner et al. 2010). Overall, regular toxicity monitoring conducted from 2006-2009 has shown relatively few incidences of acute *Hyalella* and delta smelt mortality (Werner et al. 2010 a and 2010 b, Weston et al. 2010)). However, sub-lethal, chronic effects at low, but persistent contaminant levels are likely a significant concern for delta smelt and other aquatic organisms throughout the estuary (Scholz et al. 2011). For example, a recent IEP study by Connon et al. (in review) assessed sublethal effects of ammonia exposure on delta smelt with novel molecular tools (DNA microarrays and qPCR). Results suggest that delta smelt are more sensitive to un-ionized ammonia, the toxic gas form of ammonium, than rainbow trout and ammonia primarily affects their cell membrane stability, but also energy metabolism and other physiological and neurological processes. In combination with other stressors, this can have a negative effect on health, condition, and overall fitness of delta smelt.

  The river confluence is geographically closer to agricultural and urban contaminant sources as well as to the toxic *Microcystis* blooms than the Suisun region. The lack of large wetlands in the river confluence precludes removal of contaminants through wetland processes and the supply-regulated sediment transport regime does not allow for much contaminant burial in bed sediment. Overall, this may increase the risk of exposure to toxic contaminants in the river confluence compared to the Suisun region. On the other hand, the southern margin of the Suisun region is heavily urbanized and includes the Contra Costa wastewater treatment plant which discharges ammonium and other pollutants into the western Suisun Bay near Carquinez Straight. Ammonium is converted into nitrate as it moves downstream, but elevated levels are often found in both the river confluence and the Suisun region. Higher phytoplankton productivity in the Suisun region may drive up pH levels, which could lead to increased levels of toxic un-ionized ammonia. Higher benthic productivity and resuspension of sediments in the shallow areas of the Suisun region can mobilize sediment-bound contaminants and introduce and accumulate them in the food chain. Suisun Marsh is bordered by a large urban area along its northern margin and much of its wetlands are managed by duck clubs. Urban areas and duck clubs are known to pollute Marsh sloughs with chemical contaimants and high loads of organic matter. Contaminant exposure risk may thus be overall more variable and not always lower in the Suisun region than in the river confluence.

Dynamic Biotic Habitat Components: Estuarine fishes seek areas with a combination of dynamic and stationary habitat components that are well suited to their particular life histories. In addition to abiotic habitat components, this also includes dynamic biological components such as food availability and quality and composition and predator abundance and composition.

- *Food availability and quality:* Food production in estuaries is a dynamic process that involves the entire food web, from algae, microbes, and aquatic plants at the base of the food web to intermediate and higher trophic levels populated by invertebrates such as zooplankton and benthic consumers and vertebrates such as fishes and water birds. As in many other estuaries, higher trophic level production in the open waters of the Delta and Suisun regions is fueled by phytoplankton production (Sobczak et al. 2002). In contrast to many other estuaries, however, the San Francisco estuary has overall low phytoplankton production and biomass (Cloern and Jassby 2008). Phytoplankton production in the estuary is highly variable on a seasonal and interannual basis (Jassby et al. 2002, Cloern and Jassby 2009). The San Francisco estuary also has a large amount of spatial variability in food production and food web dynamics. Estuaries and rivers often have dynamic food and biogeochemical "hot spots" (Winemiller et al. 2010) that persist in one location for some time or move with river and tidal flows. There are usually also areas with low food production and biomass.

  Not all highly productive hot spots are beneficial for consumers. For example, summer-time blooms of the cyanobacteria *Microcystis aeruginosa* that now regularly occur in the estuary can be both toxic and of very low food quality for some species of copepods (Lehman et al. 2009, Ger et al. 2010). *Microcystis* blooms can suppress copepod production and possibly affect zooplankton community composition, thus altering food quality for zooplankton consumer such as delta smelt. Similarly, the growth suppression of some, but not all, algal species by ammonium may alter phytoplankton community composition and their nutritional quality for consumers such as copepods. For example, diatom spring blooms in Suisun Bay are suppressed by high levels of ammonium (Dugdale et al. 2007), while ammonium may fuel *Microcystis aeruginosa* blooms in the summer (Kendall 2010). *Microcystis aeruginosa* grow mostly in the freshwater regions of the Delta, but are transported into the low-salinity zone in the summer and fall months. *Microcystis* blooms have been a prominent part of the phytoplankton community in the delta during the POD period, but the high flows and cool conditions of 2011 are not expected to produce a substantial bloom this year.

The temporal and spatial variability of food production, biomass, and quality in estuaries is the result of the interaction of dynamic drivers such as biomass and nutrient inputs from upstream, estuarine hydrodynamics, salinity, turbidity, and trophic interactions with stationary habitat components such as the bathymetric complexity and spatial configuration of a particular geographic area. For example, an area with shallow, well-mixed, and nutrient-rich water should have greater growth of planktonic and benthic algae and associated zooplankton than an area with deep, stratified, and nutrient-poor water (Cloern 2007). Greater bathymetric complexity may lead to a greater concentration and resuspension of particles, including planktonic organisms, than in less complex situations. In the shallow areas of the Suisun region, relatively high residence times combined with adequate light availability at shallow depths may allow for the draw-down of ammonium from the Sacramento River that may then enable greater diatom growth on nitrate (Dugdale et al. 2007). Salinity also plays a role – for example, Lehman (2000) found that in the spring, phytoplankton biomass and cell diameter was greatest toward the landward, fresher end (0.6 ppt) of the LSZ. If this were also true for the fall, a larger area at this low salinity in the Suisun region could translate into considerably larger food resources at the bottom of the food chain under high flow conditions. In general, however, spatial and temporal variations in productivity, density, and composition of plankton organisms in the LSZ at small scales that matter to delta smelt in the fall remain poorly understood for both the Suisun region and the river confluence. These small scales include the small temporal scale for the swimming speed of delta smelt while foraging (perhaps ~1 body length per second) and and the small spatial scale of its feeding ambit (perhaps no more than several meters in an area of high food concentration (i.e. a food hot spot)) (W. Kimmerer, SFSU, pers. com.).

Estuaries are open systems and food inputs from rivers and the ocean are an important driver of food web dynamics in estuaries. Of the two main tributary rivers to the San Francisco estuary, the San Joaquin River has generally more phytoplankton and zooplankton production and biomass than the Sacramento River. San Joaquin River waters along with the plankton they contain rarely reach the LSZ under low outflow conditions in the fall because the San Joaquin River is largely diverted into the water projects under these conditions. Higher outflow conditions and altered water management may allow some of the San Joaquin River biomass loads to reach the Suisun region in falls following wet springs, thus subsidizing the food available to delta smelt in the LSZ. Food production and biomass is also known to be high in some of the sloughs in Suisun Marsh (Sobczak et al 2002, Mueller-Solger et al 2002). When the LSZ extends into these sloughs, delta smelt may benefit from the production directly in some of the more open sloughs. If Suisun Marsh is a source of plankton organisms for Suisun bay, delta smelt may also benefit from Suisun Marsh food subsidies to the Suisun Bay, however the role of Suisun Marsh as a food source or sink remains uncertain. The river confluence likely receives substantial amounts of riverine organic matter from upstream, but much of this organic matter is not very nutritious and supports less higher trophic level production than autochthonous phytoplankton and fresh wetland production (Mueller-Solger et al. 2002, Sobzack et al. 2002). On the other hand, large amounts of detrital organic matter transported into and produced in the system are utilized by heterotrophic microbes (bacteria and protists) and microbial production and respiration in the system is high (Sobczak et al. 2002). Microbial biomass in the LSZ appears to nutritionally benefit at least one zooplankton species in the LSZ, the invasive cyclopoid copepod *Limnoithona tetraspina* (Bouley and Kimmerer 2006). However, in spite of its high abundance in the LSZ, this copepod species is not a good food source for juvenile and sub-adult delta smelt due to its small size (Sullivan et al. 2010). In the LSZ, microbes are often so heavily grazed by the invasive clam *Corbula amurensis* that their biomass can only be maintained through subsidies from other regions less affected by the clams (Greene et al 2011).

The overbite clam *Corbula amurensis* invaded the Suisun and river confluence regions in the late 1980s. This invasion led to a dramatic decline in the productivity in and upstream of these regions (Jassby et al. 2002). However, *Corbula* recruitment is suppressed and densities are lower in years with higher outflows and a more westward LSZ and X2 (Peterson and Vayssieres 2010, Winder et al. 2011), such as the wet 2011 – preliminary IEP monitoring results from this spring and early summer show very low numbers of live *Corbula* in the Suisun region. Without high densities of large *Corbula* in the fall, the Suisun region may have higher phytoplankton biomass this fall than in years with more *Corbula* which, along with reduced *Corbula* predation on juvenile zooplankton, would benefit zooplankton production.

This could translate into more food resources for delta smelt if the low salinity zone overlapped the productive Suisun region.

The food web in the Suisun and river confluence regions has been further altered by successive invasions of several species of zooplankton and now more closely resembles East-Asian than North-American zooplankton assemblages (Winder et al. 2011). Non-native zooplankton species started replacing native species in the upper estuary in the 1970s when increasing inputs from Asian ballast water coincided with extended drought periods. Water management reduced freshwater inflow even further, increasing drought severity and allowing unusually extreme salinity intrusions (see above). Unprecedented high salinity levels and intensified benthic grazing by the clam *Corbula amurensis* that also benefitted from the more saline and lower outflow conditions in the western estuary allowed the non-native zooplankton species to outcompete native species and colonize the system (Winder et al. 2011). At least one of these species, the calanoid copepod Pseudodiaptomus forbesi, appears to be a good food source for delta smelt. In contrast, the small cyclopoid copepod *Limnoithona tetraspina* that has become highly abundant in the LSZ since 1994 is not a good food source for juvenile and sub-adult delta smelt due to its small size (Sullivan et al. 2010). Overall, much uncertainty remains regarding the nutritional value of the non-native zooplankton species for delta smelt and other fishes.

Jellyfish (gelatinous zooplankton) have also increasingly invaded the LSZ from the Ponto-Caspian region. The estuary is now home to three species of hydromedusae (*Blackfordia virginica, Maeotias marginata,* and *Moerisia sp.)* introduced to the estuary in the 1970s (Mills and Sommer 1995, Mills and Rees 2000, Rees and Gershwin 2000). These three species inhabit the fresh to brackish regions of the estuary, including Suisun Bay, the channels of Suisun Marsh, and the western Sacramento-San Joaquin Delta, and are seasonally abundant throughout late summer and fall. As a result, they overlap both spatially and temporally with delta smelt habitat in the fall, but their role in the LSZ including any effects they might have on delta smelt is only now starting to be investigated.

In summary, food resources for delta smelt in the fall LSZ vary considerably on many spatial and temporal scales. Many uncertainties also remain about the dynamics of food resources at the small scales that matter to delta smelt survival, growth, and health in the fall. Uncertainties also remain regarding the relative importance of food subsidies from upstream regions and food produced in the LSZ. Species invasions associated with extreme salinity intrusions during droughts have greatly altered the composition of the invertebrate community in the LSZ, with uncertain effects on delta smelt. Overall, food quantity and quality may be higher for delta smelt if the fall LSZ is in Suisun Bay than if it is in the river confluence, but many uncertainties remain.

- *Predator composition and abundance*: Predators are a natural biological component of ecosystems and most organisms are exposed to predation during some part of their lives. In general, a reduction in habitat size may increase the probability of predation in that habitat. Even for a rare species like delta smelt, reduced habitat availability may increase the probability of a stochastic event such as an encounter between the core population of delta smelt and a school of predators. In the San Francisco estuary, striped bass juveniles become piscivorous and occupy much the same areas as delta smelt in the fall. Predation on delta smelt by young striped bass may be enhanced in recent years by a general increase in size of striped bass young of year and the general decrease in size of juvenile delta smelt, although the abundance of juvenile striped bass has decreased in the open waters of the estuary (Thomson et al. 2010). Striped bass occur in both the confluence and the Suisun region. Higher turbidity in the shallow areas of the Suisun region may, however, reduce predation risk for delta smelt in these areas compared to the river confluence, where turbidity is generally lower. In addition, preliminary results indicate that open-canopied beds of the native submerged aquatic vegetation (SAV) *Stuckenia pectinata* (sago pondweed) may provide cover from predation, although this has not yet been observed for delta smelt (K. Boyer, SFSU, pers. com.). This relatively salt-tolerant SAV species currently occurs in shallow off-shore areas extending from the western margin of the river confluence west into Grizzly Bay (K. Boyer, SFSU, pers. com.). In the fresher, warmer and clearer waters in and upstream of the river confluence, the dominant SAV species is the non-native *Egeria densa*. Its denser canopies provide ideal conditions for ambush predators such as largemouth bass (L. Conrad et al., DWR, pers. com.). Largemouth bass are increasingly abundant in the central and northern Delta and may potentially exert significant predation pressure on delta smelt in the river confluence and the clearer areas of the Suisun regions, although this has not yet been documented. Sacramento pikeminnow, a native predator, occurs in both regions. Mississippi silversides, another introduced species, appear to prey on larval delta smelt in the spring, but are likely too small to prey on juvenile and sub-adult delta smelt in the fall (B. Schreier, DWR, pers. com.). High predator abundance has been documented in the river confluence at the release sites for fishes salvaged in the CVP and SWP fish facilities. Overall, predator abundance and associated predation risk for delta smelt may be generally high in the river confluence, but variable in the Suisun region. Much uncertainty remains, however, about the role and magnitude of predation in these regions.

Delta Smelt Responses: The POD and HSG models suggest that delta smelt may respond in several ways to outflow-related habitat changes in the fall. Specifically, access to areas of greater bathymetric complexity such as those found in the Suisun region likely offers multiple advantages to delta smelt, although many uncertainties regarding the mechanisms that link delta smelt responses to outflow conditions and the position of the LSZ remain. Note also that the responses of delta smelt may be muted depending on the status of the population. For example, severely low adult abundance is likely to generate relatively low recruitment regardless of habitat quality. At the extreme end of low abundance, delta smelt populations may be subject to Allee effects, which cause a downward spiral that may be difficult to reverse (Baxter et al. 2008). Summer survey data suggest that delta smelt population levels have improved somewhat in 2011, hopefully reducing the risk of Allee effects.

- *Distribution:* Prior to their upstream spawning migration in the winter, delta smelt are commonly found in the LSZ (Feyrer et al. 2007, Sommer et al. 2011). While they can survive in freshwater and at salinities up to about 20 psu Swanson et al. 2000), the LSZ seems best suited to their physiology at this life stage. Older life stages of delta smelt may not require the same high turbidity levels that larval delta smelt need to successfully feed, but are most likely able to discriminate level and types of turbidity (and salinity) to find waters that contain appropriate prey resources and that will provide some protection against predation. A westward LSZ (Figure 15 b) ensures delta smelt access to a larger habitat area that overlaps the more bathymetrically complex Suisun region with its deep channels, large shallow shoal areas, and connectivity with Suisun Marsh sloughs.
- *Growth, survival and fecundity:* Distribution across a larger area with high turbidity, more food, and open-canopied native SAV beds in falls when the LSZ overlaps the Suisun region may help delta smelt avoid predators and increase survival and growth (K. Boyer, SFSU, pers. com.) although evidence for this is currently lacking. Delta smelt are poor swimmers and may also benefit from the more variable hydrodynamics associated with the more complex bathymetry of the Suisun region which include more quiescent areas that may allow delta smelt to rest and feed in addition to areas with strong flows that delta smelt may utilize to move around the LSZ without expending large amounts of energy on swimming. Distance from entrainment sites and predation hot spots (artificial physical structures, scour holes in river channels, *Egeria* beds) may also help increase survival and health. Higher phytoplankton and zooplankton production in shallow areas of the Suisun region and in San Joaquin River water may provide better food resources for delta smelt than in the deep river confluence during high outflow years when *Corbula* numbers are low and food resources in San Joaquin river water reach the LSZ in the fall. Together, these habitat features may increase delta smelt growth, survival, and fecundity.

- *Health and condition:* Similar to the mechanisms listed for growth, survival and fecundity, a broader distribution across the bathymetrically complex Suisun region can affect health and condition. For example, more habitat may help delta smelt avoid, or reduce exposure to, toxic hot spots, limit entrainment to diversions and access better food resources, compensate for degraded physical habitat elsewhere.
- *Recruitment in the next spring:* Ultimately, the factors listed above may lead to greater recruitment of delta smelt. However, before they can recruit successfully, delta smelt need to find suitable spawning and larval rearing habitat upstream of the low salinity zone. In addition to summer and fall habitat conditions, successful recruitment thus requires suitable winter and spring conditions for migration, spawning, and larval rearing. These habitat conditions depend on the interplay of a different set of stationary and changing dynamic habitat features. Only if habitat conditions are met year-round will delta smelt be able to successfully maintain their life history and genetic diversity and thus, maintain a viable population in their original habitat into the future.

Delta Smelt In the Northern Delta: While the center of the delta smelt distribution in the fall is the low salinity zone, they also occur year-round in the northern Delta, but are no longer found in their historical range in the southern Delta in the summer and fall (Nobriga et al. 2008, Sommer et al. 2011). Because delta smelt are currently found in the northern Delta in the fall, this region also constitutes current delta smelt fall habitat. It is important to note, however, that habitat quality and resulting delta smelt survival, health, growth, fecundity and recruitment contribution to the total population may differ between this region and the low salinity region. The 2011 study plan includes a comparison of dynamic and stationary habitat features and delta smelt responses in the LSZ and northern Delta habitats.

The northern Delta range of delta smelt in the fall includes the Sacramento deepwater ship channel and the Cache Slough complex with its dead-end sloughs and the large, flooded Liberty Island. This region has a number of similarities in stationary habitat features with the Suisun region: compared to the mainstem Sacramento River, it is bathymetrically complex, turbid, productive, and has low entrainment risk and variable risk of toxin exposure and predation. Dynamic habitat features include strong tidal exchanges with the Sacramento River, variable contributions of highly productive tributary waters, and increasing salinity levels up to about 0.5 psu from the mainstem Sacramento River into the ship channel and the smaller sloughs. Like the Suisun region, the northern Delta region is also targeted for habitat restoration activities. Learning more about its habitat suitability for juvenile delta smelt in the summer and fall thus provides not only an informative comparison for the low salinity habitat investigation, but will likely also yield key insights for implementing more science-based habitat restoration in both areas.

At this time we hypothesize that while the salinity range may not be physiologically optimal in the northern Delta, the interplay of the dynamic and stationary habitat features in the northern delta may result in a secondary production area for juvenile delta smelt that geographically overlaps with optimal spawning habitat, thus eliminating the need for and the associated dangers of the spawning migration. It is important to note that genetically, delta smelt are a single, panmictic population that may have different migration patterns of subsets (contingents) within the population (Sommer et al. 2011), but no persistent genetic differentiation into subpopulations (Fisch et al. 2011).

If done in concert with the low salinity habitat restoration that is afforded by higher fall outflows in wet and above normal years such as 2011, additional habitat improvements for delta smelt spawning and rearing in the northern delta may have substantial benefits for the delta smelt population. On the other hand, northern Delta habitat restoration alone will likely not be enough for delta smelt recovery – the salinity in the northern Delta is too low. With the fall outflow adaptive management plan, we intend to test and refine these predictions and associated management strategies.

(5) SET-UP ELEMENT: PREDICTIONS

A key to the adaptive approach described in this document is that the alternative fall outflow scenarios explored in the new conceptual model for 2011 lead to a suite of expected responses about dynamic habitat drivers and biological responses at multiple levels of the ecosystem. As explained in the conceptual model section, the stationary habitat components are not static. We do not, however, expect any of the stationary habitat components to change rapidly or appreciably in response to fall outflow management.

Our expectations about dynamic habitat drivers and biological responses are presented in the form of quantitative and qualitative predictions in Table 1. The science plan detailed below is designed to test these predictions (there stated in the form of hypotheses and/or study questions) and provide additional quantitative results that will be used to better quantify the predictions and improve the level of certainty with which they can be made. Quantitative results will also be used to parameterize additional quantitative models and to develop predictions for additional dynamic response variables. Several important dynamic response variables are suggested by the conceptual model, but not yet incorporated into Table 1 because there is not yet enough data available to make qualitative or quantitative predictions. This includes predator density and predation rates, contaminant concentrations and effects, jellyfish dynamics, microbial dynamics, and delta smelt responses beyond the fall such as recruitment and future abundance trends.

It is important to note that delta smelt responses may not be detectable in the first years of the action, but may require many years of careful outflow management and persistent monitoring to become detectable with a sufficiently high degree of certainty. Delta smelt are currently so rare that Allee effects may prevent their recovery for quite some time. The low delta smelt numbers also make it is difficult to detect significant trends. In addition, as described in the POD and HSG models, delta smelt and the other POD fishes are subjected to multiple and often interacting stressors, in addition to the persistently low delta outflow and high X2 in the falls of the POD years. Recovery of delta smelt ultimately depends on a reduction in many stressors that currently degrade their habitat and will likely take years, if not decades, to fully manifest itself.

The 81 km and 74 km columns in Table 1 correspond to RPA X2 targets for "above normal" and "wet" water years and the high outflow variant (Figure 15A) of the variable outflow scenario described in the new conceptual model (left side of Figure 16). The 85 km column represents the "low habitat" tier in Figure 4 and the static low fall outflow scenario (Figure 15B and right side of Figure 16). These predictions provide a starting point for development of analyses that progressively evaluate the adequacy of the existing conceptual and quantitative models and suggest new or refined ones.

Table 1. Predicted qualitative and quantitative outcomes of X2 management in the fall based on 3 levels of the action. Numbers in the "Measurements and analysis " columns designate what will be measured, see table footnotes. These measurements are explained in more detail in the Science Plan section below.

Variable (Fall Months)	Predictions for X2 scenarios			Measurements and Analysis			Notes
	85 km	81 km	74 km	Monitoring Data	Studies Data	Analysis and Modeling	
Dynamic Abiotic Habitat Components							
Average Daily Net Delta Outflow	~5000 cfs?	~8000 cfs?	11400	M 1	S 1	A 1	
San Joaquin River Contribution to Fall Outflow	0	Very Low	Low	M 1	S 1	A 1	
Hydrodynamic Complexity in LSZ	Lower	Moderate	Higher	M 1	S 1	A 1	
Average Wind Speed in the LSZ	Lower	Moderate	Higher	M 2	S 2	A 2	
Surface area of the fall LSZ	~ 4000 ha	~ 5000 ha	~ 9000 ha	M 3-a	S 3-a	A 3-a	
Average Turbidity in the LSZ	Lower	Moderate	Higher	M 3-a	S 3-a	A 3-a	
Average Secchi Depth in the LSZ	Higher	Moderate	Lower	M 3-a	S 3-a	A 3-a	
Average Ammonium Concentration in the LSZ	Higher	Moderate	Lower	M 3-b	S 3-b	A 3-b	
Average Nitrate Concentration in the LSZ	Moderate	Moderate	Higher	M 3-b	S 3-b	A 3-b	
Delta Smelt Abiotic Habitat Index	3270 ± 220	4870 ± 243	7300 ± 285	M 1, M 3-a	S 1, S 3-a	A 1, A 3-a	
Dynamic Biotic Habitat Components							
Average Phytoplankton Biomass in the LSZ (excluding Microcystis)	Lower	Moderate	Higher	M 4-a	S 4-a	A 4-a	
Contribution of Diatoms to LSZ Phytoplankton Biomass	Lower	Moderate	Higher	M 4-a	S 4-a	A 4-a	
Contribution of Other Algae to LSZ Phytoplankton biomass at X2	Higher	Moderate	Lower	M 4-a	S 4-a	A 4-a	
Average Floating Microcystis Density in the LSZ	Higher	Moderate	Lower	M 4-a	S 4-a	A 4-a	
Phytoplankton biomass variability across LSZ	Lower	Moderate	Higher	M 4-a	S 4-a	A 4-a	
Calanoid copepod biomass in the LSZ	Lower	Moderate	Higher	M 4-b	S 4-b	A 4-b	
Cyclopoid copepod biomass in the LSZ	Lower	Moderate	Moderate	M 4-b	S 4-b	A 4-b	
Copepod biomass variability across LSZ	Lower	Moderate	Higher	M 4-b	S 4-b	A 4-b	
Corbula biomass in the LSZ	Higher	Moderate	Lower	M 5	S 5	A 5	
Delta Smelt (DS) Responses							
DS caught at Suisun power plants	0	0	Some	M 6	S 6	A 6	
DS in fall SWP & CVP salvage	Some?	0	0	M 6	S 6	A 6	
DS center of distribution (km)	85 (77-93)	82 (75-90)	78 (70-85)	M 6	S 6	A 6	
DS growth, survival, and fecundity in fall	Lower	Moderate	Higher	M 6	S 6	A 6	
DS health and condition in fall	Lower	Moderate	Higher	M 6	S 6	A 6	

Table 1 Footnotes:

M 1: Delta Flow Data- inflows, outflows, and estuarine hydrodynamics
M 2: Meteorological Data - wind speed, wind direction, precipitation, and solar radiation
M 3: Water Quality Data
- M 3-a Salinity, Turbidity, Temperature
- M 3-b Nutrients, Dissolved Oxygen, Organic Carbon, pH
- M 3-c Contaminants and Toxicity

M 4: Plankton Data
- M 4-a Phytoplankton and Microcystis
- M 4-b Zooplankton and Jellyfish

M 5: Benthic Macroinvertebrate Data

M 6: Fish Data
M 7: SAV Data
S 1: Delta hydrology and hydrodynamics studies
S 2: Water Quality studies
    S 2-a Salinity, Turbidity, Temperature
    S 2-b Nutrients, Dissolved Oxygen, Organic Carbon, pH
    S 3-c Contaminants and Toxicity
S 4: Plankton Studies
    S 4-a Phytoplankton and Microcystis
    S 4-b Zooplankton and Jellyfish
S 5: Benthic Macroinvertebrate Studies 6: Fish Studies
S 7: SAV Studies
A 1: Delta hydrology and hydrodynamics analyses
A 2: Water Quality analyses
    A 2-a Salinity, Turbidity, Temperature
    A 2-b Nutrients, Dissolved Oxygen, Organic Carbon, pH
    A 3-c Contaminants and Toxicity
A 4: Plankton analyses
    A 4-a Phytoplankton and Microcystis
    A 4-b Zooplankton and Jellyfish
A 5: Benthic Macroinvertebrate analyses
A 6: Fish analyses
A 7: SAV analyses

(6) SET-UP ELEMENT: SCIENCE PLAN

The science plan for adaptive management of fall outflow (simply referred to as the "science plan" in the remainder of this document) contains monitoring and research study elements that are intended for implementation in all years, whether a fall outflow augmentation is carried out or not. This document contains the initial science plan for 2011-2012. The science plans for future years (i.e. for the *iterative phase*) will be modified based on what has been learned in preceding years.

In the following sections, we first describe monitoring and field and laboratory studies intended to address hypotheses and questions derived from the conceptual model, test the predictions listed in Table 1, and provide numerical inputs to quantitative models. We then describe data analyses and quantitative modeling intended to improve the conceptual model and provide additional quantitative predictions.

While new field studies are especially designed to take advantage of the very wet conditions of 2011, the science plan also includes analyses of existing data intended to contrast the wet 2011 and other wet years with habitat and fish responses in previous wet years as well as in drier years. Newly developed models will be validated and tested with additional field and lab studies in future years (iterative phase).

In labor and cost terms, we are fortunate that a majority of the needed long-term monitoring is are already being done by the Interagency Ecological Program (IEP, see http://www.water.ca.gov/iep/ for detailed information about IEP monitoring and research). In addition, the IEP, the Delta Science Program (DSP, www.deltacouncil.ca.gov/delta_science_program/), and the Ecosystem Restoration Program have a long history of supporting, coordinating, and carrying out shorter-term, hypothesis and question-driven studies that address scientific questions with clear management relevance. Since 2005, the IEP has implemented a series of successive work plans investigating the decline of four pelagic fish species in the estuary (known as the Pelagic Organism Decline (POD) investigations). These comprehensive workplans have included tightly coordinated monitoring and study elements funded by the IEP, DSP, ERP, and others. The most recent published POD workplan (Baxter et al. 2010) included a number of studies funded after an open proposal solicitation that focused on the effects of fall outflow management on delta smelt. Along with the long-term monitoring and a number of new studies, these ongoing POD studies form the basis for the fall outflow science plan, while the POD workplan provides the broader multi-species habitat and ecosystem context for the fall outflow science plan.

A main objective for the fall outflow science plan is to ensure the high level of coordination of the existing monitoring and studies needed to carry out the comprehensive analyses, syntheses, and modeling needed for adaptively managing fall outflow and other important system variables to accomplish the co-equal goals of water supply and ecosystem protection.

MONITORING

The IEP and others have conducted fish, invertebrate, phytoplankton, and water quality monitoring surveys in the estuary for more than four decades. These surveys are carried out year-round from several times a week (e.g. Chipps Island fish trawls) to semi-annually (e.g. spatially intensive benthos surveys). In addition, many monitoring stations in the estuary and its watershed are equipped with continuously recording instrumentation for a variety of hydrological, meteorological, and water quality variables. Together, these monitoring surveys and stations play a key role in the fall outflow science plan.

The fall outflow science plan will not change the spatial or temporal sampling design of any long-term monitoring surveys, as continuity of historical time series and the ability to test hypotheses about effects of the action based on comparison of new data to historical data are important objectives of this plan.

Two key fish monitoring surveys conducted in the summer and fall recently extended their sampling area to include new stations in the Cache Slough complex and the Sacramento Deep Water Ship Channel in the northern Delta. These surveys also collect data for zooplankton, salinity, and turbidity at the fish sampling stations. Additional special surveys are currently conducting turbidity monitoring (USGS) and toxicity monitoring (UCD and UCB) in this region. Some delta smelt from this region apparently remain resident (see Sommer et al. 2011) and measures of growth, diet etc. of these fish can provide an informative contrast with those collected from the LSZ.

At this time, the 2011-12 Science Plan does not include any augmentation of delta smelt sampling during monitoring surveys because the current abundance of delta smelt is so low. Instead, the Science Plan proposes to make limited use of surrogate species, such as age-0 striped bass, threadfin shad, and Mississippi silversides, when delta smelt catches are low. This also extends the fall outflow science plan to include two other POD species (age-0 striped bass and threadfin shad), thus broadening its scope beyond a single target species. Importantly, we recognize that there are no true surrogate species for delta smelt, *i.e.* open water planktivores with a distribution narrowly centered on the LSZ in the fall. This limits the usefulness of data from surrogates for assessing delta smelt responses to fall outflow and other management actions (Murphy et al. 2011). Young striped bass have the greatest distribution overlap with delta smelt and feed on plankton organisms in their first year of life, but they are much better able to make use of benthic and near-shore prey than delta smelt and become piscivorous starting in the first and second year of life (Sommer et al. 2011). Interpretation of surrogate species responses to fall outflow management will thus proceed with great care and data obtained directly from delta smelt will always take precedence over data obtained from other species in informing future management adaptations. Data from other fish species is mostly used for comparisons.

The following data are currently slated to be collected during routine monitoring surveys to test and refine the predictions in Table 1 and collect additional information about the habitat components and biological responses contained in the conceptual model for this study. The monitoring efforts described below are numbered according to the numbers in the "monitoring data" column in Table 1. In some cases the monitoring is augmented by ongoing special studies which are described in more detail below.

M 1: Delta Flow Data

In the conceptual model described above, inflows, outflows, and estuarine hydrodynamics are the primary dynamic habitat components responsible for the location and extent of the dynamic LSZ in the fall. The IEP agencies operate numerous flow monitoring stations in the estuary and its watershed. Raw data collected at most of these stations is generally available in real time at DWR's California Data Exchange Center website (CDEC, http://cdec.water.ca.gov/). Additional short-term studies augment the monitoring data.

- Some 35 fixed stations located throughout the Delta and Suisun regions have instrumentation for continuous recording of flow and stage. Flow is measured Acoutstic Doppler Current Profiler (ADCP) technology. These stations are operated by DWR, USBR, and USGS.
- Daily average net Delta outflow for the preceding water year (Oct-Sep) is computed once a year by DWR's Dayflow program and made available at http://www.water.ca.gov/dayflow/. The program uses daily river inflows, water exports, rainfall, and estimates of Delta agriculture depletions to estimate the "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is a key index of the physical, chemical, biological state of the northern reach of the San Francisco Estuary.

M 2: Meteorological Data

Wind is an important driver of hydrodynamics and turbidity while solar radiation is important for under-water visibility, seasonal phytoplankton production cycles, and physiological and behavioral responses to day-night cycles. The IEP agencies operate numerous weather stations in the estuary and its watershed. Raw data collected at most of these stations is generally available in real time at DWR's California Data Exchange Center website (CDEC, http://cdec.water.ca.gov/) and DWR's Irrigation Management Information System (CIMIS, http://www.cimis.water.ca.gov/cimis/). Additional short-term studies augment the monitoring data.

- Six fixed stations operated by IEP agencies in the Delta and Suisun region have instrumentation for continuous recording of air temperature, wind speed and direction and irradiance. Two more stations on the San Joaquin River (Vernalis and Mossdale) are slated for installation December 2011. Raw data from all of these stations are available at CDEC (see above). Stations in DWR's Irrigation Management Information System network provide additional data on air temperature, solar radiation, wind speed, wind direction, precipitation etc. around the estuary and in its watershed.

M 3: Water Quality Data

The IEP agencies, the San Francisco Bay Regional Monitoring Program (Bay RMP) conducted by the San Francisco Estuary Institute (SFEI), various dischargers with NPDES permits, and others conduct comprehensive water quality monitoring in the estuary at continuously recording fixed stations, along transects, and at fixed sites that are generally visited once a month by boat or from shore. Several of the monitored water quality constituents are key dynamic components of delta smelt habitat in the fall.

M 3-a Salinity, Turbidity, Temperature

- Salinity (as electrical conductivity, EC), temperature, and turbidity (nephelometric) are measured and recorded continuously (every 15 minutes) at dozens of fixed stations operated by DWR, USBR, and USGS. The raw data from these stations are usually available in real time at DWR's California Data Exchange Center website (CDEC, http://cdec.water.ca.gov/). CDEC also provides calculated real-time X2 estimates (station ID "CX2").

- The DWR-led IEP Environmental Monitoring Program (EMP, see http://www.water.ca.gov/iep/activities/emp) conducts monthly continuous transect sampling along routes connecting the EMP's discrete monitoring sites and the home port of its research vessels in Antioch. Water is continuously pumped from 1 m water depth to sensors that measure salinity (as specific conductance), temperature, and turbidity (nephelometric) Geographical position is recorded along with the monitoring data.
- The IEP EMP also measures temperature, EC, turbidity, and Secchi depth along with total suspended solids in grab samples collected at 25 stations that are visited monthly. The EMP also conducts vertical profile measurements of temperature and EC at these stations. In addition, vertical profile measurements are also conducted at two floating stations that follow the 2 psu and 6 psu isohalines along the axis of the estuary.
- The Bay RMP (USGS for SFEI, see http://sfbay.wr.usgs.gov/access/wqdata/index) includes monthly water quality transect surveys at 39 fixed sampling stations spaced 3 to 6 km apart along the axis of the estuary from South San Francisco Bay to Rio Vista on the Sacramento River. Four of these stations are located in the Suisun region and four are located in the Sacramento river portion of the river confluence region. These surveys include vertical profiles of temperature, EC, and total suspended solids (optical backscatter). These data have been collected regularly for more than two decades.
- EC, turbidity, and Secchi depth are also measured at discrete sites during fish sampling surveys described below. In particular, temperature, EC, turbidity, and Secchi depth data is collected at 138 stations during the fall midwater trawl fish sampling events. Summer and spring fish surveys (SKT and TNS, see below) also include discrete turbidity and Secchi depth measurements at each of their fish sampling sites and the Chipps Island trawl and Suisun Marsh surveys include Secchi depth, temperature and EC measurements.

M 3-b Nutrients, Dissolved Oxygen, Organic Carbon, pH

- Several fixed stations have instrumentation for continuous recording of dissolved oxygen and pH. A few stations also have instrumentation for continuous recording of organic carbon and anions, including nitrate. Raw data collected at most of these stations is generally available in real time at DWR's California Data Exchange Center website (CDEC, http://cdec.water.ca.gov/).

- The IEP EMP conducts monthly continuous transect measurements at 1 m water depth for dissolved oxygen along the routes connecting its discrete monitoring sites and the home port of its research vessels in Antioch.
- The IEP EMP measures nutrients (including ammonium, nitrate and orthophosphate), dissolved oxygen, organic carbon, and pH at stations that are visited monthly. This includes vertical profiles of dissolved oxygen. The EMP nutrient monitoring is augmented by additional stations associated with several ongoing special studies in the Suisun region and elsewhere in the estuary (described below).
- The IEP EMP also conducts spatially intensive, biweekly dissolved oxygen monitoring surveys along the San Joaquin ship channel from about June to November of each year. This includes surface and bottom measurements.
- The Bay RMP (USGS for SFEI, see http://sfbay.wr.usgs.gov/access/wqdata/index) measures nutrients during monthly water quality transect surveys at the 39 fixed sampling stations along the axis of the estuary described above.
- Routine nutrient monitoring is augmented by additional stations associated with several ongoing special studies in the Suisun region and elsewhere in the estuary (described below).

M 3-c Contaminants and Toxicity

The San Francisco Bay Regional Monitoring Program (Bay RMP) conducted by the San Francisco Estuary Institute (SFEI) is a comprehensive, coordinated contaminant monitoring program for San Francisco Bay and the Suisun region. A similar program for the Delta (Delta RMP) is currently under development by the Central Valley Regional Water Quality Control Board (CVRWQB), but has not yet been implemented. In its absence, there is a diffuse network of discharge permit driven contaminant monitoring in the Delta (Johnson 2010). In addition, the IEP sponsored a 4-year invertebrate toxicity monitoring effort conducted by UC Davis from 2006-2009 at selected the fish monitoring sites, but this has been discontinued. Results showed that toxicity to invertebrates was quite rare at these sites. An ongoing IEP- CVRWQB sponsored as well as a newly funded DFG-ERP study include monitoring of pyrethroid toxicity to invertebrates in the Cache Slough Complex, but there is no consistent contaminant monitoring effort in the western Delta and Suisun region.

M 4: Plankton Data

Phytoplankton, zooplankton, and benthic invertebrates have been regularly monitored in the estuary over several decades by the IEP agencies and others. While phytoplankton and zooplankton represent the food base for delta smelt and other pelagic fishes, benthic invertebrates are generally not consumed by delta smelt and the non-native benthic clams *Corbula* and *Corbicula* compete with the fishes for zooplankton and reduce phytoplankton biomass. In recent years, several IEP fish surveys have started monitoring zooplankton at fish survey stations. Jellyfish are also monitored by a few programs. Microbial organisms, benthic microalgae, and submerged and emergent aquatic vegetation and associated invertebrate and algal communities are currently not routinely monitored. *Microcystis aeruginosa* blooms are monitored with a qualitative surface bloom density ranking system during fish and water quality monitoring surveys.

M 4-a Phytoplankton and Microcystis

- Several fixed stations have instrumentation for continuous recording of chlorophyll *a* fluorescence which can be used as a surrogate for phytoplankton biomass. These sensors are regularly calibrated and maintained by DWR. Raw data collected at most of these stations is generally available in real time at DWR's California Data Exchange Center website (CDEC, http://cdec.water.ca.gov/).
- The IEP EMP conducts monthly continuous transect measurements at 1 m water depth for chlorophyll *a* fluorescence along the routes connecting its discrete monitoring sites and the home port of its research vessels in Antioch. An additional continuously recording spectrofluorometer (bbe FluoroProbe) that measures the relative contributions of green, brown, blue-green, and cryptophyte algae to total chlorophyll *a* was added to the EMP transect measurements in 2008.
- The IEP EMP also measures chlorophyll *a* concentrations and microscopically identifies and enumerates phytoplankton species in discrete grab samples collected at stations that are visited monthly.
- The Bay RMP (USGS for SFEI, see http://sfbay.wr.usgs.gov/access/wqdata/index) collects vertical chlorophyll *a* fluorescence profiles during monthly water quality transect surveys at the 39 fixed sampling stations along the axis of the estuary described above. It also collects discrete chlorophyll *a* and phytoplankton grab samples for microscopic identification and enumeration.
- *Microcystis aeruginosa* bloom distribution and density is currently assessed qualitatively (ranked visually) during several monitoring surveys (EMP, TNS, FMWT). Remote sensing based monitoring tools are still under development.

M 4-b Zooplankton and Jellyfish

- The IEP EMP includes a monthly zooplankton monitoring component conducted by DFG which collects, identifies, and enumerates macrozooplankton (mainly mysids), mesozooplankton (mainly copepods and cladocerans), and microzooplankton (rotifers, copepod nauplii)
- Several IEP fish monitoring surveys conducted by DFG (see below for details) also collect zooplankton at fish monitoring sites: the 20-mm survey has collected mesozooplankton samples at all its sites since 1995; the summer

townet survey has collected mesozooplankton samples at all its stations since 2005; The UCD Suisun Marsh has intermittently collected zooplankton samples and began doing so again in 2010. Macro- and mesozooplanktion monitoring is proposed for some of the DFG Fall Midwater Trawls stations. (See below for more details about these surveys).

- The DFG Bay Study identifies, counts and reports gelatinous plankton (jellyfish) from all its sampling stations (since 2000). The DFG Fall Midwater Trawl has enumerated jellyfish since 2001. The DFG Summer Townet Survey began enumerating jellyfish in 2007. The UCD Suisun Marsh survey has reported jellyfish since this survey began.

M 5: Benthic Macroinvertebrate Data

Benthic macroinvertebrates have been regularly monitored in the estuary over several decades by the IEP agencies. Benthic invertebrates are generally not consumed by delta smelt and the non-native benthic clams *Corbula* and *Corbicula* compete with fishes for zooplankton and reduce phytoplankton biomass. *Corbula* biomass is highest under high X2 and low outflow conditions.

- Grab samples for benthic macroinvertebrates including the clams *Corbula* and *Corbicula* will be collected once per month at 13 IEP EMP stations. All invertebrates will be identified and enumerated. In addition, clams will be weighed and measured to assess their biomass.
- Benthic macroinvertebrates will also be collected and enumerated during a spatially-intensive IEP survey using a general randomized tessellation survey design (GRTS) that is conducted by DWR and USGS in October and and May. An additional GRTS survey focusing on the confluence and Suisun region will be conducted by DWR in August 2011 to assess clam abundance and biomass before the fall months.

M 6: Fish Data

Fall outflow management is predicted to affect delta smelt and other fishes monitored in the estuary and its watershed. The IEP monitoring program includes 16 fish monitoring surveys in the estuary (Honey et al. 2004). Many of these surveys are required by OCAP Biological Opinions and deliver critical data for status and trends assessments and water project operations. IEP fish monitoring is carried out by five organizations: California Department of Fish and Game (DFG), California Department of Water Resources (DWR), University of California Davis (UC Davis), US Bureau of Reclamation (USBR), and US Fish and Wildlife Service (USFWS). Most of the fish monitoring surveys have been conducted for several decades. The oldest continuing surveys are the DFG's Summer Townet Survey (TNS, since 1959) and Fall Midwater Trawl survey (FMWT, since 1967). These two surveys routinely deliver key data on delta smelt abundance and distribution before (TNS) and during (FMWT) the fall season. Two other surveys, the DFG's Spring Kodiak Survey (SKT) and 20-mm Survey deliver data on adult and juvenile delta smelt abundance and distribution in the winter and spring. Additional delta smelt data is available from DFG's San Francisco Bay study, FWS's Delta Juvenile Fish beach seine survey and Chipps Island midwater trawl surveys, UCD's Suisun marsh survey, fish collected at the Suisun Bay powerplants, and fish collected at the Skinner and Tracy water project fish facilities (salvage).

- Delta smelt and other fish data will be collected by several IEP fish surveys. Delta smelt fall abundance and distribution data will be collected primarily by the IEP Fall Midwater Trawl (FMWT) Survey conducted by DFG. The FMWT survey samples 138 stations monthly September through December, including 6 new stations as of 2009 and 2010 in the Cache Slough complex and the Sacramento Deep Water Ship Channel. Additional information will come from the DFG San Francisco Bay Study (Bay Study, 52 stations monthly, year-round), the UCD Suisun Marsh Study (21 stations monthly, year-round), the USFWS Chipps Island Trawl (one location, 10 tows, 3 or more times per week, year-round), and the USFWS Delta Juvenile Fish Beach Seine Survey (57 sites sampled weekly, year-round). Pre-fall distribution and abundance information will be generated by the DFG 20 mm Survey (41 stations biweekly, mid-March through mid-July) and DFG Summer Townet Survey (TNS, 40 stations biweekly June through August), including 8 new stations in Cache Slough and the Sacramento Deep Water Ship Channel. Post-fall information will come primarily from the DFG Spring Kodiak Trawl Survey (SKT, 39 stations monthly, January through May (see Honey et al. 2004 for sampling details and IEP web pages (http://www.dfg.ca.gov/delta/) under 'Surveys, Studies and Programs' for more information and recent survey sampling enhancements).
- Delta smelt collected during the August TNS and FMWT (all months) monitoring surveys described above will be handled and stored appropriately to determine body condition and conduct otolith growth, otolith chemistry (looking for migratory or resident signature), and diet and overall health assessments. In addition, fish from January through March SKT samples will be assessed for fecundity and potentially indicators of repeat spawning. Much of this fish processing has not been done on a consistent basis historically and will be conducted by UC Davis scientists (Dr. Swee Teh, Dr. Jim Hobbs, and others). We will evaluate the utility and feasibility of these analyses for incorporation into routine monitoring. Fish collection, handling, and analyses will be carried out by staff from DFG and UC Davis. Delta smelt as well as selected age-0 striped bass, threadfin shad, and Mississippi silversides will be examined, prepared, and analyzed as follows.

The following will be done in the field, immediately after capture:

- Identify, measure length, (mm FL) and assign an individual code to each delta smelt and other target fishes.
- Measure fish weight (0.1 gr) for body condition, hepatosomatic index
- Visually assess injury and disease status for general health index
- Extract, examine, prepare, preserve and archive tissue for laboratory analysis:
    - Gills – extracted, weighed (0.1 gr) and preserved;
    - Liver – extracted, weighed (0.1 gr) and preserved for histopathic exam, glycogen content, lipid and fatty acid analysis;
    - Stomach – for content identification;
    - Gonads (if present) – weigh fresh, assess egg quality - to estimate fecundity, assess the likelihood of previous spawning or future spawning (i.e., multiple spawning in a season);
    - Genetic fin clip samples – to assess delta smelt population structure;
    - Head – preserved in 95%ETOH for otolith chemistry to determine salinity history and potentially migratory timing, otolith incremental growth;
    - Dorsal muscles (& possibly livers) – for stable isotope analyis.
    - Preserve and archive remaining carcass in buffered formalin.

STUDIES

As mentioned above, the IEP, DSP, ERP have a long history of supporting, coordinating, and carrying out short-term studies that address scientific questions with clear management relevance. The IEP POD workplans have attempted to coordinate and integrate studies funded by all three programs in order to answer questions about the POD. We view the fall outflow science plan as a logical part and extension of the POD workplans. The most recent published POD workplan (Baxter et al. 2010) includes a number of studies about fall outflow effects on other dynamic habitat variables and responses by delta smelt. These ongoing studies are included in the fall outflow science plan. New studies are added to address additional questions about the effects of fall outflow after the very wet spring of 2011 and to provide data for modeling efforts. The new studies include several that recently funded by the DSP and the ERP. These studies will be coordinated and integrated by the fall habitat study group.

Fall habitat studies focus on the western Delta and Susiun regions, but also include studies conducted in larger areas and in the northern Delta.

The following studies about habitat components and delta smelt responses listed in Table 1 are currently slated to be conducted as part of the fall outflow science plan. In addition, studies are also conducted to quantify habitat dynamics for components for which we could not yet make a prediction in Table 1. These are listed in Table 2, using the same numbering system as in Table 1. In many cases, data collected as part of these studies augments and complements data collected by the monitoring surveys described above. The ongoing and new studies described below are placed in categories that are numbered according to the numbers in the "studies data" column in Table 1.. Modeling studies are listed in the Analysis and Modeling sections.

Variable (Fall Months)	Measurements and Analysis			Notes
	Monitoring Data	Studies Data	Analysis & Modeling	
Dynamic Abiotic Habitat Components				
Contaminant Concentrations	M 3-c	S 3-c		
Dynamic Biotic Habitat Components				
Average Bacterioplankton Biomass in the LSZ		S 4-a		
Average Protozoan Plankton Biomass in the LSZ		S 4-a		
SAV cover, distribution, and species composition in the LSZ	M7	S 4-a		
Invertebrate Biomass and species composition associated with SAV in the LSZ		S 4-a		
Jellyfish biomass in the LSZ	M 4-b			
Jellyfish biomass variability across LSZ		S 4-b		
Delta Smelt (DS) Responses				
DS recruitment	M 6	S 6		
DS abundance	M 6	S 6		

Table 2: Additional variables investigated by special studies.

Abiotic Habitat components:

S 1: Delta hydrology and hydrodynamics studies – see S 2-a, below.
S 2: Water Quality studies

S 2-a Salinity, Turbidity, Temperature

Ongoing:

IEP 2011-XXX. Scott Wright, USGS, and others: "Delta sediment measurements to support numerical modeling of turbidity." The total three-year budget for the five-year project is $1,955,213. The purpose of the proposed work is to collect data that will support the development, calibration, and validation of numerical models of sediment transport and turbidity in the Sacramento-San Joaquin Delta. While some data on sediment transport and geomorphology exist for the Delta, there are major data gaps that preclude accurate specification of model boundary and initial conditions. Also, measurements are needed to constrain model parameters related to various physical processes, such as erosion rates and settling velocities. Data is provided immediately, provisionally, on an ongoing basis to facilitate model development in the near-term.

IEP 2011-XXX. Jon Burau, USGS, and others: "Measurement of boundary condition data in support of a sediment transport model and improved web-based data visualization software." The total budget for the five-year project is $1,884,291. The goals of this project are four-fold: (1) measure the flows and turbidity at four new sites to establish boundary conditions for numerical hydrodynamic and sediment transport models and to allow the computation of suspended solids flux into and out of the Delta and between regions within the Delta; (2) estimate the complete scalar field (including turbidity) along a transect between Mallard and Liberty Island for each slack water; (3) collect acoustic backscatterance data as a surrogate that can be calibrated to turbidity and suspended solids concentrations by replacing aging Sontek Sideward-Looking Acoustic Doppler Current Profilers (ADCP) at ten sites with RDI 600 kHz units; and (4) improve visualization of time-series data and scalar fields, including turbidity.

S 2-b Nutrients, Dissolved Oxygen, Organic Carbon, pH

IEP 2010-164 R,. Dugdale, SFSU, and others: "Spatial and Temporal Variability in Nutrients in Suisun Bay in Relation to Spring Phytoplankton Blooms". The goal of this study is to answer the two questions: How do nutrients vary in Suisun Bay temporally and spatially and how does this relate to spring phytoplankton blooms? What are the major sources of ammonium in Suisun Bay?
This study is an extension of earlier work on the effect of ammonia on phytoplankton blooms in the estuary. The purpose of this project is to quantify and better understand the variability of nutrients in Suisun Bay, their relation to spring phytoplankton blooms, and sources of ammonium.

IEP 2010-173. R. Dugdale, SFSU, and others: "Distribution, Concentrations and Fate of Ammonium in the Sacramento River and the Low Salinity Zone: Determination of Phytoplankton Uptake and Bacterial Nitrification Rates." Cost: $77,000. This research will quantify 2 key biological processes influencing river NH_4^+ distribution, bacterial nitrification (= NH_4^+ oxidation) and phytoplankton uptake, and in future years will investigate the degree of river flow-dependence on these processes. The first step is to develop a protocol for measuring water column nitrification using 15N-labeled NH4+ as a tracer. The protocol is then applied to archived river samples that will be incubated and collected in spring and summer 2010 (as part of the CALFED-funded "Two Rivers" project, Dugdale and Mueller-Solger, Lead-PIs) and the Fall 2010 IEP Foodweb (Parker, et al., 2010). C. Kendall, USGS, will also be involved by collecting samples for natural abundance stable isotope work, for independent estimates of nitrification and phytoplankton N uptake. This project addresses the questions: Can pelagic nitrification rates be measured (and validated to a degree) in the San Francisco Bay using 15N labeling, the NH4+ micro-diffusion technique and mass spectrometry? What are the rates of (a) bacterial/archaeal nitrification and (b) phytoplankton NH4+ uptake downstream from Sacramento to Suisun Bay in spring, summer and fall? Does the fate of NH4+ (i.e., uptake and nitrification) change with season, salinity and flow?

IEP 2010-174. A. Parker, SFSU, and others: "The influence of elevated ammonium (NH4) on phytoplankton physiology in the San Francisco Estuary Delta during fall: exploring differences in nutrients and phytoplankton in the Sacramento and San Joaquin Rivers and how variation in irradiance via changing river flow, modulates NH4 effects." Cost: $114,000. Elevated NH4 concentrations (>4 µmol L-1) appear to inhibit phytoplankton NO3 uptake. One outstanding question is whether the NH4 inhibition effect or the NO3 shift-up that follows NH4 exhaustion occurs at low irradiances characteristic of the natural system. Research in marine settings has demonstrated an irradiance response for phytoplankton DIN uptake, including a differential response for phytoplankton NH4 and NO3 uptake. Phytoplankton DIN versus irradiance relationships are not clear for the SFE or estuarine environments in general. This study addresses the questions: What are the rates of primary production and phytoplankton NO3 and NH4 uptake in the Sacramento and San Joaquin rivers during the fall period? What role does DIN composition and concentration play in modulating the above phytoplankton rates and phytoplankton species composition? How does river flow affect nutrient distribution and phytoplankton rates? Does the conceptual model of NH4 suppression of phytoplankton NO3 uptake and primary production hold under low-light conditions?

Variable	DS Response	DS Source	DS Life Stage	PI	At	$	Study ID	Type
Dynamic Abiotic Habitat Components								
Salinity	Feeding, survival, swimming behavior	FCCL	juvenile to adult	J. Lindberg	UCD	50,000		Ongoing
Turbidity	Feeding, survival, swimming behavior	FCCL	juvenile to adult	J. Lindberg	UCD	50,000		Ongoing
(... and predation)	Feeding behavior, oxygen consumption	FCCL	larval to juvenile	L. Sullivan	SFSU			Ongoing
Hydrodynamic complexity	??? (Has study with swimming at different flows etc been dione by Tina? Someone else?	FCCL	juvenile to adult					
Contaminants	Site-specific gene expression and TIEs after 7-d toxicity assays with water from Delta and Suisn Marsh sites	FCCL	larval to juvenile	R. Connon	UCD			Ongoing
Dynamic Biotic Habitat Components								
Simulated predation (and turbidity)	DS Feeding behavior, oxygen consumption	FCCL	larval to juvenile	L. Sullivan	SFSU			Ongoing
Jellyfish predation	DS Ingestion by jellyfish	FCCL	larval to juvenile	L. Sullivan	SFSU			Ongoing
Silverside predation	DS genes in silverside guts	Field monitoring and studies	larval to juvenile	B. Schreier	DWR			Ongoing
Striped bass predation	DS genes in striped bass guts & microscopic gut content analysis	Field monitoring and studies	all	F. Feyrer	USBR			Ongoing
Copepod density	Feeding rate, oxygen consumption	FCCL	larval to juvenile	L. Sullivan	SFSU			Ongoing
Zooplankton food quality (different zooplankton species) (...& salinity)	Growth rate, fatty acid profile - (did Lindsey already do enough?). Behavioral response (Loge?)?	FCCL	juvenile to adult	Could use Nann Fangue's postdoc				
Stuckenia beds	Delta smelt abundance in Stuckenia beds	Field	all	K. Boyer	SFSU			New
New Delta Smelt Study Tools								
SmeltCam underwater towed imagin	DS abundance and distribution	FCCL & Field tests	all	Don Portz	USBR			Ongoing
JSATS tag development	Delta smelt swimming responses	FCCL	1- & 2-year old adult	F. Loge	UCD			Ongoing

Table 3: S6 Studies that directly link habitat components and delta smelt responses.

ANALYSES AND MODELING

The monitoring and study elements described above will provide data for comprehensive analysis and modeling efforts. These efforts are intended to test hypotheses and answer questions about responses of delta smelt to fall outflow management and affected habitat components. Example hypotheses and questions related to each habitat component in the conceptual model are listed below, along with the analysis and modeling approaches that will be used to address them. In many cases, these efforts bring together data collected by a variety of monitoring surveys and studies. In addition to data collected in 2011-12, the analysis and modeling efforts described here also rely heavily on historical data, where available. The numbering below corresponds to the "Analysis" column in Tables 1 and 2. There are no numbers for the stationary habitat components.

Stationary Abiotic Habitat Components

The stationary (geographically fixed) abiotic habitat components in the fall outflow conceptual model are bathymetric complexity, erodible sediment supply, contaminant sources, and entrainment sites. They differ between the two regions in which the LSZ is placed in the fall through the outflow management prescribed in the BiOp – the Suisun region during falls following wet springs and the river confluence during falls following dryer springs. These components are not expected to be affected by fall outflow management. They are not static, but they change much more slowly than the dynamic habitat components. Importantly, their interactions with the dynamic habitat components are expected to produce different delta smelt responses when the LSZ is in the Suisun region compared to when the LSZ is in the river confluence. In order to assess these interactions, the stationary habitat features need to be clearly documented.

Fortunately, good, recent data and documentation exists for bathymetry and bed sediment volume (Schoellhamer 2011), the location of entrainment sites, and contaminant sources (Johnson 2010). The study plan thus merely contains a data portal element for this information and notes that bathymetry surveys need to be repeated at regular intervals. Because less is known about bed sediment composition across the bays of the Suisun region, the science plan also contains a study element to address the questions: How does bed sediment composition vary among and within the shallow and deep areas of the Suisun region and river confluence? What are the sources of the bed sediments in the Suisun region and river confluence? *("fingerprinting" of sediment cores)*

Dynamic Abiotic Habitat Components

A 1: Delta hydrology and hydrodynamics studies

A 2: Water Quality analyses

Hypothesis: The amount of abiotic habitat for delta smelt varies with X2. Questions: Does fall turbidity vary with fall X2? How does X2 affect habitat volume/area based on salinity and water clarity? How does X2 affect the habitat of delta smelt predators such as striped bass and largemouth bass? Does X2 affect the abundance and distribution of submerged aquatic vegetation (SAV) such as Egeria?
Does SAV proliferation affect delta smelt spawning habitat?

Hypothesis: High fall X2 exacerbates contaminant effects. Questions: How does fall X2 affect the distribution, concentration, and effects of ammonia and ammonium? How does fall X2 affect the distribution, concentration, and effects of other contaminants? How does fall X2 affect the frequency of occurrence and distribution of acute and chronic toxicity of ambient water to delta smelt and their food organisms?

Hypothesis: High X2 increases losses to agricultural diversions. Questions: Does high X2 shift delta smelt distribution to an area with a higher risk of agricultural entrainment? How do agricultural operations in the western delta change in response to higher X2? How do agricultural losses of delta smelt vary with X2?

Hypothesis: High X2 increases losses to power plants. Questions: Does high X2 shift delta smelt distribution to an area with a higher risk of power plant entrainment in the Sept-Nov period? How do power plant losses of delta smelt vary with X2? Does power plant entrainment present a substantial risk of mortality?

Hypothesis: High X2 increases losses to SWP and CVP export facilities. Questions: How does the probability of fish entrainment during winter upstream migration vary with fall X2?

Interactions with abiotic habitat components in other seasons

In analyzing the importance of fall X2 variability and the effects of RPA 3 we must look for evidence of sporadic, non-linear, or interactive effects of flows in the fall with other drivers and in other seasons. Most of the hypotheses and questions about these types of interactions follow from the hypotheses and questions about the effects of individual drivers, and in several cases the questions included under the individual drivers above already address various interactions.

Hypothesis: Conditions in the spring affect flow effects on delta smelt in the fall. Questions: How does distribution of delta smelt in the spring and summer affect their distribution and growth in the fall? How do delta smelt "find" suitable fall habitat? How do pesticide exposure and toxicity to delta smelt in the fall vary with flows? How do pesticide exposure and toxicity in the spring affect the delta smelt population in the fall? What is the fate of contaminants mobilized in wet springs under different fall flow conditions? Do summer Microcystis blooms affect delta smelt distribution in the fall? How do flows affect this interaction? How do agricultural use patterns in the Delta or energy demands on power plants in Suisun Bay change with springtime conditions, and does this amplify the impacts on delta smelt by higher X2 in the following fall?

Biotic Habitat components:

A 4: Plankton Analyses and Modeling

Hypothesis: Low flow results in reduced transport of *Pseudodiaptomus* copepods from the freshwater Delta into the LSZ. Questions: What is the quantitative change in transport and in the subsidy to the copepod populations in the LSZ as flow changes? How is this affected by the greater distance between the LSZ and the central delta when flows are higher?
Approach:

Hypothesis: Low flow results in reduced transport of dissolved and particulate organic materials (detritus, phytoplankton, bacteria, and microzooplankton) from the freshwater Delta into the LSZ. Questions: How does the transport rate of these

materials to the LSZ change at the level of flows proposed for the fall? What is the relative importance of transport and turnover rates of these materials in the LSZ? How does food quantity and quality for copepods change as flow increases in the fall?
Hypothesis: High X2 exposes foodweb organisms, including phytoplankton, microzooplankton, and copepods (esp. *Pseudodiaptomus*) to pumping losses, with the result being lower copepod abundance in the LSZ.
Questions: How does the fractional daily loss of chlorophyll and labile organic matter change with X2 and export pumping rate? What fraction of the *Pseudodiaptomus* population is lost to export pumping? How do these losses affect conditions in the LSZ?

Hypothesis: Production or abundance of *Microcystis* increases with high X2. *Microcystis* may interfere with the LSZ foodweb through various mechanisms including toxic effect, nutritional deficiency, and interference with feeding by copepods. Questions: How does X2 affect the abundance, distribution, or effects of *Microcystis*? What are the trophic dynamics by which *Microcystis* changes the zooplankton community composition? What is the population-level impact of *Microcystis* on copepods such as *Pseudodiaptomus*? How do pelagic foodwebs change when *Microcystis* blooms? How do *Microcystis* bloom dynamics change with X2?

Hypothesis: Lower outflows result in higher concentration of ammonium, suppressing phytoplankton growth and therefore biomass accumulation.
Questions: How important is ammonium suppression of diatom growth in the freshwater and in the low salinity regions of the estuary, compared with the suppression of biomass by clam grazing, and suppression of growth by high turbidity? How do the relative magnitudes of these limits on phytoplankton change as X2 changes?

Hypothesis: Changes in the shape or size of the LSZ cause a reduction in production when X2 is high. Questions: Using refined models, how does the size and shape of the LSZ change as X2 changes? How does the change in depth (or fraction of the area shallow enough for net phytoplankton production) translate to changes in phytoplankton productivity or impact of benthic grazers on all foodweb components?

Hypothesis: Overlap between *Pseudodiaptomus* and *Limnoithona* increases with a landward X2, intensifying competition for food between these apparent competitors. Questions: What is the nature and magnitude of competition for food between the copepods in the upper estuary? How does this change with X2?

Hypothesis: Overlap between *Pseudodiaptomus* and *Acartiella* increases with a landward X2, intensifying predation by *Acartiella* on early stages of

Pseudodiaptomus. Questions: What is the predation rate of *Acartiella* on different life stages of *Pseudodiaptomus*, and is it an important source of mortality? How does mortality and predation rate change with X2?

Hypothesis: Recruitment of gelatinous plankton to the LSZ is higher when X2 is high; this increases predation on zooplankton which in turn causes reduction in abundance of food for delta smelt. Questions: Are jellyfish important components of the plankton in terms of their consumption rates? Does jellyfish abundance in the LSZ vary with X2?

Hypothesis: Low flow favors nutritionally inferior phytoplankton and zooplankton species. Questions: To what extent does low flow (high X2) affect the community composition and nutritional quality of phytoplankton and zooplankton in the LSZ?

A 5: Benthic Macroinvertebrate Analyses and Modeling

Hypothesis: A persistently high X2 results in recruitment of *Corbula* and, in turn, reduction in biomass of phytoplankton, bacteria, microzooplankton, and mesozooplankton. Questions: What is the response of *Corbula* to changing salinity/variable X2? For example, how does recruitment vary with salinity? What conditions promote large recruitment events? What conditions limit recruitment or limit successful growth of *Corbula* into juveniles?

Hypothesis: Movement of X2 causes a mismatch between the location of *Corbula* populations and the LSZ, reducing consumption of phytoplankton and zooplankton by clams; conversely, a stable X2 (particularly during clam recruitment periods) allows for these locations to match over a period of time, maximizing consumption by clams. Questions: Does tidal and longer-term movement of X2 result in mismatch of clam, phytoplankton, and copepod populations? How much difference does that mismatch make to overall consumption? What is the magnitude of consumption of phytoplankton, microzooplankton, and mesozooplankton? What is the resulting effect on calanoid copepods in the LSZ?

A 6: Delta smelt responses:

Hypothesis: High fall X2 results in lower abundance of delta smelt. Questions: How does delta smelt adult abundance vary with fall X2? How does production of juvenile smelt vary with fall X2?

Hypothesis: High fall X2 affects life history. Questions: How do fall conditions affect population structure or life history characteristics of delta smelt?

Hypothesis: High fall X2 reduces delta smelt growth rates. Questions: How does delta smelt growth vary with X2 in the fall?

Hypothesis: High fall X2 results in lower fecundity of delta smelt. Questions: How does delta smelt fecundity vary with fall X2? How does egg quality vary with fall X2?

Hypothesis: High fall X2 reduces condition of delta smelt. Questions: How does delta smelt condition vary with fall X2?

Hypothesis: High fall X2 reduces health of delta smelt. Question: How does delta smelt health vary with fall X2?

Hypothesis: Delta smelt are food limited in the fall. Questions: To what extent are individual delta smelt limited by food supply in terms of their ingestion rate, growth rate, development, or survival? How does subsequent fecundity of delta smelt in late winter-early spring respond to feeding conditions in the fall?

Additional environmental studies, characterizations, and analyses that will help inform and provide context for the above-outlined study efforts:

- USFWS (Newman et al.) state-space modeling project to address uncertainty in estimating delta smelt abundance estimates
- Rivercourse Engineering (MacWilliams et al.) 3-dimensional modeling project for hydrology, salinity, and turbidity
- UC Berkeley (Stacey and Wagner) hindcasting study and Delta Science Program (Enright and Culberson) study detailing temperature and heat transfer processes in the Estuary
- DWR and USGS (Thompson et al.) GRTS-related benthic analysis for foodweb underpinnings
- DWR water quality profile analyses with improved spatial resolution to show process-based effects on salinity, turbidity, chlorophyll a, dissolved oxygen, and temperature
- SFSU (Kimmerer et al.) sampling to understand zooplankton transport into the low salinity zone

ITERATIVE ELEMENT: ASSESSING OUTCOMES FOR DECISION SUPPORT

Assessing outcomes is closely tied to modeling and will be laborious and technically difficult. It will also be very dependent on the final form of the models we are developing. For reasons outlined below, we plan to jointly staff assessment with modeling and to allow one or more skilled analysts time on a year-round basis to develop results and work with policymakers and stakeholders to formulate decision support information.

The process model assumptions articulated earlier establish four linked levels of expected effects, including: 1) flow and X2 on physical conditions (salinity, temperature, turbidity, area of potential habitat), 2) physical conditions on zooplankton density and distribution, delta smelt survival, and transport of food from production to consumption areas, 3) food and habitat quality on growth, health, condition and survival rates, and 4) size, health and condition on fecundity and egg size or quality, and hence recruitment. At each level, the assessment requires both measurements or estimates of the outcomes and an evaluation of the uncertainty propagated to each outcome. Providing these is the major objective of the integrative quantitative modeling discussed earlier.

In general, outcome assessment is based on the degree of difference between observed outcomes and the predictions. Setting aside the simple cases (all predictions borne out; all predictions contradicted; all predictions unresolved), there are other permutations that may pose more interesting interpretive challenges. Outcome patterns that uniformly enhance or diminish the role of model links have obvious interpretation. On the other hand, internally contradictory results (for example, independent lines of evidence that at once say that zooplankton density is increasing and decreasing) imply that we are measuring something incorrectly or that the underlying dynamics are more complicated than envisioned in our process model. Sorting these issues out is very situation-specific.

Because some internal variables, for example those measuring delta smelt health, have no history on which to base quantitative predictions, evaluation of outcomes will initially be a matter of judgment. As the monitoring data voids are filled, assessments will become better formalized.

As the decision analysis becomes clearer, we intend to consider the use of multicriteria decision analysis (Linkov et al. 2006a,b) and other tools to make the adaptive management process more efficient. We also propose to require publication or public release of annual assessment reports and key scientific results bearing on important management decisions, recognizing the public interest in this process.

ITERATIVE ELEMENT: DECISIONS AND COORDINATION

As we described above, Reclamation's plan places a high value on learning about the efficacy of the fall outflow action, and on generating the information needed to adjust or change the action should understanding so require. For this reason, we proposed initially examining a strongly contrasting pair of alternatives: implement the targets of the 2008 RPA or implement a reduced-outflow alternative supported by the USFWS. The choice of which alternative to implement in a given "wet" or "above normal" year implicates the first type of annual decision agency managers face: what should the management alternatives be?

This type of decision fundamentally belongs to the three agencies engaged in the operations consultation under Section 7: USFWS, Reclamation, and DWR. Because of the potential for a fall outflow action to interact with Shasta carryover storage, there is also a nexus with NOAA Fisheries Service. We anticipate that the choice of alternatives would be reviewed by these agencies annually after the technical review of the previous year's activities and findings is completed, and would be the last management decision made in each annual cycle.

The second category of decision includes those decisions required to implement the action or elements of the monitoring and evaluation program. The strictly technical implementation decisions would be taken by the agencies responsible for funding and/or carrying out the relevant work. Implementation decisions that potentially affect ESA obligations would entail additional consultation involving the .

Potential affects of fall outflow augmentation on Shasta carryover storage is a special case. NOAA Fisheries Service included a prescription in its 2009 RPA to deal with this, as follows (NOAA 2009, p. 593).

> **Action I.2.2.A Implementation Procedures for EOS Storage at 2.4 MAF and Above**
> If the EOS storage is at 2.4 MAF or above, by October 15, Reclamation shall convene a group including NMFS, USFWS, and CDFG, through B2IT or other comparable process, to consider a range of fall actions. A written monthly average Keswick release schedule shall be developed and submitted to NMFS by November 1 of each year, based on the criteria below. The monthly release schedule shall be tracked through the work group. If there is any disagreement in the group, including NMFS technical staff, the issue/action shall be elevated to the WOMT for resolution per standard procedures.
>
> The workgroup shall consider and the following criteria in developing a Keswick release schedule:
>
> 1. Need for flood control space: A maximum 3.25 MAF end-of-November storage is necessary to maintain space in Shasta Reservoir for flood control.
>
> 2. Need for stable Sacramento River level/stage to increase habitat for optimal spring-run and fall-run redds/egg incubation and minimization of redd dewatering and juvenile stranding.
>
> 3. Need/recommendation to implement USFWS' Delta smelt Fall X2 action as determined by the Habitat Study Group formed in accordance with the 2008 Delta smelt Opinion. NMFS will continue to participate in the Habitat Study Group (HSG) chartered through the 2008 Delta smelt biological opinion. If, through the HSG, a fall flow action is recommended that draws down fall storage significantly

from historical patterns, then NMFS and USFWS will confer and recommend to Reclamation an optimal storage and fall flow pattern to address multiple species' needs.

This plan assumes that the approach described here would be used to address carryover storage issues arising through implementation of fall outflow adaptive management.

The third category of annual decision is scientific: what has been learned, and what are the next investigative steps? We envision an annual management and science conference and report on findings to date, with the report used to inform a standing review panel and the agencies that are parties to the operations consultation.

ITERATIVE ELEMENT: OUTSIDE EXPERT REVIEW

Independent expert review of this plan is critical. It is also critical that there be ongoing independent review of the results of management and other scientific activities to support management review of the effectiveness of the conservation action and learning program. After discussion with the Delta Stewardship Council's Delta Science Program leadership, we have concluded that the most effective approach to satisfying both of these needs is to establish a permanent panel for the purpose.

As currently envisioned, the panel would convene to review Reclamation's draft adaptive management plan before implementation in order to ensure that it is of sufficient robustness and scientific quality to serve the intended purposes. Results of the review would be implemented in the draft plan before the plan is made final. The same panel of experts would then be retained to conduct an annual review of progress and findings and would provide a report to Reclamation and the Service detailing each panel member's findings. This report, along with other information available at the time, would be used to inform management decisions pertaining to adaptive management of Fall outflow.

References Cited

Abelson, R.P. 1985. A Variance Explanation Paradox: When a Little is a Lot. Psychological Bulletin 97: 129-133.

Alpine, AE, Cloern, JE. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnology and Oceanography 37:946-955.

Bridgeman, B., N. Burton, and F. Cline. 2009. A Note on Presenting What Predictive Validity Numbers Mean. Applied Measurement in Education 22: 109-119.

Baskerville-Bridges, B, Lindberg, JC, Doroshov, SI. 2004. The effect of light intensity, alga concentration, and prey density on the feeding behavior of delta smelt larvae. American Fisheries Society Symposium 39:219-228.

Bennett, WA. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3:http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1.

Bennett, WA, Hobbs, JA, Teh, S. 2008. Interplay of environmental forcing and growth-selective mortality in the poor year-class success of delta smelt in 2005. Final Report to the Interagency Ecological Program.

Burkhardt-Holm, P., and K. Scheurer. 2007. Application of the weight-of-evidence approach to 4744 assess the decline of brown trout (*Salmo trutta*) in Swiss rivers. Aquatic Sciences 69:51–70. Christensen, V, Pauly, D. 1998. Changes in models of aquatic ecosystems approaching carrying capacity. Ecological Applications 8 (Supplement):S104-S109.

California Department of Water Resources (CDWR), 2005. Flooded Islands Pre-Feasibility; RMA Delta Model Calibration Report. June 30, 2005.

California Department of Water Resources (CDWR), 2008. San Francisco Bay-Delta UnTRIM Model Calibration Report: POD 3-D Particle Tracking Modeling Study. December 19, 2008.

Close, A., W. M. Haneman, J. W. Labadie, D. P. Loucks (Chair), J. R. Lund, D. C. McKinney, and J. R. Stedinger. 2003. A strategic review of CALSIM II and its use for water planning, management, and operations in Central California. CALFED Science Program Report. 14 pp.

D'Andrade, R., and J. Dart. 1990. The Interpretation of r Versus r^2 or Why Percent of Variance Accounted for Is a Poor Measure of Size of Effect. Journal of Quantitative Anthropology 2: 47-59.

Dege, M., and L. R. Brown. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. Pages 49-65 *in* F. Feyrer, L. R. Brown, R. L. Brown, and J. J. Orsi, editors. Early life history of fishes in the San Francisco Estuary and watershed, 39 edition. American Fisheries Society, Bethesda, Maryland.

Dugdale, RC, Wilkerson, FP, Hogue, VE, Marchi, A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal, and Shelf Science 73:17-29.

Enright, C., and S. D. Culberson. 2009. Salinity trends, variability, and control in the northern reach of the San Francisco Estuary. San Francisco Estuary and Watershed Science, 7(2).

Feyrer, F, Nobriga, ML, Sommer, TR. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Feyrer, F, Newman, K, Nobriga, M, Sommer, T. 2010. Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34:120-128.

Fisch. K.M. 2011. Conservation genetics of the endangered delta smelt (*Hypomesus transpacificus*) in the San Francisco Estuary. PhD Dissertation. University of California, Davis.

Ganju, N.K., Schoellhamer, D.H., Murrell, M.C., Gartner, J.W., and Wright, S.A., 2007, Constancy of the relation between floc size and density in San Francisco Bay, in Maa, J.P.-Y., Sanford, L.P., and Schoellhamer, D.H., ed., Estuarine and Coastal Fine Sediments Dynamics: Elsevier Science B.V., p. 75-91.

Fischer, H. B., E. J. List, R. C. Y. Koh, J. Imberger, N. H. Brooks. 1979. Mixing in inland and coastal waters. Academic Press, Inc. New York. 483 pp.

Hilderbrand, RH. 2003. The roles of carrying capacity, immigration, and population synchrony on persistence of stream-resident cutthroat trout. Biological Conservation 110:257-266.

Hobbs, JA, Bennett, WA, Burton. 2006. Assessing nursery habitat quality for native smelts (Osmeridae) in the low-salinity zone of the San Francisco estuary. Journal of Fish Biology 69:907-922.

Honey, K., R. Baxter, Z. Hymanson, T. Sommer, M. Gingras, P. Cadrett. 2004. IEP long-term fish monitoring program element review. Interagency Ecological Program for the San Francisco Bay/Delta Estuary Technical Report 78. 67 page plus appendices

Jassby, AD, Cloern, JE, Cole, BE. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47:698-712.

Jassby, AD, Kimmerer, WJ, Monismith, SG, Armor, C, Cloern, JE, Powell, TM, Schubel, JR, Vendlinski, TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289.

Kimmerer, WJ. 2004. Open-water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2: http//repositories.cdlib.org/jmie/sfews/vol2/iss1/art1.

Kimmerer, WJ, Gartside, E, Orsi, JJ. 1994. Predation by an introduced clam as the likely cause of substantial declines in zooplankton of San Francisco Bay. Marine

Ecology Progress Series 113:81-93.

Kimmerer, W. J., E. S. Gross, and M. L. MacWilliams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts 32:375-389.

Kimmerer, WJ, Orsi, JJ. 1996. Changes in the zooplankton of the San Francisco Bay estuary since the introduction of the clam Potamocorbula amurensis. Pages 403-423 in Hollibaugh, JT (ed), San Francisco Bay: the ecosystem. American Association for the Advancement of Science.

Kimmerer, W. and M. Nobriga. 2008. Investigating dispersal in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science. Vol. 6, Issue 1, Article 4.

Kupschus, S. 2003. Development and evaluation of statistical habitat suitability models: an example based on juvenile spotted seatrout *Cynoscion nebulosus*. Marine Ecology Progress Series 265:197-212.

Linkov, I., F.K. Satterstrom, G. Kiker, C. Batchelor, T. Bridges, E. Ferguson. 2006a. From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. Environmental International 32: 1072-1093.

Lucas, L.V., and Cloern, J.E., 2002, Effects of tidal shallowing and deepening on phytoplankton dynamics: a modeling study: Estuaries, v. 25, p. 497-507.

Luo, J, Hartman, KJ, Brandt, SB, Cerco, CF, Rippetoe, TH. 2001. A spatially-explicit approach for estimating carrying capacity: an application for the Atlantic menhaden (*Brevoortia tyrannus*) in Chesapeake Bay. Estuaries 24:545-556.

Mac Nally, R, Thompson, JR, Kimmerer, WJ, Feyrer, F, Newman, KB, Sih, A, Bennett, WA, Brown, L, Fleishman, E, Culberson, SD, Castillo, G. 2010. An analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modelling (MAR). Ecological Applications 20: 1417-1430.

Manderson, JP, Phelan, BA, Meise, C, Stehlik, LL, Bejda, AJ, Pessutti, J, Arlen, L, Draxler, A, Stoner, AW. 2002. Spatial dynamics of habitat suitability for the growth of newly settled winter flounder *Pseudopleuronectes americanus* in an estuarine nursery. Marine Ecology Progress Series 228:227-239.

Manly, B.J.F. and M.A. Chotkowski. 2006. Two new methods for regime change analysis. Archiv für Hydrobiologie 167:593–607.

Maravelias, C. 1999. Habitat selection and clustering of a pelagic fish: effects of topography and bathymetry on species dynamics. Can. J. Fish. Aquat. Sci. 56:437-450.

Moyle, PB, Herbold, B, Stevens, DE, Miller LW. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121:67-77.

Newman, KB. 2008. Sample design-based methodology for estimating delta smelt abundance. San Francisco Estuary and Watershed Science 6: http//repositories.cdlib.org/jmie/sfews/vol6/iss3/art3.

Nobriga, ML. 2002. Larval delta smelt diet composition and feeding incidence: environmental and ontogenetic influences. California Fish and Game 88:149-164.

Nobriga, ML, Sommer, TR, Feyrer, F, Fleming, K. 2008. Long-term trends in summertime habitat suitability for delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science 6: http//repositories.cdlib.org/jmie/sfews/vol6/iss1/art1.

Orsi, JJ, Mecum, WL. 1996. Food limitation as the probable cause of a long-term decline in the abundance of *Neomysis mercedis* the oppossum shrimp in the Sacramento-San Joaquin estuary. Pages 375-401 in Hollibaugh, JT (ed), San Francisco Bay: the ecosystem. American Association for the Advancement of Science, San Francisco.

Ruhl, C.A., and Schoellhamer, D.H., 2004, Spatial and Temporal Variability of Suspended-Sediment Concentrations in a Shallow Estuarine Environment: San Francisco Estuary and Watershed Science. v. 2, no. 2, article 1. http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art1

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, in McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343-357. URL: http:// ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf

Schoellhamer, DH. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 35: DOI 10.1007/s12237-011-9382-x.

Schoellhamer, D.H., and Burau, J.R., 1998, Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, California, U.S. Geological Survey Fact Sheet FS-047-98, 6 p. http://sfbay.wr.usgs.gov/sediment/circulation/

Schoellhamer, D.H., Wright, S.A., and Drexler, J.Z., in press, Conceptual Model of Sedimentation in the Sacramento – San Joaquin River Delta: San Francisco Estuary and Watershed Science.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, 5445 M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. 5446 The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6):270–277. Sweetnam, DA. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85:22-27.

Sommer, T., L. Grimaldo, F. Mejia, M. Nobriga, and F. Feyrer 2011. The Spawning Migration of Delta Smelt in the Upper San Francisco Estuary. San Francisco Estuary and Watershed Science (in press).

Stacey, M.T., Brennan, M.L., Burau, J.R., and Monismith, S.G., 2010, The tidally averaged momentum balance in a partially and periodically stratified estuary: Journal of Physical Oceanography, v. 40, no. 11, p. 2418-2434.

Sweetnam, D.A. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85:22–27.

Stoner, AW, Manderson, JP, Pessutti, JP. 2001. Spatially explicit analysis of estuarine habitat for juvenile winter flounder: combining generalized additive models and geographic information systems. Marine Ecology Progress Series 213:253-271.

Swanson, C, Reid, T, Young, PS, Cech, JJ, Jr. 2000. Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123:384-390.

Thomson, JR, Kimmerer, WJ, Brown, LR, Newman, KB, Mac Nally, R, Bennett, WA, Feyrer, F, Fleishman, E. 2010. Bayesian change-point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20: 1431-1448.

USGS (U.S. Geological Survey). 2008. Tracking organic matter in Delta drinking water. Science Action: News from the CALFED Science Program, April 2008. Sacramento, CA: State of California, CALFED Science Program.

USBR (U.S. Bureau of Reclamation). 2008. Appendix R. Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise, OCAP-BA, July, 2008. Available online at: *http://www.usbr.gov/mp/cvo/OCAP/sep08_docs/Appendix_R.pdf.*

USFWS (United States Fish and Wildlife Service). 2008. Formal Endangered Species Act consultation on the proposed coordinated operations of the Central Valley Project (CVP) and State Water Project (SWP).

USFWS (United States Fish and Wildlife Service). 2010. 2008 CVP/SWP Coordinated Operations Delta Smelt Fall Habitat Action Adaptive Management Program Implementation Plan.

Walters, C. 1986. Adaptive management of renewable resources. McGraw-Hill, New York, NY, USA.

Warner, J.C., Schoellhamer, D.H., Ruhl, C.A., and Burau, J.R., 2004, Floodtide pulses after low tides in shallow subembayments adjacent to deep channels: Estuarine, Coastal and Shelf Science, v. 60, no. 2, p. 213-228.

Wolanski, E. 2007. Estuarine Ecohydrology. Elsevier. New York. 157pp.

APPENDIX I: Study Descriptions

Descriptions of each study are provided below; the delta sediment measurements element is not part of the HSG package but is included for completeness. As noted in the preceding section, Reclamation is also working with others to develop UnTRIM/SEDIMORPH-based tools to carry out physical modeling tasks required to carry out this plan.

Hydrodynamic and particle tracking modeling of delta smelt habitat and prey

Wim Kimmerer (SFSU) and Lenny Grimaldo (USBR)

This study is using existing modeling tools and laboratory and field data to accomplish two broad goals. The first goal is to better understand the variability of physical habitat with variation in X2 for key fish species including delta smelt. The second goal is to better understand the population dynamics of calanoid copepods, the most important food for delta smelt in summer and fall. These two goals are closely linked in that the same hydrodynamic simulations can be used to achieve both goals. This study seeks to answer three research questions: (i) How can existing or new monitoring data, modeling, or other methods be applied to better define and monitor smelt habitat; (ii) How do abiotic or biotic conditions during spring and summer influence how flow affects smelt habitat and ecological processes important to smelt during fall; and (iii) How much food is available for delta smelt in the LSZ, what is its quality and how are they affected by flow variability? The study is using the UnTRIM 3-dimensional hydrodynamic model to quantify flow-habitat relationships for delta smelt and other fish by simulating seven steady Delta outflow conditions over a wide range of X2 values. It will also perform sensitivity analyses to determine the effect of modified export flows on model outcomes at low Delta outflows. The study is also using the UnTRIM model in combination with the Flexible Integration of Staggered-grid Hydrodynamics Particle Tracking Model (FISH-PTM) to simulate the vertical migration, retention and transport of the calanoid copepod *Pseudodiaptomus forbesi.* The goal is to construct a four-box model of the Delta-LSZ to simulate the population dynamics of *P forbesi* and to link the boxes using advective and dispersive terms estimated from the hydrodynamic and particle tracking Model with an adjustment to reduce seaward movement as indicated by the retention analysis for the life stages that migrate (copepodites and adults). This work will culminated with the development of an Individual-Based Model (IBM) of *P. forbesi* that will be linked to the FISH-PTM.

Delta sediment measurements to support numerical modeling of turbidity

Scott Wright (USGS) and Dave Schoellhamer (USGS)

The purpose of this 3-year study is to collect data that will support the development, calibration,and validation of numerical models of sediment transport and turbidity in the Sacramento-SanJoaquin Delta. One component of the study focuses on the measurement of suspended sediment fluxes into and through the Delta by continuously monitoring turbidity at a dozen locations and calibrating turbidity measurements against velocity-weighted mean concentrations of suspended sediment. These data will address the following questions. How much sediment is entering the Delta from the various river sources, and how much is transported from the Delta downstream to San Francisco Bay? What are the concentrations and particle size distributions of suspended sediment in the Delta, and how do these properties vary spatially and temporally? What are the relationships between turbidity, suspended sediment concentration, and particle size? How do pulses of suspended sediment that are delivered by the upstream watersheds move throughout the Delta, i.e. what are the transport pathways and how are these pathways linked with Delta hydrodynamics? Another component of the study focuses on the estimation of suspended and bed sediment parameters for incorporation into numerical models. Questions addressed include the following. What are the erodibility and critical shear stresses for erosion of Delta sediments? How much flocculation of sediment particles occurs in the Delta, and what are the settling velocities of the flocs? How do erosion and settling properties vary spatially and temporally in the Delta? What are the particle size distributions of the bed sediment in the Delta? What are the spatial patterns in size distributions and how do these patterns change temporally? Are there "hotspots" of deposition and erosion cycles within the Delta?

<u>Delta smelt feeding and food web interactions</u>

Wim Kimmerer (SFSU) and Larry Brown (USGS)

The purpose of this study is to investigate the food supply for delta smelt, how it is affected by predators and competitors, and how these interactions depend on delta outflow. This study seeks to answer two questions: (i) To what extent is growth or survival of delta smelt food limited; and (ii) What limits the availability of food for delta smelt? The study will determine ingestion rate and oxygen consumption rate of larval and juvenile delta smelt incubated under a range of copepod densities. It will also determine the response of delta smelt to changes in turbidity and the presence of predator stimuli under controlled laboratory conditions. The study will conduct feeding experiments using naturally-occurring food to link ambient food quantity and quality with copepod reproduction and development rates and to assess the overlap in feeding between *P. forbesi* and *L. tetraspina*. The study will also measure the abundance and distribution of gelatinous predators throughout the upper regions of the San Francisco Estuary and conduct incubation experiments to quantify predation rates on crustacean zooplankton and larval fish.

POD fish diet and condition

Steven Slater and Randall Baxter (DFG)

The purpose of this study is to examine the diet, feeding incidence, stomach fullness and body condition of delta smelt and some of the other POD fishes to determine if these assessments provide evidence of food limitation, either seasonal or spatial. This study has and continues to examine delta smelt diet regionally and seasonally, and has derived estimates of maximum stomach fullness and mean body condition at length to act as references when assessing the well being of delta smelt. To date, unpublished study information suggests there are potential spring transition and fall periods when food might be limited, and a regional gradient, from western Suisun Bay through the lower rivers just above the confluence, of increasing stomach fullness and body condition during summer and early fall. This study is ongoing and will process delta smelt not otherwise directed to other projects (see

Monitoring inter-annual variability in delta smelt population contingents and growth

James Hobbs (UCD)

The primary goal of this research is to gain a better understanding of the mechanisms (e.g. climate variability, hydrology) responsible for apparent success of different life history contingents and how entrainment as indexed by salvage at CVP and SWP could alter life history diversity. Archived samples from 1999 – 2008 monitoring surveys, already prepared for otolith microstructure and microchemistry studies, will be assayed with a laser line from the core to the edge to reconstruct the entire life history. Sub-adult and adult sampled collected by the IEP in 2010/2011 will be examined for microchemistry and growth rates will be quantified by otolith microstructure analysis. The primary research questions are:

1. Can life-history and growth of fish salvaged at CVP and SWP be compared to fish that survive the TNS to determine the effects of entrainment and salvage? What are the habitat effects on delta smelt population dynamics?

2. Do life-history contingents vary inter-annually, in association with growth, freshwater outflow, water temperature, abundance?

3. Does growth rate increase with increased fall outflow?

This work will be continued into the fall-winter of 2011/2012 to focus on examining the issues of variable fall growth and salinity history between putative resident delta smelt in Cache Slough and the Sacramento Deep Water Ship Channel region and those in the Suisun Bay and river confluence region. These analyses should provide evidence for (or against) upstream residence in the Cache Slough and the Sacramento Deep Water Ship Channel region, and provide a general contrast in fall growth exhibited in Suisun Bay responding to increased fall flows and the Cache Slough Region, which should be less influenced by any fall flows.

Health of threatened fish: role of contaminants, disease and nutrition

Swee Teh (UCD)

In collaboration with IEP fish monitoring surveys and studies, this project proposes to determine the biological effects of contaminants, pathogens/diseases, and nutritional status of striped bass, threadfin shad, splittail and tule perch from three regions in the upper estuary, Cache Slough complex, Suisun Marsh and the lower San Joaquin River. Dr. Teh has agreed to incorporate delta smelt from IEP monitoring surveys into his study design. The study's main goal is to establish a conceptual framework that proposes and investigates relationships among stressor effects, ecosystem variables, and the health indices of the fish (see objectives below).

Study objectives include the following;
1) Detecting differences in physiological and morphological health of fish based on body condition factor and organo-somatic indices (e.g., hepato-somatic index);
2) Employing biomarkers capable of selectively recognizing specific types of contaminants (e.g. P450 induction from PCB exposure, vitellogenin or choriogenin induction in males from endocrine disruptor exposure) and biomarkers specific for both exposure and deleterious effects (e.g. endocrine disruption and histopathology);
3) Identify the presence and severity of pathogens/disease as a significant health indicator and relate to both other stressors discussed above and below and to environmental variables; and
4) Determine the nutritional status of fish through measures of lipid and fatty acid content and protein composition.

Much of the information collected will be used to establish baselines for various health indices (e.g., body condition, hepatosomatic indices, etc.), The proposed suite of measures, if they can be made on sufficient numbers of each fish species, should provide an important assessment of whether contaminants and pathogens/disease affects are present and related to the nutritional status of the fish, including delta smelt.

Metabolic responses to variable salinity environments in field-acclimatized *Corbula amurensis*

Jonathon Stillman (SFSU) and Jan Thompson (USGS)

This study seeks to characterize the metabolic physiology of *Corbula amurensis* in locations representing the extremes of their salinity distribution ranges in the northern San Francisco estuary. The overarching questions addressed by this research are the following. How does *Corbula amurensis* affect the food web supporting delta smelt, how is *Corbula* physiology affected by flow variability, and what are the seasonal carry-overs between fall flow and physiology of clams in the spring? More specifically, this research asks:

(i) How much metabolic variation exists in *Corbula* acclimatized to different salinities across sites (low to high salinity variability) and seasons?

(ii) How are *Corbula* acclimatized to different salinity regimens partitioning energy into different physiological categories (e.g., osmotic content, growth, reproduction, storage, metabolic pathways)?

(iii) How much of the variation in *Corbula* metabolic physiology in specimens collected at different sites or time of year is due to variation in water chemistry and variation in the planktonic assemblage?

The study requires a year-round monthly sampling regime to collect clams at 9 stations along a salinity gradient. At each monthly sampling, water samples are collected and filtered to determine water quality (e.g., water temperature, pH, specific conductance and turbidity) and the size distribution of plankton (as measured by size-fractionated chlorophyll, total organic carbon and total nitrogen measurements). *In vivo* physiological performance assays include filtration and metabolic rate measurements. Biochemical assays to determine osmotic content, growth, reproductive output potential, energy storage and biochemical indicators of metabolic state of clams are also performed using field-frozen specimens. Statistical analyses will be performed to determine how water quality variation affects *Corbula* physiological performance.

<u>Distribution, concentration and fate of ammonium in the Sacramento River and the low salinity zone</u>

Richard Dugdale (SFSU) and Carol Kendall (USGS)

The goal of this study is to determine the distribution, concentration, and fate of ammonium ($NH4^+$) in the Sacramento River and low salinity zone (LSZ) of the San Francisco Estuary/Delta. Specifically, this research will quantify two key biological processes influencing $NH4^+$ distribution: bacterial nitrification ($NH4^+$ oxidation) and phytoplankton uptake. The first year of this 3-year effort will focus on developing a protocol for measuring water column nitrification using 15N-labeled $NH4^+$ as a tracer. The subsequent two years will focus on determining how river flow affects these processes. This task addresses the following questions:

(i) Can pelagic nitrification rates be measured (and validated) in SF Bay using 15N labeling, the NH4 micro-diffusion technique and mass spectrometry;
(ii) What is the distribution of $NH4^{+}$downstream from Sacramento to Suisun Bay in spring, summer and fall;
(iii) What are the rates of a) bacterial/archaeal nitrification and b) phytoplankton $NH4^{+}$ uptake downstream from Sacramento to Suisun Bay in spring, summer and fall; and
(iv) Does the fate of $NH4^{+}$ (i.e. uptake and nitrification) change with season, salinity and flow? To address these questions will require the following sub-tasks.

<u>Influence of elevated ammonium (NH4) on phytoplankton physiology in the Sacramento-San Joaquin Delta during fall</u>

Alex Parker (SFSU) and Larry Brown (USGS)

The goal of this study how nutrients affect the food web supporting delta smelt in the low salinity zone and how nutrients in turn are affected by flow variability. More specifically, the questions addressed by this study include: (i) What are the rates of primary production and phytoplankton NO3 and NH4 uptake in the Sacramento and San Joaquin Rivers during the fall period and how do they compare between the two rivers; (ii) What role does dissolved inorganic nitrogen (DIN) composition and concentration play in modulating these rates; (iii) What role does DIN composition play in shaping the phytoplankton community; (iv) Are there differences in phytoplankton taxa between the Sacramento and San Joaquin Rivers; (v) If so, can these differences be attributed to differences in DIN composition; and (vi) How does river flow affect nutrient distribution and phytoplankton rates. Additional questions addressed by the study include the following: (i) How do primary production and phytoplankton N uptake rates vary in response to irradiance in the Sacramento and San Joaquin Rivers during the fall; (ii) What are the nitrate uptake-irradiance relationships for the SFE; (iii) Are there differences in the irradiance response for phytoplankton using NH4 and NO3; and (iv) Does the conceptual model of NH4 suppression of phytoplankton NO3 uptake and primary production hold under low light conditions?

Appendix II: Quantitative models

In the previous section we erected a set of assumptions capturing what is currently known or believed to be known about the effects of fall outflow on delta smelt habitat and subsequent abundance. This section develops a novel integrative analysis based on these assumptions that will incorporate existing historic data and new kinds of data yet to be collected. Note that the expression 'quantitative models' is used here to refer to statistical models. We also rely on hydrodynamic models for certain purposes, but our uses are not novel.

Because the approach described here has not previously been implemented and is of high importance, its development is a key priority of this plan. The modeling will be tightly integrated with the life-history modeling effort led by Ken Newman at USFWS, in which Reclamation and USGS scientists and several academics are active participants. Models will be used to make quantitative predictions that serve as benchmarks to assess the performance of management actions. Bayesian state-space models are used because they offer a great deal of flexibility and are designed to integrate data obtained from different sources and levels of temporal and spatial resolution.

Models will be used to address key questions, some of which are expected to require additional supporting laboratory and/or field studies. Supporting studies will focus on elucidating mechanisms and estimating parameters that would be difficult to study with an observational approach where explanatory factors naturally covary, leading to ambiguous or highly variable parameter estimates. For example, the functional response linking zooplankton abundance, turbidity and fish sized to rate of intake of net energy can only be determined in the lab. Key questions are:

1. What amount and quality of LSZ delta smelt habitat could be expected for what duration by varying the Fall outflow prescription?
2. What is the effect of habitat area and distribution on delta smelt distribution?
3. How does fish condition/health vary across a gradient of habitat quality?
4. How will delta smelt growth rates be affected if food density, composition, or distribution is changed during fall?
5. Does fish health/condition affect over-winter survival?
6. How does fecundity and egg quality change as a function of fish size, condition, and health?
7. What is the effect of outflow-driven changes in ammonium and N:P ratio on the composition and productivity of plankton?
8. What are the most important mechanisms linking Fall outflow to survival and fecundity?

Learning will be optimized by using the models to forecast multivariate effects of the action. The nature of the multivariate difference between predicted and observed system states will be analyzed to guide future management actions and to improve the models. Posterior distributions of state and parameter estimates can be used to optimize additional measurements to reduce uncertainty.

In the following sections, the modeling approach is illustrated by listing the variables that characterize the system, proposing equations for a few key processes and establishing relationships between state variables (e.g., delta smelt abundance) and observed quantities (e.g., catch).

The estuary is viewed as a series of regions as depicted in Figure 5 above. The late summer, fall and winter seasons are divided into a series of two-week periods, more or less consistent with the intervals between fish sampling events. Each region is characterized each time step by the spatiotemporal averages of a series of variables listed below. Sampling events and observation methods yield observed values that are modeled as functions of the true values of state variables.

Variables

System state at any give time (t) and region (r) is characterized by the following variables:

1. Number of delta smelt (DS)
2. Delta smelt size (FL)
3. Abundance of zooplankton (Zoop)
4. Abundance of phytoplankton (Phy)
5. Water turbidity (Secchi)
6. Bottom salinity (Sal)
7. Water temperature (Temp)
8. NH4 concentration (Ammo)
9. N:P ratio (NP)
10. P concentration (Phos)
11. Abundance of silversides (SSide)
12. Abundance of striped bass (Sbass)
13. Abundance of interspecific competitors (Comp)
14. Abundance of predators (Pred)
15. Abundance of *Corbula amurensis* and similar clams (Corb)
16. Abundance of other clams
17. Average X2 (X2)
18. Flow rate (Flow)

19. Wind speed (Wind)
20. Microcystis bloom or abundance (Micro)
21. Volume of water in marsh habitat (Vmarsh)
22. Volume of water in shallow water habitat (Vshall)
23. Volume of water in river channel habitat (Vchan)

Modeling approach

A Bayesian state-space approach is promising because of several characteristics of the problem. First, the system is large and heterogeneous. Its state must be described by multiple variables in many places and times. Second, the true state of the system is not directly observable, but we can observe proxies of state, uncontrolled inputs, and auxiliary variables. For example, the population of delta smelt is so low that it challenges the ability of current methods to detect it with acceptable certainty. Both the observation and the biological processes need to be modeled as outlined below. Third, bay-delta state variables are connected by a complex network of relationships that need to be taken into account in an integrated fashion, but data available come from diverse sources with different spatial and temporal resolutions. Finally, effects of unpredictable uncontrolled inputs such as precipitation, contamination events, invasions and *Microcystis* blooms are incorporated into system state and cause deviations from the goal. The fact that process noise is incorporated into system state makes adaptive management indispensable, because even if management is optimized, system state will deviate from expectations and corrections will be necessary.

According to the state-space approach, we formulate both process and observation equations. Note that the state variables defined above represent the actual state of the system and are not the same as the observations. Following the state-space approach, we consider that observed values result from sampling and measurement processes that introduce errors about the true system state.

Sources of uncertainty

There are four main sources of uncertainty made explicit in adaptive management: environmental, control, process and observation. Environmental uncertainty is due to the fact that there are important factors that affect the system (delta smelt) whose values are not known in advance. A management action (for instance, the 2008 RPA Fall outflow element) prescribes either outflow magnitudes or positions for X2 for specific durations. The results of applying this management depend on the sequence of water years into the future. An ex-ante prediction of action effects must incorporate the uncertainty due to not knowing what the precipitation will be in the future. Ex-post predictions remove environmental uncertainty from the model and allow identification of deviations due to other sources of uncertainty. Environmental uncertainty is incorporated into system state.

Control uncertainty refers to the fact that the controllable factors (decision variables, in this case X2) are not perfectly controllable. The actual average X2 obtained in a month may differ from the goal. This uncertainty may be difficult to assess quantitatively if it depends on rare events or complex institutional and/or legal processes. Control "errors" are incorporated into system state and propagate into the future.

Process uncertainty or error is due to the lack of complete agreement between the model and the actual biophysical process modeled. The difference between model and system state becomes part of the true state and it propagates forward with the process. Thus, process uncertainty is also incorporated into system state. Process uncertainty is a major component of our current ability to manage the system, particularly because the knowledge about the various processes has not been integrated into tools that can yield quantitative predictions. Such an integrative modeling is a key component of the present adaptive management plan.

Observation error is the difference between the actual system state and estimates based on samples. More generally, observation error results from the complex sampling, observation and measurement process that generates data. The most common source of observation error is sampling error. Observation errors are not incorporated or propagated forward in the system.

Latent variables can be useful to consider the observation error in covariates. For example, the model states that food availability affects delta smelt growth. However, the "true" availability experienced by an individual fish is not measurable and is represented by a latent variable that is related to the measureable zooplankton density.

Delta smelt process equations

The purpose of these equations is to provide a framework for the modeling process. Equations will have to be improved or modified on the basis of a more detailed study of data available and importance of processes and covariates. The selection of temporal and spatial resolutions will have to be refined and adjusted to the data and inherent scale of processes modeled.

Three main delta smelt population processes are modeled, growth, survival, and movement of delta smelt. The season of interest does not involve reproduction, and the regions modeled span the whole range of the species. Time is treated as discrete with steps of two weeks, and space is represented as a series of regions as in Newman (2008) and Feyrer et al., (2007).

For computation purposes, a specific order of processes is assumed. Growth takes place first. Second, death and survival are calculated. Movement is the third and last step.

Growth

$$E\{FL^{*}_{rt}\} = FL_{rt-1} + E\{\Delta FL_{rt-1}\} \quad (1)$$

$$g(E\{\Delta FL_{rt-1}\}) = \Sigma\, f_k(\mathbf{X}_{FL}) \quad (2)$$

$$FL^{*}_{rt} \sim \text{Lognormal}(E\{FL^{*}_{rt}\}, \sigma_{FL}) \quad (3)$$

where g( ) is a link function, E{ } indicates expectation, sumation if over k from 1 to p functions, and $f_k(X_{FL})$ are smoothing functions of the vector of covariate values X_{FL}.; i.e., growth is described with a generalized additive model (GAM). Elements of X_{FL} are Zoop, Secchi, Sal, Comp, DS, Temp, Sbass, Sside, Age, FL_{rt-1}, Micro, Vmarsh, Vshall, Vchan and Pred.

Growth (ΔFL_{rt-1}) could be modeled more parsimoniously with, for example, a mechanistic bioenergetic approach such as the one presented in Fujiwara et al., (2005). The mechanistic approach could combine (1) an equation for net energy intake derived from food abundance, competitor abundance, temperature, salinity and Secchi, (2) an equation for energy cost of gains derived from age and size and net energy intake, and (3) an equation to relate mass and length changes as a function of age and length. These relationships and the necessary parameters can be derived experimentally and independently of the field data, thus increasing the power and precision of the main model.

Because growth may be different in different regions, movement will result in a mixing of sizes. It is assumed that the average size of fish that migrate is the same as the average for the area prior to movement. Thus, fork length after movement is a weighted average of sizes calculated as

$$FL_{rt} = \Sigma\, DS_{r\leftarrow j}\, FL^{*}_{jt}/DS_{rt} \quad (3)$$

where the subscript r←j indicates the movement from region j to region r.

Survival

Expected proportion of fish surviving from time t-1 to t can be modeled as a GAM or a logistic function of covariates. We describe the logistic approach with a binomial distribution.

$$DS^{*}_{rt} = s_{rt}\, DS_{rt-1} \quad (4)$$

$$\text{Logit}(E\{s_t\}) = \mathbf{X}'_s\, \boldsymbol{\beta}_s \quad (5)$$

$$s_t \sim \text{Binomial}(DS_{t-1}, E\{s_t\}) \quad (6)$$

The vector of covariates $\mathbf{X}_s$ includes Sbass, Pred, FL_t, Age, Sside, Micro, Temp and Sal. Equation 6 may need to be modified to incorporate the lack of independence of mortality events resulting from groups of fish being exposed to predation or physiologically stressful conditions. Rate of survival could be modeled more mechanistically by developing equations for the different sources of mortality such as predation, chemical pollution, physiological stress, and depleted energy reserves.

Further refinement of the survival model may consider the distribution of FL and other covariates within regions. Instead of being a set of at identical individuals, as implied in equations 4-6, each fish could have its own expected survival rate based on its FL, Age, and most likely set of conditions experienced within the region.

Movement

Modeling movement can require many parameters, and it is particularly difficult because there are no direct observations movement of individual delta smelt. Our practical approach is to assume that most fish move among first and second order neighboring regions during the period from t-1 to t. Delta smelt movement is promoted by differences in covariate values between regions (gradients), and hindered by distance between regions.

The redistribution of fish among all regions is calculated as

$$\mathbf{DS}_t = \mathbf{M}_t \, \mathbf{DS}^*_t \tag{7}$$

$$E\{m_{ijt}\} = \exp(\mathbf{X}'_{mijt}\, \beta_{mij})/[1 + \Sigma_i \exp(\mathbf{X}'_{mijt}\, \beta_{mij})] \quad \text{when } i \neq j \tag{8}$$

$$E\{m_{ijt}\} = 1/[1 + \Sigma_i \exp(\mathbf{X}'_{mijt}\, \beta_{mij})] \quad \text{when } i = j$$

$$\mathbf{m}_{.jt} \sim \text{Multinomial}\{DS^*_{jt};\, E\{m_{ijt}\},\, i \in N_j\} \tag{9}$$

where $\mathbf{DS}_t$ is the vector of fish abundances in all regions at time t after movement, $\mathbf{DS}^*_t$ is fish abundance prior ot movement, $\mathbf{M}_t$ is a matrix with elements m_{ijt} representing the expected proportion of delta smelt moving from region j to region i. The vector $\mathbf{m}_{.jt}$ is column j of $\mathbf{M}_t$ which results from a multinomial process. The vector $\mathbf{X}'_{mijt}$ contains values for Zoop, Temp, Sal, Secchi, Pred, Comp, Sside, Sbass, volume of water in each type of habitat (marsh, shallow and channel) and DS both at the origin and destination of movement. It also includes values for the distance between i and j, net particle movement between i and j, PT_{ijt}, as determined, for example, by the particle tracking model PTM of DSM2, (Kimmerer and Nobriga, 2008) and net linear stream velocity. The vector β_{mij} contains the corresponding parameters.

The sum of elements in each column of $\mathbf{M}_t$ equals one, which ensures conservation of population size. Each column of $\mathbf{M}_t$ is a multinomial logistic function with probabilities that increase as gradients and flows increase and distances decrease. These equations are stated in very general terms, which requires many parameters. Number of parameters could be greatly reduced by assuming that habitat selection depends on the relative differences of covariates between source and destination. Further experimentation to determine habitat selection and movement behavior or delta smelt will be crucial to develop more mechanistic and parsimonious equations for the movement process.

Table 1. Symbols and variables

FL^{*}_{rt}	Average fork length before movement
FL_{rt}	Average fork length after movement
ΔFL_{rt-1}	Growth in fork length from t-1 to t in region r
$f_k(\mathbf{X}_{FL})$	Smoothing function of covariates for fork length
$\mathbf{X}_{FL}$	Vector of covariates that affect fork length growth
$DS_{r \leftarrow j}$	Number of delta smelt that move from region j to r
DS^{*}_{rt}	Delta smelt abundance in region r after death and before movement
DS_{rt}	Delta smelt abundance in region r after death and before movement
$\sim$	Symbol to indicate "is distributed as"
$\mathbf{X}'_s$	Vector of covariates that affect survival
β_s	Vector of parameters to calculate survival
$\mathbf{DS}_t$	Vector of delta smelt abundances in each region
$\mathbf{M}_t$	Matrix of movement probabilities.
$E\{m_{ijt}\}$	Expected proportion of fish that will move from region j to i at time t
$\mathbf{X}'_{mijt}$	Vector of covariate values in source and destination regions
β_{mij}	Vector of parameters for the multinomial logistic movement equation
$\mathbf{m}_{.jt}$	Column j of redistribution matrix $\mathbf{M}_t$
R	Number of regions
N_j	Set of region numbers that are 1st or 2nd order neighbors of j.
PT_{ijt}	Net particle movement from j to i
V_{rt}	Volume of water in region r at time t
n_{rt}	Number of delta smelt in the volume swept by the gear

Because we are not focusing on processes outside fall, we can model FL and DS between summer and fall or even between falls as empirical structural models with potentially nonlinear trends.

Other biotic processes

The main biotic processes to be considered are zooplankton dynamics, *Microcystis* blooms, and growth, movement and mortality of predators and competitors.

Movement and mortality of other fish

Movement and mortality of predators and competitors can be modeled using the same equations above, perhaps simplified to eliminate the growth process.

Zooplankton abundance

Statistical process models for, phytoplankton, zooplankton and *Microcystis* models will be developed on the basis of existing mechanistic models (e.g., Lucas and Cloern

2002) Meanwhile, zooplankton can be modeled with GAMs where the vector of covariates includes $Zoop_{t-1}$, $Corb_t$, $Temp_t$, $Secchi_t$, density of zooplankton consumers, transport of zooplankton to and from neighbors, light intensity, volume of water in each habitat type, and water flows.

Physical processes

Physical modeling is needed to simulate the physical dynamics of the LSZ, and for particle tracking simulations. Key physical dynamics needed for this application include water motion, salinity, and suspended sediment (as a conservative substitute for turbidity). Particle tracking applications include fish, plankton, and point-source solute movement. Historically (e.g. USBR 2008), we have used DSM2 and DSM2 PT for these purposes. However, because of the well-known limitations of DSM2, we are moving toward the use of UNTRIM as the platform for Delta hydrodynamic modeling, including work needed for fall outflow. In addition to the obvious advantages, UNTRIM has been coupled with the fractioned sediment transport model SEDIMORPH, enabling the joint simulation of hydrodynamics and turbidity dynamics. We hope to build on UNTRIM/SEDIMORPH development for Delta applications that has already been done for the Army Corps of Engineers, and are currently supporting work by Wright and Schoellhamer at USGS to develop empirical data with which to calibrate SEDIMORPH in this application.

In general terms, the physical processes relevant to the present application can be incorporated directly by looking up data from physical model runs, or meta-modeled with "empirical" equations that capture most of the behavior elicited by the physical models.

Observation equation

Catch

The observation model for catch has to describe the sampling distribution of number of fish caught and their sizes as a function of the average abundance and size of fish in each region at each time step. One of the major challenges here is to model the gear selectivity (Newman 2008) or probability that a fish of length FL within the volume of water to be swept ends up being caught (p(FL)). Different sampling equipment such as the summer townet and the fall midwater trawl result in potentially different relationships between p(FL) and FL. The probability of being caught can be included as a parameter in the model. The Department of Fish and Game has generated data from several side-by-side sampling with different equipment. Those data can be used to model p(FL) for fall midwater trawl directly to provide empirical prior distributions for p(FL), or they could be incorporated as part of the overall likelihood component of the model.

Assuming that fish have a Poisson distribution in the water volume, the number present in the volume swept by the net is

$$n_{rts} \sim \text{ziNegativeBinomial}(p_0, DS_{rt}/V_{rt}, k) \quad (10)$$

where p_0 is the probability that no delta smelt are in the volume sampled, and the other two parameters describe the mean and overdispersion of the negative binomial distribution.

Each sample (say, trawl) results in a collection of delta smelt fork lengths fl_{rts}, where the subscript refers to region, time and sample (tow, trawl, etc). This vector is the result of size-specific catch probabilities (Newman 2008) applied to the vector FL_{rts} of actual lengths of all fishes present in the volume sampled. FL_{rts} and fl_{rts} are vectors of fork lengths. Each element in FL_{rts} has a probability $p(FL_{rtsi})$ of being present in fl_{rts}, which could be described by a logistic function of FL.

$$\text{Logit}[p(FL\ rtsi)] = \exp(\mathbf{X'}_p\ \boldsymbol{\beta}_p) \quad (11)$$

Where $\mathbf{X'}_p$ contains a column of1's and one with the fork lengths in the sampled volume, and $\boldsymbol{\beta}_p$is the corresponding set of parameters.

Other observation equations for variables that are more directly observed without bias or selectivity can be specified as the distributions of the deviations about the mean, for example, for water temperature:

$Temp_{rt} \sim \text{Normal}(E\{Temp_{rt}\}, \text{observation variance})$