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

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. The plan provides for direct experimental manipulation of fall outflow within the boundaries of the management action. 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 manipulative experimentation 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.

BACKGROUND

Delta smelt is undoubtedly the most estuary-dependent native fish species that lives in the San Francisco Estuary (Moyle et al. 1992; Bennett 2005). It completes its entire life cycle in the low salinity zone of the estuary except for spawning and

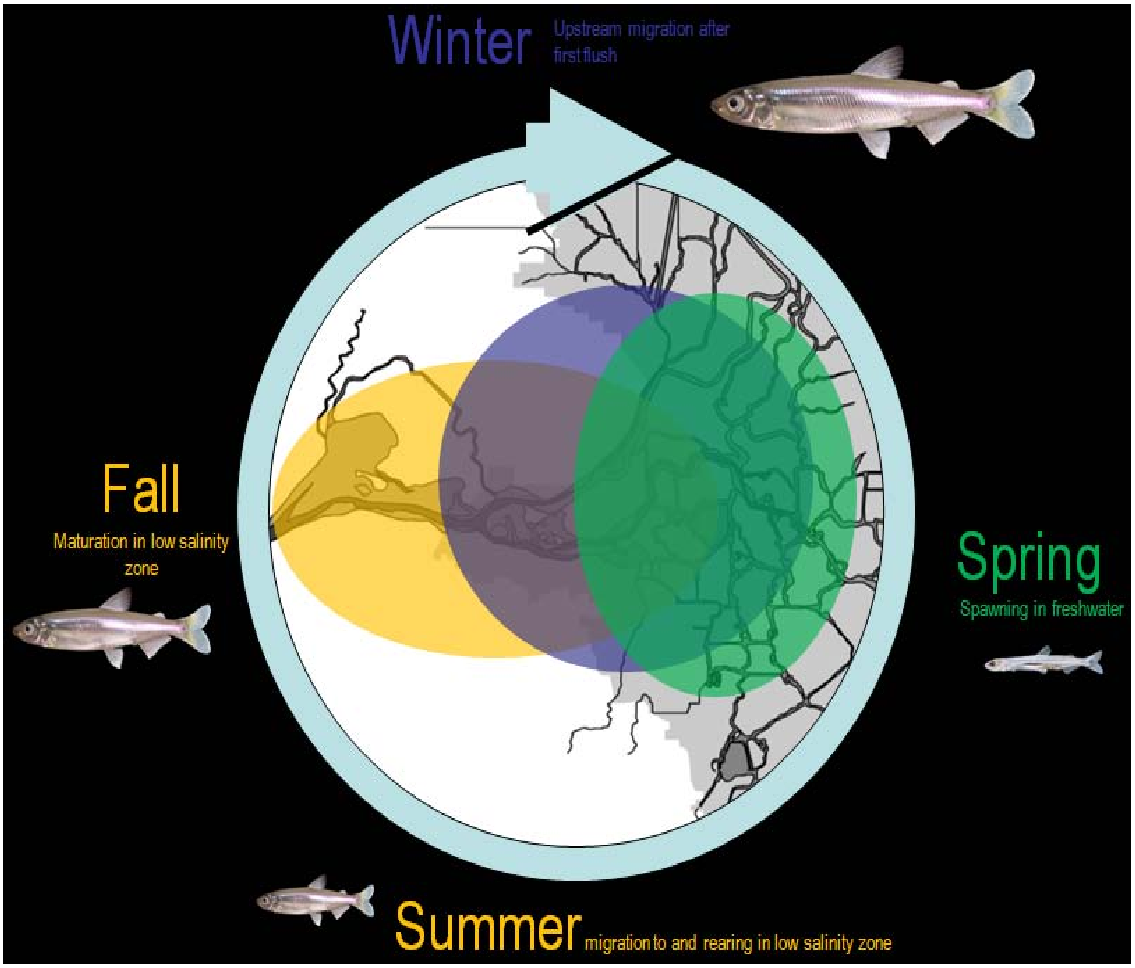

Figure 1. Simple conceptual diagram of the delta smelt life cycle.

juvenile rearing, which occurs seasonally just upstream in freshwater (Figure 1; Bennett 2005). Because it is endemic to the San Francisco Estuary, the continued existence of the species is therefore dependent upon its ability to successfully grow, develop, and survive in the low salinity zone (LSZ) of the estuary. Delta smelt distribution and life history was first described by Moyle et al. (1992). A number of recent studies have examined delta smelt habitat in more detail. Bennett (2005) described general patterns of delta smelt habitat use by life stage, which is in part the foundation of the conceptual life history diagrammed in the models and hypotheses section of this document. 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. (in press) examined delta smelt habitat and distribution shifts from fall through the spring months. Together, these studies demonstrate that delta smelt reside in the low salinity zone, with a center of distribution at approximately the 2 psu isohaline, except during winter and spring months when spawning and early development occur in freshwater.

Sommer et al. (in press) 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 probably does not utilize the low salinity zone. 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 era" described in Baxter et al. (2010) and was particularly marked in the "POD [Pelagic Organism Decline] era" (Baxter et al. 2010).

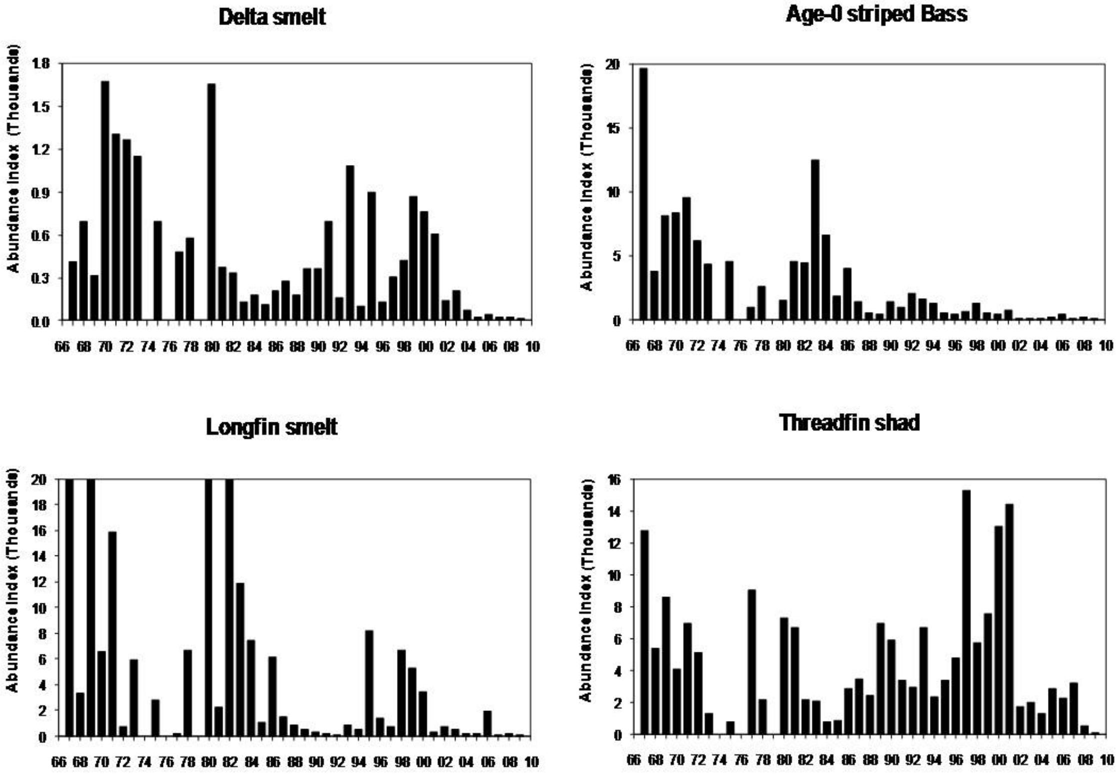

Figure 2. Trends in abundance indices for four pelagic fishes from 1967 to 2009 based on the Fall Midwater Trawl, a California Department of Fish and Game survey that samples the upper San Francisco Estuary. No sampling occurred in 1974 or 1979 and no index was calculated for 1976. Note that the y-axis 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)

Long term trend analyses confirm that step decline marks the transition from the post-reservoir era to the POD era (Manly and Chotkowski 2006, Thompson et al. 2010).

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:

(1) <u>Abiotic, or physical habitat used by delta smelt in the low salinity zone during the fall months has diminished in availability because of changes in water project operations</u>. A review 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. During the fall, the salinity portion of the envelope defining habitat during the fall months approximately coincides with the low salinity zone. Consequently, the location and extent of habitat falling within the salinity/turbidity envelope is predicted by X2 and local geography. Over time, project operations have pushed fall X2 upstream. This change has reduced the frequency with which the low salinity zone opens into Suisun Bay, reducing the extent of habitat falling within the physical habitat envelope. An analysis of climate change prepared by the US Bureau of Reclamation for use in the 2008 CVP/SWP Operations Biological Assessment (USBR 2008) indicates that X2 will be driven further inland as sea level rises over the coming decades, exacerbating the loss of habitat.

(2<u>) There is a discernible effect of good-quality abiotic habitat availability and delta smelt abundance</u>. Delta smelt are strongly associated with low salinity and high turbidity, which have been used to model the availability and suitability of smelt habitat (Feyrer et al. 2007). Fall habitat suitability has shown a long-term decline (Feyrer et al. 2007), with clear corresponding changes in delta smelt distribution.

Reduction of habitat area likely interacts with bottom-up and top-down mortality mechanisms to affect delta smelt survival. In the same peer-reviewed study, Feyrer and colleagues inferred that abiotic habitat variables explained about 20% of the variance in subsequent juvenile abundance. In a different context, 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 report of its activities in 2010. With Reclamation funding, the HSG studies were begun in 2010 under the administration of the Interagency Ecological Program.

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, some published studies bearing directly on outflow effects and other issues, 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) project effects on Delta hydrology, X2 and delta smelt habitat; and (5) the specific X2 action prescribed in the BiOp.

(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, Bennett 2005, Feyrer 2007, Nobriga et al. 2008). Two studies (Feyrer et al. 2007; 2010) have characterized the abiotic habitat of delta smelt using the Fall Midwater Trawl (FMT) data set. Since 1967, the FMT 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 era is the same as what constituted abiotic habitat during the post-reservoir era. Feyrer et al. (2007; 2010) found that delta smelt have been found a wide range of salinity and water clarity levels, but the probability of observing a delta smelt is greatest at low salinities, centering on about 2 psu, and at relatively high turbidities. They analyzed the FMT 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. (in press) found that one measure of smelt distribution, the center of distribution, is strongly correlated with X2 (Figure 3).

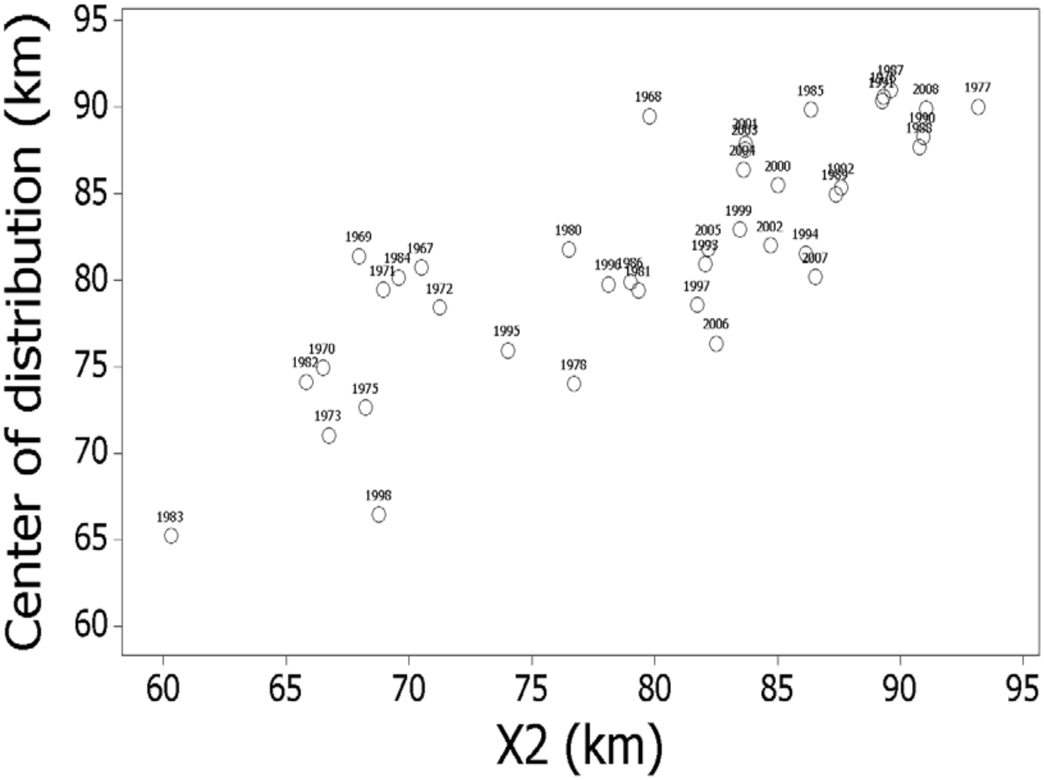

Figure 3. Center of delta smelt distribution during fall plotted against X2. Figure recreated from analyses in Sommer et al. (2011).

One issue that we cannot tackle in time to inform this document, but are addressing as we proceed, arises from the fact that the FMT samples at fixed geographical points without reference to the phase of the tides. The FMT 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 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 upstream, then seek refuge in the boundary layer near the bottom, or in littoral areas, during the ebb to avoid being swept too far downstream by the combination of net delta outflow and the ebb. Recent work by Burau and Bennett (unpublished) may confirm the expectation that delta smelt strongly tidally surf upstream on the flood during periods of high net outflow.

Tidal surfing behavior, in combination with the fixed sampling plan of the FMT seem likely to blur analyses like Feyrer's, making the range of salinities and turbidities that constitute better delta smelt habitat fuzzier than would be the case in the absence of these effects. However, Feyrer's result seems robust despite this, reinforcing the conclusion that abiotic LSZ delta smelt habitat can be clearly defined on the basis of salinity and turbidity.

Feyrer et al.'s 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. (2010) demonstrated that the strong association between delta smelt occurrence and these factors was consistent over the history of the FMT 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 FMT series to develop an abiotic habitat index, which incorporated both quantity and quality of habitat as defined by salinity and water transparency. The annual abiotic habitat index is a unitless quantity that can be thought of as surface areas for regions of the estuary corrected for salinity and water clarity conditions preferred by delta smelt. This annual index exhibited a stepped relationship with X2 (Figure 4). The steep, stepped portion of the curve occurs over X2 ranging between about 86 km and 74 km, with less change outside this range.

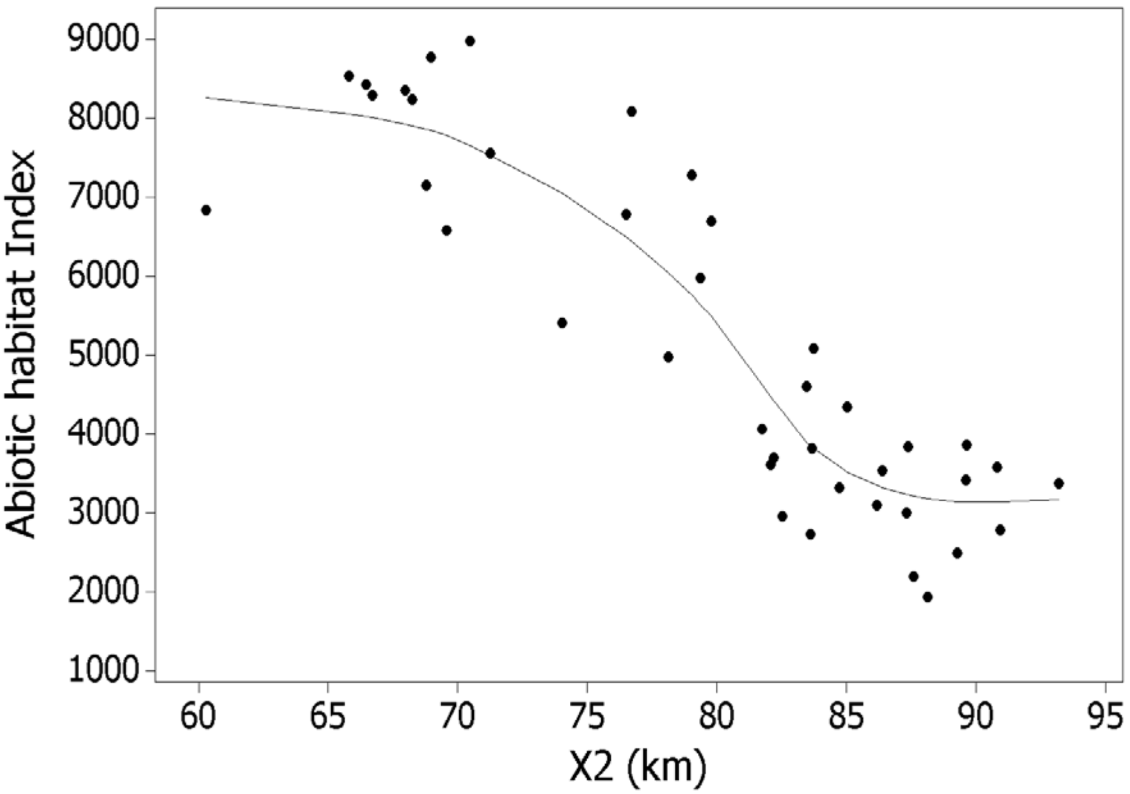

Figure 4. Delta smelt abiotic habitat index plotted against X2. Figure re-drawn from Feyrer et al. (2010). Curve is a LOESS smooth.

Across this 12-km range of X2 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).

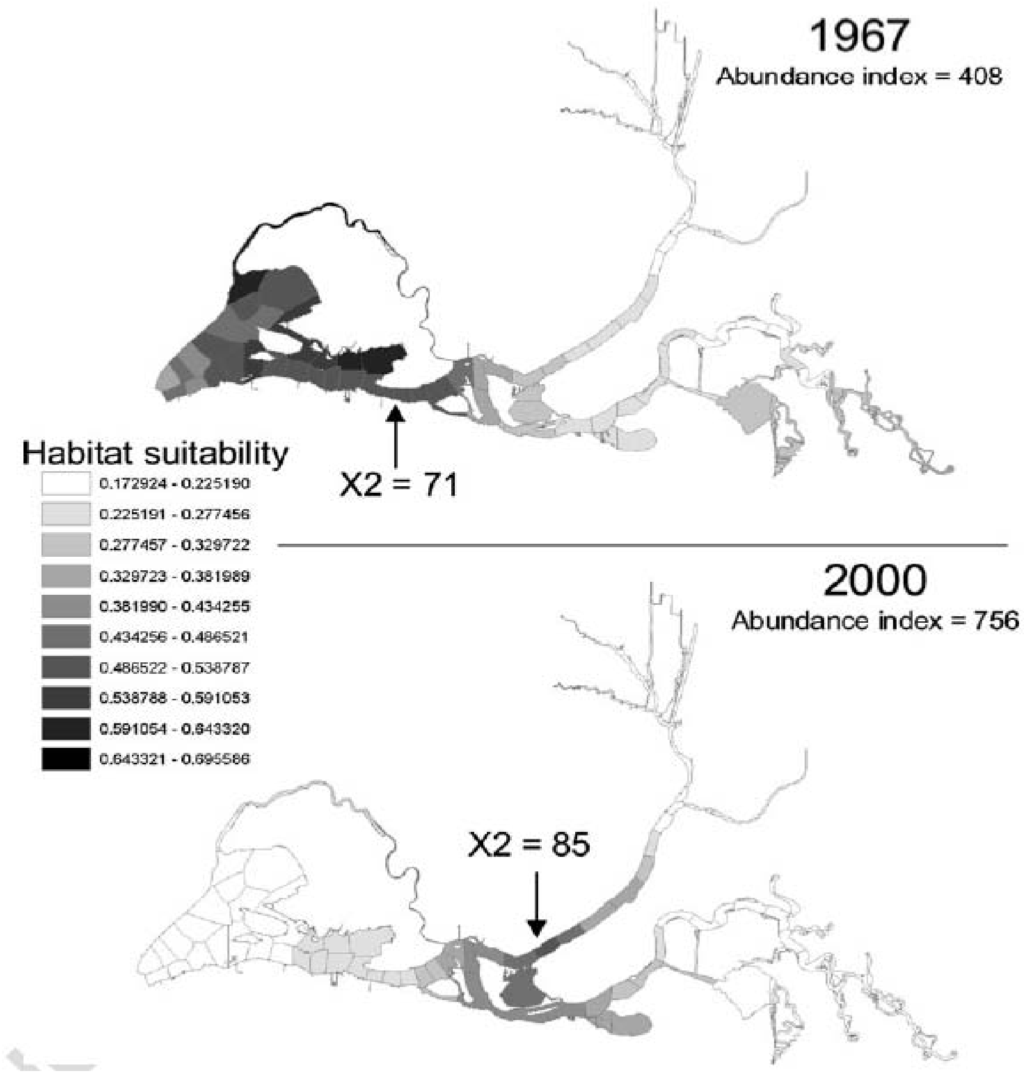

Figure 5. Spatial distribution of habitat suitability for delta smelt under different X2 conditions. Figure taken from Feyrer et al. (2010).

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, suitable physical and chemical characteristics are often necessary preconditions for suitability. The LSZ is not quite the rocky intertidal zone, but the power of salinity and turbidity to reliably predict where fish 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. 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 (FMT) 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 with 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.

Feyrer et al. (2010) also demonstrated an interesting relationship between the annual delta smelt abiotic habitat index and the FMT abundance index (Figure 6). Against a background of high overall uncertainty in FMT, the boundary values that envelope the floor (lowest values) and especially the ceiling (highest values) in this relationship define regions of the graph in which combinations habitat index and FMT abundance index have not been observed. The pattern of these data strongly suggests that although there is substantial uncertainty in the relationship between habitat index and FMT abundance, there appears to be an upper limit to FMT abundance that is an increasing function of X2. The primary concern, therefore, is that X2 limits the delta smelt carrying capacity of the estuary.

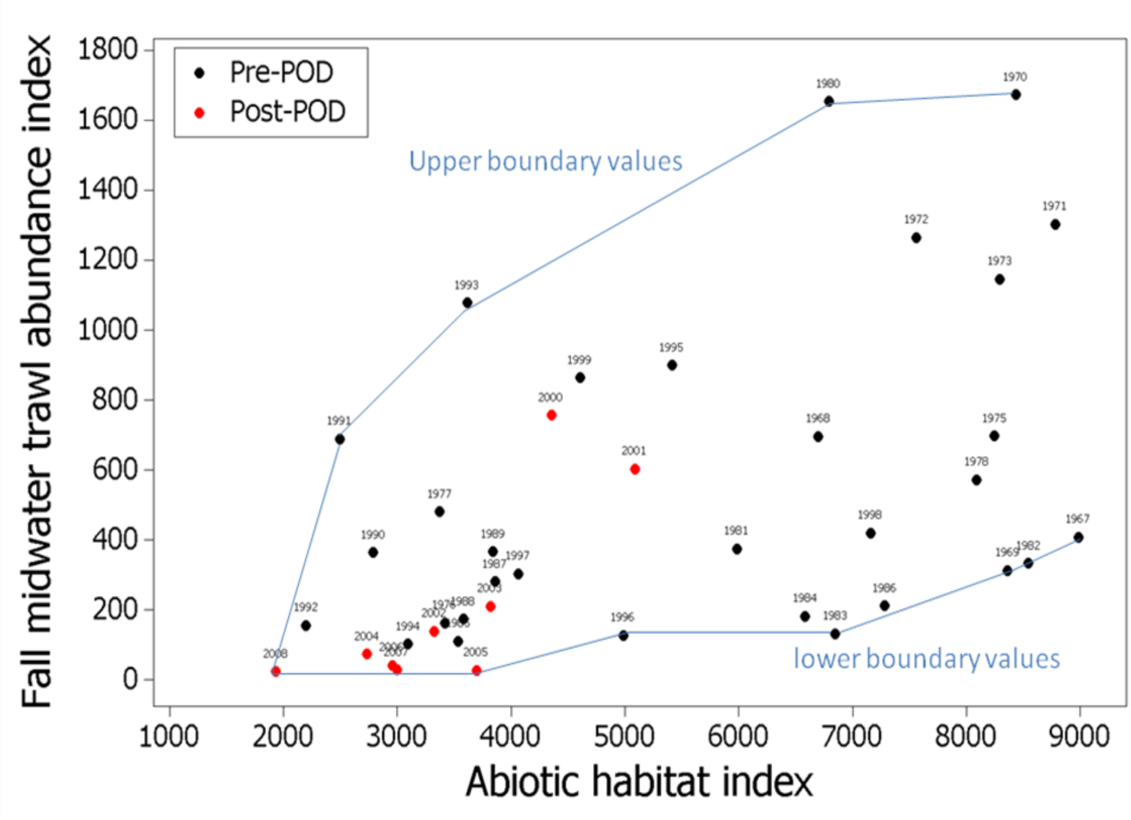

Figure 6. Delta smelt abiotic habitat index plotted against the Fall midwater trawl abundance index for the same year. Blue lines connecting the high and low boundary values were hand-drawn. Pre-POD period is 1967-1999. Post-POD period is 2000-2008. Figure is adapted from Feyrer et al. (2010).

(4) Project effects on 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 era 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 era 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).

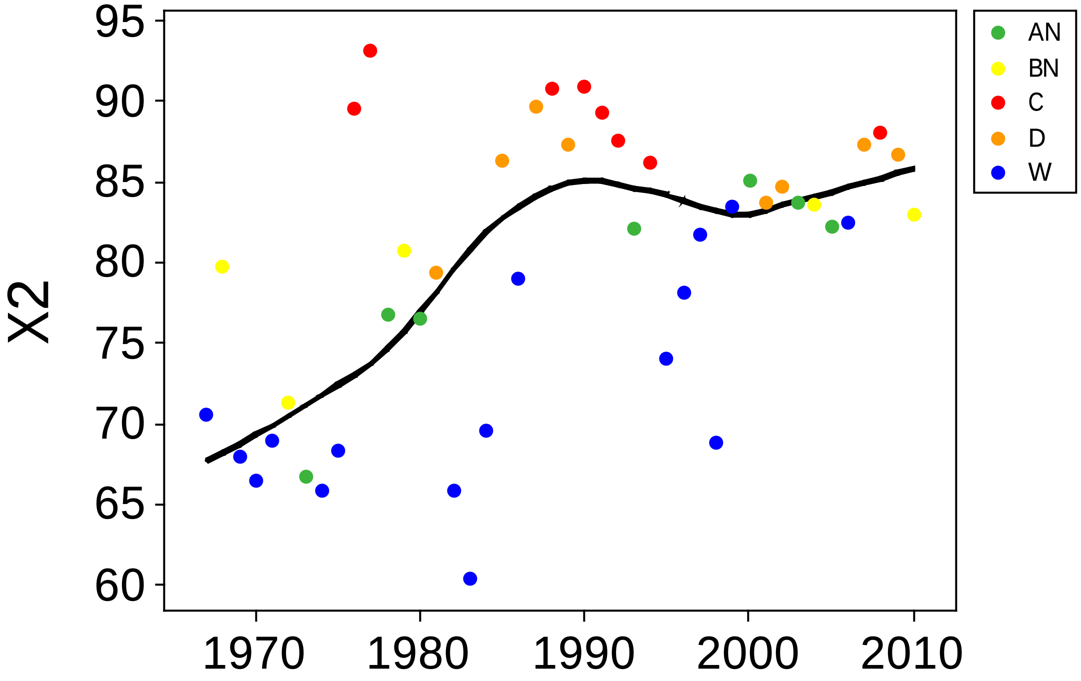

Figure 7. Time series of fall X2 since 1967. Water year types represent the preceding spring. A LOESS smooth is fitted to the data.

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. (2010) calculates 78%). This decline in delta smelt habitat has coincided with the long-term decline in delta smelt abundance (Feyrer et al. 2010). Operations modeling done 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. (2010) concluded that the effects of future project operations in combination with climate change is likely to lead to further declines in delta smelt habitat in all water year types.

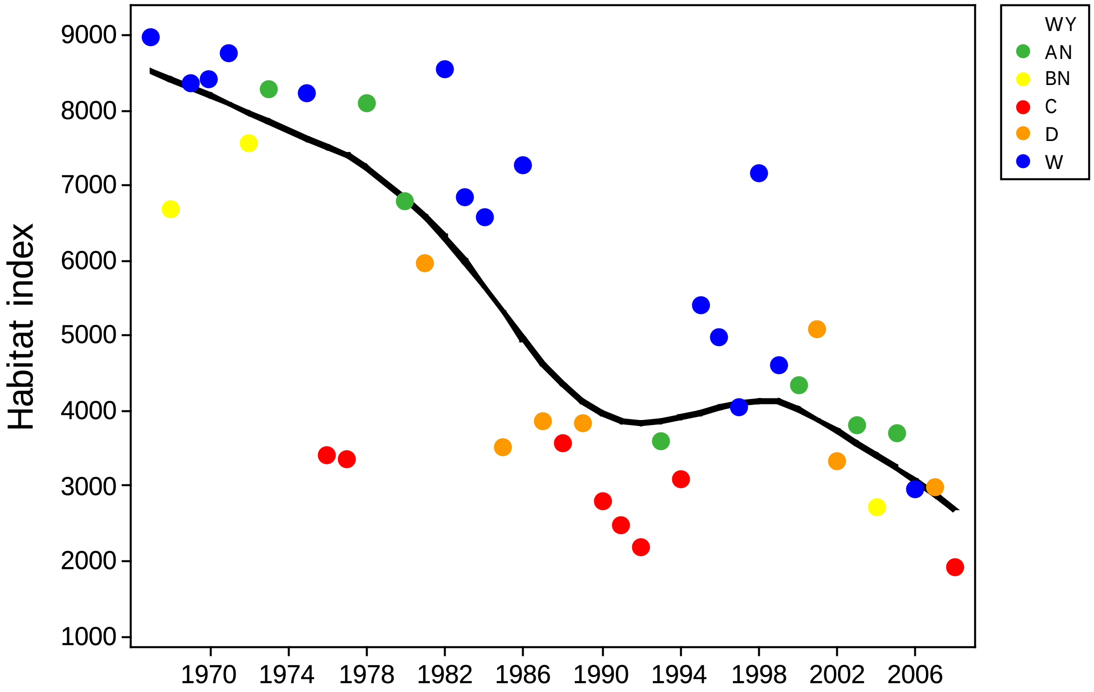

Figure 8. Delta smelt habitat index time series. A LOESS smooth is fitted to the data.

(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 negative trends in X2 for September, October, and November but not December in both wet and above normal years.

Late fall and winter precipitation often drives X2 downstream in December, and to a lesser extent November (USBR 2008). 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 era, average outflow is still more frequently elevated than either October or September. September and October have exhibited little variability in X2 in the POD era, and have seen larger changes in monthly average X2 compared with the post-reservoir era. Consequently, the first two fall months appear to be a reasonable time period to implement an outflow action meant.

The choice of outflow 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 tiers: a high habitat 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 tiers is a consequence of geography (Feyrer et al. 2007). The high habitat tier corresponds to X2 opening into Suisun Bay, with the low tier corresponding to X2 in the more constrained river channels upstream.

During most of the post-reservoir era, average X2 fell in the high habitat tier in falls after many wet and above-normal springs. This has not been the case in the POD era. Feyrer et al.'s results suggest that reaching the high habitat tier (X2 at 74 km or less) approximately doubles the expected abiotic habitat index above POD-era values. Because the loss of high-tier habitat represents the biggest fall outflow change since the end of the post-reservoir era, an outflow action that restores it in the years that used to have it appears to us to be justified and very likely to produce habitat and 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 era conditions and variability.

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. Consequently, we conclude that the biological rationale for the 2008 RPA action is sound.

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.

BASIC MANAGEMENT FRAMEWORK

Adaptive management is management undertaken in the face of uncertainty. The draft plan follows the Department of Interior (DOI) Technical Guide (http://www.doi.gov/initiatives/AdaptiveManagement/) fairly closely. The DOI Guide defines the general adaptive management approach as a looped process having six steps (Figure 9).

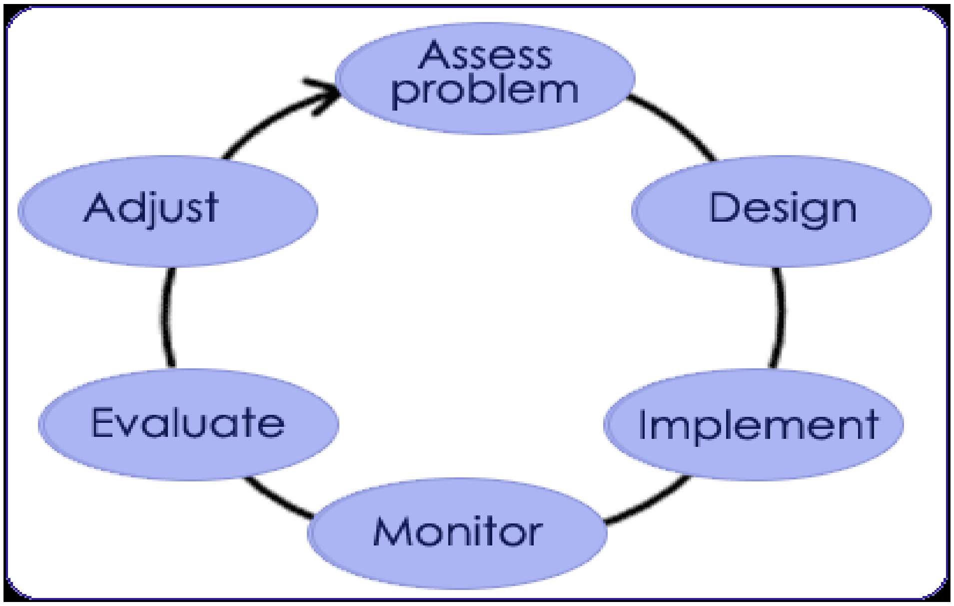

Figure 9. Adaptive management cycle (reproduced from DOI Adaptive Management Technical Guide).

The loop is initially entered at the "assess problem" step, which includes setting overall goals. For Fall outflow, we expect that the basic feedback loop would be closed annually. This implies that field and possibly laboratory data would be collected annually, regardless of water-year type and whether Fall outflow were augmented. After each year's experience, a workshop and expert panel review would be used to explore 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:

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 FMT 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. Experimental manipulation of Fall outflow offers a better chance to learn about population level Fall outflow effects. Given the potentially high water costs of implementing Fall outflow actions and concomitant need to learn about the effectiveness of high-outflow management alternatives as quickly as possible, the active approach is strongly to be preferred and its use is a premise of this exercise.

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.

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. The use of both 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.

ELEMENTS OF A PLAN

The preceding discussion reviewed the background for Fall outflow management and the basic adaptive management framework that the plan is based on.

The succeeding sections of this document lay out plan elements that observe the conventions of adaptive management as described in the DOI Guide. The "set-up" elements include a description of the conceptual model and working hypotheses about the system, a draft approach to evaluating outcomes that is based on quantitative statistical models and monitoring, and a discussion of initial experimental alternatives. The approach follows the DOI Guide and others in assuming that management decision-making in the "iterative" phase of adaptive management is based on ongoing assessment of the relative performance of competing beliefs about the behavior of the system in the face of experience implementing contrasting management alternatives.

We have adopted the POD conceptual model, with the addition of more detailed fall processes following the analysis in Feyrer and others (2007, 2010). These processes describe how variation in outflow may drive changes in abiotic delta smelt habitat quality and quantity, which in turn causes biological effects, including some that may alter the vital rates of delta smelt or indirectly cap subsequent recruitment. The intent of monitoring and performance evaluation in this plan is to determine whether these beliefs are true, and, if not, what the correct process model is.

A message repeated in the document is that this plan represents the starting point for an ongoing, labor-intensive process of action, observation, analysis, and decision. While we have tried to develop quantitative predictions of management outcomes at all levels in advance of this plan, it has become quite clear that while the IEP and others are monitoring many things, they are not currently conducting all of the kinds of monitoring that will be needed in this undertaking. Moreover, the modeling framework needed to generate predictions of some of the internal quantities of interest is presently under development and not ready for use. Consequently, some of our current predictions are qualitative.

We have given a good deal of thought to the quantitative modeling approach. The present concept is related in this plan; it provides a basis to complete a system of models that will support prediction of the variables that are currently of interest. However, it does attempt to model all the processes occurring in various seasons that are thought to have important effects on FMT delta smelt abundances. We have therefore planned that the quantitative modeling element of this plan be compatible with, and ultimately integrated with, the delta smelt life cycle model currently being developed by Ken Newman and colleagues.

As both the fall outflow model and the Newman life cycle model are refined, we expect that they will inform each other. However, this is a major project that will extend into the future. Newman et al. expect to have a working model running soon, but it is likely that a great deal of additional work will be needed before the model is ready for widespread management use. At present, other delta smelt life cycle models we are aware of are either not spatially explicit or not sufficiently detailed to address Fall outflow effects.

SET-UP ELEMENT: GOALS

The goals addressed by this plan are (1) to manage Fall outflow for conservation benefits to delta smelt while minimizing water supply and water supply reliability impacts; (2) 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.

SET-UP ELEMENT: MODELS AND HYPOTHESES ABOUT SYSTEM

Conceptual model

This plan relies on a Bay-Delta pelagic fishes conceptual framework developed by the Interagency Ecological Program 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). The basic conceptual model (Figure 10) is rooted in classical food web and fisheries ecology and 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 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)

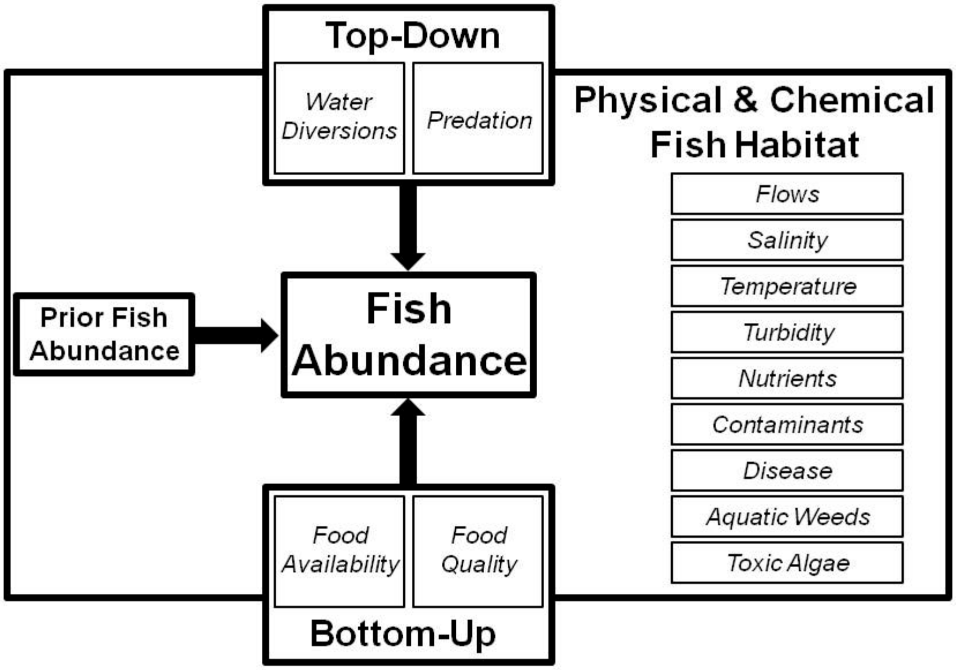

Figure 10. The basic conceptual model for the pelagic organism decline (updated from Sommer et al. 2007). Adapted from Baxter et al. 2010.

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 (Figure 11; Baxter et al. 2010).

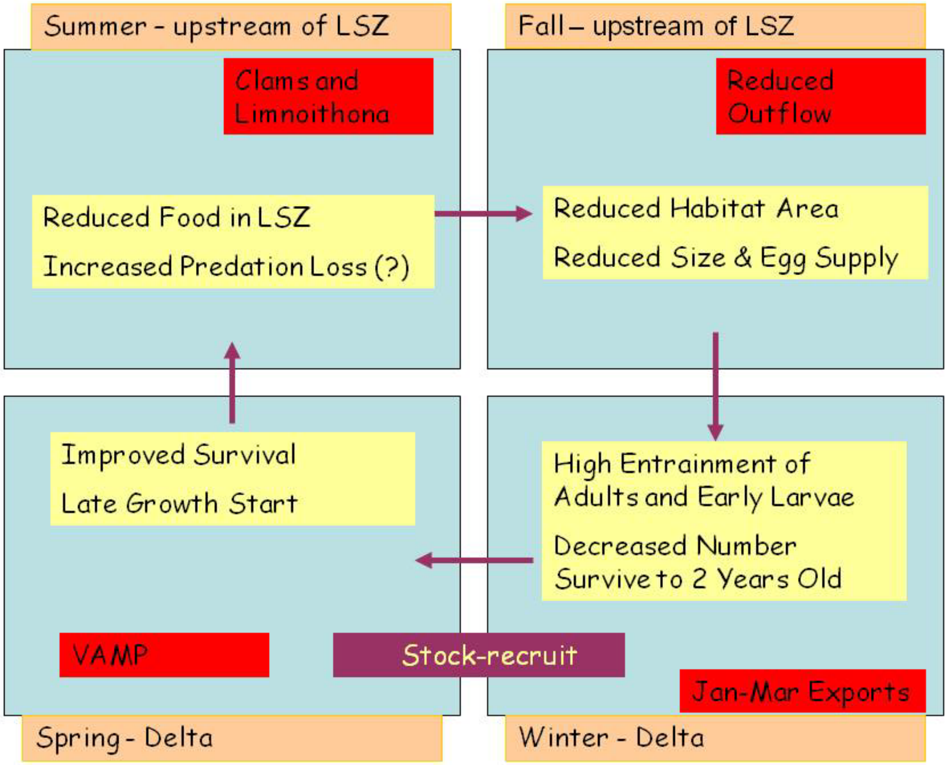

Figure 11. Delta smelt species model. Adapted from Baxter et al. 2010.

This species conceptual model was designed to be consistent with the draft DRERIP delta smelt model (Delta Regional Ecosystem Restoration Implementation Plan; http://www.dfg.ca.gov/ERP/DRERIP.asp), which is still in revision. As with the basic conceptual model, it was developed on the basis of a qualitative *weight of evidence* approach (Burkhardt-Holm and Scheurer 2007). The POD team identified the most *plausible* linkages between drivers and fish life stages based on its evaluation of all available POD laboratory results, long-term monitoring data, correlations, models, and the team's understanding of how the estuary functions.

The model identifies key seasonal drivers in red, with proximal causes and effects in yellow. For the delta smelt model, summer and fall are dominated by food availability and habitat drivers. 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. We develop a more specific model of the bottom-up processes affecting habitat quality and quantity below.

Key Process Model: Habitat quantity and quality

The carrying capacity for any species is determined by a suite of factors that collectively determine habitat quantity and quality and other drivers, thus determining how many individuals can survive to successfully reproduce. Studies of stream ecosystems have tended to define carrying capacity for salmonid fishes in terms of physical habitat area (e.g., Hilderbrand 2003), while studies of large marine ecosystems have tended to define carrying capacity for fishes in terms of food web productivity (e.g., Christensen and Pauly 1998). There are few studies that have tried to explicitly quantify carrying capacities for estuarine fishes, but a mix of biotic (food web) and abiotic (physical parameters) factors have been used to define habitat suitability (Stoner et al. 2001; Manderson et al. 2002) and carrying capacity (Luo et al. 2001) for estuarine fishes along the U.S. Atlantic coast.

The fall represents the time of year when delta smelt are juveniles within a few months of sexual maturity. It is a period when water temperatures are cooling down toward optimal levels for delta smelt growth and therefore, the fish may be able to make a final energetic push to acquire the calories needed to survive the winter and produce high quality eggs the following spring. The fall is also the time when freshwater flows to the estuary reach annual minima. This can restrict the region of suitable delta smelt habitat to a fairly small area (Feyrer et al. 2007; 2010).

Like other fishes, delta smelt habitat suitability is determined by a mixture of abiotic (Swanson et al. 2000; Bennett 2005; Feyrer et al. 2007; 2010; Nobriga et al. 2008; Kimmerer et al. 2009) and biotic (Nobriga 2002; Bennett 2005) factors *and their interactions* (Baskerville-Bridges et al. 2004; Hobbs et al. 2006; Mac Nally et al. 2010). For the purpose of articulating processes linking outflow to delta smelt, we introduce the following arguments and considerations.

(1) Abiotic smelt habitat can be described in terms of salinity and turbidity as described by Feyer et al. 2007. Furthermore, steady-state abiotic habitat extent and location can be predicted on the basis of outflow in accordance with Feyrer et al. 2010.

(2) Delta smelt are food-limited prior to and during fall (Bennett et al. 2008; and the persistent fork length decline since circa 1990 shown by Sweetnam 1999 and Bennett 2005).

(3) Changing fall outflow probably affects carrying capacity by changing the way or frequency with which space translates into opportunities for feeding, escape from predators, or other effects not related to crowding.

(4) Copepod/mysid dynamics probably not affected by outflow.

    a. Based on historical food web and stomach contents data, delta smelt productivity is most efficiently supported by a diatom → calanoid copepod/mysid shrimp trophic link (see Moyle et al. 1992 for 1970s diet data and Kimmerer and Orsi 1996; Orsi and Mecum 1996 for diatom-zooplankton linkages).

   b. The primary factors influencing diatom, calanoid copepod and mysid shrimp productivity are three things that *will not be meaningfully influenced by fall flow variation in the range being discussed* - overbite clam grazing (Kimmerer et al. 1994; Orsi and Mecum 1996; Jassby et al. 2002), wastewater ammonium load (Dugdale et al. 2007), and water temperature (Kimmerer 2004).

   c. Thus, we do not expect outflow manipulation within the range that is being discussed to substantially influence per-volume low-salinity zone productivity.

(5) Some delta smelt will get a food web benefit from increased outflow, but it will be caused by increased opportunity to find adequate prey, not increased LSZ zooplankton productivity. Specifically, the increased Delta outflow will broaden the spatial distribution of delta smelt such that it includes more of the upper estuary. A broader spatial distribution will lead to more frequent overlap with food-producing regions like Suisun Marsh so that a greater proportion of individuals will find zooplankton densities, possibly coming from external sources like Suisun Marsh, that are sufficient to meet their metabolic needs.

(6) Turbidity at X2 is higher when X2 overlaps Suisun Bay than when it's in the river channels east of the Sac-SJ confluence because the estuarine currents and wind shear over the shallow Grizzly and Honker bays can continually resuspend sediment throughout the water column. We are aware this may not occur as strongly as it did historically (Schoellhamer 2011), but the degree to which changes are a factor is investigable in the field and via advanced hydrodynamic modeling coupled with sediment transport modeling.

   a. Higher turbidity is expected to reduce predation rates on delta smelt, because most diurnal piscivores are visually-oriented.

   b. Higher turbidity might lead to higher or lower histopathologic scores or other nutritional health indicators (e.g., energy density) depending on whether potential benefits of turbidity (lower energy expended finding food and evading predators) outweigh potential detriments (higher exposure to sediment-bound pesticides). Both of these questions are accessible to study.

(7) Predatory fish densities in the LSZ may be higher when the LSZ is centered upstream of the confluence because the LSZ is more compressed. This might lead to higher per-capita predation risk for delta smelt. This question appears to be addressable via sonar camera technology.

A simplified model integrating these assumptions is presented as (Figure 12). This model represents habitat, bottom-up, and top-down elements and Fall X2 as a filter modifying them. 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.

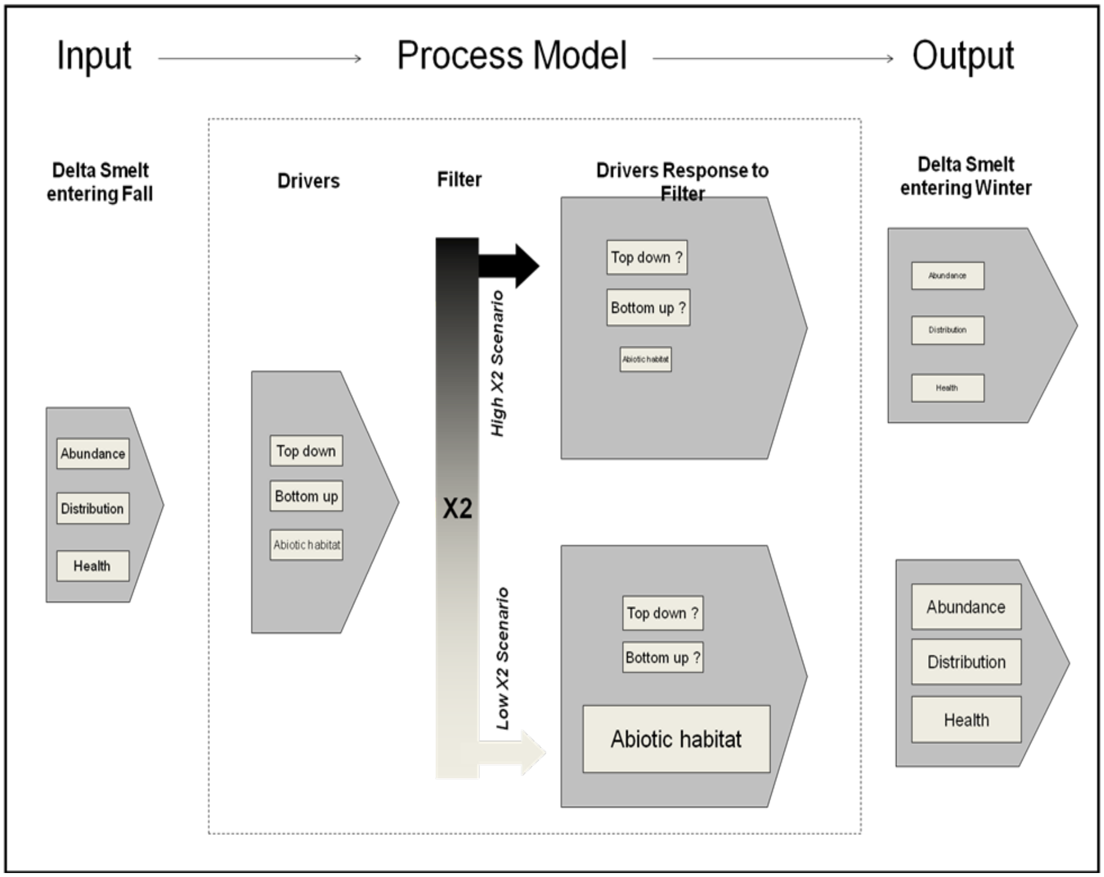

Figure 12**.** Process model of effects of Fall outflow on delta smelt through changes in habitat quantity and quality. Fall outflow affects (either directly or indirectly) the quantities on the left.

The process assumptions described above can be used to make predictions, and can be quantitatively modeled. In the next section, we develop a quantitative modeling approach that allows us to evaluate the conceptual model using a combination of historical data and new data that will be collected as management proceeds.

SET-UP ELEMENT: 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. <u>Environmental</u> 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.

<u>Control</u> 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.

<u>Process</u> 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

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

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

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

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

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

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.

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

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

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

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

$$\mathbf{DS}_t = \mathbf{M}_t\,\mathbf{DS}^*_t \qquad (7)$$

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

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

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

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 $\boldsymbol{\beta}_{mij}$ 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
~	Symbol to indicate "is distributed as"
$\mathbf{X'}_s$	Vector of covariates that affect survival
$\boldsymbol{\beta}_s$	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

$\boldsymbol{\beta}_{mij}$	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

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

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.

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

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:

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

SET-UP ELEMENT: PREDICTIONS

A key to the adaptive approach described in this document is that alternative conceptual models lead to a suite of predictions at multiple levels of the ecosystem. The conceptual models section provided a list of variables about which informative predictions might be made, and the quantitative modeling approach described above provides the means to make predictions. Our expectations are presented in quantitative and qualitative form, as appropriate, in Table 2. The 81 km and 74 km columns correspond to RPA X2 targets for "above normal" and "wet" water years. The 86 km column represents the "low habitat" tier in Figure 4. These predictions provide a starting point for development of analyses that progressively evaluate the adequacy of the existing conceptual and process models and suggest new or refined ones.

Table 2. Predicted effects of downstream movement of X2 in the fall based on 3 levels of the action. The number of + or - symbols represents the expected relative size of the effect.

Variable	86 km	81 km	74 km
DS distribution (km)	85 (77-93)	82 (75-90)	78 (70-85)
Habitat index	3270 ± 220	4870 ± 243	7300 ± 285
Total habitat with food density above critical level	-	+	+++
Total habitat with turbidity above critical level	--	+	+++
DS growth in fall	-	++	+++
Corbula density at X2		-	--
DS abundance in fall	Continued declining trend	uncertain	+ reversal of trend
DS growth response to density of current zooplankton composition		+	++
Rate of transfer of copepod from production to DS habitat sites		++	++++
Piscivorous fish density at X2	+	uncertain	-

DS recruitment increase prediction (relative to 86 km)	NA	+	++

We will make quantitative predictions about the relationships once quantitative models are parameterized. The values of estimated parameters themselves will constitute hypotheses about the size and sign of effects described in Table .

Predictions from two quantitative models are provided. Estimates for delta smelt distribution were made from a linear regression fit to the data in figure 3. Following Feyrer et al. (2010), delta smelt abiotic habitat index was predicted based on a LOESS model fit to the data in Figure 4.

SET-UP ELEMENT: MONITORING AND STUDIES PLAN

a. Monitoring

We plan to conduct the full suite of monitoring called for in this plan in all years, whether a fall outflow augmentation is carried out or not. This section lists monitoring needed to support analysis of the effects of fall outflow. In labor and cost terms, we are fortunate that a majority of the work is already being done by the Interagency Ecological Program (IEP). Besides its fish surveys, the IEP operates continuous sensor compliance monitoring that is a central part of the Habitat Study Group design and key to the active adaptive management strategy developed here.

We prefer to avoid changing any of the IEP long-term monitoring projects, 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. Because the current abundance of delta smelt is so low, we do not intend to substantially augment smelt sampling that is already occurring. We believe some reliance on measurements of surrogate species, such as age-0 striped bass and Mississippi silversides, may be appropriate.

The following data are currently slated to be collected in the Fall:

1. Delta smelt abundance and distribution (primarily from the more than 100 FMWT stations plus other monitoring programs such as the San Francisco Bay Study, Suisun Marsh Survey, Chipps Island Trawl, and beach seine surveys)
2. Temperature (continuously at several stations, plus discrete measurements once per month at the more than 100 FMWT stations as well as discrete measurements associated with other fish sampling like Chipps Island trawl, beach seine surveys, Suisun Marsh surveys, etc.)
3. Turbidity (continuously at several stations, plus discrete Secchi depth measurements once per month at the more than 100 FMWT stations as discrete measurements associated with other fish sampling like Chipps Island trawl and Suisun Marsh surveys, etc.)

4. Ammonium concentration and other water quality characteristics (monthly at up to 22 EMP stations)
5. *Corbula* density (once per quarter at 13 EMP stations as well as during a spatially-intensive study conducted by DWR and USGS)
6. Specific conductance (continuously at several stations, plus discrete measurements once per month at the more than 100 FMWT stations as discrete measurements associated with other fish sampling like the Suisun Marsh survey)
7. Abundance and distribution of all species collected during fisheries monitoring surveys during the fall.
8. Copepod and other potential prey density (monthly at up to 22 EMP stations and at 40 core FMT stations coincident with fish sampling)
9. Chlorophyll *a* concentration (monthly at up to 22 EMP stations)
10. *Microcystis* survey (qualitative distribution assessment during routine monitoring)

b. Key Ongoing Studies

As described earlier, the 2010 HSG plan included initiating a package of key studies designed to elucidate aspects of the processes underlying fall outflow effects. 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 preceeding 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?

Delta smelt feeding and food web interactions

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.

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.

Distribution, concentration and fate of ammonium in the Sacramento River and the low salinity zone

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.

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

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?

SET-UP ELEMENT: INITIAL MANAGEMENT ACTION AND ALTERNATIVE

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.

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.

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 improved 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.

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