Independent Peer Review of Two Sets of Proposed Actions for the Operations Criteria and Plan's Biological Opinion

November 19, 2008

Prepared for:

United States Fish & Wildlife Service
Sacramento Fish & Wildlife Office
2800 Cottage Way
Room W-2605
Sacramento, CA 95825

Prepared by:

PBS&J
1200 2nd Street
Sacramento CA 95814

TABLE OF CONTENTS

Table of Acronyms

TERM	DEFINITION
BA	Biological Assessment
BDCP	Bay-Delta Conservation Plan
BO	Biological Opinion
BOR	Bureau of Reclamation
CVP	Central Valley Project
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
EA	Effects Analysis
EQ	Environmental Quality
FOTAG	Fisheries Operations Technical Advisory Group
km	Kilometer(s)
FMWT	Fall Midwater Trawl
NMFS	National Marine Fisheries Service
OCAP	Operations Criteria and Plan
OMR	Old and Middle Rivers
PCE	Primary Constituent Elements
PEI	Potential Entrainment Index
POD	Pelagic Organism Decline
PTM	Particle Tracking Model
RMA	Resource Management Associates, Inc. – Finite Element Model
SWG	Smelt Working Group
SWP	State Water Project
USFWS	U.S. Fish and Wildlife Service
UnTRIM	Unstructured grid tidal residual intertidal mudflat model
VAMP	Vernalis Adaptive Management Program
X2	Location in the Delta defined by the 2 parts-per-thousand salinity threshold

Introduction

The U.S. Fish and Wildlife Service (USFWS) requested an independent peer review of two sets of proposed operational actions that would result in modified operations of the State Water Project (SWP) and Central Valley Project (CVP). These actions are intended to help protect different life stages of delta smelt. One set of actions was prepared by the USFWS and the other by the Department of Water Resources and Bureau of Reclamation (DWR/BOR). These actions could become part of the Biological Opinion (BO) on delta smelt for the Operations Criteria and Plan (OCAP).

In their request for the review, the USFWS asked that the Panel address the following questions:

1. Is a reasoned basis articulated for each action that relates the action to specific effects identified in the effects analysis, and how robust is the scientific support for each action?
2. Is each action clearly described and likely implementable?
3. Given the status of the species, environmental baseline, and effects of the action, what are the strengths and weaknesses of each set of actions (taken as a whole) in contributing to both the survival and recovery of the delta smelt?
4. Given the status of designated critical habitat, environmental baseline, and effects of the action, how helpful is an action that episodically restores pre-POD era delta outflow during the fall (September, October, and November) likely to be in maintaining the intended conservation role of one or more of critical habitats primary constituent elements?
5. Is the proposed action in each set likely to achieve the objectives stated for that action? Why or why not?
6. a. Given the status of the species, environmental baseline, and effects of the action, how would you estimate the likelihood that either set of actions can appropriately contribute to both the survival and recovery of the delta smelt population, and maintain it thereafter, to the extent recovery can be facilitated by alteration of water project operations alone? b. How effectively and reliably can the actions be implemented when delta smelt population numbers are very low (as in present levels)?
7. Given the status of designated critical habitat, the environmental baseline for critical habitat, and effects of the action on critical habitat, how would you estimate the likelihood that either set of actions will restore and maintain the intended conservation role of the primary constituent elements?

Following conclusion of the review of the Effects Analysis (EA; PBS&J 2008) for the BO, the USFWS hired PBS&J to organize, facilitate and conduct the independent review of the two sets of proposed actions. Four Panel members were selected and approved by the USFWS. Three of the Panelists participated in the review of the EA. Brief biographies of the Panel members are included in Appendix A.

The review Panel received both sets of actions on Monday, November 3, 2008. The questions were submitted by the USFWS and distributed to the Panel on Friday November 7, 2008. The Panel convened in Sacramento November 17th through 19th. Requests for additional information and clarification of the review questions were submitted via e-mail to the USFWS before the Panel met and during the three days in Sacramento. The Panel points out that the review was conducted in a three-day period under a tight schedule.

Caveats and positive comments are presented first followed by responses to the USFWS's questions. General comments that apply across all actions and plans and comments specific to Action 4 are next described. The final section is minor comments on the actions.

Caveats and Positive Comments

The Panel's review would have benefited by having access to any analyses of historical data designed to evaluate the effectiveness of the actions, and how the action plans would be packaged with supporting documents in the BO. We were unable to answer some of the questions posed to the Panel by the USFWS as completely as possible because responses required quantitative information that is available but was not provided to the Panel, and three days is not enough time for the Panel to do the analyses itself. The Panel also reviewed the actions as if they were stand-alone documents and therefore we included comments that may be addressed when the plans are packaged with other documents.

The Panel commends the USFWS for requesting this review and we offer our comments to be constructive and to ultimately improve the USFWS's action plan. The Panel notes several important positive aspects of the USFWS's plan. It is clear to the Panel that the USFWS's plan involved a lot of careful thought about how to use environmental and biological information to efficiently reduce the impacts of water project operations on delta smelt. The definitions of the triggers, targets, and off-ramps within a life cycle framework reflect a great deal of thought and examination of data and available information. The actions described appear to be implementable and practical, and the use of near real-time data from multiple sources, together with the use of particle tracking model (PTM) results, is quite innovative. The reliance of most actions on Old and Middle River (OMR) flows is sound, and the Panel endorses the idea of considering both mortality and habitat for recovery.

Responses to the Seven Questions

The Panel was unable to answer some aspects of the questions because of a lack of information and analytical results, and because they were not science-based questions. We therefore parsed several of the questions so it is clear which aspects we answered. Below we answer the questions, parsed if necessary, in summary form.

Question 1

Is a reasoned basis articulated for each action that relates the action to specific effects identified in the effects analysis, and how robust is the scientific support for each action?

The actions described by the USFWS generally have a reasoned basis that relates to their effects analysis, although the reasoning is not always clearly or completely presented, and the justifications for the specific aspects of the actions are inadequately documented. The conceptual basis for each action is clear; however, the basis for triggers, numerical targets, and numerical values for off-ramps is unevenly justified with data and information (see comment 15) and some are scattered throughout the text (see comment 14). For example, the triggers for Part A of Action 1 (page 6) do not mention the salvage-based triggers described on pages 25-26. Furthermore, the expected outcomes of the actions, beyond general statements like "reduced salvage", are not described. The Panel was impressed with the thoughtfulness of the USFWS's plan, especially when the Panel mapped out the actions themselves and mentally simulated how the actions would be triggered and how they linked to each other (Table 1).

DWR/BOR's plan focuses entirely on reducing entrainment so it also matches up with the effects analysis. However, the scientific basis for DWR/BOR's actions is less clearly presented than for the USFWS's plan. DWR/BOR's plan cites relatively few unpublished and published analyses (see comment 15). The actions in DWR/BOR's plan had similar, very generally stated, objectives to those in the USFWS's plan, but in contrast, DWR/BOR's plan proposed no actions targeted at habitat.

The actions delineated in both plans appear to be based on robust scientific evidence, although not as robust as the plans assume (see comment 13). All of DWR/BOR's actions, and 4 of the 5 USFWS actions, are related to OMR flows. The OMR-salvage relationship seems to work on average but its robustness is less clear (see comment 10). How well the triggers and targets will work in reducing entrainment and enabling recovery is not assessed or reported in either plan (see comments 2 and 3). The science underlying Action 4 of the USFWS's plan, which is targeted specifically at habitat, is less robust than for the entrainment-based actions that rely on OMR flows (see comments on Action 4).

Question 2

Is each action clearly described and likely implementable?

Both plans are generally described in sufficient detail, but the information is scattered throughout the documents and is difficult to find (see comment 14). Some of triggers, targets, and off-ramps are very complicated, especially in the USFWS's plan, and both plans include mechanisms to override the triggers and targets. This results in uncertainty in whether actions will be implemented and to what duration and degree (see comment 5). DWR/BOR's actions were easier to link together simply because the triggers and off-ramps tended to be fewer and simpler. This is not necessarily an advantage if this simplicity leads to less reduction in entrainment. The Panel had a difficult time piecing together the sequence of actions related to OMR flow, especially with the complicated triggers and targets for the USFWS's actions. We had to diagram the actions of both plans to understand how they compared across plans and with other actions within the same plan (Table 1; see comment 9).

The Panel is unqualified to address whether either suite of actions can be implemented in terms of operations, water budget, transfers, economics, or politics, and has ignored potential shifts in impacts to other seasons and other species (see comment 12).

All of the actions in both plans appear to be implementable at the simplest level: most triggers and off-ramps are based on clearly measurable variables, and the actions would apply operational measures that are applied routinely (e.g., reduction of exports). We were concerned about the ambiguity surrounding the roles of the SWG, FOTAG, and other groups (see comments 5 and 6). The use of real-time data collection and assessment together with particle-tracking modeling is an innovative approach the details of which need to be thought out better (see comments 11 and 13).

Question 3

Given the status of the species, environmental baseline, and effects of the action, what are the strengths and weaknesses of each set of actions (taken as a whole) in contributing to both the survival and recovery of the delta smelt?

The Panel finds that the USFWS's plan is more comprehensive in scope and has the potential to be more protective of delta smelt than DWR/BOR's plan. However, we cannot determine the degree to which either plan may increase the survival of individual smelt, let alone address the higher order issue concerning recovery of the population (see comment 1). Neither plan presented analyses with historical data quantifying the likely protectiveness of the actions for individual smelt, which is a relatively straightforward and a much better approach than mental modeling of how each plan would perform (see comments 2 and 3). Both plans focus on controllable and measured quantities for triggering, targets, and outcomes. Although the USFWS's plan may reduce entrainment more than DWR/BOR's plan, and additionally increase fall habitat, the degree to which it does this more is not known, although the benefit to smelt could be estimated using historical data. Neither plan discusses how reductions in entrainment and increases in habitat would translate into increased survival and enhanced recovery. The more

Table 1. Summarized comparison of Actions proposed by DWR/BOR and USFWS.

Agency	Action 1 Part A	Action 1 Part B	Action 2	Action 3	Action 5	Action 4
DWR/BOR	None	Dates: December 20 start Trigger: • 3-day average Sacramento flows 25,000-80,000 cfs AND • Average turbidity >12 for 2 consecutive days at all three stations (False River, Prisoners Pt, and Holland Cut) Action: • Average OMR of -2000 to -5000 cfs over 10-day w/in 2 days of trigger (average net flow) • Only occurs once Off-ramp: • 10 days OR • 3 days Sacramento flow over 80,000 cfs OR • Spawning begins [note: not defined but could be defined similarly as Action 2 trigger]	Dates: None Trigger: • Increase in salvage for 3 days unless 3-day average Sacramento flow >80,000 cfs OR • Significant smelt in the Southern or Central Delta Action: • -5,000 cfs OMR 14-day running average, 7-day running average w/in 1,000 cfs of 14-day running average Off-ramp: • Spawning detected (females in Kodiak or Salvage) OR • Average daily temperatures >12° C at three stations (Mossdale, Antioch, Rio Vista)	Dates: None Trigger: • Smelt maybe beginning to spawn (detected or daily 3-station average temperatures >12°C) Action: • OMR not to exceed targets as determined using fish distribution, abundance, and PTM. • PEI determined by PTM not to exceed 5% in any 20-day period • 14-day running average with 7-day running average w/in 1,000 cfs OMR flow (expected -2,000 to -8,000 cfs OMR). Off-ramp: • June 20	None	None
USFWS	Dates: December 1-20 Trigger: • SWG may recommend a start date OR • Cumulative/FMWT>15 AND • Daily Salvage/FMWT>1 Action: • OMR no more than -2,000 cfs 7-day running average for a period of 14 days (max -2,400 cfs) Off-ramp: • Temperature >12°C OR • Spawning (spent female at Kodiak or Banks/Jones)	Dates: December 20 to March Trigger: • 3-day average turbidity >12 OR • 3-days of salvage at either Jones or Banks OR • Amplitude/0.5 FMWT >0.5 OR • SWG can recommend delay Action: • -2,000 cfs 7-day running average (max -2,400 cfs) Off-ramp: • Temperature >12°C OR • Spawning (spent female at Kodiak or Banks/Jones)	Dates: N/A Trigger: • Next day after Action 1 ends • SWG (if/then) – [list includes salvage index, turbidity, circumstances, data, FMWT, PTM, Kodiak-spatial data] Action: • 7-day running average OMR of -5,000 to -1,250 set weekly by SWG Off-ramp: • 3-day average flow at Rio Vista >90,000 cfs AND 10,000 cfs at Vernalis OR • Temperatures >=12°C OR • Onset of spawning (spent female at Kodiak or Banks/Jones)	Dates: w/in 20 days of reaching trigger [note: 20-day lag based on egg to larvae period] Trigger: • Temperature >12°C OR • Spent female or larva detected Action: • OMR flows set weekly by SWG • OMR flow -5,000 to -1,250 7-day running average with 3 days within 20 % of target • OR if conditions are different, then FWS sets OMR flow based on max entrainment of 1% based on PTM at Station 815 [page 32] Off-ramp: • June 30 OR • 3-day mean temperature of 25°C	Dates: April to May 15 Trigger: • PTM <1% at Station 815 w/ HORB [note: inverted to allow action] Action: • Install barrier AND • If before May 15, flap gates fixed open until May 15 Off-ramp: • May 15 OR • Action 3 ends	Dates: Sept 1-Nov 30 Trigger: • Wet and Above Normal WY for Sept-Nov (as determined previously) Action: • X2 maintained <=average X2 (Previous April-June)+15 Off-ramp: • Nov 30

protective nature (temporally extensive and more restrictive of export operations) of the USFWS's plan, and the consideration of habitat, are clearly its strengths. Major weaknesses in both plans are: lack of performance measures and monitoring needs in order to assess effectiveness; no quantification of the cumulative effects of actions on entrainment and habitat of smelt; no mechanism for linking survival of individual fish to the recovery of the population; ignoring how cumulative actions will affect recovery; and no stated mechanism for how the plans would learn and improve the actions over time. DWR/BOR's plan largely ignores habitat and the USFWS's plan does not consider any other habitat enhancing actions other than Action 4 (see comment 8)

Question 4

Given the status of designated critical habitat, environmental baseline, and effects of the action, how helpful is an action that episodically restores pre-POD era delta outflow during the fall (September, October, and November) likely to be in maintaining the intended conservation role of one or more of critical habitats primary constituent elements?

The Panel chose to answer a parsed version of question 4: Is Action 4 of the USFWS's plan a scientifically sound approach to enhancing delta smelt habitat in the fall? Action 4 is the only action in either plan truly aimed at enhancing habitat, which is a bit surprising, given the emphasis on critical habitat throughout the effects analysis and USFWS's plan. This may be due to the difficulty in assessing and affecting the habitat of a pelagic species. The Panel found Action 4 to be a worthwhile and potentially valuable approach to restoring habitat (see comment 7), provided it is done in the context of adaptive management (see Specific Comments on USFWS Action 4 discussion).

Question 5

Is the proposed action in each set likely to achieve the objectives stated for that action? Why or why not?

Because the objectives in both plans are stated in general, non-quantitative terms, it would be difficult to argue that they could not be achieved. However, the Panel strongly recommends aiming toward quantitative targets (see comment 2), and analyzing the data to provide estimates of the individual and net benefits of each action and all actions combined (see comment 3). The objectives as stated are too vague to be useful and the supporting analyses are incomplete (see comments 13, 14, and 15). For example, objectives of USFWS Actions 1, 2, 3, and 5, and all DWR/BOR actions can be generally paraphrased as: reduce entrainment mortality. Yet there is apparently no plan to determine entrainment mortality or the extent to which it is reduced, nor is there a stated link between this mortality and recovery (the ultimate goal of all this). If the objective is to reduce entrainment mortality, and entrainment is indexed by salvage, then reducing negative OMR flow reduces mortality. Lacking a quantitative target, this statement is a tautology. The critical aspect is to evaluate the performance of the actions using historical data and as they are implemented in the future.

Question 6

a. Given the status of the species, environmental baseline, and effects of the action, how would you estimate the likelihood that either set of actions can appropriately contribute to both the survival and recovery of the delta smelt population, and maintain it thereafter, to the extent recovery can be facilitated by alteration of water project operations alone? b. How effectively and reliably can the actions be implemented when delta smelt population numbers are very low (as in present levels)?

The Panel parsed this question into a series of more manageable sub-questions. We do not address the future maintenance of the population because that would involve considerations beyond the scope of this review (e.g., climate change, risks to Delta levees, future introduced species, and other probable changes in the Delta) and additional analyses.

Question 6a: To what extent can recovery be facilitated by alteration of water project operations alone?

We cannot answer this directly, but can offer our opinion and suggestions on how to answer this question more rigorously. There are data available that can provide some insight into this question. In our opinion, we do not think either plan's actions by themselves can assure recovery of the population; there have been too many other changes to the ecosystem that hinder delta smelt survival, growth, and reproduction. We view reducing the impacts of project operations as necessary but likely insufficient for ameliorating these other changes. Given that management has limited influence on many of these changes, other potential actions for addressing population recovery might include large-scale habitat actions, similar to Action 4 (see comment 8), actions reducing the establishment and spread of exotic species, actions reducing toxic chemical loading into the smelt habitat, and even a scientifically-based captive-rearing program. Nonetheless, a more rigorous answer to this question is possible with additional information but is beyond the scope of this Panel. First, what are the quantitative proximate effects of the proposed actions on delta smelt survival or habitat when they are applied to historical data (see comment 2)? Second, how do those effects accumulate across the life cycle? Third, what would be the resulting change in trajectory of the population, and would the decline be reversed? Finally, what future activities or events are likely to alter that trajectory?

Question 6b: To the extent that recovery can be facilitated by water project operations alone, how and how much does each set of actions contribute to recovery?

Again, the information provided is insufficient to compare the contribution to recovery between the Services' and DWR/BOR's plans. Although the contribution of the USFWS's actions to recovery will likely be greater than those proposed by DWR/BOR because the USFWS's actions are more comprehensive in terms of lower OMR flows for longer periods and includes a habitat action, the magnitude of the difference cannot be determined with the information provided.

Revised Question 6c: How effectively and reliably can the actions be implemented when delta smelt population numbers are very low (as in present levels)?

There are two ways that low population abundance can influence the effectiveness or reliability of the actions. If depensatory mortality occurs (e.g., population is so rarefied that females become mate-limited), then the rate of population decline will accelerate and the population will go extinct rather quickly. There is not enough information available about delta smelt population dynamics to determine if they can or will show depensatory mortality.

The second mechanism for effects of abundance is through the ability of investigators to monitor and assess the population. The fewer fish there are, the larger the confidence limits around estimates, and the less information about demography, responses of individuals, habitat use, and proportional losses to export entrainment. This reduces the reliability of actions because the necessary feedback on effectiveness is weaker; and it reduces their effectiveness because there is no basis for refining them. A low density of fish can also affect the reliability of biologically-based triggers, such as detecting spent females in the Kodiak trawls and use of 20-mm survey results to seed PTM simulations. Neither plan describes the degree of conservatism (protective of the species) of their triggers, targets, and off-ramps, and how their numerical values might be adjusted to account for uncertainty at low population levels (see comment 13).

Question 7

Given the status of designated critical habitat, the environmental baseline for critical habitat, and effects of the action on critical habitat, how would you estimate the likelihood that either set of actions will restore and maintain the intended conservation role of the primary constituent elements?

As with question 4, the Panel's answer addresses delta smelt habitat overall, rather than element by element. The DWR/BOR plan offers to build shallow habitat, but this will not happen for a long time and it is unlikely to benefit delta smelt, a pelagic species. The USFWS's Action 4 is the only action directed specifically toward habitat (see Question 4 and Specific Comments on USFWS Action 4).

The actions designed to reduce entrainment will also affect habitat in ways that would be difficult to predict. We assume that OMR flows would be reduced by cutting export flows, which in turn would result in a reduction in inflow (with lower export flow, operational criteria could be met with a lower inflow). The net effect would be an increase in residence time across the Delta (Kimmerer and Nobriga 2008), which could increase phytoplankton biomass (Jassby et al.

2002), with cascading effects through the foodweb. However, these effects will vary by season, and lower flow and longer residence time can have other effects (e.g., reduced dilution of contaminants). Thus the net effects of the change in Delta habitat due to reducing export flows could be positive or negative.

General Comments About Both Sets of Actions

1. What happened to recovery?

Both plans lack sufficient assessment and discussion of how their suite of actions would contribute to recovery of the delta smelt. Although this is a very difficult question to answer, ultimately it is the question. For actions designed to manipulate OMR flows, there is a strong and logical link between reducing export pumping and reducing entrainment mortality. The link between reduced mortality and subsequent population size is equally logical but quantitatively much less certain. This is because of variability in population abundance that obscures the effect of entrainment mortality, and because that mortality itself may be small relative to other sources of mortality. This means that modeling is a superior approach to correlative analyses for estimating entrainment mortality and the contribution of reducing that mortality to recovery. Likewise, the link between increased habitat and recovery is difficult to make, but should be attempted.

The design of actions linked to specific life stages is a good start toward an analysis of recovery. As performance measures are defined and quantified, the contribution of actions to recovery can be determined. For example, if actions result in only small changes in salvage, days of vulnerability of larvae, or fall habitat, relative to historical patterns, then these actions likely contribute little to recovery. A true Population Viability Analysis could be developed within the next few years that can take the measured changes and translate them to changes in population trajectories. In the meantime, much can be done to assess how actions affect recovery potential through careful use of historical data and careful selection of performance measures.

We recommend that the USFWS add a concluding section to its action plan that describes the expected benefits of the actions in fostering recovery.

2. Quantify the expected responses of the actions

Neither plan reported the results of using historical data to quantify how its actions would perform. Both plans approached the calculations, and discussed some of the results (USFWS) or presented some of the needed information (DWR/BOR), but then stopped short of reporting the results. Figure 2 in DWR/BOR's action plan is a good approach (although the details of the graphs are confusing), but then DWR/BOR only describes in the text how salvage would be reduced or large events missed by their proposed actions. It appears that the USFWS has also made at least some of these calculations. The action plan states "The USFWS used the CALLite operations model to evaluate different operational scenarios. Different operational parameters were run to evaluate their influence upon predicted entrainment (page 1)." Yet, neither plan reported an evaluation using historical data to simulate how their actions would have reduced salvage of adults, entrainment of larvae, and increased smelt habitat. The Panel requested the results of any such analyses from the USFWS for this review but we were not provided any results.

The Panel knows the problems with simulating actions with historical data and using such results to infer future responses, particularly when only some aspects of the actions can be simulated; however, such simulations are feasible and can be very informative. DWR/BOR and the USFWS have performed at least some of the possible analyses, and so we are perplexed as to why they were not part of the action plans. This situation is perfect for gaming. Not only can the effectiveness of the proposed actions be roughly quantified, but the actions can be fine-tuned by trying different triggers, targets, and off-ramps using the historical data with uncertainty explicitly incorporated (see comment 13). The effectiveness of the actions in reducing salvage, decreasing larval vulnerability to entrainment, and increasing habitat should be evaluated and the results presented. The lack of such analysis, or its omission from the presentation, is a major omission that seriously weakens the scientific robustness of both plans.

Both DWR/BOR and the USFWS present actions that indicated that the objectives were to protect from entrainment (USFWS Actions 1 and 2), minimize entrainment (USFWS Actions 3 and 5), or avoid entrainment (DWR/BOR Action 3). The Panel recommends that both plans use "reduce" to more accurately reflect what is being attempted. To be a bit snippy, the Panel points out that to minimize or avoid entrainment, one would set pumping to zero.

3. Need for performance measures

The lack of specific and quantitative performance measures in both plans is a significant omission. Two types of performance measures are needed: implementation and response. The implementation measures allow determination of whether the action achieved the desired local or proximate effects, and the response measures determine whether the desired outcome was achieved. Each action may have several implementation and response performance measures. For example, an implementation measure might be OMR flow in relation to the target level, and response measures could be the resulting reduction in salvage, an estimate of the reduction in entrainment and population impacts, and the range of birthdates back-calculated from surviving delta smelt. Some of the measures would need to be computed from data from existing monitoring programs or from investigations designed specifically for this purpose. The USFWS should define these measures and examine the existing monitoring to determine if additional monitoring, assessment, or analysis is needed. Neither plan describes whether or how the current monitoring can be used to assess the effectiveness of the actions in the short- and long-term.

The USFWS should include system-level metrics related to hydrology as part of the performance measures. For example, derived flow fields in the Delta can be used to assess the performance of specific actions. Flow fields would integrate the actions with operations and other activities in the system and with inflow and outflow. PTM simulations can show at least qualitatively whether desired shifts in spatial distribution of larvae were achieved. The plan should have a monitoring component that not only looks at implementation and response performance measures, but also measures such as PTM-derived distributions, fall X2, and possibly *Corbula* distributions (see Specific Comments on USFWS Action 4), and should include careful determination of whether exports have been shifted within the year or to the next year to offset actions taken. The ecological effects of such shifts should also be analyzed but in a more qualitative way.

The ultimate performance measure is the response of the delta smelt population as it recovers. Recently, much progress has been made in estimating the delta smelt population abundance from the various sampling programs. However, there is still much uncertainty associated with the population estimates, especially with the population at a very low abundance. Although the ultimate long-term performance measure is the recovery of the population, and population indices should be closely watched, the implementation and response performance measures will ensure that the actions are achieving their short-term objectives. These measures will provide immediate feedback on the effectiveness of the actions and allow for their improvement.

The current advisory structure seems sufficient to evaluate the implementation and proximate performance measures, although additional monitoring, analysis, and assessment will be essential. All of the actions should be evaluated together once per year by an outside advisory panel.

4. Adaptive management

The Panel recommends that the USFWS eliminate the term “adaptive management” in describing their suite of actions. Adaptive management is used to mean a variety of activities, and means different things in different circumstances, naturally resulting in confusion. The USFWS’s action plan appropriately describes a flexible approach that considers changing conditions and interannual variation. DWR/BOR acknowledges that its plan is not truly adaptive management, and they refer to their action plan as an “adaptive approach.”

Adaptive management is described in the scientific literature (e.g., Walters 1997) as a mode of operation in the face of uncertainty. It is far more formal and rigorous than the USFWS’s action plan. Adaptive management includes a clearly stated conceptual model, predictions of outcomes, a study design to determine the results of the actions, a formal process for assessment evaluation (i.e., learning), and a program of periodic peer review. None of this is described in either action plan.

Clearly the likely effectiveness of these or other actions is highly uncertain, suggesting that both plans would benefit from adding at least some elements of true adaptive management to their approaches. The idea of formally evaluating results of actions as they are implemented and having a mechanism for using these results to then fine-tune the actions for future implementation would strengthen the science and increase the efficiency of the action plan. Other elements of adaptive management that would be helpful to the plans are tailoring the data collection to the needs of the actions, and use of competing models (or hypotheses) in evaluating the actions. Neither plan describes performance evaluation, learning mechanisms, targeted data collection, or competing models.

5. Ambiguity is not flexibility

In most of the actions proposed by the USFWS, specific triggers and targets are stated, but then qualified by vague statements about how advisory groups can recommend deviations from the triggers and targets. Although the USFWS clearly states they have final authority, this type of management structure creates the appearance of ambiguity, rather than flexibility. The same concern applies to DWR/BOR's plan. Without firmer guidelines, no one is sure under what conditions the actions will be triggered and what the targets will actually be. This is not adaptive management, but management trying to be flexible and potentially tending towards ambiguous. The Panel supports flexibility but suggests that the document must be clearer about whether actions will be taken or not. One approach would be to include a minimum set of actions that would be guaranteed to be implemented.

6. Articulate organizational pathways

In addition to the problem of ambiguity in when the actions would be implemented, the use of advisory groups or decision-making bodies makes the decision process itself ambiguous. DWR/BOR's plan implies in several places that the final decision about triggers and targets could be decided by operations people or committees. The USFWS plan also states that triggers and targets can be overridden using input from advisory groups. Both of these situations can appear as if the "fox is guarding the hen-house." Appearances can be important in these situations. Decision-making should made transparent in both plans. DWR/BOR's plan should state how "suggestions" from the groups outside of the USFWS would be passed on to the USFWS. The USFWS's plan should explain how advice from advisory groups will be used and provide a clear description of the make-up of the advisory groups and assurances of their independence.

The USFWS should set up an advisory group[1], apart from those already proposed, that would be truly independent. This group would provide peer review of implementation and effectiveness of the actions on an annual (or other regular) basis, providing valuable feedback to the USFWS.

7. Addressing habitat and mortality is a good thing

The Panel supports including actions designed to address habitat needs for delta smelt in addition to actions for reducing pumping-related mortality. The USFWS's Action 4 is a good idea in principle because the bottlenecks in the delta smelt life cycle are not clearly known, and empirical evidence suggests the importance of summertime habitat and the influences of X2 and temperature (see Action 4 comment). DWR/BOR's plan also discusses habitat but in terms of restoring marshes sometime in the future, which is unlikely to be linked to the recovery of this pelagic species.

8. Alternative habitat improvements using water

A variety of actions should be considered to improve habitat for delta smelt during critical times. Given that the ESA specifically addresses the provision of critical habitat (as defined by various PCEs), a suite of open water habitat measures could be nested with Action 4 (see Action 4 comment). Although Action 4 may have the potential to improve summertime habitat conditions, it is also likely to require a substantial amount of water (potentially shifting impacts to other times of year), and would be applied only in specific water-year types. A portfolio of such actions tailored to specific water year scenarios would be a considerable improvement over this single action. Such a portfolio would require development of specific objectives and analyses that would quantify the likely benefits to delta smelt. One such alternative might include maintaining appropriate habitat conditions (e.g., salinity and temperature) in Suisun Marsh during summer and early fall. Targeting conditions in Suisun Marsh may be a promising complement to Action 4, because the marsh is regularly inhabited by delta smelt, typically has higher copepod densities than adjacent Suisun Bay, and is regularly managed for low salinity during other times of the year. Conceivably, the tidal gates at Montezuma Slough would divert low salinity water into the marsh on ebb tides at a frequency sufficient to maintain low salinity into the fall. Tidal flooding of the marsh during nighttime provides a natural cooling mechanism, providing a range of suitable water temperatures in parts of the marsh. Although considerable planning of triggers, targets, off-ramps, and performance measures would be required for such an action, one compelling feature is that managing Suisun Marsh can have substantial benefits for delta smelt. We encourage the USFWS to consider this and other actions to enhance habitat for delta smelt.

[1] Please ignore the self-serving aspect of a Panel recommending that a review panel be created.

9. The plans would benefit from simplification

Both plans, and especially the USFWS's, are complicated enough to create confusion and hinder implementation. The Panel diagrammed the actions for both plans (see Question 2, Table 1), and struggled to understand how the different triggers relate to each other. The "and" versus "or" checks on triggers can get confusing and the multiple triggers and off-ramps led to uncertainty about whether there would be gaps in time between actions. There appeared to be situations in which actions affected or overlapped other actions, and it was unclear which target would have priority in overlapping actions. Gaps between some of the actions, during which delta smelt could go unprotected, should be clearly described. The simulation of historical data would help here in terms of understanding how the actions fit together into a cohesive protection and recovery plan for delta smelt.

10. Additional confirmatory analyses of OMR flows and salvage

The relationship between OMR flows and salvage should be examined on shorter time scales, either daily or weekly. Both plans make extensive use of the relationship between OMR flows and salvage. This relationship is a sound and valuable way to set targets to reduce entrainment. The USFWS also presents a reasonable regression analysis to determine the break-point in the OMR-salvage relationship, including a resampling scheme to deal with variability (the analysis appeared to be well done but was poorly described and largely undocumented). The breakpoints determined by these analyses were used to justify the selection of target OMR flows. DWR/BOR showed the OMR flows and salvage on a monthly basis (January and February means), and the USFWS used annual values for winter. The accuracy and precision of the relationship between OMR flows and salvage should be confirmed by examining daily and weekly data (i.e., the scale on which management occurs) since the averaging required for the seasonal analysis may excessively smooth the relationships.

11. Provide more details about the use of PTM simulations

The USFWS's plan makes use of PTM results in several places, which the Panel generally supports. The details of the PTM simulations should be clearly documented: will historical conditions or anticipated future hydrological conditions be used, how many particles will be tracked, and how will the 20-mm survey results be used to seed the simulations? The latter may be inadvisable given the low abundance in the 20mm survey (and consequently high uncertainty in inferred distributions). The Panel was also not familiar with the control-point method that the USFWS stated would be used to set OMR flows as part of Action 3.

The USFWS should also consider the state of the DSM2 and other models. No calibration of the DSM2 PTM has been published (see Kimmerer and Nobriga 2008), and that should be done before this model is used for setting OMR target flows. At the same time, several more sophisticated models that include PTM components are becoming available (e.g., RMA, UnTRIM). The USFWS should remain aware of these developments and take advantage of new capabilities as they become available.

12. Coordination of related activities

The Panel knows that the USFWS is aware of the NMFS OCAP BO but would be remiss if we did not mention somewhere in this review that actions proposed for delta smelt could have negative effects on the other listed species in the ecosystem. The intersection between the delta smelt OCAP BO and the OCAP BO for salmonids, green sturgeon, and killer whales should be considered. Potential interactions with other ongoing activities in the Delta (e.g., BDCP) should also be considered.

Both plans make assumptions about, or fail to mention, how current programs that have an end date enter into the design and implementation of the actions. For example, VAMP may end in a few years. What do the actions in either plan presume about the continuation of VAMP? How do the requirements of VAMP interact with the manipulations of USFWS Action 5?

13. Address Uncertainty

Many of the uncertainties associated with the triggers, targets, and off-ramps for the specific actions are not discussed. Uncertainty must be considered in two respects. First, cause-effect links in a dynamic estuarine system can be weak and variable, so that the same action may elicit different responses at different times and places; yet, the actions in both plans assume the system is relatively deterministic. Second, parameters determined from field data (e.g., FMWT index, salvage levels) are treated as point estimates, whereas they are samples from a distribution with inherent variability and measurement error.

Uncertainties seem to be simply ignored in DWR/BOR's plan, and dealt with in the USFWS's plan by putting in flexibility (see comment 5). Instead of analyzing the effectiveness of the actions with uncertainty included, the USFWS plans to use expert opinion to adjust the actions in light of uncertainty. Such flexibility, if incorporated correctly (see comment 5), is a reasonable and practicable approach for dealing with year–to-year variability (i.e., stochasticity) and uncertainty. However, gaming and analysis of historical data can also provide guidance as to the frequency and severity of unexpected conditions. Further, guidelines should be formulated for ensuring that decisions err on the side of protecting the species. This will be particularly critical at low levels of smelt abundance, at which the relative errors in all estimates (population levels, triggers, off-ramps, and performance measures) will be greater and the need for protection very important.

14. Organization and clarity

Both action plans are generally well written and well organized. The USFWS's plan, in particular, was clearly assembled thoughtfully by people with a good understanding of the underlying science.

Both plans lacked sufficient detail to ensure clarity. DWR/BOR's plan was quite short and missing most of the supportive information, and the Panel did not see a clear link between the actions proposed by DWR/BOR and the analyses provided in Manly's reports that were included as appendices. The USFWS's report contained much more scientific evidence justifying the actions and how the triggers, targets, and off-ramps were selected, but also fell short on providing sufficient details and scientific citations. This is unfortunate in that the scientific basis of the USFWS's plan includes very current analyses, and a clearer presentation of the value and robustness of these analyses would greatly bolster not only the clarity of the document, but also the likely reception by its intended audience.

15. Lack of citations for analysis supporting decision points

Both plans, but especially DWR/BOR's plan, suffer from a lack of documentation about the sources of data and information used to formulate the actions. As just one example of many, DWR/BOR's plan states "Recent DWR analyses indicate… (page 11)" without providing the analysis or citations. The USFWS's plan provides more information about the logic and science used to formulate the actions, but provides no further guidance as to where supporting information can be found. The sections in the USFWS's plan about the justification for the triggers are very informative, but even more documentation is needed, as some aspects of actions are not fully justified. Lack of citations can create the impression that the details of the actions are arbitrary, whereas in many cases they were determined from empirical data and careful thought. Without proper documentation (citations, presentation of the data), the science underlying the actions is not apparent and may be assumed not to exist.

The Panel strongly recommends that the USFWS include the needed information in the action plan (e.g., as appendices), and provide cross-references to direct the reader to the exact source of supporting information. The document should explain how information was manipulated or extracted from the original source for use in the action plan.

Specific Comments on USFWS Action 4

The Panel's comments on DWR/BOR's actions and actions 1, 2, 3 and 5 from the USFWS are addressed in responses to the questions and general comments 1 through 15. The Panel had additional comments specific to Action 4 that are presented below.

Action 4 is the only action concerned specifically with habitat of delta smelt. The other actions target entrainment but can have secondary effects on habitat. The objective of recovery and the critical habitat requirements of the ESA dictate a need to consider habitat. Except for spawning, the habitat of delta smelt is open water. Open water habitat is dynamic in both time and space. Previous analyses have shown turbidity, salinity, and temperature as important attributes of open water habitat during the summer and fall (Feyrer et al. 2007, Nobriga et al. 2008). Additional attributes of open water habitat that could be important include depth, depth variability, and proximity to shore and shoreline attributes (as surrogates for predation risk).

The action and triggers are quite simple: when a water year is classified as wet or above normal, X2 during fall (September – November) of the corresponding calendar year should be within 15 km of that during the spring of that year (April – June).

The justification for the action is that the extent of suitable habitat, as defined by the attributes analyzed in the above references, increases as X2 moves seaward. Put more simply, the area or volume of water located between where salinity is too high (salinity ~10) and where temperature is too warm (~25°C) increases with X2 more seaward. Furthermore, in recent years, fall X2 has been consistently high irrespective of the water year type, whereas in previous years fall X2 varied with spring X2. Presumably this has been due to a shift in export pumping from spring to fall. The apparent constriction in habitat has been termed a "squeeze" and it may have resulted in lower survival of delta smelt. There is also an interaction between the squeeze and food limitation.

The degree to which moving X2 seaward will affect delta smelt habitat is not well supported by the analyses presented, and the additional arguments presented for this action also seem weak. It should be possible for the USFWS to bolster the justification for moving X2 by a careful, clear analysis. This analysis could start from the results presented in the papers above to develop relationships between X2 and the number of stations (representing the extent) weighted by the EQ indices reported in these papers. Then the temperature-salinity relationships for late summer to early fall should be presented, and how these relationships varied with X2 determined. An interaction in slope between salinity and X2 would indirectly reflect a shift in the quantity of habitat; in other words, if temperature increases more rapidly with X2 in low-salinity than high-salinity water, it implies that less suitable habitat is available. An additional analysis (not previously available to USFWS, although some of the EA authors have seen previous versions) uses a 3D hydrodynamic model, together with a similar analysis of delta smelt distribution to the above papers, to show that the extent of delta smelt habitat as defined by salinity increases as X2 moves seaward (Kimmerer et al., in press). These analyses and tools would enable the USFWS to estimate the variability in physical extent of habitat with X2, and therefore better support the justification for Action 4 and to allow for performance to be quantified and learning to take place.

There are some misstatements in the text. For example, "… X2… determines the amount of suitable abiotic habitat" ("influences" may be more appropriate); "The long-term upstream shift in X2 during fall has caused a long-term decrease in habitat area…". This statement is unsupported by the citations.

The ancillary arguments (listed on page 44) are also not all well supported:

1. *Westward movement of habitat is said to reduce entrainment risk and distribute the smelt more broadly.* There is no entrainment risk to speak of during summer – fall.

2. *Variable flow conditions might reduce effects of Microcystis.* Although this is an appealing idea, we are unaware of any support for it; if there is some it should be provided.

3. *Constant salinity in fall has allowed Corbula to establish year-round populations further east.* This may be true but the link to smelt habitat or population is unclear. The logical link is through the zooplankton food of the smelt, but this is not explored and we are unaware of any convincing analyses showing this link to be important. Furthermore, the general pattern of *Corbula* biomass in the last few years is similar to that in the 1990s; why is the more recent period expected to be different?

In general, we believe Action 4 is worthwhile, but if implemented then its performance should be monitored and assessed; ideally, the action would be implemented in a true adaptive management framework. The USFWS's document mentions, but does not address, the link between population size and habitat limitation. Habitat can be limiting in cases of density dependence (when population levels are high), but there are reasonable scenarios by which habitat can limit a population even in the absence of compensatory density dependence. The USFWS should consider this possibility.

The current routine monitoring is insufficient to provide the necessary performance measures for this action. For example, the Environmental Monitoring Program samples *Corbula* at very few stations and does not measure biomass (Jan Thompson, USGS, has measured biomass in these and some additional samples, but that program has ended). A new sampling design overlaid on the existing program is needed. Similarly, measurements of *Microcystis* are probably too few and far between, and the likely influence of this action on the species would require specific investigation. Most importantly, the relationship between habitat use by delta smelt and X2 should be investigated using a combination of hydrodynamic modeling and data analysis; this too may require some additional sampling for verification of model results.

Minor Comments on the Actions

Many of the Panel's comments are covered in the answers to the questions and the general comments. Below are specific comments accumulated from the Panelists either amplifying the comments above or deemed individually worth mentioning.

USFWS Actions

Page 9 item a: "The SWG will review the totality of circumstances and request updated entrainment simulations and/or other information,…" What does the last part of this sentence mean?

Page 10 top: "Adult delta smelt entrainment is characterized by a pulse of pre-spawning migrants entering the Central and South Delta following a "first flush" flow event in winter." This is a very important event for protection and can be subject to considerable uncertainty. The ability of the flow and turbidity trigger to properly detect the true pulse of pre-spawning migrants needs to be supported better, and presented in a more statistically rigorous way.

Page 10: "Figures A-1 and A-2 below graphically depict the relationship.." There are better ways to depict the relationship between salvage and flow and turbidity.

Page 17: Paragraph 3 is very circuitous. Simply saying that the salvage index normalizes salvage to the population size as indexed by previous FMWT index would be fine.

Page 18: Table A-2 is confusing. This is total adult salvage (distinguished from juveniles how – we get the same numbers but the algorithm should be explained). If it is true that the time from the trigger to the peak of salvage varies between 12 and 52 days, doesn't that suggest that the trigger is not very helpful?

Page 18 last sentence: what is "salvage frequency"?

Pages 19-23: Figures A7-A11 are potentially misleading because they show mostly salvage of juveniles, whereas the section is on salvage of adults.

Page 24: Entire page. This seems too ad hoc. How can this be made more firm?

Page 26 top line: "salvage index exceeding 15 appears indicative of an unacceptable risk threshold." No risk analysis has been done, nothing in the document relates salvage to mortality or risk, and there is no definition of what is to be considered acceptable or not. The same is true for the second sentence referring to a peak amplitude of 1.0.

Page 26: In the second paragraph "Turbidity associated with freshets" needs support or citation.

Page 26 third paragraph: The specific values for the 12 NTU criterion and 12°C trigger are not backed up by good evidence.

Page 26: In the last two paragraphs it is unclear what was done here. It is not clear exactly what statistical model, described as piecewise polynomial, was fit. Which and how were alternative models evaluated? The fit statistics should be provided. What does the last sentence about maintaining the actual covariance structure mean?

Page 27 first paragraph: This explanation might go better with equations to supplement the text.

Page 28 paragraph 1 and Page 29 paragraph 1: Both paragraphs have a statement that smelt are "…holding more tightly to their selected spawning areas." What is the basis for the statements about what the smelt do during the period from migration to spawning?

Page 29 line 3: The term "predicted entrainment risk" should be clearly defined.

Page 29 paragraph 2 last sentence: "it is believed" – provide evidence.

Page 32 item (e): "…particle entrainment at Station 815…" – the discussion of how PTM results will be used in general is confusing.

Page 37 Item 4: How is entrainment risk determined, and what is meant by "tolerable"

Page 38 Item 5: "Both acclimation to and variation of water temperatures in the water column would increase water temperature tolerance as it is measured in the environment." This statement is unsupported and likely incorrect.

Page 39: Please define the term "resilience".

General: The map of critical habitat was not useful because it was too coarse and not broken down by life stage. Much knowledge about delta smelt has been gained since critical habitat was first designated.

DWR/BOR Actions

Page 1: DWR/BOR states that "Simply controlling the operation of the water projection operations will not recover endangered fish in this estuary to the levels sought by the NMFS and USFWS." While this may be true, such statements need to be justified by also presenting the reasons and data that lead them to such a conclusion.

Page 2: DWR/BOR appears to put an enormous level confidence in the BDCP planning process to solve this long-standing conflict. The Panel does not share the same high level of confidence expressed by DWR/BOR.

Page 2: DWR/BOR wants to use a biological benefits to water costs approach for evaluating actions.

Page 2 para2: Under "adaptive approach"- It is true that manipulations on endangered fish are unlikely to be approved. However, adaptive management is a method of managing under uncertainty. Although it is generally associated with experimental management, that is not always the case and elements of adaptive management would be very useful in this program.

Page 3: DWR/BOR's plan is targeted at delta smelt and then DWR/BOR jumps in logic to state that "While these actions are targeted to protect delta smelt they occur at times that will also provide benefits to salmonid species." Such a general statement is uninformative. DWR/BOR should explain which species and life stage and the biological basis of how actions would benefit salmonid recovery.

Page 8: "This high variability" No credible statistical relationship between export flows or losses and subsequent delta smelt population size has been found. It is also clear that a number of factors may be affecting delta smelt, some understood better than others. However, absent compensatory density-dependent feedback in the population, changes in survival through any life stage linearly affect subsequent life stages and subsequent recruitment. The lack of evidence for density dependence, the low abundance of the population, and the general principle that one should err on the side of species protection all suggest that density independence should be assumed (unless there is depensation). The inability to detect the effects of entrainment mortality statistically means either that the effect is small or invariant, or that other factors and sampling error hide the signal in the noise. Unless these other factors are inversely correlated with entrainment mortality (which seems unlikely), reducing that mortality will result in a corresponding increase in population size, whether it can be detected statistically or not.

Page 9: *Limnoithona* may be considered an inferior food source by some, but not by larval delta smelt.

Page 10: last sentence "minimize the turbidity plume into the Central and southern Delta" What does this mean, how is it detected, and how can it be "minimized"?

Page 10: DWR/BOR proposes an off-ramp after 10 days for Action 1, without any evidence of whether this would result in periods of little protection. Also, Action 2 is not assured of starting right after Action 1, which can create a gap in protection.

Page 13 line 4: "adaptively manage" meaning what? What criteria will be used to select one flow or another?

Page 13 Para. 3 line 3: "significant number" meaning how many? How would this be adjusted as the population continues to change?

Page 13: End of Action: how many spent females?

Literature Cited for Review of Effects Analysis

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

Jassby, A.D., J.E. Cloern, and B.E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal estuary. Limnol. Oceanogr. 47: 698-712.

Kimmerer, W.J., Gross, E.S., M.L. MacWilliams. Variation of physical habitat for estuarine nekton with freshwater flow in the San Francisco Estuary. In press, Estuaries and Coasts.

Kimmerer, W.J. and M.L. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science 6: http//repositories.cdlib.org/jmie/sfews/vol6/iss1/art4.

Nobriga, M., T. Sommer, F. Feyrer, and K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt, Hypomesus transpacificus. San Francisco Estuary Watershed Sci. 6: Issue 1 Article 1.

PBS&J 2008. Independent Peer Review of USFWS's Draft Effects Analysis for the Operations Criteria and Plan's Biological Opinion. Prepared for the US Fish and Wildlife Service.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology [online]1(2):1. Available from the Internet. URL: http://www.consecol.org/vol1/iss2/art1/

Appendix A

Panel Member Resumes

KENNETH A. ROSE

Department of Oceanography and Coastal Sciences
Energy, Coast and Environment Building
Louisiana State University
Baton Rouge, LA 70803-7503
Phone: (225) 578-6346
E-mail: karose@lsu.edu

EDUCATION:
Ph.D., Fisheries Science, University of Washington, 1985.
M.S., Fisheries Science, University of Washington, 1981.
B.S., Biology and Mathematics, State University of New York at Albany, 1979.

PROFESSIONAL EXPERIENCE:
2001-present Professor, Coastal Fisheries Institute and Department of Oceanography and Coastal Sciences, Louisiana State University.
1998-2001 Associate Professor, Coastal Fisheries Institute and Department of Oceanography and Coastal Sciences, Louisiana State University.
1987-1998 Scientist, Environmental Sciences Division, Oak Ridge National Lab.
1983-1987 Scientist, Martin Marietta Environmental Systems (now Versar), Columbia, MD.

Adjunct Faculty: Department of Ecology and Evolutionary Biology, University of Tennessee
School of Natural Resources and Environment, University of Michigan
Department of Marine Sciences, University of South Alabama

SELECTED PROFESSIONAL ACTIVITIES:
Associate Editor: Transactions of the American Fisheries Society, Ecological Applications, Environmetrics, Canadian Journal of Fisheries and Aquatic Sciences, Marine and Coastal Fisheries
Fellow of the American Association for the Advancement of Science (AAAS)
Ad-hoc reviewer for over 25 journals

Member of the Independent Review Panel of the Delta Risk Management Strategy (DRMS)
Member of the Review Team of NOAA's OCAP Biological Opinion on Endangered Salmon
Member of the Independent Science Advisors for the Bay Delta Conservation Plan
Member of the Tier 3 Independent Advisory Science Panel (never activated)
Past Member of the Science Review Panel of the Environmental Water Account Program
Past Member of the Independent Science Board of CALFED
Member of the Review Panel of the Regional Salmon Outmigration Study Proposal

Co-PI on the CALFED funded project entitled "Modeling the Delta Smelt Population of the San Francisco Estuary"
Consultant to the DWR POD-funded project entitled "Development and Implementation of Life-Cycle Models of Striped Bass in the Bay-Delta Watershed"
Chairperson of 12 graduate student committees; member of another 20 student committees.
Speaker of over 50 invited presentations; co-author on over 150 presentations made by others.

SELECTED PUBLICATIONS (from a total greater than 100):
Winemiller, K.O., and **K.A. Rose**. 1992. Patterns of life-history diversification in North American fishes: Implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* 49:2196-2218.

Clark, M.E., and **K.A. Rose**. 1997. Individual-based model of sympatric populations of stream resident rainbow trout and brook char: model description, corroboration, and effects of sympatry and spawning season duration. *Ecological Modelling* 94:157-175.

Jaworska, J.S., **K.A. Rose**, and L.W. Barnthouse. 1997. General response patterns of fish populations to stress: an evaluation using an individual-based simulation model. *Journal of Aquatic Ecosystem Stress and Recovery* 6:15-31.

Van Winkle, W., **K.A. Rose**, B.D. Shuter, H.I. Jager, and B.D. Holcomb. 1997. Effects of climatic temperature change on growth, survival, and reproduction of rainbow trout: predictions from a simulation model. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2526-2542.

Clark, M.E., **K.A. Rose**, J.A. Chandler, T.J. Richter, D.J. Orth, and W. Van Winkle. 1998. Simulating smallmouth bass reproductive success in reservoirs subject to water level fluctuations. *Environmental Biology of Fishes* 51:161-174.

Breitburg, D., **K. Rose**, and J. Cowan. 1999. Linking water quality to larval survival: predation mortality of fish larvae in an oxygen-stratified water column. *Marine Ecology Progress Series* 178:39-54.

McDermot, D., and **K.A. Rose**. 1999. An individual-based model of lake fish communities: application to piscivore stocking in Lake Mendota. *Ecological Modelling* 125:67-102.

Rose, K.A. 2000. Why are quantitative relationships between environmental quality and fish populations so elusive? *Ecological Applications*10: 367-385.

Clark, M.E., **K.A. Rose**, D.A. Levine, and W.W. Hargrove. 2001. Predicting climate change effects on brook and rainbow trout populations in southern Appalachian streams: combining GIS and individual-based modeling. *Ecological Applications* 11: 161-178.

Clark, J.S., S. Carpenter, M. Barber, S. Collins, A. Dobson, J. Foley, D. Lodge, M. Pascual, R. Pielke, W. Pizer, C. Pringle, W. Reid, **K. Rose**, O. Sala, W. Schlesinger, D. Wall, and D. Wear. 2001. Ecological forecasts: an emerging imperative. *Science* 293: 657-660.

Rose, KA., J.H. Cowan, K.O. Winemiller, R.A. Myers, and R. Hilborn. 2001. Compensatory density-dependence in fish populations: importance, controversy, understanding, and prognosis. *Fish and Fisheries* 2: 293-327.

Jager, Y., and **K.A Rose**. 2003. Designing optimal flow patterns for fall chinook salmon in a Central Valley, California river. *North American Journal of Fisheries Management* 23:1-21.

Rose, K.A., and J.H. Cowan. 2003. Data, models, and decisions in US marine fisheries management: lessons for ecologists. *Reviews for Ecology, Evolution, and Systematics* 34:127-151.

Rose, K.A., C.A. Murphy, S.L. Diamond, L.A. Fuiman, and P. Thomas. 2003. Using nested models and laboratory data for predicting population effects of contaminants on fish: a step towards a bottom-up approach for establishing causality in field studies. *Human and Ecological Risk Assessment* 9:231-257.

WIM J. KIMMERER, PH.D

Telephone:	(W)	(415) 338-3515
	(H)	(510) 848-7388
FAX:		(415) 435-7120
Email:		kimmerer@sfsu.edu
Web:		http://online.sfsu.edu/~kimmerer/

Current Position

Research Professor, Romberg Tiburon Center for Environmental Studies, San Francisco State University.

Education

University of Hawaii, Ph.D. 1980, Biological Oceanography
U.S. Navy Nuclear Power School, 1968.
Purdue University, B.S. 1967, Chemistry

Research and Professional Experience

1994-present	Senior Research Scientist & Research Professor, Romberg Tiburon Center
1986-1995	Senior Scientist, BioSystems Analysis Inc.
1982-1985	Research Fellow, University of Melbourne (Australia), Zoology Dept.
1980-1982	Research Associate/Assistant Director, Hawaii Institute of Marine Biology
1976-1980	Research Assistant, University of Hawaii
1973-1980	Graduate student, University of Hawaii
1972-1973	Flight instructor
1967-1972	U.S. Navy submarine force, final rank Lieutenant

Research Interests

The ecology of estuaries and coastal waters, with emphasis on the San Francisco Estuary. Influence of physical environment including freshwater flow, tidal currents, and turbulence on behavior, movement, and population dynamics of plankton and fish. Predatory control of species composition and abundance of plankton populations. Modeling of ecosystems, populations, and material cycling. Modeling and analyzing salmon populations in California's Central Valley. Human impacts on aquatic ecosystems and the interaction of science and management.

Other Professional Activities

- Member, Strategic Planning Core Team, CALFED Bay-Delta Program, 1998-99
- Co-Chair, Science Board, CALFED Bay-Delta Ecosystem Restoration Program, 2000-2005
- Co-founder and Past President, California Estuarine Research Society, the newest affiliate society of the Estuarine Research Federation.
- Chair, Estuarine Ecology Team, Interagency Ecological Program for the San Francisco

Estuary.

- Advisor to the CALFED Lead Scientist
- Advisory committee, Georgia Coastal Estuaries LTER Program, J.T. Hollibaugh, PI.
- Invited participant in workshops at the University of Rhode Island (effects of freshwater flow on estuaries), Louisiana Universities Marine Consortium (coastal restoration), and the University of British Columbia (science needs for coastal management).
- Associate Editor, San Francisco Estuary and Watershed Science.
- Reviewer for professional journals including Limnology and Oceanography, Marine Biology, Marine Ecology Progress Series, Estuaries and Coasts, Estuarine, Coastal, and Shelf Science, ICES Journal of Marine Science, Hydrobiologia, Environmental Biology of Fishes.
- Reviewer of grant proposals for the National Science Foundation, EPA, and Seagrant offices.
- Steering committee, Bay-Delta Modeling Forum, 1995-2001
- Co-convenor, CALFED Ecosystem Restoration Program workshop on adaptive management, 2002
- Co-convenor, CALFED workshops on salmonids and delta smelt, 2001 and 2003, and Environmental Water Account review, 2006.
- Co-convenor, CALFED workshop on hatchery impacts on Battle Creek, California, 2003.
- Member, Steering Committe, Delta Risk Management Strategy (Department of Water Resources).

Recent and Current Students

Keun-Hyung Choi (research associate), Diego Holmgren, Karen Edwards, Lindsay Sullivan (post-docs); Heather Peterson, Lenny Grimaldo, Jena Bills, Paola Bouley, John Durand, Renny Talianchich, Allegra Briggs, Alison Gould, Laurie Kara, Valiere Greene (all Masters' students).

Selected Publications

Kimmerer, W.J., and A.D. McKinnon. 1987. Growth, mortality, and secondary production of the copepod *Acartia tranteri* in Westernport Bay, Australia. Limnol. Oceanogr. 32:14-28.

Kimmerer, W.J. and A.D. McKinnon. 1989. Zooplankton in a marine bay. III. Evidence for influence of vertebrate predation on distributions of two common copepods. Mar. Ecol. Progr. Ser. 53:21-35.

Kimmerer, W.J. and A.D. McKinnon. 1990. High mortality in a copepod population caused by a parasitic dinoflagellate. Mar. Biol. 107:449-452.

Kimmerer, W.J. 1991. Predatory influences on copepod distributions in coastal waters. Pp. 161-174 in S.I. Uye, S. Nishida, and J.-S. Ho, eds., Proceedings of the Fourth International Conference on Copepoda. Bull. Plankton Soc. Japan, Spec. Vol., Hiroshima

Kimmerer, W.J., S.V. Smith, and J.T. Hollibaugh. 1993. A simple heuristic model of nutrient cycling in an estuary. Estuarine, Coastal and Shelf Science 37:145-149

Kimmerer, W.J., E. Gartside, and J.J. Orsi. 1994. Predation by an introduced clam as the probable cause of substantial declines in zooplankton in San Francisco Bay. Marine Ecology-Progress Series 113:81-93.

Peterson, W.T. and W.J. Kimmerer. 1994. Processes controlling recruitment of the marine calanoid copepod *Temora longicornis* in Long Island Sound: Egg production, egg mortality, and cohort survival rates. Limnol. Oceanograph. 39:1594-1605.

Kimmerer, W.J. and J.R. Schubel. 1994. Managing freshwater flows into San Francisco Bay using a salinity standard: results of a workshop. Pp. 411-416 In K.R. Dyer and R.J. Orth (eds.), Changes in fluxes in estuaries. Olsen and Olsen, Fredensborg, Denmark.

Jassby, A.D., W. J. Kimmerer, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5:272-289

Kimmerer, W.J. and J.J. Orsi. 1996. Causes of long-term declines in zooplankton in the San Francisco Bay estuary since 1987. pp. 403-424 in San Francisco Bay: The Ecosystem. J.T. Hollibaugh (ed.). American Association for the Advancement of Science, San Francisco.

Kimmerer, W.J., W.A. Bennett, and J.R. Burau. 1998. Tidally-oriented vertical migration and position maintenance of zooplankton in a temperate estuary. Limnol. Oceanogr. 43: 1697-1709.

Kimmerer, W.J., J.H. Cowan Jr., L.W. Miller, and K.A. Rose. 2000. Analysis of an estuarine striped bass population: Influence of density-dependent mortality between metamorphosis and recruitment. Can. J. Fish. Aquat. Sci. 57: 478-486.

Kimmerer, W. 2000. Sacramento River Chinook Salmon Individual-based Model. Conceptual Model and Functional Relationships. Report to the US Fish and Wildlife Service, Sacramento CA.

Sommer, T, B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6-16

Kimmerer, W.J., J.H. Cowan Jr., L.W. Miller, and K.A. Rose. 2001. Analysis of an estuarine striped bass population: Effects of environmental conditions during early life. Estuaries 24:556-574.*

Kimmerer, W., B. Mitchell, and A. Hamilton. 2001. Building models and gathering data: can we do this better? Pp. 305-307 in R.L. Brown (ed.), Contributions to the biology of Central Valley salmonids, Volume 2. California Department of Fish and Game Fish Bulletin 179.

Sommer, T, B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6-16

Kimmerer, W.J., W.A. Bennett, and J.R. Burau. 2002. Persistence of tidally-oriented vertical migration by zooplankton in a temperate estuary. Estuaries 25(3):359-371*

Bennett, W. A., W.J. Kimmerer, and J.R. Burau. 2002. Plasticity in vertical migration by native and exotic fishes in a dynamic estuarine low-salinity zone. Limnol. Oceanogr. 47:1496-1507

Kimmerer, W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55.**

Monismith, S.G., W. Kimmerer, J.R. Burau, and M.T. Stacey. 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Journal of Physical Oceanography 32:3003-3019.

Kimmerer, W.J. 2002. Physical, biological, and management responses to variable freshwater flow into the San Francisco estuary. Estuaries.25:1275-1290.*

Kimmerer, W.J. 2004. Open-Water Processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science [online serial]. Vol. 2, Issue 1 (February 2004), Article 1. http://repositories.cdlib.org/jmie/sfews/vol2/iss1/art1

Sommer, T.R., W. Harrell, A. Mueller-Solger, B.Tom, and W. Kimmerer. 2004. Effects of reach-scale hydrologic variation on the biota of channel and floodplain habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14:247-261.

Fisher, K. and W. Kimmerer. 2004. Fractal distributions of temperature, salinity and fluorescence in spring 2001-2002 in south San Francisco Bay. In Novak, M.M. (Ed.). Thinking in Patterns: Fractals and Related Phenomena in Nature. World Scientific, Singapore.

Kimmerer, W., D. Murphy, and P. Angermeier. 2005. A landscape-level model of the San Francisco Estuary and its watershed. San Francisco Estuary and Watershed Science [online serial]. Vol. 3, Issue 1 (February 2004), Article 2. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art2

Kimmerer, W.J. 2005. Long-term changes in apparent uptake of silica in the San Francisco Estuary. Limnology and Oceanography 50: 793-798.*

Choi, K-H., W. Kimmerer, G. Smith, G.M. Ruiz, and K. Lion. 2005. Post-exchange zooplankton in ships ballast water coming to the San Francisco Estuary. Journal of Plankton Research 27: 707-714.

Kimmerer, W.J., M.H. Nicolini, N. Ferm, and C. Peñalva. 2005. Chronic food limitation of egg production in populations of copepods of the genus *Acartia* in the San Francisco Estuary. Estuaries 28: 541–550.*

Gross, E.S., M.L. MacWilliams, and W. Kimmerer. 2006. Simulating Periodic Stratification in San Francisco Bay. Proceedings of the Ninth Estuarine and Coastal Modeling Conference, ASCE, pp. 155-175.

Kimmerer, W.J. 2006. Response of anchovies dampens foodweb responses to an invasive bivalve (*Corbula amurensis*) in the San Francisco Estuary. Marine Ecology Progress Series 324:207-218.*

Bouley, P.B. and W.J. Kimmerer. 2006. Ecology of a highly abundant, introduced cyclopoid copepod in a temperate estuary. Marine Ecology Progress Series 324:219-228.*

Kimmerer, W.J., A.G. Hirst, R.R. Hopcroft, and A.D. McKinnon. 2007. Measurement of juvenile copepod growth rates: corrections, inter-comparisons and recommendations. Marine Ecology Progress Series 336: 187-202.

Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32(6): 270-277.

Kimmerer, W.J. and M.L. Nobriga. 2008. Investigating dispersal in the Sacramento-San Joaquin Delta using a particle tracking model. In press, San Francisco Estuary and Watershed Science. [online serial]. Vol. 6, Issue 1 (February 2008), Article 4.

Mcmanus, G. B., J. K. York, and W. J. Kimmerer. 2008. Microzooplankton dynamics in the low salinity zone of the San Francisco Estuary. Verh. Internat. Verein. Limnol. 30: 196-202.

Kimmerer, W. J. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. [online serial]. Vol. 6, Issue 2 (June 2008), Article 2.

Choi, K-H. and W. Kimmerer. 2008. Mate limitation in an estuarine population of copepods. Limnology and Oceanography 53:1656-1664

Brown, L.R., W.J. Kimmerer, and R.L. Brown. 2008. Managing water to protect fish: a review of California's Environmental Water Account. Environmental Management. DOI 10.1007/s00267-008-9213-4

Kondolf, G. M., P. Angermeier, K. Cummins, T. Dunne, M. Healey, W. Kimmerer, P. B. Moyle, D. Murphy, D. Patten, S. Railsback, D. Reed, R. Spies, and R. Twiss. 2008. Projecting cumulative benefits of multiple river restoration projects: An example from the Sacramento-San Joaquin River System in California. In Press, Enviromental. Management.

Choi, K.-H. and W. Kimmerer. Mating success and its consequences for population growth of an estuarine copepod. Under revision, Marine Ecology Progress Series.

Kimmerer, W.J., E.S. Gross, and M.L. MacWilliams. Variation of physical habitat for estuarine nekton with freshwater flow in the San Francisco Estuary. Submitted, Estuaries and Coasts.

Gross, E.S., M.L. MacWilliams, and W.J. Kimmerer. Three-Dimensional Modeling of Tidal Hydrodynamics in the San Francisco Estuary. Submitted, San Francisco Estuary and Watershed Science.

Grimaldo, L., W. Kimmerer, and A.R. Stewart. Diets and carbon sources of fishes from open-water, intertidal edge, and SAV habitats in restored freshwater wetlands of the San Francisco Estuary. Under revision, Marine and Coastal Fisheries.

In preparation

Bills, J., G. Smith, K.-H. Choi, G. Ruiz, and W. Kimmerer. Efficiency of the removal of estuarine zooplankton from ships' ballast tanks by mid-ocean exchange. In preparation for Biological Invasions.

Kimmerer, W.J. and R.L. Brown. Winter Chinook salmon in the Central Valley of California: Life history and management. In preparation for San Francisco Estuary and Watershed Science.

Edwards, K.P., K.A. Rose, W.J. Kimmerer, and W.A. Bennett. Individual-based modeling of delta smelt population dynamics in the Upper San Francisco Estuary. 1. Model description and baseline simulations. In preparation for Ecological Modelling.

* Available in pdf format at http://online.sfsu.edu/~kimmerer/Files/

Selected Presentations

Kimmerer, W.J. 2004. Ecosystem-level changes following foodweb disruption by an introduced clam in the San Francisco Estuary. CALFED Science Conference, Sacramento, October 2004.

Kimmerer, W.J. 2004. Population trends and the influence of restoration actions on winter-run Chinook salmon. Invited, CALFED Science Conference, Sacramento, October 2004.

Kimmerer, W.J. 2004. Assessing the CALFED Bay-Delta Ecosystem Restoration Program: Racing to Catch Up. Invited plenary talk, First National Conference on Ecosystem Restoration, Orlando

Kimmerer, W.J. 2005. The importance of scale and frame of reference in understanding and restoring an estuarine ecosystem. Humboldt Bay Symposium, Arcata, CA, March 2005.

Kimmerer, W.J. 2005. Searching for clues to declines in the pelagic food web of the upper San Francisco Estuary. Invited, State of the Estuary conference, October 2005; Invited, Estuarine Research Federation, October 2005.

Kimmerer, W.J. 2005. Ecosystem-level changes following foodweb disruption by an introduced clam in the northern San Francisco Estuary. Invited, Estuarine Research Federation, October 2005.

Kimmerer, W.J. and J.K. Thompson. 2006. Thresholds and Amplifiers in an Estuarine Ecosystem. Ocean Sciences Meeting (ASLO/AGU), Honolulu, HI**.**

Kimmerer, W.J. Foodweb support for the threatened delta smelt: Subtle interactions may be a cause of the pelagic organism decline. CALFED Science Conference, Sacramento, October 2006.

Kimmerer, W.J. 2005. The importance of scale and frame of reference in understanding and restoring an estuarine ecosystem. Humboldt Bay Symposium, Arcata, CA, March 2005.

Kimmerer, W.J. 2005. Some comments on the Pelagic Organism Decline. California Bay-Delta Authority, August 2005.

Kimmerer, W.J. 2005. Searching for Clues to Declines in the Delta Pelagic Food Web. Invited, State of the Estuary conference, October 2005.

Kimmerer, W.J. 2005. Ecosystem-level changes following foodweb disruption by an introduced clam in the northern San Francisco Estuary. Invited, Estuarine Research Federation, October 2005.

Kimmerer, W.J. 2005. Searching for Clues to Declines in the Pelagic Food Web of the Upper San Francisco Estuary. Invited, Estuarine Research Federation, October 2005; also seminar, U.C. Davis, December 2005.

Kimmerer, W.J. and J.K. Thompson. 2006. Thresholds and Amplifiers in an Estuarine Ecosystem. Ocean Sciences Meeting (ASLO/AGU), Honolulu, HI.

Kimmerer, W.J. 2007. Indirect human impacts on an estuarine foodweb illustrate the false dichotomy of top-down and bottom-up. Fourth Zooplankton Production Symposium, Hiroshima Japan, May 2007.

Kimmerer, W.J. 2008. Variation of Physical Habitat for Estuarine Fish with Freshwater Flow. Invited, Interagency Ecological Program Annual Meeting, Asilomar, CA, February 2008.

Kimmerer, W.J. 2008. Modeling Approaches for Delta Smelt and Other Fishes in the San Francisco Estuary. Invited presentation to the CALFED Independent Science Board, May 2008.

G. Roy Leidy

Senior Scientist, Aquatic Ecologist

PBS&J

Education

B.S., Forestry and Resource Management, University of California, Berkeley, 1972

Certifications

Certified SCUBA Diver, N.A.U.I., 1978

Certified Fisheries Scientist, #1730, American Fisheries Society, 1985

California Registered Environmental Assessor, #02704, 1991

George R. "Roy" Leidy is a Certified Fisheries Scientist who specializes in conservation biology and fish and wildlife management. His responsibilities include technical review and guidance of natural resource studies, as well as regulatory permitting and compliance. Roy has broad technical expertise based on his 37 years as a fish and wildlife biologist and regulatory specialist. He frequently assists clients and their legal counsels as an expert witness in both technical and regulatory matters.

Roy's technical experience includes fish and wildlife impact assessments using HEP, WHR and IFIM, wetlands delineations and assessments, endangered species surveys and impact evaluations, HCP/HMP planning, river-reservoir ecosystem modeling, reservoir fisheries management, water quality modeling, toxicological analysis, stream channel stability, watershed assessments, fish passage and screening design, Clean Water Act permitting, and water resources development evaluations. He possesses extensive knowledge of resource management issues in the western United States.

Over the past 37 years, Roy has published professional papers on a wide range of environmental topics and contributed to hundreds of unpublished reports on various environmental issues related to natural resource management, including endangered species, water resources, watershed management, mining impacts and remediation, instream flows, water quality, habitat restoration, and regulatory compliance.

Water Resources Development

Mammoth Lakes Basin Comprehensive Water Management Environmental Impact Report, Mammoth Lakes, California. Roy was the project manager and CEQA specialist for an EIR evaluating a full range of alternatives for managing the water resources of the Mammoth Lakes Basin for the Mammoth County Water District. The project involved coordination with the U.S. Forest Service, Inyo National Forest. Key issues evaluated included fisheries impacts, aesthetics, recreation, and groundwater and surface water management.

Garden Bar Dam and Reservoir Pumped Storage Hydroelectric Project, Nevada, Yuba, and Placer Counties, California. Roy, project manager and senior scientist, for a large team of scientists conducting extensive, multi-year reservoir/river fisheries investigations of Camp Far West Reservoir and the Bear River for the South Sutter Water District. He directed investigations that included an instream flow study (IFIM), water quality and temperature simulation modeling for various reservoir operational modes, riparian impacts to the Bear River, fisheries and wildlife (HEP) impacts, a migratory mule deer study, and endangered plant surveys. He directed work on the biological and water quality topics for a Federal Energy Regulatory Commission license application and for the draft Environmental Impact Report (CEQA). Responsibilities also included public meeting participation and coordination with numerous local, state, and federal agencies.

Santa Ana River Supplemental Water Supply Project, San Bernardino County, California. Roy served as the lead aquatic ecologist and expert witness in support of water rights applications to the State Water Resources Control Board for the appropriation of up to 200,000 acre-feet per year of local water captured by Seven Oaks Dam during flood control operations. Lead agencies included the San Bernardino Valley Municipal Water District and Western Municipal Water District. Roy and his team evaluated the impacts of maintaining a conservation pool at Seven Oaks Dam on aquatic and riparian resources in the inundation zone upstream of the dam and along the Santa Ana River between Seven Oaks Dam and Prado Dam located 20 miles downstream. Investigations focused on threatened native fishes, water temperature and water quality, hydrology, and riparian vegetation maintenance. Roy also participated in mitigation discussions with the California Department of Fish and Game.

Big Bear Lake Sediment Loading Analysis, Big Bear Lake, California. EIP Associates conducted a sediment loading analysis for the Rathbone Creek watershed for Big Bear MWD. At issue was the contribution of sediment from the watershed to Big Bear Lake. Roy Leidy and Dr. Jack Humphrey surveyed Rathbone Creek to develop data for use in the HSPF model. Local climatology and hydrology was developed as well. The modeling results indicated that about 90 percent of the sediment loading to Big Bear Lake occurred during infrequent severe storm events with an exceedance frequency of 10 percent or less. In addition, the modeling indicated that most of the sediment was derived from granitic soils on land managed by the U.S. Forest Service, and was not derived from urban development near the lake. The study results were used to address TMDL issues at Big Bear Lake.

Environmental Impact Evaluations

Amador Water System Transmission Project Environmental Impact Report and Section 7 Compliance, Amador County, California. Roy was the technical lead in the preparation of an EIR for the Amador Water Agency. This EIR evaluated the impacts of replacing a 23-mile long Gold Rush-era mining ditch that delivered the primary water supply for much of Amador County with an 11 mile buried pipeline. Over the length of the ditch up to 50 percent of the surface flows was historically lost to leakage. Key issues focused on surface and groundwater water hydrology, special-status plants and animals, water quality, cultural resources, and aesthetics. Following field studies, Roy also completed consultations with the California Department of Fish and Game regarding several special-status species, and with the U.S. Fish and Wildlife Service regarding the California red-legged frog. The EIR was certified and the pipeline constructed.

Bodie Mineral Exploration Program Environmental Impact Report, Mono County, California. Roy served as project manager for a comprehensive EIR for a proposed mineral exploration program adjacent to Bodie State Historic Park for the Mono County Planning Department. Extensive field investigations and analyses were completed to address a wide range of environmental issues including endangered species, resident and migratory wildlife, wetlands, water quality, noise, aesthetics, archeological resources, and air quality. A mitigation and monitoring program was developed to address the significant effects of the project.

Conway Ranch Environmental Impact Report, Mono County, California. Roy was project manager and CEQA specialist for a team of resource specialists in the preparation of draft and final EIRs for a proposed destination fly fishing resort at Conway Ranch for the Mono County Planning Department. Key issues addressed in the EIRs were aesthetics and visual resources, biological impacts, socioeconomics, provisions for community services such as fire, water, and garbage, and wetland impacts. The final EIR was certified by the Mono County Board of Supervisors.

Instream Flow Studies

Fisheries Investigations of the Yuba River, Yuba County, California. Roy led a large team of fisheries scientists in the completion of an instream flow study (IFIM) for the lower Yuba River downstream of Englebright Dam, a U.S. Army Corps of Engineers facility. The focus of the study, prepared for the California Department of Fish and Game, was to determine appropriate flows for the maintenance of steelhead and fall run Chinook salmon. Flows were also need to maintain fluvio-geomorphic processes and to allow fish passage over Daguerre Dam.

Rush Creek Instream Flow Study, Mono County, California. Roy directed this high-profile flow study (IFIM) for Rush Creek, located in the Mono Basin. Landmark litigation regarding the maintenance of streamflows for fish downstream of Grant Lake, a Los Angeles Department of Water and Power facility, required that the flow needs of rainbow and brown trout be evaluated and appropriate flows established. For the California Department of Fish and Game, Roy and his team completed the flow study and proposed flow releases based on maintaining trout habitat conditions similar to pre-diversion conditions.

American River Instream Flow Evaluation, Sacramento County, California. Roy was retained as the lead aquatic biologist and expert witness in litigation regarding the instream flow needs for steelhead and fall run Chinook salmon in the lower American River downstream of Nimbus Dam, a U.S. Bureau of Reclamation facility. Roy evaluated the instream flow study (IFIM) completed by the U.S. Fish and Wildlife Service and testified in Superior Court regarding the flows required to maintain suitable habitat in the river. Ultimately, the court ruled in favor of Roy’s clients, the County of Sacramento and Friends of the American River, and required streamflows similar to those recommend in his testimony.

Ecological Studies

Tributary Production Enhancement Report to Congress, Central Valley, California. Roy served as project manager and senior scientist in the preparation of a Report to Congress for the U.S. Fish and Wildlife Service. This report addressed the requirements of the Central Valley Project Improvement Act to restore and enhance the production of Chinook salmon and steelhead populations in tributary streams to the Sacramento and San Joaquin rivers. Specifically, the report evaluated the feasibility, cost, and desirability of implementing measures to eliminate migration barriers and to enhance the natural production of salmonids in 24 Central Valley streams. Roy also managed public participation and landowner involvement.

Ecology, Status and Management of the Giant Garter Snake, Central Valley, California. Roy conducted field work and prepared an extensive report describing the ecology and status of this threatened species in California for the Natomas Landowners Association. The report was presented to the U.S. Fish and Wildlife Service for use in its listing process under the Endangered Species Act. A financial bonus was paid by the client in recognition of the quality of the work performed.

Special-Status Species Survey and Riparian Vegetation Assessment for the Angels Creek Project, Calaveras County, California. For the Calaveras County Water District, Roy conducted extensive field investigations for rare, threatened, and endangered flora and fauna along Angels Creek, Cherokee Creek, and the South Fork Calaveras River in support of a proposed water diversion from the Stanislaus River Basin to the Calaveras River Basin. He evaluated the impacts of diversion on the riparian communities of these streams and on aquatic fauna. A technical report was provided to the client and the California Department of Fish and Game.

Hydroelectric Projects

Facilitation and Relicensing of Three Southern California Edison Company Hydroelectric Projects, San Bernardino County, California. Roy was retained to assist 14 water agencies, with biological and hydrological issues related to the relicensing proceedings for the Santa Ana River 1 and 3, Mill Creek, and Lytle Creek hydroelectric projects operated by Southern California Edison Company. Technical analyses and evaluations were conducted related to instream flow evaluation, hydrology, water quality and water temperature, sediment transport, historical stream channel stability, fisheries, aquatic invertebrates, riparian vegetation, terrestrial wildlife, threatened and endangered species, recreation, groundwater, and habitat restoration. A collaborative effort with the State Water Resource Control Board led to the issuance of a Clean Water Act section 401 Water Quality Certification for the SAR 1 and 3 Project. Following NEPA compliance, the Federal Energy Regulatory Commission (FERC) issued new licenses for each project.

Upper American River Project and the Iowa Hill Pumped Storage Hydroelectric Project, El Dorado and Placer Counties, California. Roy was retained by the Sacramento Municipal Utilities District's (SMUD) legal team to provide technical assistance in preparing responses to resource agency submittals to the FERC regarding licensing of the UARP. He completed various technical analyses on instream flow, water quality, fisheries, macroinvertebrate, and geomorphic issues contested during the licensing process. Roy served as aquatic resources senior scientist for SMUD in the preparation of a Supplemental Preliminary Draft Environmental Assessment. He was also senior aquatic scientist and expert witness for SMUD in the preparation of reports and submittals for trial-type hearings before the Department of Agriculture.

El Dorado Hydroelectric Project, El Dorado County, California. Roy provided the El Dorado Irrigation District with technical assistance in the completion of the license for the El Dorado Hydroelectric Project located in the South Fork American River watershed. He was responsible for management and technical guidance for 17 studies ranging in diversity from bat surveys to visual resource analysis. He assisted EID staff in the settlement negotiation process on issues of instream flow, water quality, and fluvio-geomorphology.

Expert Witness Testimony

- Technical work and testimony on fishery issues in Alameda Superior Court regarding instream flow needs for steelhead and Chinook salmon in the American River, Sacramento County, California

- Technical work and testimony on aquatic resource issues before the State Water Resources Control Board regarding Bear Creek, San Bernardino County, California

- Testimony on fishery issues before the State Water Resources Control Board regarding a Bay/Delta Water Transfer, Sacramento River, California

- Technical work and testimony on aquatic resource issues before San Francisco Superior Court regarding Forest Creek, Calaveras County, California

- Technical work and testimony on aquatic resource issues before the State Water

Resources Control Board regarding water conservation at Seven Oaks Dam, San Bernardino County, California

WORK EXPERIENCE
1996-Present Director, Fisheries and Aquatic Sciences. EIP Associates

Director, Natural Resource Sciences. EIP Associates, a division of PBS&J

- Senior biologist specializing in fish and wildlife management. Responsible for project management, technical review, guidance, and field implementation of natural resource studies and all aspects of federal, state, and local regulatory compliance. Management and administrative responsibilities included: planning, organization coordination and project management for numerous projects often exceeding $500,000 in budget; fiscal management of the Natural Resource Sciences; supervision and personnel management of seven environmental specialists; management of subcontractor contracts and contractor work performance; preparation of proposals; representation of EIP/PBS&J and its clients before various governmental agencies.
- Senior Aquatic Ecologist. Technical assistance to the Sacramento Municipal Utility District legal team in preparing responses to resource agency submittals to the FERC regarding licensing of the Upper American River Project and the Iowa Hill Pumped Storage Hydroelectric Project. Completed various technical analyses on instream flow, water quality, fisheries, macroinvertebrate, and geomorphic issues contested during the licensing process. Aquatic resources senior scientist for SMUD in the preparation of a Supplemental Preliminary Draft Environmental Assessment. Also senior aquatic scientist and expert witness for SMUD in the preparation of reports and submittals for trial-type hearings before the Department of Agriculture.
- Senior Scientist and Project Manger. Provided the El Dorado Irrigation District with technical assistance in the completion of the license for the El Dorado Hydroelectric Project located in the South Fork American River watershed. Responsible for management and technical guidance for 17 studies ranging in diversity from bat surveys to visual resource analysis. Assisted EID staff in the settlement negotiation process on issues of instream flow, water quality, and fluvio-geomorphology.
- Technical Director and Project Manager. Retained by Lake Elsinore & San Jacinto Watersheds Authority to prepare a Fisheries Management Plan for Lake Elsinore, California. The primary goal of the FMP was to develop a detailed rehabilitation and enhancement program for fisheries resources at Lake Elsinore.
- Technical Director and Project Manager. Collaborated with 14 water agencies with biological and hydrological issues related to the relicensing proceedings for the Santa Ana River 1 and 3, Mill Creek, and Lytle Creek hydroelectric projects operated by Southern California Edison Company.
- Technical Director and Project Manager. Prepared a Report to Congress for the U.S. Fish and Wildlife Service on salmon and steelhead production enhancement opportunities in 24 tributaries to the Sacramento and San Joaquin rivers, California.
- Project Manager and Principal Scientist. Evaluated of the impacts of heavy metals from cement kiln dust effluent on the biota of Sullivan Creek, a tributary to the Pend Oreille River, Washington, supporting bull trout and westslope cutthroat trout.

- Project Manager. Conducted an evaluation of the potential for steelhead habitat restoration in Pilarcitos Creek, a coastal stream south of San Francisco, California.
- Project Manager. Conducted an environmental assessment of the effects of flushing sediment from three diversion dams on the biota of the North Fork Stanislaus River, California.

- Project Manager and Expert Witness. Designed and implemented a biomonitoring program for aquatic resources in Bear Creek, a designated Wild Trout stream located within San Bernardino National Forest, California.

1995-1996 Ecologist. Georgia-Pacific West, Inc.

Fish, wildlife and botanical project/resource manager for 125,000 acres of private, commercial timberland in the Sierra Nevada. Provided technical expertise to foresters and the California Department of Forestry and Fire Protection on the management of flora and fauna to ensure viable populations of all biota on managed timberlands. Provided technical expertise on all non-forestry environmental issues requiring regulatory compliance (e.g., state and federal endangered species laws and regulations, water quality laws and regulations, and mine closure permitting, reclamation and monitoring). Provided expertise to G-P staff on the interpretation of various state and federal environmental statutes (e.g., Endangered Species Act, California Environmental Quality Act, Forest Practice Rules, Water Code of California, Fish and Game Code of California). Responsible for the preparation and fiscal management of the environmental budget, organization, and management of G-P's environmental compliance and monitoring program, and the management of subcontractors. Served as G-P's representative to various professional and public organizations, including the Mokelumne River Association, the El Dorado- Amador Forest Forum, and the Sierra Nevada Ecosystem Project. Selected projects:

- Project Manager. Routinely surveyed for state and federally listed rare, threatened, or endangered species, including the Sierra Nevada red fox, great gray owl, southwestern willow flycatcher, and California red-legged frog.

- Project Manager. Prepared a 100-year wildlife habitat management plan that integrated forest practices with maintenance of biological diversity. Developed a methodology for predicting the potential impacts of forest practices on individual wildlife species and wildlife communities for any spatial and temporal scale desired, including a procedure for evaluating long-term cumulative effects.

- Project Manager and Technical Director. Technical lead in permitting and management of a program developed in cooperation with the Central Valley Regional Water Quality Control Board to reclaim, close and monitor soil and water quality at the Hazel Creek Mine site located on G-P property. Directed the testing of soils and surface waters for various constituents of concern at this site which was classified as a Group B waste management unit.

- Developed a water quality and cumulative watershed effects program to monitor the effects of forest practices on water quality and sediment in watersheds subject to timber harvesting. Emphasis was placed on the identification of road related problems that required remedial action to correct historical design problems.

1993-1995 Manager, Biological Resources Group. EIP Associates.

Project and technical manager for natural resource studies and local, state, and federal regulatory compliance. Technical work included: review and guidance of natural resource studies and regulatory and compliance, including NPDES permitting. biological impact assessments using HEP, WHR and IFIM modeling techniques; wetland delineations; endangered species field studies; preparation of Habitat Conservation Plans/Habitat Management Plans; river reservoir ecosystem modeling; water quality modeling and analysis; stream channel stability analysis and watershed assessments; preparation of Environmental Impact Reports and Environmental Impact Statements necessary to comply with the provisions of the California Environmental Quality Act and the National Environmental Policy Act; and expert witness testimony. Management and administrative responsibilities included: planning, organization coordination and project management for numerous projects often exceeding $500,000 in budget; fiscal management of the Biological Resources Group; supervision and personnel management of seven environmental specialists; management of subcontractor contracts and contractor work performance; preparation of proposals; representation of EIP and its clients before various governmental agencies. Selected projects:

- Project Manager and Senior Scientist. Central Valley Project Improvement Act. Prepared a report to Congress on behalf of the U.S. Fish and Wildlife Service on the feasibility of restoring and enhancing salmon and steelhead in over 24 streams tributary to the Sacramento and San Joaquin rivers. Also managed public participation and landowner involvement.

- Technical Director. Yolo County Habitat Conservation Plan. Developed with staff a county wide state and federal HCP for over 30 species of threatened and endangered flora and fauna pursuant to section 10 of the Endangered Species Act and section 2081 of the Fish and Game Code of California. Extensive public involvement and intergovernmental coordination with the cities of West Sacramento, Davis, Woodland, and Winters. The draft HCP was considered by the U.S. Fish and Wildlife Service to be a "model" multi-species plan. Managed project budget and directed and coordinated the work of a large staff of technical experts. Prepared administrative and technical reports for this large, multi-year project.

- Project Manager and Senior Scientist. Mill Creek Stream Channel Stability and Watershed Assessment. Prepared a report for a private forest products company on the characteristics and condition of the channel of Mill Creek and its tributaries in the Mokelumne River Basin, California. Field data collection included characterization of instream habitat types, riparian vegetation, aquatic resources, water quality, sedimentation, and land uses.

- Project Manager and Senior Scientist and Expert Witness. Bear Creek Instream Flow Study, San Bernardino National Forest, California. Conducted extensive investigations of the instream flow needs of Bear Creek, included aquatic invertebrate diversity, fish population composition and distribution, water quality, sedimentation, impact assessment on bald eagles, wetlands, and reservoir fisheries. Provided expert testimony before the California State Water Resources Control Board on instream flow and water quality issues. Managed project budget and the work of several subcontractors.

1992-1993 Manager and Senior Scientist. Pacific Environmental Consultants. Founder and principal owner of Pacific Environmental Consultants. Areas of technical work included fish and wildlife management, habitat restoration, environmental impact assessment (CEQA/NEPA), regulatory compliance and permitting, and endangered species investigations. Responsible for the fiscal, administrative, and personnel management of PEC. Managed the consultancy from its inception to a successful business with six months of backlogged contracts. PEC was purchased by EIP Associates in 1993 to expand its ability to provide environmental services to its clients. Selected projects:

- Project Manager and Senior Scientist. Ecology, Status and Management of the Giant Garter Snake. Conducted field work and prepared an extensive report describing the ecology and status of this threatened species in California. Presented results to the U.S. Fish and Wildlife Service for use in its listing process under the Endangered Species Act. A financial bonus was paid by the client in recognition of the quality of the work performed.

- Project Manager and Senior Scientist. Special Status Species Survey and Riparian Vegetation Assessment for the Angels Creek Project. Conducted extensive field investigations for rare, threatened, and endangered flora and fauna along Angels Creek, Cherokee Creek, and the South Fork Calaveras River for the Calaveras County Water District in support of a proposed water diversion from the Stanislaus River Basin to the Calaveras River Basin. Evaluated the impacts of diversion on the riparian communities of these streams. Report provided to the client and the California Department of Fish and Game.
- Project Manager and Senior Scientist. Gerlach KGRA Special Status Species Surveys. Completed field surveys and report preparation related to the occurrence of threatened and endangered species on public lands managed by the U.S. Bureau of Land Management within the Gerlach (Nevada) Known Geothermal Resources Area. Extensive focus on rare reptiles, spring snails, and flora of this desert region.

1986-1992 Regional Manager and Senior Scientist. Beak Consultants Inc.

Founder and Regional Manager of Beak's Sacramento office from 1986 to 1990. Responsibilities included office administration, fiscal management, personnel management, project management, and technical support to staff. Developed the consultancy from one individual to a team of twelve scientists and support staff over a five-year period. Selected projects:

- Project Manager and CEQA Specialist. Bodie Mineral Exploration Program Environmental Impact Report. Managed a team of resource specialists in the preparation of a draft EIR for the Mono County Planning Department for a mineral exploration project near Bodie State Historic Park. Areas of analysis personally prepared included: application for NPDES permit, cultural resources, geology, water resources, fish and wildlife resources, aesthetics and visual resources, and socioeconomics. Developed a mitigation monitoring program for the proposed project.

- Project Manager and CEQA Specialist. Mammoth Lakes Basin Comprehensive Water Management Environmental Impact Report. This project, which was subsequently held in abeyance by the Mammoth County Water District, involved the preparation of an EIR evaluating a full range of alternatives for managing the water resources of the Mammoth Lakes Basin, California. The project involved coordination with the U.S. Forest Service, Inyo National Forest. Key issues evaluated included fisheries impacts, aesthetics, recreation, and groundwater and surface water management.

- Project Manager and CEQA Specialist. Conway Ranch Environmental Impact Report. Managed a team of resource specialists in the preparation of draft and final EIRs for the Mono County Planning Department for a proposed destination fly fishing resort at Conway Ranch in the Mono Basin, California. Key issues addressed in the EIRs were aesthetics and visual resources, biological impacts, socioeconomics, provisions for community services such as fire, water, and garbage, and wetland impacts. The final EIR was subsequently certified by the Mono County Board of Supervisors.

- Project Manager and Senior Scientist. Garden Bar Dam and Reservoir Pumped Storage Hydroelectric Project. Managed a large budget and team of scientists conducting extensive, multi-year reservoir/river fisheries investigations of Camp Far West Reservoir and the Bear River, California, for the engineering firm of Parsons, Brinckerhoff, Quade & Douglas. Directed studies that included an instream flow study (IFIM), water quality and temperature simulation modeling for various reservoir operational modes, riparian impacts to the Bear River, fisheries and wildlife (HEP) impacts, a migratory mule deer study, and endangered plant surveys. Directed work on the biological and water quality topics for a Federal Energy Regulatory Commission license application and for the draft Environmental Impact Report (CEQA). Responsibilities also included public meeting participation and coordination with numerous local, state, and federal agencies.

1984-1986 Senior Fisheries Scientist. Ott Water Engineers, Inc.

Served as Senior Fisheries Scientist for Ott and also supervised the environmental staff of the Bellevue, Washington office. Responsible for all aspects of fisheries and aquatic resource work, including fish passage and screening, hatchery design, habitat improvement, and hydropower licensing. Selected projects:

- Senior Fisheries Scientist. Bonneville Second Powerhouse Fish Passage Evaluation, Columbia River, Oregon and Washington. Conducted an evaluation for the U.S. Army Corps of Engineers of downstream juvenile migrant passage problems for salmonids at Bonneville Second Powerhouse, including hydraulic conditions at turbine intakes and fish migratory behavior.

- Senior Fisheries Scientist. Lemhi River Habitat Improvement Study, Lemhi River, Idaho. Project completed for the Bonneville Power Administration involved the evaluation of fishery management alternatives for various water management scenarios. Responsibilities included extensive consultations with state and federal agencies to find workable solutions to water management issues.

1979-1984 Senior Staff Specialist. U.S. Fish and Wildlife Service.

Senior Staff Specialist for the Service's Division of Ecological Services, Sacramento, California. Responsible for directing and managing all work by staff biologists involving hydropower assessment, review, and consultation. Directed and participated in the assessment of environmental effects of over 800 hydroelectric projects involving the FERC process. Supervised data collection and analysis, provided technical guidance, and reviewed all work products for technical accuracy and compliance with all regulatory and legal mandates. Served as technical expert to the

U.S. Fish and Wildlife Service, Washington. D.C. office on the effects of hydro development on biological resources and water quality, and the regulatory aspects of the Federal Power Act.

1975-1979 Reservoir Fish Research Biologist. U.S. Fish and Wildlife Service.

Responsible for directing and managing river reservoir ecosystem modeling for the National Reservoir Research Program of the Service in Fayetteville, Arkansas. Developed fishery, zooplankton, and benthos models to assess the effects of reservoir operations on aquatic resources. Published technical reports for the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, on the results of various modeling studies.
1974-1975 Aquatic Biologist. California Department of Transportation.

Served as aquatic biologist for the Caltrans Transportation Laboratory, Sacramento, California. Conducted research on the effects of road de-icing salts on aquatic systems. Assisted transportation engineers throughout California with environmental issues related to road design and construction. Coauthored an identification key to the families of California aquatic insects. Conducted environmental impact assessments related to Caltrans activities.

1970-1974 Biometrician. U. S. Forest Service.

Forestry Aid (Biometrician) at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Performed computer programming and data analysis for research scientists on various topics ranging from predicting fire hazards to simulating optimum forest road system design.

1972-1974 Research Assistant. University of California. Berkeley.

Conducted microhabitat utilization research on rainbow and brook trout at Sagehen Creek, California. Completed field data collection for a study evaluating the effects of air pollutants on aquatic resources in the San Bernardino Mountains of California. Served Dr. Don Erman as a research assistant in aquatic ecology.

Publications

Leidy, George R., J. F. Irwin, E. A. Read, J. H. Humphrey, and S. K. Dickey. 2001. The Ecology of Mill Creek, Bear Valley Mutual Water Company et al., 350 pp.

Leidy, George R. 1998. Draft Report to Congress on the Feasibility, Cost, and Desirability of Implementing Measures Pursuant to Subsections 3406(e)(3) and (e)(6) of the Central Valley Project Improvement Act (Tributary Production Enhancement Report), U.S. Fish and Wildlife Service, Central Valley Fish and Wildlife Restoration Program Office, Sacramento, California.

Leidy, George R., Smallwood, K. S., Wilcox, B., and Yarris, K. 1998. Indicators Assessment for Habitat Conservation Plan of Yolo County, California, USA, Environmental Management, Vol. 22(6): 947– 958.

Leidy, George R. 1992. Ecology, Status and Management of the Giant Garter Snake (Thamnophis gigas) , North Natomas Landowners Association, Inc., 352 pp.

Leidy, George R., and Ott, R. F. 1986. Selecting Fish Screens for Small Hydropower Installations, Hydro Review, Vol. 5(2): 56– 60.

Leidy, George R., and Meyers. M. M. 1984. Fishery Management Problems at Major Central Valley Reservoirs, California, U.S. Bureau of Reclamation, Sacramento, California, Special Report.

Leidy, George R., and Leidy, R. A. 1984. Life Stage Periodicities of Anadromous Salmonids in the Klamath River Basin, Northwestern California, U.S. Fish and Wildlife Service, Division of Ecological Services, Ecological Services Technical Report No. 1, Sacramento, California.

Leidy, George R. 1982. Step by Step: Negotiating an Appropriate Streamflow, Hydro Review, Vol. 1(3): 25.

Leidy, George R. 1981. Federal Energy Regulatory Commission Procedures for Licensing Hydroelectric Projects , instructional handbook prepared for workshops for the U.S. Fish and Wildlife Service biologists, Sacramento, California.

Leidy, George R., and Ploskey, G. R. 1980. Simulation Modeling of Zooplankton and Benthos in Reservoirs: Documentation and Development of Model Constructs , U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Technical Report E-80-4.

Leidy, George R., and Jenkins, R. M. 1977. The Development of Fishery Compartments and Population Rate Coefficients for Use in Reservoir Ecosystem Modeling, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, Miscellaneous Report Y 77-10.

Leidy, George R., and Winters, G. R. 1976. A Simplified Taxonomic Key to the Families of California Aquatic Insects, California Department of Transportation, Transportation Laboratory, Sacramento, California, Final Report CA-DOT-TL-7108-7-76-5-1.

Leidy, George R., and Erman, D. 1975. Downstream Movement of Rainbow Trout Fry in a Tributary of Sagehen Creek Under Permanent and Intermittent Flow, Transactions of the American Fisheries Society, Vol. 104(3): 467– 473.

Presentations

Leidy, George R. 2007. Historical Changes in the Freshwater Fish Fauna of the Santa Ana River, paper presented at the annual meeting of the Southern California Academy of Sciences, Fullerton, California.

Leidy, George R. 1996. Wildlife Management on Private Timberlands in the Sierra Nevada of California, paper presented at the El Dorado-Amador Forest Forum, Sutter Creek, California.

Leidy, George R. 1988. Ethics in Environmental Consulting, paper presented at the annual meeting of the California/Nevada chapters of the American Fisheries Society, Ventura, California.

Leidy, George R. 1985. Technical Developments for Environmental Protection at

Small Hydro Installations, paper presented at the U.S. Environmental Protection Agency's Small Hydro Workshop, Chicago, Illinois.

Leidy, George R. 1984. IFG 4 Model Selection and Quality Evaluation, instructional handbook and workshop presented by Ott Water Engineers, Inc. and Thomas R. Payne and Associates, Sacramento, California.

Leidy, George R. 1982. Solving Instream Flow Issues, paper presented at the meeting of the National Association of Hydroelectric Energy Producers, San Francisco, California.

Leidy, George R. 1977. Reservoir Fisheries Modeling, paper presented at the joint annual meeting of the U. S. Fish and Wildlife Service's National Reservoir Research Program and the Tennessee Valley Authority, Knoxville, Tennessee.

Leidy, George R. 1974. Downstream Movement of Rainbow Trout in Sagehen Creek, California, paper presented at the annual meeting of the California/Nevada chapters of the American Fisheries Society, Monterey, California.

Leidy, George R. 1970-present. Contributions to hundreds of unpublished reports on various environmental issues related to natural resource management, including endangered species, water resources, watershed management, mining impacts and remediation, instream flows, water quality, habitat restoration, air quality, and regulatory compliance.

Professional Development

University of California, Berkeley. Wildland Resource Science. Two years of graduate work toward M.S. degree researching salmonid behavior, 1972-1974
University of California, Davis. Aquatic Entomology, 1975
University of Arkansas, Fayetteville. Mathematical Modeling, 1976
University of Washington, Seattle. Modeling Aquatic Ecosystems, 1977
University of Arkansas, Fayetteville. Calculus and Analytic Geometry, 1978
U.S. Fish and Wildlife Service, Sacramento. Wetlands Classification, 1980
U.S. Army Corps of Engineers, Portland. Planner Orientation, 1980
U.S. Fish and Wildlife Service, Sacramento. Instream Flow Negotiations, 1980
U.S. Fish and Wildlife Service, Portland. Instream Flow Field Techniques, 1981
U.S. Fish and Wildlife Service, Ft. Collins. Use of the Computer Based Physical Habitat Simulation System, 1983
Colorado State University, Ft. Collins. Expert Witness Training, 1985
U.S. Fish and Wildlife Service, Ft. Collins. Hydraulics in Physical Habitat Simulation, 1985
Trimble Navigation, Coos Bay. Global Positioning Systems, 1995
California Department of Fish and Game, Sacramento, California Wildlife Habitat Relationships System, 1995
Dr. Denton Belk (University of Texas), Sacramento. Fairy Shrimp Taxonomy and Identification, 1996

Honors and Awards

Audubon Society Scholarship and Wilderness Foundation Scholarship to attend a marine biology research camp, Santa Catalina Island, California, 1966

California Alumni Scholarship to attend the University of California at Berkeley, 1968

Member Upper Division and Graduate Students Honor Society, U.C., Berkeley, 1971

Member Xi Sigma Pi (forestry honor society), 1971

Frank Schwabacher Memorial Scholarship in Forestry to attend Graduate School at the School of Forestry and Conservation, U.C., Berkeley, 1972

Grant from the Foundation For Environmental Education to pursue research on the interaction of brook and rainbow trout fry, 1973

Grant from the Union Foundation Wildlife Fund to pursue research on the interaction of brook and rainbow trout fry, 1973

Quality Performance Award, U.S. Fish and Wildlife Service, 1981

Howard M. Post Technical Achievement Award 2006 presented by Post, Buckley, Schuh, and Jernigan

Professional Affiliations

American Fisheries Society
American Society of Limnology and Oceanography
Desert Fishes Council
North American Benthological Society
American Society of Icthyologists and Herpetologists
American Institute of Fishery Research Biologists
Southern California Native Aquatic Fauna Working Group
Santa Ana Sucker Conservation Team

CURRICULUM VITAE

WILLIAM ANDREW BENNETT

Address: University of California, Davis
Center for Watershed Sciences,
John Muir Institute of the Environment,
Bodega Marine Laboratory
P.O. Box 247
Bodega Bay, California 94923

Phone: (707)-875-1979
FAX : (707)-875-2089

Internet: wabennett@ucdavis.edu

EDUCATION

Ph.D. in Ecology 1993
University of California, Davis, CA
Dissertation: Interaction of food limitation, predation, and anthropogenic intervention on larval striped bass in the San Francisco Bay estuary.

M.S. in Population Biology 1984
University of Massachusetts, Boston, MA
Thesis: Scale of investigation and the detection of competition: an example from two finch species introduced into North America.

B.S. in Biology 1980
University of Massachusetts, Boston, MA
Senior Undergraduate Honors Thesis: Competition in three bird species.

PROFESSIONAL EXPERIENCE

2006-present, Associate Research Ecologist I, Center for Watershed Sciences, John Muir Institute of the Environment, University of California, Davis.

1999-2005, Assistant Research Ecologist IV, Center for Watershed Sciences, John Muir Institute of the Environment, University of California, Davis.

1994-1999, Postgraduate Researcher, Bodega Marine Laboratory, University of California, Davis

1991-present, Committee Member, Interagency Ecological Program for the San Francisco Estuary. Estuarine Ecology, Suisun Bay/Entrapment Zone, Contaminant Effects, Delta Smelt, and Pelagic Organism Decline, Project Work Teams.

1995 (Summer), Environmental Protection Specialist, U.S. Environmental Protection Agency, 75 Hawthorn Street, San Francisco, California.

1991-1994, Postgraduate Researcher, Dept. Wildlife, Fish, and Conservation Biology, UC-Davis.

1987-1991, Research Assistant, Dr. Peter Moyle, Dept. Wildlife, Fish, and Conservation Biology, UC-Davis.

1981-1982, Research Assistant, Dr. Richard Levins, Dept. Population Studies, Harvard School of Public Health, Boston, MA.

1975-1986, Carpenter, Self-employed

1965-1984, Machinist, Custom Machine & Tool Company (Family Business), 22 Station Street, P.O. Box 890040, East Weymouth, MA 02189-0001.

PUBLICATIONS (REFEREED)

1. **Bennett, W.A.** 1990. Scale of investigation and the detection of competition: an example from the house sparrow and house finch introductions in North America. American Naturalist 135: 725-747.

2. Brown, L.R., P.B. Moyle, **W.A. Bennett**, and B.D. Quelvog. 1992. Implications of morphological variation among populations of California roach *Lavinia symmetricus* (Cyprinidae) for conservation policy. Biological Conservation 62:1-10.

3. **Bennett, W.A.**, D.J. Ostrach, and D.E. Hinton. 1995. Condition of larval striped bass in a drought-stricken estuary: evaluating pelagic food web limitation. Ecological Applications. 5: 680-692.

4. Rogers-Bennett, L., **W.A. Bennett**, H.C. Fastenau, and C.M. Dewees. 1995. Spatial variation in red sea urchin reproduction and morphology: implications for harvest refugia. Ecological Applications 5:1171-1180.

5. **Bennett, W.A.** and P.B. Moyle. 1996. Where have all the fishes gone?: factors producing fish declines in the San Francisco Bay estuary. In, San Francisco Bay: the Ecosystem. J.T. Hollibaugh, editor. Pacific Division, American Association for the Advancement of Science, San Francisco, California.

6. Kimmerer, W.J., J. Burau, and **W.A. Bennett**. 1998. Tidally-oriented migration and position maintenance of zooplankton in northern San Francisco Bay. Limnology and Oceanography 43: 1697-1709.

7. **Bennett, W.A**., W.J. Kimmerer, and J.R. Burau. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography 47: 1496-1507.

8. Kimmerer, W.J., J. Burau, and **W.A. Bennett**. 2002. Persistence of tidally-oriented vertical migration by zooplankton in a temperate estuary. Estuaries 25:359-371.

9. Rogers-Bennett, L., D.W. Rogers, **W.A. Bennett**, and T.A. Ebert. 2003. Modeling red sea urchin growth using six growth functions. U.S. Fishery Bulletin 101: 614-626.

10. **Bennett, W.A.**, K. Roinestad, L. Rogers-Bennett, L.S. Kaufman, B. Heneman. 2004. Inverse regional responses to climate change and fishing intensity by the recreational rockfish (*Sebastes*, spp.) fishery in California. Canadian Journal of Fisheries and Aquatic Sciences 61:2499-2510.

11. Fujiwara, M., B.E. Kendall, R.M. Nisbet, and **W.A. Bennett**. 2005. Analysis of size trajectory data using
an energetic-based growth model. Ecology 86:1441-1451.

12. **Bennett, W.A**. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science. 3(2): 71pgs. (http://repositories.cdlib.org/jmie/sfews/ vol3/iss2/art1/)

13. Hobbs, J.A., Q. Yin, J. Burton-Hobbs, and **W.A. Bennett**. 2005. Retrospective determination of natal habitats for an estuarine fish with otolith strontium isotope ratios. Journal of Freshwater and Marine
Research. 56: 655-660.

14. Anderson, S.L., G.N. Cherr, S.G. Morgan, C.A. Vines, R.M. Higashi, **W.A. Bennett**, W.L. Rose, A.J. Brooks and R.M. Nisbet. 2006. Integrating contaminant responses in indicator saltmarsh species. Marine Environmental Research 62:S317-S321.

15. Hobbs, J.A. **W.A. Bennett**, and J. Burton-Hobbs. 2006. Assessing nursery habitat quality for native fishes in the low-salinity zone of the San Francisco Estuary, California. Journal of Fish Biology 69:
907-922.

16. Hobbs, J.A., **W.A. Bennett**, and J. Burton-Hobbs. 2007. Modification of the biological intercept model to
account for otogenetic effects in laboratory-reared delta smelt (*Hypomesus transpacificus*). U.S. Fishery Bulletin. 105:30-38.

17. Hobbs, J.A., **W.A. Bennett**, J. Burton-Hobbs, M. Gras. 2007. Classification of larval and adult delta smelt to nursery areas by use of trace elemental fingerprinting. Transactions of the American Fisheries Society 136:518-527.

18. Bano, N., A. deRae Smith, **W.A. Bennett**, L. Vasquez, and J.T. Hollibaugh. 2007. Dominance of
Mycoplasma in the guts of the long-jawed mudsucker, *Gillichthys mirabilis*, from five California salt marshes. Environmental Microbiology 9: 2636-2641.

MANUSCRIPTS SUBMITTED & IN PREPARATION

1. Bennett, W.A., J.A. Hobbs, S.J. Teh. Selection via large-scale water extraction accelerates decline of an endangered estuarine smelt: Where’s your Big-Mama? Ecology Letters (*In preparation*).

2. Bennett, W.A., J.A. Hobbs, S.J. Teh. Interactive processes regulating an endangered smelt: collapse of a
pelagic assemblage in a highly altered estuary: Ecological Applications. (*In preparation*).

3. Bennett, W.A., G. N. Cherr, S.L. Anderson, R.M. Nisbet, A.J. Brooks, C.A. Vines, S.J. Teh, and L.S. Lewis. Toxicology in an ecological context: assessment of tidal-marsh goby populations in California. Ecological Applications. (*In preparation*).

OUTREACH PUBLICATIONS

Bennett, W.A., G.A. Cherr, C.A. Vines, and R. Nisbet. 2006. Integrating indicators across multiple levels of biological organization: a statistical approach for developing a comprehensive index of fish condition. Final Report for U.S. EPA Science to Achieve Results (STAR) EAGLE Program. Pacific Estuarine Ecosystem Indicator Research (PEEIR) consortium. URL: http://www.bml.ucdavis.edu/peeir/brochures/Fish_Integrated_Indicators.pdf

Kimmerer W.J. and Bennett, W.A. 2005. A plan for understanding the mechanisms underlying X2. Interagency Ecological Program for the San Francisco Estuary Newsletter 18 (Spring): 56-68.

Dettinger, M., W.A. Bennett, D. Cayan, J. Florsheim. M. hughes, B.L. Ingram, A. Jassby, N. Knowles, F. Malamud-Roam, D. Peterson, K. Redmond, and L. Smith. 2002. Climate science issues and needs of the CALFED Bay-Delta Program. Extended abstract submitted to the American Meteorological Society.

Bennett, W.A., K. Roinestad, L. Rogers-Bennett, L.S. Kaufman, B. Heneman. 2001 Regional response of the nearshore recreational fishery to shifting climate: using historical science to identify a framework for regional management. A “whitepaper” submitted to the California Department of Fish and Game, Marine Region.

Bennett, W.A., 2000. Delta smelt population structure and factors influencing dynamics: Implications for the CALFED restoration program. Draft white-paper submitted to the CALFED Ecosystem Restoration Program.

Bennett, W.A. 2000. Delta smelt studies: contaminant and inland silverside effects. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 13(2):8.

Bennett, W.A. and E. Howard, 1999. Climate change and the decline of striped bass. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 12(2):53-56.

Bennett, W.A. 1998. Vertical migration and retention of native and exotic larval fishes in the entrapment zone of a tidally dominated estuary. California Interagency Ecological Program, Technical Report 56. California Department of Water Resources, Sacramento, California.

Bennett, W.A. and E. Howard, 1997. El Ninos and the decline of striped bass. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 10(4):17-21.

Estuarine Ecology Project Work Team (one of 12 co-authors, equal authorship). 1997.An assessment of the likely mechanisms underlying the “fish-X2" relationships. California Interagency

Ecological Program, Technical Report 52. California Department of Water Resources, Sacramento, California.

Kimmerer, W.J. and W.A.Bennett. 1996. Science, policy, and the Interagency Program. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 8(4):17-21.

Bennett, W.A 1996. Framework for evaluating pesticide effects on fish populations. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 8(2):7-12.

Bennett, W.A. 1995. Potential effects of exotic inland silversides on delta smelt. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter. 7(1): 4-6.

Estuarine Ecology Project Work Team (one of 12 co-authors, equal authorship). 1995. Conceptual Models for the food web of the San Francisco Bay estuary. California Interagency Ecological Program, Technical Report 42. California Department of Water Resources, Sacramento, CA

Puccia, C.J. and W.A. Bennett. 1982. Qualitative analysis in the setting of the east coast marine benthos. In: Environmental Biology State of the Art Seminar. U.S.E.P.A. publication #600/9-82-007.

CONFERENCES, BRIEFINGS, & WORKSHOPS

Delta Smelt Program Review, Scientific Advisory Group, Interagency Ecological Program for the San Francisco Estuary, Tiburon, CA. April 13-14, 2006.

Briefing for the Pelagic Organism Decline Management Committee, Interagency Ecological Program for the San Francisco Estuary, Sacramento, CA. March 10, 2006.

Briefing for Board of Directors, CA State Water Contractors. Sacramento, CA. January 19, 2006.

Benthic-pelagic linkages in MPA design: Exploring the application of science to vertical zoning approaches. Vertical Zoning of Marine Protected Areas. National Marine Protected Area Center, and Urban Harbors Institute, University of Massachusetts, Boston. Monterey, CA. November 15-16, 2005. (Invited Participant).

Briefing for CA State Assembly-woman Lois Wolk. John Muir Institute of the Environment, University of California, Davis. November 8, 2005.

Briefing for CA State Senator Michael Machado. John Muir Institute of the Environment, University of California, Davis. September 20, 2005.

Briefing for Directors of CA Farm Bureau Federation. Sacramento, CA. February 23, 2005.

Briefing for Directors of CALFED, CA Department of fish and Game, CA Department of Water Resources, and U.S. Fish and Wildlife Service. Sacramento, CA. February 3, 2005.

Delta Smelt Environmental Account Workshop 2004. Sponsored by CALFED Bay-Delta Authority, Davis, CA, September 8-9, 2004 (Invited Speaker & Participant).

Scientific Review of the North Delta Improvements Project (NDIP). University of California, Davis Watershed Center, and The California Nature Conservancy. University of California, Davis, April 7, 2004. (Invited Review Panel Member).

Scientific Review of the North Delta Improvements Project (NDIP). University of California, Davis Watershed Center, and The California Nature Conservancy. University of California, Davis, November 13, 2003. (Invited Review Panel Member).

CALFED Environmental Water Account review workshop. Sponsored by CALFED Science Program Sacramento, CA, October 14-16, 2003. (Invited Participant).

CALFED Delta Smelt Workshop. Sponsored by CALFED Science Program, Santa Cruz, CA, August 17-19, 2003. (Invited Speaker & Participant).

CALFED Water Operations and Environmental Protection Conference. Sponsored by CALFED Science Program, Sacramento, CA, June 18-20, 2003 (Invited Speaker & Participant).

Delta Smelt Environmental Account Workshop 2002. Sponsored by CALFED Bay-Delta Authority, Davis, CA, September 4, 2002 (Invited Speaker & Participant).

Scientific Review of the CALFED Delta-Cross-Channel Investigations. Sponsored by CALFED Ecosystem Restoration Program for the San Francisco Estuary, Courtland, CA, May 24, 2001 (Invited Review Panel Member).

CALFED Science Conference 2000. Sponsored by CALFED restoration process for the San Francisco Estuary, Sacramento, CA, October 3-5, 2000 (Co-Technical Program Chair).

Review of the CDFG Delta Outflow-San Francisco Bay Study by the Scientific Advisory Group. Sponsored by the Interagency Ecological Program, Bay Model, Sausilito, CA, October 28-29, 1999 (Invited *Ad Hoc* Review Panel Member).

Conference on the Restoration Priorities for the Endangered Delta Smelt. Sponsored by the Interagency Ecological Program and CALFED. Sacramento, CA, October 1, 1998 (Invited Speaker and Panel Member).

Use of Conceptual Models in the Design of a Comprehensive Monitoring, Assessment, and Research Program for the CALFED Process. Sponsored by CALFED. University of California, Davis, CA, June 17-18, 1998 (Invited Speaker and Panel Member).

Workshop on the X2 Salinity Standard. Sponsored by California Department of Water Resources and Metropolitan Water District. Contra Costa Water District, Concord, CA, March 11, 1998. (Invited Speaker and Panel Member).

Facilitated Scientific Review of the CALFED Bay-Delta Program's Ecosystem Restoration Plan for the San Francisco Bay-Delta estuary. Sponsored by CALFED Bay-Delta Program. Sacramento, CA, October 6-9, 1997 (Invited Technical Advisor).

Restoration of the San Francisco Bay/Delta/River: choosing indicators of ecological integrity. Workshop of estuarine scientists on restoration goals for the San Francisco Estuary." Sponsored by U.S.E.P.A. and U.C. Berkeley's Center for Sustainable Resource Development. U.C. Berkeley, October 28, 1995 (Invited Participant).

Goals for restoring a healthy estuary. Workshop of estuarine scientists on restoration goals for the San Francisco Bay estuary. Sponsored by 14 State/Federal agencies, environmental, and industrial organizations. Romburg Tiburon Center for Environmental Studies, Tiburon, CA, October 2, 1995 (Invited Participant).

TEACHING EXPERIENCE

2005-present. Guest lecturer, **Marine Ecology & Conservation**. Ecology Graduate Group, University of California, Davis.

1987 (Fall). Teaching Assistant and Lecturer, **Wildlife Ecology and Conservation**. Dept. Wildlife, Fish, and Conservation Biology, UC-Davis.

1985 (Summer) Teaching Fellow, **Marine Biology**. Introduction to marine systems emphasizing evolutionary ecology and behavior of local invertebrates. Museum of Comparative Zoology, Harvard University, Cambridge, MA.

1985 (Spring) Lecturer, **Marine Invertebrate Zoology Laboratory**. Field and laboratory exercises emphasizing taxonomy, life history and evolutionary ecology of marine invertebrates. Dept. Biology, University of Massachusetts, Boston, MA.

1984 (Fall) Lecturer, **Ecology Laboratory**. Field and laboratory exercises emphasizing experimental design, statistical analyses, and report writing. Dept. Biology, University of Massachusetts, Boston, MA.

1981-1984 Teaching Assistant, **Evolutionary Ecological Methods and Genetics**. Dept. Biology, University of Massachusetts, Boston, MA.

STUDENTS & UNIVERSITY SERVICE

Advisor:

James A. Hobbs, Ph.D. (2004) & Post-doctoral Fellow (2005-present). Ecology Graduate Group, University of California, Davis (Co-advisor: Dr. Peter B. Moyle, WFCB). Thesis Title: Microscale

patterns – macroscale implications: the application of otolith microstructure and microchemistry to
assess nursery habitat quality for the threatened delta smelt in the San Francisco Estuary.

Oral Examination & Dissertation Committee:

Robert Schroeder, Ph.D. Candidate, Ecology Graduate Group, University of California, Davis (Advisor: Dr.
Peter B. Moyle, WFCB)

Lenny Grimaldo, Ph.D. Student, Ecology Graduate Group, University of California, Davis (Advisor: Dr. Peter B. Moyle, WFCB)

Renny Talianchich, Master's Student, Romberg Tiburon Laboratories, San Francisco State University (Advisor: Dr. Wim Kimmerer, SFSU)

Other Committees:

Graduate Admissions Committee, 2006. Graduate Group in Ecology, UCD.

Boating Safety Committee, 2003-2006, UCD.

Academic Merit and Promotion Committees. 1999-present. John Muir Institute of the Environment, UC-Davis.

GRANTS

CALFED Ecosystem Restoration Program. $1,500,000. (2006-2009) Monitoring responses of the delta Smelt population to multiple restoration actions in the San Francisco Estuary. (PI: Bennett).

CBDA Science Program. $1,200,000 (2006-2008) Modeling the delta smelt population in the San Francisco
Estuary (PI: W. Kimmerer, SFSU).

California Interagency Ecological Program. $950,000. (2005-2006) Application of otolith growth, histology,
and bioassay techniques to understand the decline of pelagic fishes in the San Francisco Estuary (PI Bennett).

UC Davis Wildlife Health Center and Department of Fish and Game Resource Assessment Program (RAP).
$49,000. (2005-2006). Reproduction and longevity of delta smelt in the San Francisco Estuary (PI Bennett).

CALFED Ecosystem Restoration Program. $75,000 (2004-2006) A plan for determining the mechanisms underlying the fish-X2 relationships (PI: W. Kimmerer, SFSU).

California Interagency Ecological Program. $99,700 (2003-2005). Feeding success of delta smelt. (PI: Bennett and W.Kimmerer, SFSU).

U.S. Geological Survey. $10,000 (2004) CALFED Climate Change Whitepaper (PI: Bennett)

CALFED Science Program. $97,000 (2003-2005) The spatial ecology of
delta smelt revealed by otolith biogeochemistry. Graduate Fellowship for J.A. Hobbs (PI: Bennett).

California Interagency Ecological Program. $35,000 (2003-2005). Learning from particle tracking models.
(PIs: Bennett, W. Kimmerer SFSU, M. Nobriga CDWR).

National Fish and Wildlife Federation. $75,000 (2001-2002) Developing a scientific basis for management
of the California nearshore fisheries (PI: Bennett).

Packard Foundation. $30,000 (2002-2003) Developing a scientific basis for management
of the California nearshore fisheries (PI: Kaufman, Co-PI: Bennett).

California Department of Fish and Game $25,000 (2002-2003). Review of fishery independent
data sources for near-shore fishes in support of the Marine Life Management Act (PI: Bennett).

U.S Environmental Protection Agency. $6,000,000 (2000-2005). Western Center for Estuarine
Ecosystem Indicator Research (PI: Susan Anderson, BML, Co-PI: Bennett with several others)
Sonoma County Fish and Wildlife Advisory Board. $12,000 (2000-2001) Growth assessment of
fishes in support of fisheries management on the Sonoma coast (PI: Bennett).

CALFED Ecosystem Restoration Program. $109,000 (2000-2004) Effects of
introduced species in the food web of the San Francisco Bay-Delta (PI: Kimmerer, SFSU, Co-PI: Bennett).

California Interagency Ecological Program. $70,000 (2000-2001). Evaluating the effects of
exotic inland silversides on the endangered delta smelt (PI: Bennett).

California Interagency Ecological Program. $170,000 (2000-2001). Ecological role of Grizzly
Bay as shallow-water nursery habitat for resident fishes (PI: Bennett).

CALFED Ecosystem Restoration Program. $437,000 (1999-2001).
Influence of genetic and tissue condition on individual growth rates and population
dynamics of the endangered delta smelt (PI: Bennett).

California Interagency Ecological Program. $70,000 (1998-1999). Evaluating the effects of
exotic inland silversides on the endangered delta smelt, and exotic bivalves on zooplankton
(PI: Bennett).

U.S. Bureau of Reclamation. $25,000 (1998). Establishment of research and monitoring
priorities for the CALFED Restoration Process for the San Francisco estuary (PI: Bennett).

California Interagency Ecological Program. $43,000 (1998-1999). Interaction of hydrodynamics and
behavior of larval fish in the entrapment zone of the San Francisco Bay Estuary (PI: Bennett).

U.S. Bureau of Reclamation. $50,000 (1997). Cooperative Agreement with USBR to conduct
special projects (PI: Bennett).

U.S. Bureau of Reclamation. $29,929 (1996-1997). Potential emigration and the decline in striped bass abundance following the 1976-1977 drought in the San Francisco Bay/Delta. (PI: Bennett).

California Interagency Ecological Program. $40,489 (1996-1997). Interaction of hydrodynamics and behavior of larval fish in the entrapment zone of the San Francisco Bay Estuary under high-outflow conditions. (PI: Bennett).

California Interagency Ecological Program. $26,215 (1995-1996). Interaction of hydrodynamics and behavior of larval fish in the entrapment zone of the San Francisco Bay Estuary under high-outflow conditions. (PI: Bennett).

California Interagency Ecological Program. $26,215 (1994-1995). Interaction of hydrodynamics and behavior of larval fish in the entrapment zone of the San Francisco Bay Estuary under low-outflow conditions. (PI: Bennett).

California Department of Water Resources. $24,917 (1993-1994). Intraguild predation by exotic fish and low outflow as co-factors influencing the decline of delta and longfin smelt.(Bennett wrote grant and was responsible for research. Dr. P.B. Moyle, Dept. Wildlife, Fish, and Conservation Biology, UC-Davis, served as P.I.).

California Water Resources Control Board. $110,000 per year (1991-1994). Morphometric and histopathologic condition of larval striped bass. (Bennett wrote grant and was responsible for research. Dr. D.E. Hinton, Dept. of Medicine, UCDavis, served as P.I.).

California Interagency Ecological Program, Academic Involvement Research Program for the San Francisco Bay estuary. $33,000 (1992). Interactive effects of starvation and predation on larval striped bass: field experiments using mesocosms. (Bennett wrote grant and was responsible for research. Dr. P.B. Moyle, Dept. Wildlife, Fish, and Conservation Biology, UCDavis, served as P.I.)

California Department of Water Resources. $110,000 per year (1988-1990). Larval striped bass condition studies and North Bay Aqueduct larval fish monitoring. (Bennett wrote grant and was responsible for research. Dr. P.B. Moyle and Dr. D.E. Hinton, served as Co-P.I.'s).

AWARDS & SCHOLARSHIPS

R. Merton Love Student Seminar Award. (1993) Stripers, silversides, and smelt: food web and human impacts on the San Francisco Bay estuary. Ecology Graduate Group, University of California, Davis.

Marin Rod & Gun Club Scholarship. (1989) Changes in the food web enhancing the decline of striped bass in the San Francisco Bay estuary.

PROFESSIONAL SOCIETIES

Ecological Society of America
Estuarine Research Federation
American Fisheries Society
Western Society of Naturalists

SELECTION OF INVITED & CONTRIBUTED SEMINARS

Delta smelt and the POD: a series of unfortunate events? Annual Conference of the California Interagency Ecological Program for the San Francisco Bay Estuary. Asilomar, CA, March 3-5, 2005.(Invited).

Is the delta smelt a canary? Natural and anthropogenic impacts on California coastal and Delta fisheries. **Coastal Environments and River Deltas at Risk Seminar Series**, John Muir Institute of the Environment, Public Service Research Program, and the International House, UC Davis. January 11, 2006 (Invited).

Climate shift influences on striped bass, delta smelt, and the near-shore rockfish fishery. **UC Davis, Climate Change Symposium: Challenges and Solutions for California Agricultural Landscapes.** Davis, CA, May 12-13, 2005 (Invited).

Stage-based projection models for the delta smelt population. **CA Environmental Water and Modeling Forum**. Annual Asilomar Conference, Pacific Grove, CA, March 1-3, 2005. .(Invited).

The state of delta smelt science. **Annual Conference of the California Interagency Ecological Program for the San Francisco Bay Estuary**. Asilomar, CA, March 3-5, 2005.(Invited).

One fish, two fish, three fish, four: estimating abundance and mortality for the threatened delta smelt. **CALFED Science Conference**, Sacramento CA, October 4-6, 2004.

Recent discoveries that may help us manage delta smelt and water operations in the San Francisco Estuary. **Association of California Water Agencies 2004 Spring Conference**. Monterey, CA, May 5, 2004. (Invited).

Estimating the abundance of the threatened delta smelt population in the San Francisco Estuary: counting from afar with myopia. **CA Estuarine Research Section (CAERS), Estuarine Research Federation annual meeting**, Bodega Marine Laboratory, Bodega Bay, March 23-25, 2004.

Climate change and fish populations from estuaries to the nearshore ocean: unveiling the invisible present. **School of Fisheries and Ocean Sciences, University of Alaska, Juneau**. April 16, 2004. (Invited).

An integrated approach for assessing contaminant effects on fish populations. **CALFED Contaminant Effects Workshop**, Sacramento, CA, February 4, 2004 (Invited).

Can we separate human from natural influences on fish populations in the estuary? **6th Biennial State of the San Francisco Bay-Delta Estuary Conference,** Oakland, CA, October 21-23, 2003. (Invited).

Effects of climate change on fish populations in the San Francisco Estuary. **Estuarine Research Federation, Biannual Conference**. Seattle, WA. September 14-18, 2003.

Is recruitment success of delta smelt, *Hypomesus transpacificus*, limited in the larval or juvenile stage? **American Fisheries Society, Early Life History Symposium**, Santa Cruz, August 21-23, 2003

Climate change and fisheries management from estuaries to the near shore ocean: unveiling the invisible present. **U.S. Geological Survey Seminar Series**, Menlo Park, CA. March 27, 2003. (Invited).

Effects of climate change on fish populations of the San Francisco Estuary. **CALFED Science Conference**, Sacramento, CA, January 14-16, 2003.

Integrated monitoring to understand the health, survival, and population dynamics of delta smelt. **CALFED Science Conference**, Sacramento, CA, January 14-16, 2003.

Acquiring essential fishery information under the Marine Life Management Act: an example from the nearshore fishery. **California and the World Ocean Conference**, Santa Barbara, CA, October 27-30, 2002

State of knowledge of delta smelt and implications for the Environmental Water Account. **CALFED Science Program Review Workshop on Environmental Water Account**, Sacramento, CA, October 21-22, 2002 (Invited).

Tissues and tummies: field measurement of stressors to understand delta smelt population dynamics. **2002 CALFED Delta Smelt Workshop**, UC- Davis , CA, September 4, 2002 (Invited)

Science challenges for understanding threats to delta smelt. **Water Operations and Environmental Protection in the Delta**. CALFED Science Program Briefing Workshop for Bennett Raley (USDOI) and Mary Nichols (CRA), Sacramento, CA, April 22-23, 2002 (Invited)

Factors Influencing the population dynamics of delta smelt. **Workshop on delta smelt and the CALFED Environmental Water Account**, Ryde, CA, October 25-27, 2001 (Invited)

Interactive effects of food web alterations and contaminant exposure on fish populations in the San Francsico Estuary: identifying the relevance of ecological indicators. **2001 EMAP Symposium, U.S. EPA**, Pensacola Beach, FLA, April 24-27, 2001 (Invited)

Longevity, behavior, and factors influencing the dynamics of the delta smelt population in the San Francisco Estuary. **Annual Conference of the American Fisheries Society, CalNeva Chapter.** Ventura, CA. March 30-April 1, 2000. (Invited).

Delta smelt: what's going on? **Annual Conference of the California Interagency Ecological Program for the San Francisco Bay Estuary**. Asilomar, CA, February 29-March 3, 2000.(Invited).

Climate change versus human interventions and the decline striped bass in the San Francisco estuary. **Seminar Series on the San Francisco Estuary, Department of Environmental Sciences and Policy, University of California, Davis**, Davis, CA. April 28, 1999. (Invited).

Interactive role of climate change, food web processes, and human interventions on fish populations in an urbanized estuary. **Seminar Series, Institute of Marine Sciences, University of California, Santa Cruz**. Santa Cruz, CA. March 17, 1999. (Invited).

Effects of intraguild predation on the endangered delta smelt. **Annual Conference of the American Fisheries Society, CalNeva Chapter.** Sacramento, CA. April 24-25, 1998. (Invited).

Climate change and the management of fish populations in the San Francisco estuary. **14th International Conference of the Estuarine Research Federation.** Providence, Rhode Island, October 12-16, 1997 (invited).

Climate change, policy, and the decline of California's striped bass population. **Annual Conference of the California Interagency Ecological Program for the San Francisco Bay Estuary**. Asilomar, CA, February 27-March 1, 1997.(invited)

Vertical migration and retention of larval fishes in the estuarine turbidity maximum of a tidally dominated estuary. **American Society of Limonology and Oceanography Annual Conference**, Santa Fe, New Mexico, February 10-14, 1997 (invited).

Physical hydrodynamics, exotic species, and fish recruitment in the San Francisco Bay estuary. **Friday Harbor Laboratories Seminar Series**, Friday Harbor, WA, August 21, 1996 (invited).

Evaluating the effects of agricultural pesticides on fish populations in the San Francisco estuary: ships that pass in the night? **Annual Conference of the California Interagency Ecological Program for the San Francisco Bay estuary**. Asilomar, CA, February 27- March 1, 1996.

Habitat selection by larval fishes in an estuary: the interaction of hydrodynamics and larval behavior. **Bodega Marine Laboratory Research Seminar Series**, Bodega Bay, CA August 15, 1995.

Food web and human factors affecting fish recruitment processes in the San Francisco estuary. **Institute of Marine Science, University of California, Santa Cruz**, Santa Cruz, CA April 5, 1995. (Invited)

Interaction of larval fish behavior and estuarine hydrodynamics in the entrapment zone of the San Francisco Bay estuary. **Annual Conference of the California Interagency Ecological Program for the San Francisco Bay estuary**. Asilomar, CA, March 8-10, 1995. (Invited)

Potential Intraguild predation by exotic inland silversides as a factor in the decline of delta smelt in the San Francisco Bay estuary. **American Fisheries Society Conference**. Napa,CA, February 3-5, 1995.

Introduced species enter the water wars: effects of exotic inland silversides on California's threatened delta smelt. **Bodega Marine Laboratory Research Seminar Series**, Bodega Bay, CA November 1, 1994.

Where have all the fishes gone? factors producing fish declines in the San francisco Bay estuary. **75th Annual AAAS Conference**, San Francisco, CA, June 17-23, 1994.

Stripers, silversides, and smelt: Food web and human impacts on the San Francisco Bay estuary. **Bodega Marine Laboratory Seminar Series**, Bodega Bay, CA, February 1994. (invited)

Stripers, silversides, and smelt: Food web impacts in the San Francisco bay estuary. **Biology Colloquium, Sonoma State University**, Rohnert Park, CA, October 1993. (invited)

Interaction of food limitation and predation on mortality of larval striped bass. **San Francisco Bay and Estuarine Association**, California Academy of Sciences, San Francisco, CA, April 1993. (invited)

Evaluating the starvation hypothesis for larval striped bass using quantitative morphometry and histopathology. **11th Biennial Estuarine Research Federation Conference**, San Francisco, CA, November 1991.

Evaluating the starvation hypothesis for larval striped bass. **Natural Resource Policy Seminar Series**, Division of Environmental Studies, University of California, Davis, CA, May 1991. (invited)

Are the larvae of striped bass starving to death in the Sacramento-San Joaquin estuary? **American Fisheries Society Annual Conference**. South Lake Tahoe, Nevada, February 1990.

Scale of investigation and the detection of competition: Why house sparrows may interest marine ecologists. **Bodega Marine Laboratory Seminar Series**, Bodega Bay, CA, September 1988. (invited)

Evidence for competition between the house sparrow and house finch in North America. **Nuttall Ornithological Club, Harvard Biological Laboratory**, Cambridge, MA, October 1984. (invited)

Scale of investigation and the detection of competition: an example from two finch species introduced into North America. **Population Biologists of New England Conference**, University of Massachusetts, Amherst, MA, April 1984.

Appendix B

Draft Actions Reviewed by the Panel

Draft USFWS Proposed Actions

October 24, 2008

Introduction to the Service's Actions

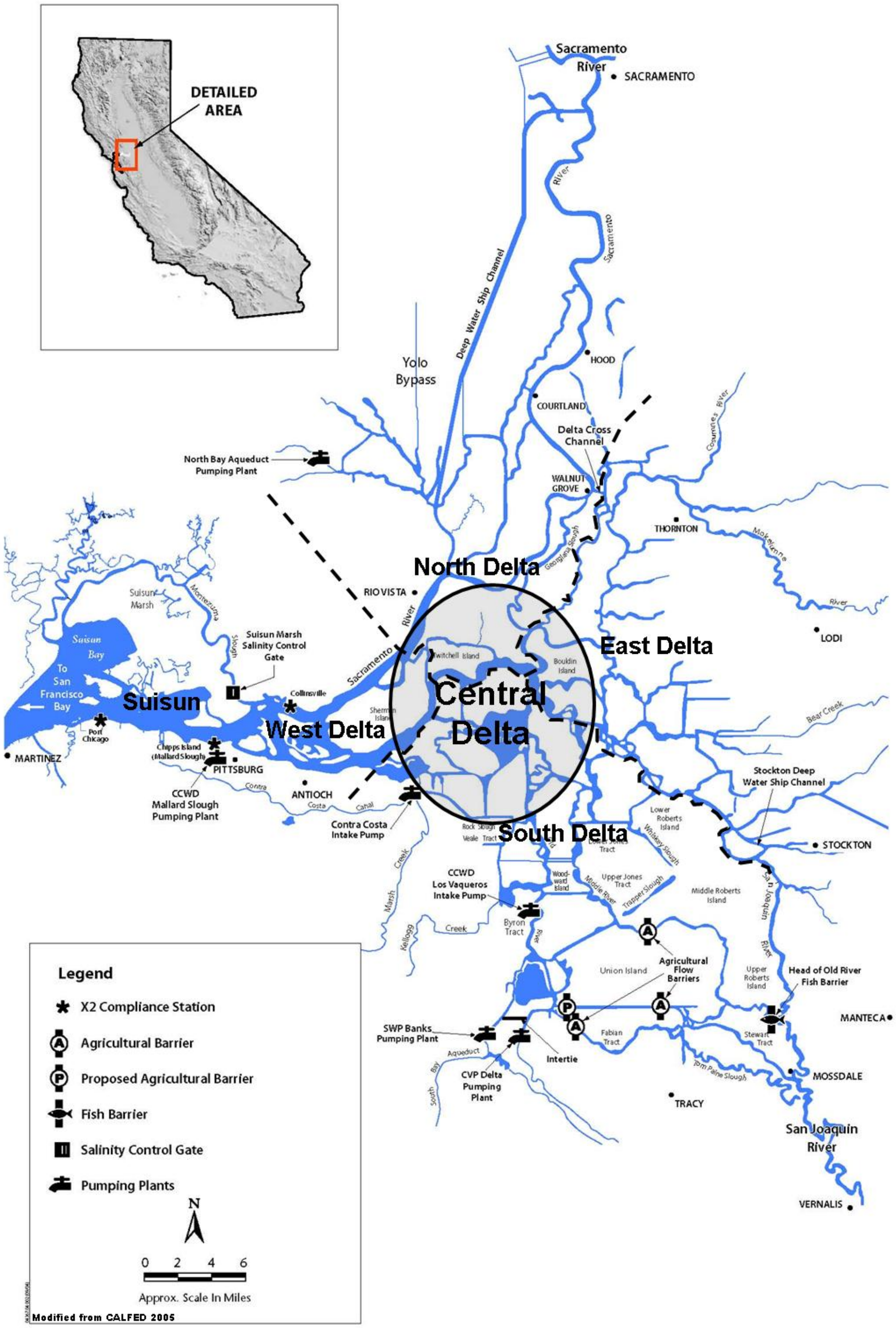
There are three major factors related to operations of the CVP/SWP affecting delta smelt population resilience and long-term viability. It is also recognized that the hydrologic changes from the CVP/SWP result in ecological conditions that influence delta smelt interactions with other stressors within the Delta. The following actions were developed to counter these adverse effects based upon the Baseline and Effects Analysis of the BO.

These three factors are: 1) direct mortality associated with entrainment of pre-spawning adult delta smelt by CVP/SWP operations; 2) direct mortality of larval and early juvenile delta smelt associated with entrainment by CVP/SWP operations; and, 3) indirect mortality and reduced fitness through reductions to and degradation of delta habitats, most notably in the fall by CVP/SWP operations. The actions below address these factors and will ameliorate the adverse effects that are brought about from the hydrologic modifications that influence delta smelt interactions with other stressors in the Delta.

The metric for monitoring direct mortality of delta smelt is salvage at Banks and Jones that is caused by exports (pumping). However, this metric alone cannot be used to trigger operational changes in CVP/SWP to prevent entrainment. This is because CVP/SWP operations have the ability to draw delta smelt into the South and Central Delta (see Map1) where they are more susceptible to entrainment by the facilities prior to any delta smelt salvage. This necessitates a pre-emptive strategy in order to sufficiently protect delta smelt from entrainment.

To develop these actions, we re-evaluated the Interim Remedies for delta smelt protection as proposed in the Service's declarations of July 3, 2007 and August 3, 2007 (Cay Collette Goude 2007), and implemented in the Wanger Interim Remedies Order. The Service used the CALLite operations model to evaluate different operational scenarios. Different operational parameters were run to evaluate their influence upon predicted entrainment. These parameters included export-inflow (EI) ratios, Qwest, X2, and OMR flows, among others.

During these sessions, two clear patterns became evident. First, shifting operations to reduce exports during any one given month resulted in a shift in operations to increase exports in other months. Second, holding one particular parameter steady did not prevent other parameters from adapting to meet similar water supply objectives. For example, modeling Qwest to some static number still allowed considerable variability in negative OMR flows, due to the contribution of other intervening variables to Qwest, including operation of the DCC and Sacramento and San Joaquin River flows. For these reasons, the most logical operational criterion for protecting delta smelt from entrainment is controlling the magnitude of flows in the South and Central Delta towards the export facilities. This is reflected quantitatively as net negative OMR flows during the time periods when delta smelt are present and subject to entrainment.



Map 1: Delta Regions

Delta Smelt Evaluation Team

In July 2008, the Service convened a team of experts comprising members of the Adaptive Management Planning Team (AMPT) of the ERP, technical staff from the Department of Fish and Game and the Service, and an expert hydrodynamicist to conduct evaluations of Interim Remedy actions using the evaluation process and conceptual models developed for the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) in light of the current project description.

To the extent practicable, the DRERIP evaluation tools were used in formulating potential actions to ameliorate the anticipated effects of the proposed action. The DRERIP tools include peer reviewed ecosystem and species conceptual models for the Delta drafted by teams of experts. These models represent a compilation of the current state of scientific knowledge regarding specific ecosystems and fish species, including delta smelt.

The full DRERIP evaluation process was not applied to the potential actions for delta smelt, but elements of the process were considered and followed during the initial phases of actions development and evaluation. The nature of the task before the evaluation team finally necessitated direct involvement of technical experts in providing up-to-date quantitative analysis and detailed evaluation exceeding the level of detail inherent in the current DRERIP conceptual models.

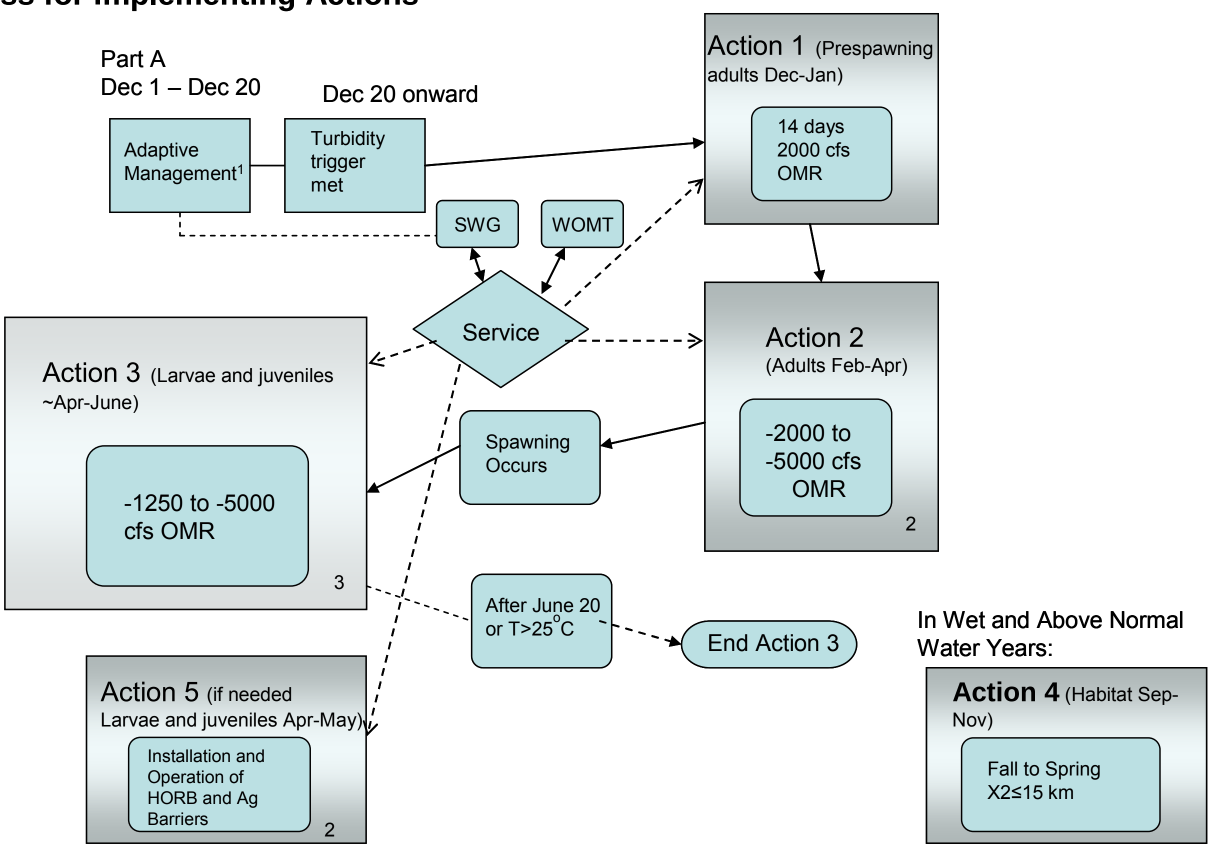
At this stage of the actions evaluation, and given the time constraints, it was most advantageous to merge the existing actions evaluation team with the group of technical experts from the advisory team the Service convened to assist with technical elements associated with development of the baseline and effects section of the biological opinion. The final evaluation team utilized to assess and recommend the current actions to the Service comprised a broad range of expertise in delta smelt biology, ecology, population dynamics, delta hydrodynamics, ecosystem modeling, and applied regulatory science. However, all conclusions and the final decision reached on protective criteria, actions, and prescriptions reflected in this document are the opinion of the Service.

As discussed in the Baseline and Effects Analysis sections of the BO, there are other impacts to delta smelt through reduction and degradation of habitat. These effects are functional year-round, through mechanisms defined and discussed in those sections. Indirect mortality and reduced fitness of juvenile delta smelt due to degraded environmental quality (habitat suitability) in the fall impacts delta smelt. The mechanism of this impact is habitat constriction, entrainment of primary and secondary productivity leading to food-web deprivation for prey species, decreased dilution flows resulting in increased exposure to lethal and sublethal concentrations of contaminants. Additionally it results in reduced habitat variability that is necessary to control invasive species such as *Corbula* or *Microcystis* that either compete with, or directly impact survival of delta smelt. The operational criteria to restore habitat quality for rearing juveniles in the estuary are directly related to increasing delta outflows during fall months (September through November) of above-normal and wet water years to restore habitat variability.

Actions Summary

Actions 1 and 2 will reduce the direct mortality of pre-spawning adult delta smelt (Adult Entrainment). Action 3 will reduce the direct mortality of larval and juvenile delta smelt (Larval/Early Juvenile Entrainment). Action 4 will restore habitat quality for rearing juveniles in the estuary that are directly related to increasing delta outflows during fall months (September through November) of above-normal and wet water years to restore habitat variability. Action 5 describes the installation and operations of the spring temporary Head of Old River Barrier (HORB) and the temporary agricultural barriers to reduce juvenile entrainment. The detailed elements of these prescriptions, including rationale and justification, appear in subsequent sections of this document, by Action.

Process for Implementing Actions



1 This information is based on salvage, hydrology, and distribution of delta smelt. Triggering the action prior to December 20 is expected to be infrequent based on historical data

2 The OMR target will be determined based on salvage, hydrology, and distribution of delta smelt

3 The OMR target will be determined based on salvage, hydrology, and distribution of delta smelt and PTM runs looking at entrainment at station 815

Role of Adaptive Management

As discussed in the baseline and effects sections, we recognize that there are multiple factors affecting delta smelt population dynamics and that not all are directly influenced by operations of the CVP/SWP. With respect to direct mortality from entrainment, the prescriptions and triggers presented in actions 1, 2, and 3 are based on historical data. Changing OMR flows will change a key underlying driver of future salvage. Based on the low numbers of delta smelt and therefore the difficulties in delta smelt monitoring and the uncertainty in relying on historical data, the use of adaptive management with regulatory sideboards is essential.

It is very important that the control mechanisms used to implement the actions be sufficiently robust to work when delta smelt densities are low. Delta smelt densities are likely to remain low for the foreseeable future. When delta smelt occur in low densities, it becomes difficult to reliably infer distribution based on IEP monitoring data. In circumstances where it is difficult to reliably infer distribution, automated control mechanisms that assume reliable distribution information are likely to fail.

The real-time monitoring and adaptive management of final flow prescriptions within these actions should be part of the final actions. Such a strategy utilizes weekly review of the sampling data and real-time salvage data at the CVP/SWP. It utilizes the most up-to-date technological expertise and knowledge relating population status and predicted distribution to monitored physical variables of flow and turbidity, and thereby adapts to current conditions. This would provide protection to delta smelt and reduce operational constraints when the risk of delta smelt entrainment is low based on distribution and data analysis. Such a strategy would provide necessary protections while utilizing the minimum possible regulatory constraints on the project.

ACTION 1: Adult Migration and Entrainment (First Flush)

Objective: A fixed action to protect pre-spawning adult delta smelt from entrainment during the first flush, and to provide advantageous hydrodynamic conditions early in the migration period.

Action: Limit exports so that OMR flows are no more negative than -2,000 cfs on a 7-day running average for a period of 14 days with no single day's actual flow more negative than -2,400 cfs.

Timing:

Part A: December 1 to December 20 – Based upon an examination of turbidity data from Prisoner's Point, Holland Cut, and Victoria Canal and salvage data from CVP/SWP (see below), and other parameters important to the protection of delta smelt including, but not limited to, preceding conditions of X2, FMWT, and river flows; the Smelt Working Group (SWG) may recommend a start date to the Service. The Service will make the final determination.

Part B: After December 20 – The default trigger is the 3 day average turbidity at Prisoner's Point, Holland Cut, and Victoria Canal exceeds 12 NTU. However the SWG can recommend a delayed start or interruption based on the turbidity 3 day average not being met, or variation in other conditions which may affect vulnerability to entrainment.

Triggers (Part B):

Turbidity: 3-day average of 12 NTU or greater @ *all three* stations (Prisoner's Point, Holland Cut, Victoria Canal)

Salvage: Three days of delta smelt salvage at either facility or cumulative daily salvage count that is above a risk threshold based upon the "daily salvage index" approach reflected in a daily salvage index value ≥0.5 (daily delta smelt salvage > one-half prior year FMWT index value).

The window for triggering Action 1 concludes when either offramp condition described below is met. These offramp conditions may occur without Action 1 ever being triggered. If this occurs, then Action 3 is triggered unless the Service concludes on the basis of the totality of available information that Action 2 should be implemented instead.

Off-ramps:

Temperature: Water temperature reaches 12^{o}C.

Biological: Onset of spawning (presence of spent females in SKT or at Banks or Jones).

ACTION 2: Adult Migration and Entrainment

Objective: An action implemented using adaptive management to tailor protection to changing environmental conditions after Action 1. As in Action 1, the intent is to protect pre-spawning adults from entrainment and, to the extent possible, from adverse hydrodynamic conditions.

Action: The range of OMR flows will be no more negative than -5,000 to -1,250 cfs. Depending on extant conditions (and the general guidelines below) specific OMR flows within this range are recommended by the SWG from the onset of Action 2 through its termination (see Adaptive Management Process in Introduction). The SWG would provide weekly recommendations based upon review of the sampling data, from real-time salvage data at the CVP and SWP, and utilizing most up-to-date technological expertise and knowledge relating population status and predicted distribution to monitored physical variables of flow and turbidity. The Service will make the final determination.

Timing: Beginning immediately after the last day of Action 1. The SWG will recommend specific targets OMR flows based on salvage and on physical and biological data on an ongoing basis.

Off-ramps:

Flow: Three day flow average is greater than or equal to 90,000 cfs at Sacramento River at Rio Vista and 10,000 cfs at San Joaquin River at Vernalis.

Temperature: Water temperature reaches 12^{o}C

Biological: Onset of spawning (presence of spent females in SKT or at either facility)

Adaptive Management Guidelines:

Two scenarios bookend the circumstances likely to exist during Action 2. First, the low-entrainment risk scenario. There may be a low risk of adult entrainment because (a) there has been no discernable migration of adults into the South and Central Delta OR (b) the upstream migration has already occurred but turbidity is low and there is no or little evidence of ongoing adult entrainment. In this scenario, higher negative OMR flow rates as high as -5,000 cfs may be ventured as long as entrainment risk factors and salvage permit. The second scenario, the high-entrainment risk scenario, is one in which either (a) there is evidence that upstream adult migration is currently occurring, or (b) upstream migration has already occurred and there are adult fish in the South and Central Delta and turbidity is high, increasing the risk of entrainment, or (c) there is evidence of ongoing entrainment, regardless of other risk factors. In this case, OMR will be set to reduce entrainment and/or the risk of entrainment as the totality of circumstances warrant. Generally, if the available distributional information suggests that most of the delta smelt are in the North or North/Central Delta, then OMR can be chosen to minimize Central Delta entrainment. However, if the distributional information suggests there are delta smelt in the Central or South Delta, then OMR will have to be set lower to reduce entrainment of delta smelt.

The following two paragraphs describe how these action guidelines would be implemented at the start of Action 2 and at other times during Action 2.

1. OMR setting at initiation of Action 2

a) If salvage is zero during the final 7 days of Action 1 and turbidity is below 15 NTU, then increase negative OMR to no more negative than -5,000 cfs on a 7-day running average with a simultaneous 3-day running average within 20% of the applicable target OMR[1], *AND* with no single day more negative than -6,000 cfs during the first 7 days; *UNLESS*

b) If salvage is less in the most recent three days than in the preceding three days and the maximum Daily Salvage Index is ≤1 during the prior 7 days, then limit exports to achieve OMR flows no more negative than -3,500 cfs on a 7-day running average for 7 more days (or until 4 consecutive days of zero salvage or any 5 of 7 days with zero salvage), with no single day during the first 7 days more negative than -4,200 cfs; *OR*

c) If salvage is greater or equal in the last three days than in the preceding three days, and maximum Daily Salvage Index ≥1 during any of those days, then continue OMR flow at no more negative than -2,000 cfs on a 7-day running average for an additional 14 days (or until 4 succeeding days of zero salvage or any 5 of 7 days zero salvage), with no single day more negative than -2,400 cfs during the first 7 days.

d) If circumstances existing at the initiation of Action 2 are, in the judgment of the Service, markedly different from those anticipated in (a) through (c) above, then the OMR flow prescription in (c) will be applied and the SWG will review available data and recommend an initial flow rate to the Service.

---

[1] The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the seven day running average described previously.

2. OMR setting after initiation of Action 2

a) The SWG will review the totality of circumstances and request updated entrainment simulations and/or other information, as needed, on a weekly basis to decide whether the current OMR limitation is appropriate or should be changed.

b) If delta tributary river discharges are not so high that OMR is grossly positive despite water project operations, then important variables that affect the risk of adult entrainment during Action 2 include (1) salvage or other actual entrainment indicators, (2) turbidity, (3) available monitoring results, hydrologic variables other than export pumping rates that affect OMR flow, (4) apparent population size from the preceding FMWT survey, (5) particle tracking or other model-based entrainment risk information.

c) As described above, the risk of entrainment is generally higher when there is evidence of ongoing entrainment or turbidity is high, and these two variables are the most likely triggers of decisions to raise or lower restrictions on OMR flow.

d) Based on historical experience, OMR flow limitation between the limits of -2,000 cfs and -5,000 cfs is likely to be adequate in most years. The exception is years in which there appears, for whatever reasons, to be a substantial fraction of the adult spawning migrant population in the Central and/or South Delta. When this occurs, more stringent OMR limitation (possibly to no more negative than -1,250 cfs) may be required.

BACKGROUND

Adult delta smelt entrainment is characterized by a pulse of pre-spawning migrants entering the Central and South Delta following a "first flush" flow event in winter. This event generally involves a coincident increase in turbidity; which, along with the flows, is a cue for delta smelt migration. The interaction of these migratory cues—flow, turbidity, temperature, and season—leads to migration patterns that are difficult to predict yearly. However, historical salvage of delta smelt at Banks and Jones provides an index of entrainment that can be compared against key general predictors like flow and turbidity. Figures A-1 and A-2 below graphically depict the relationship of these variables against daily smelt salvage at Banks and Jones during two example water years. Once the initial pulse of pre-spawning migration passes, it is believed that spawning adults moderate their movements to maintain their geographical range to a smaller area, when conditions stay favorable and to the extent that delta smelt can control their location based on extant flow variables.

Entrainment effects upon delta smelt populations can become substantial. In one historically common scenario, a tight coincidence between calendar timing, sudden influx of turbid (>12 NTU) fresh water into the Delta, and high Delta exports. The coincidence of these circumstances has historically often led to high amplitude spikes in adult delta smelt salvage. Such events occurred in WY's 1993 and 2003, as displayed in Figures A-3, A-4—which plot turbidity and negative OMR on workable scales against total salvage. If this scenario plays out in years where there are few delta smelt, it may be difficult to detect salvage spikes even if they represent substantial proportional entrainment events.

In a second scenario there are no large salvage spikes, but chronic entrainment over a sufficient duration adds up to a relatively large cumulative salvage. Alternatively, there may be multiple entrainment spikes in years where the timing of migratory cues is diffuse or occurs in episodes. This would appear graphically as a curve with generally low-amplitude prolonged over a long period. Examples of such entrainment years would include WY 2004 and 2005, as displayed in Figures A-5, and A-6.

As a proportion of the pre-spawning adult population, total entrainment depends on precipitation patterns, ambient air temperature, controlled and uncontrolled releases from waterways feeding the Delta, specific operation of facilities such as the DCC, condition of that year's pre-spawning cohort based on current year habitat quality, because all of these may affect the distribution of delta smelt adults as and after they migrate into the Delta. However, the list of variables known or believed to influence delta smelt distribution during this period is not complete, and there is substantial apparently stochastic variation in the use of Delta habitats by adult delta smelt.

Figure A-1: 1995 WY OMR, Turbidity, Salvage

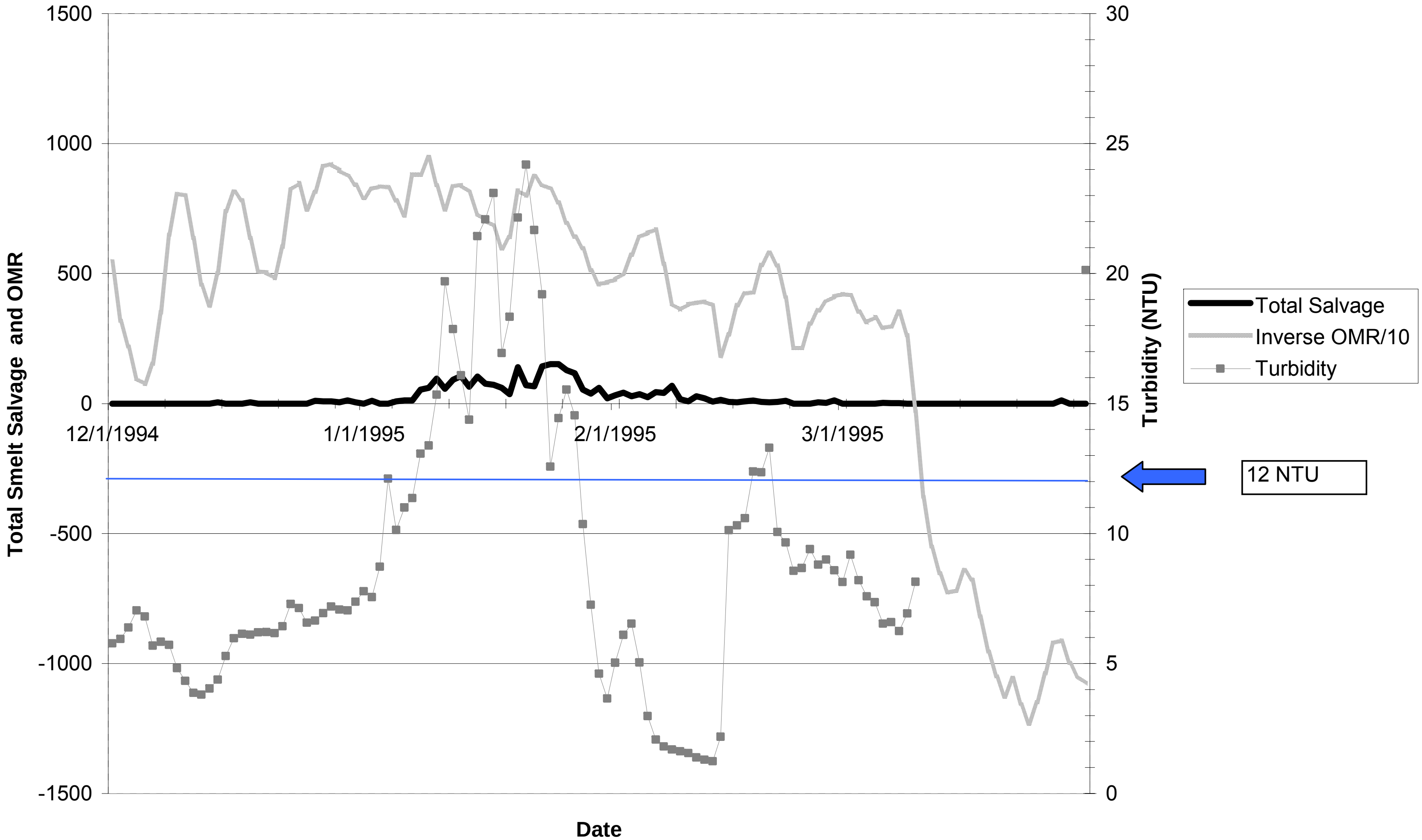


Figure A-2: 2002 WY OMR, Turbidity, Salvage

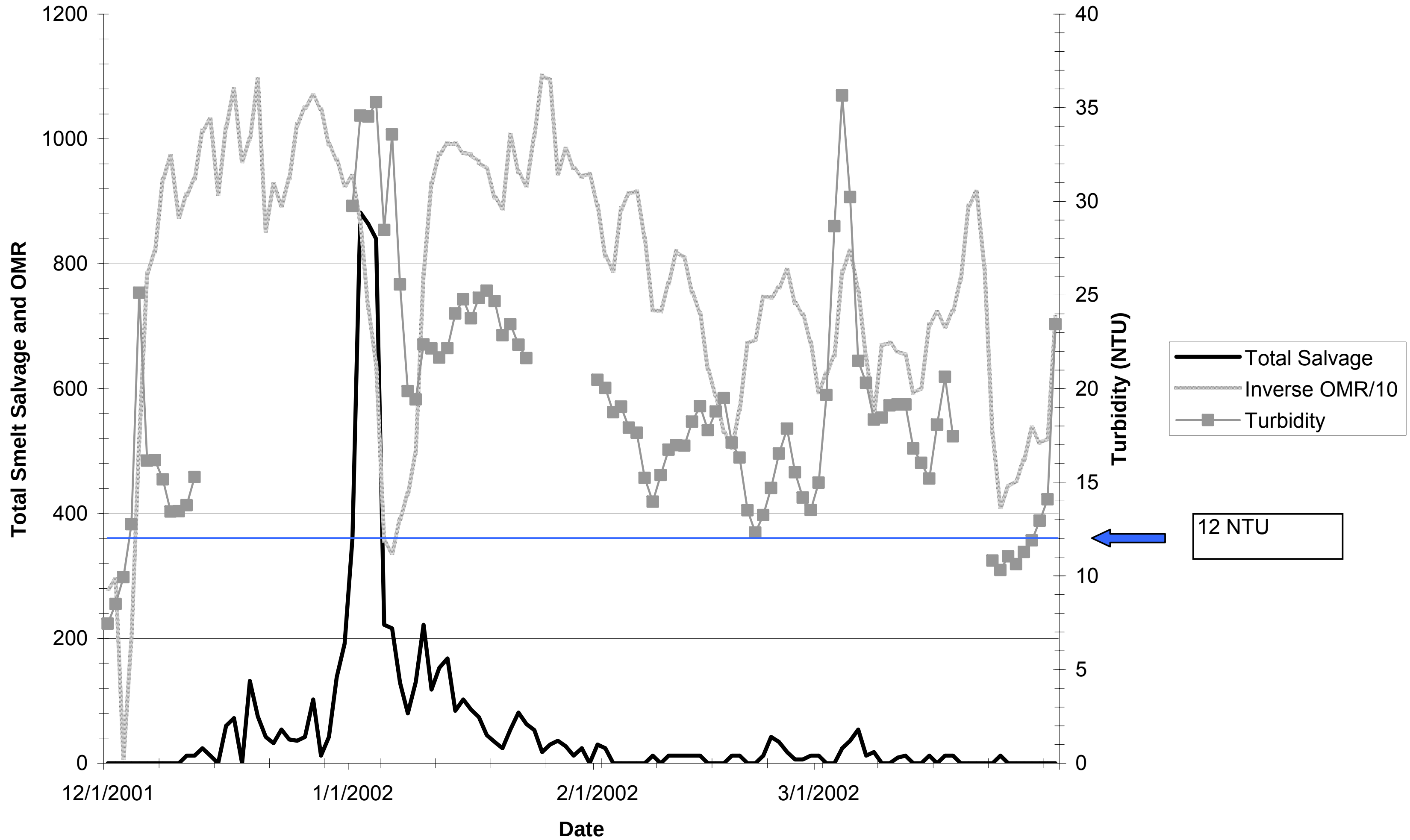


Figure A-3: 1993 WY OMR, Turbidity, Salvage

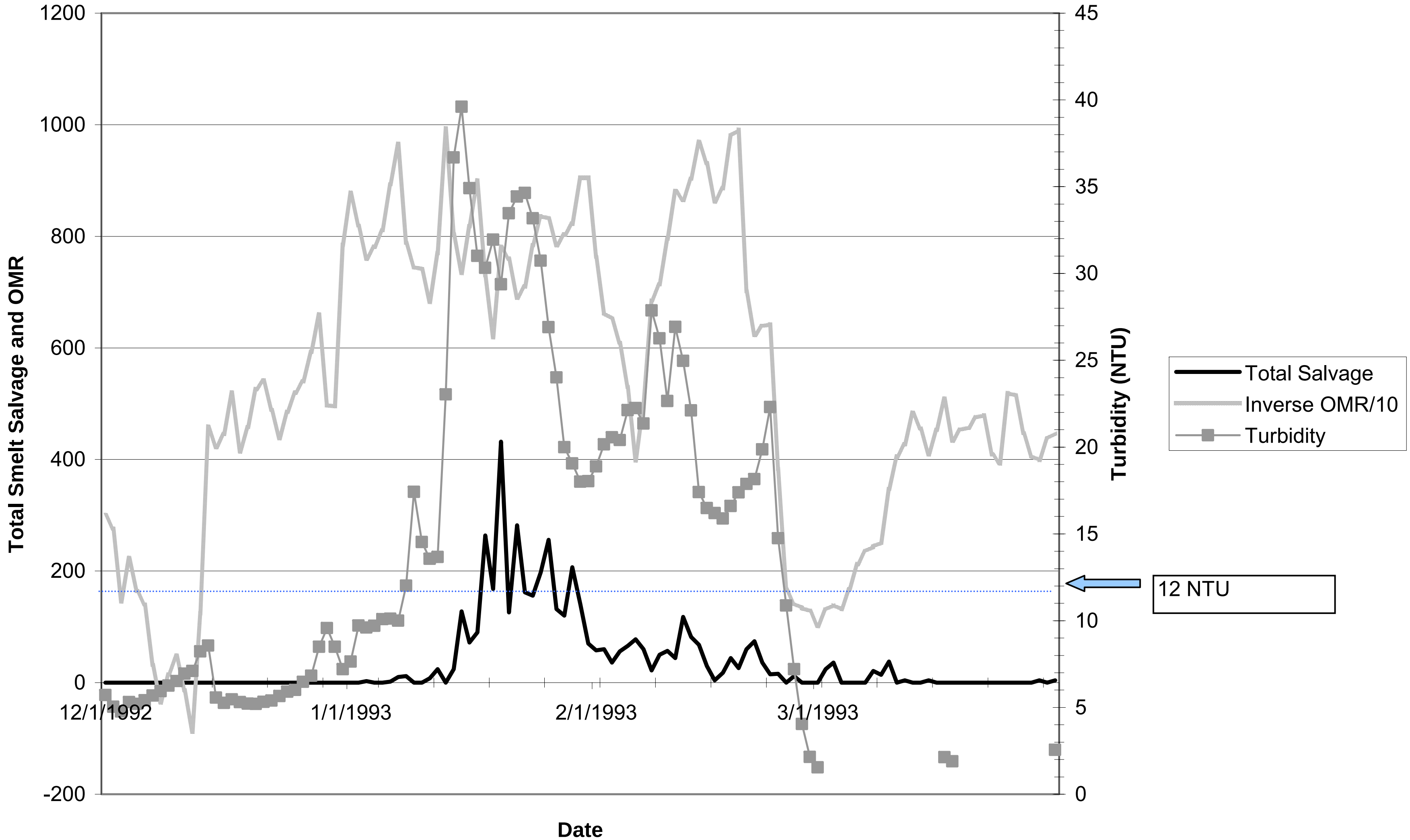


Figure A-4: 2003 WY OMR, Turbidity, Salvage

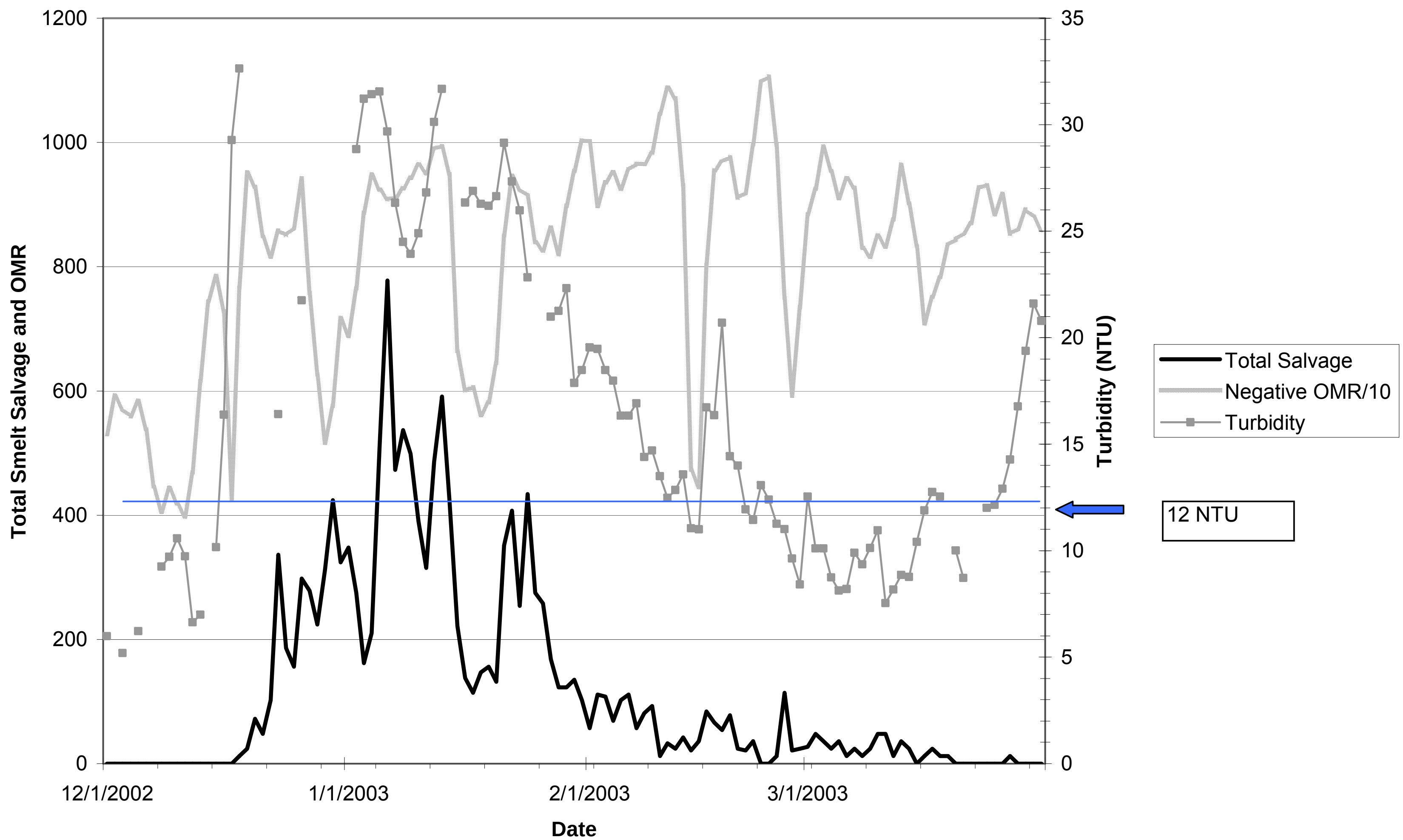


Figure A-5: 2004 WY OMR, Turbidity, Salvage

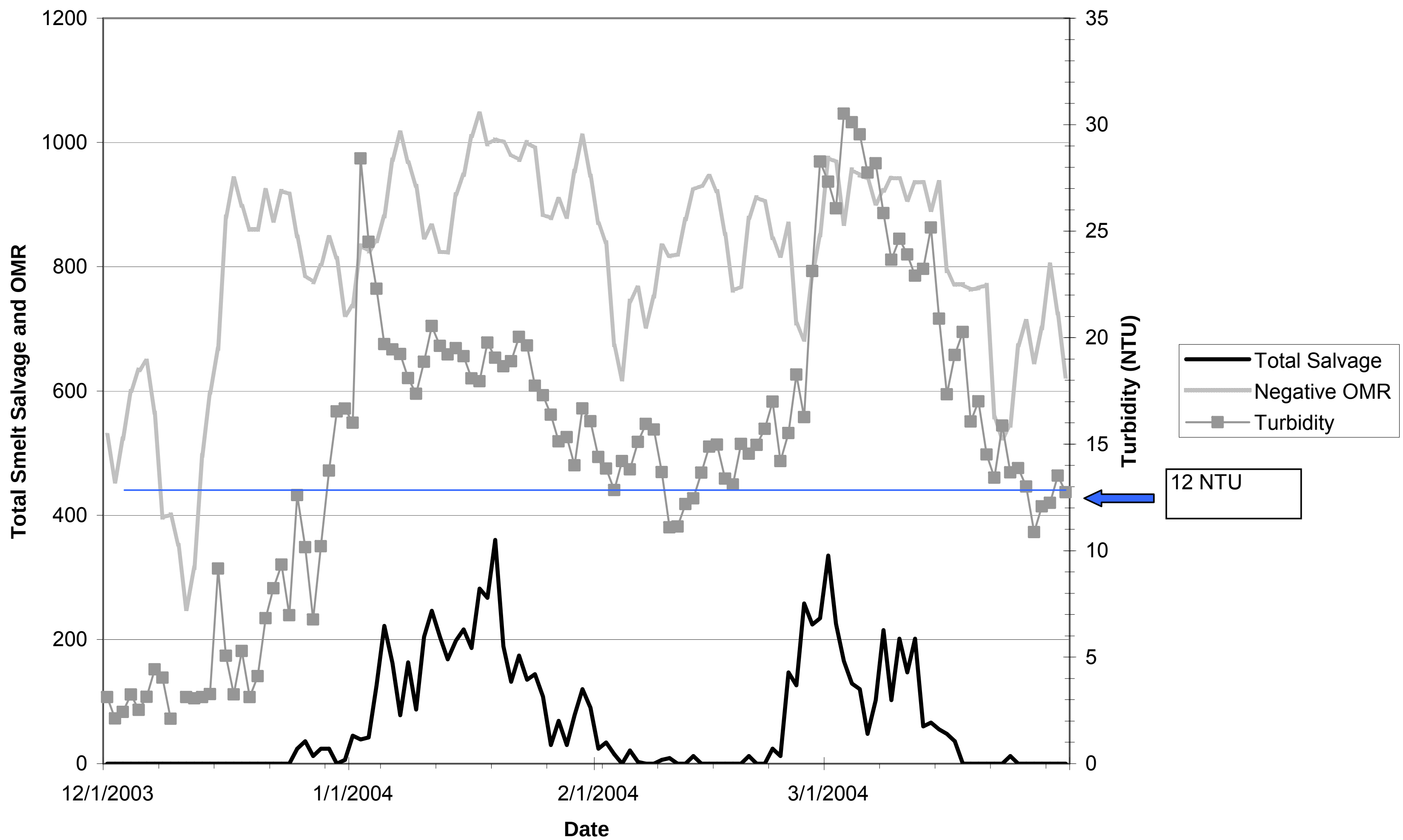
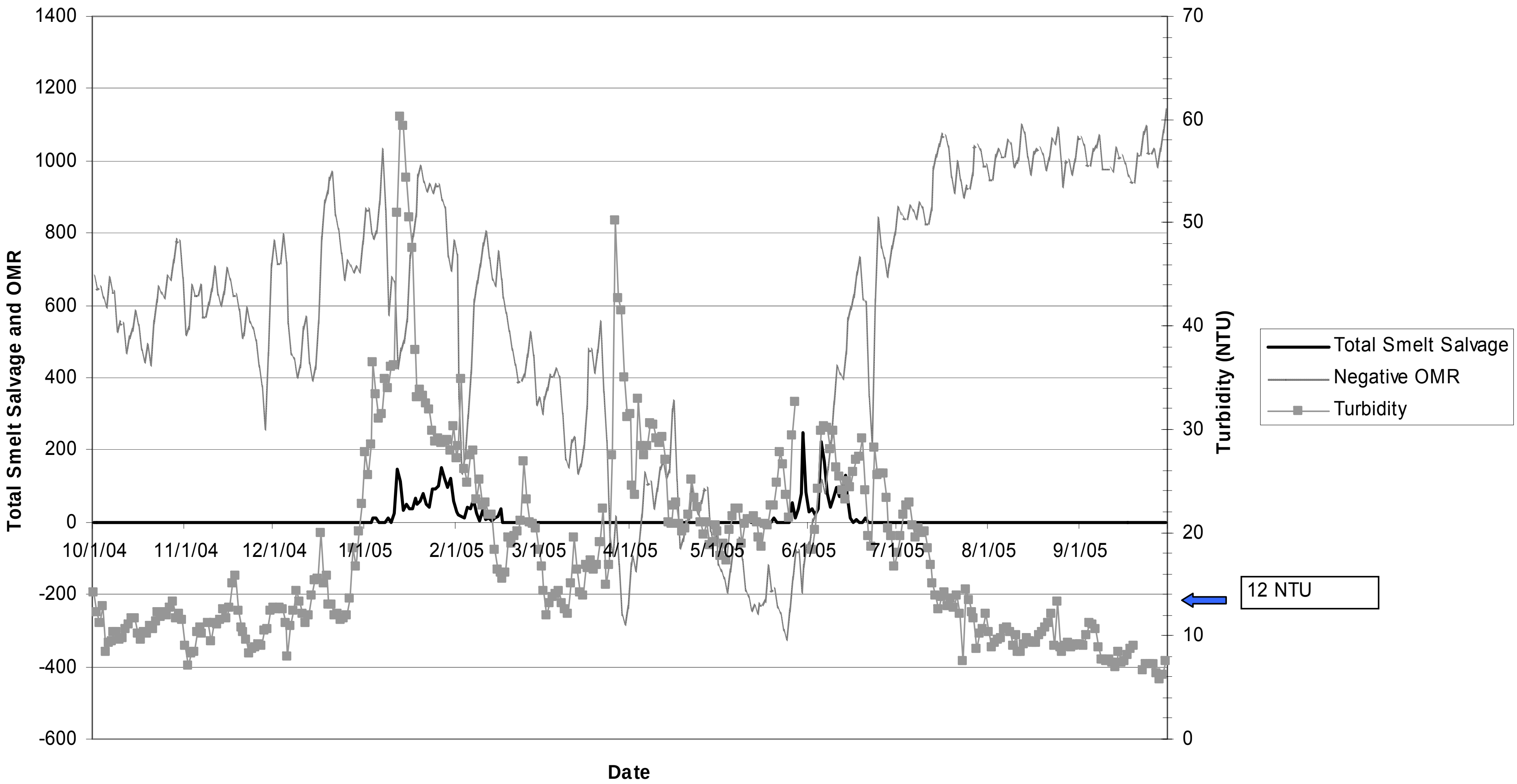


Figure A-6: 2005 WY OMR, Turbidity, Salvage



Entrainment

Up to fifty percent of the pre-spawning adult population has been entrained at the export facilities in recent years, depending on circumstances (Kimmerer 2008). Entrainment risk depends most importantly upon the distribution of delta smelt relative to the entrainment footprint of the CVP/SWP export facilities. Monitoring programs such as the FMWT and SKT provide a useful basis for estimating the abundance and distribution of delta smelt, despite having drawbacks (Newman 2008). The margin of error associated with abundance and distribution inferences increases at low abundances that have characterized the last several years. Abundances near the detection threshold of the sampling techniques makes it very difficult to draw reliable inferences about how many delta smelt there are and where they are located.

To provide context to determine the magnitude of effect of pre-spawning adult direct mortality through entrainment within any given season (as measured by salvage), it is necessary to consider two important factors. First, although salvage is an index of entrainment, it is not a direct quantitative equivalent. The number of delta smelt that are actually counted at the salvage facilities represents a small percentage of the actual number entrained (See baseline section). Efficiency of sampling methodology is another consideration given the delicate tissues of the delta smelt, and this decreases inversely with fish size (adults are most accurately counted, while juvenile salvage efficiency is much lower, while <20mm smelt are mostly undetectable at the salvage facilities). Finally, although surviving individuals are held and released to the Delta, it is generally thought that they do not survive. Therefore salvage at the Banks and Jones facilities greatly underestimates actual adult delta smelt mortality through entrainment (See baseline section).

The second factor to consider when relating salvage data to population-level significance is that the total number salvaged at the facilities does not necessarily indicate a negative impact upon the overall delta smelt population. To provide this context, it is, at minimum, necessary to normalize salvage data by some measure of delta smelt density since the number of delta smelt varies from year to year. The metric used in this process to normalize salvage data to delta smelt density is represented by dividing daily salvage by the prior year's FMWT Index. This quotient has been described as the Salvage Index:

Salvage Index = Number of Delta Smelt Salvaged ÷ Prior Year FMWT Index

Summaries of delta smelt salvage are presented by water year type in Table A-2. Figures A-7 through A-11 display salvage data normalized to prior-year FMWT for the POD years (WY2002-WY2006). These plots have consistent units on the y-axis, reflecting the Salvage Index. The area under the salvage curve reflects the total number of smelt salvaged, and this is a metric that can be related to total demographic impacts through entrainment.

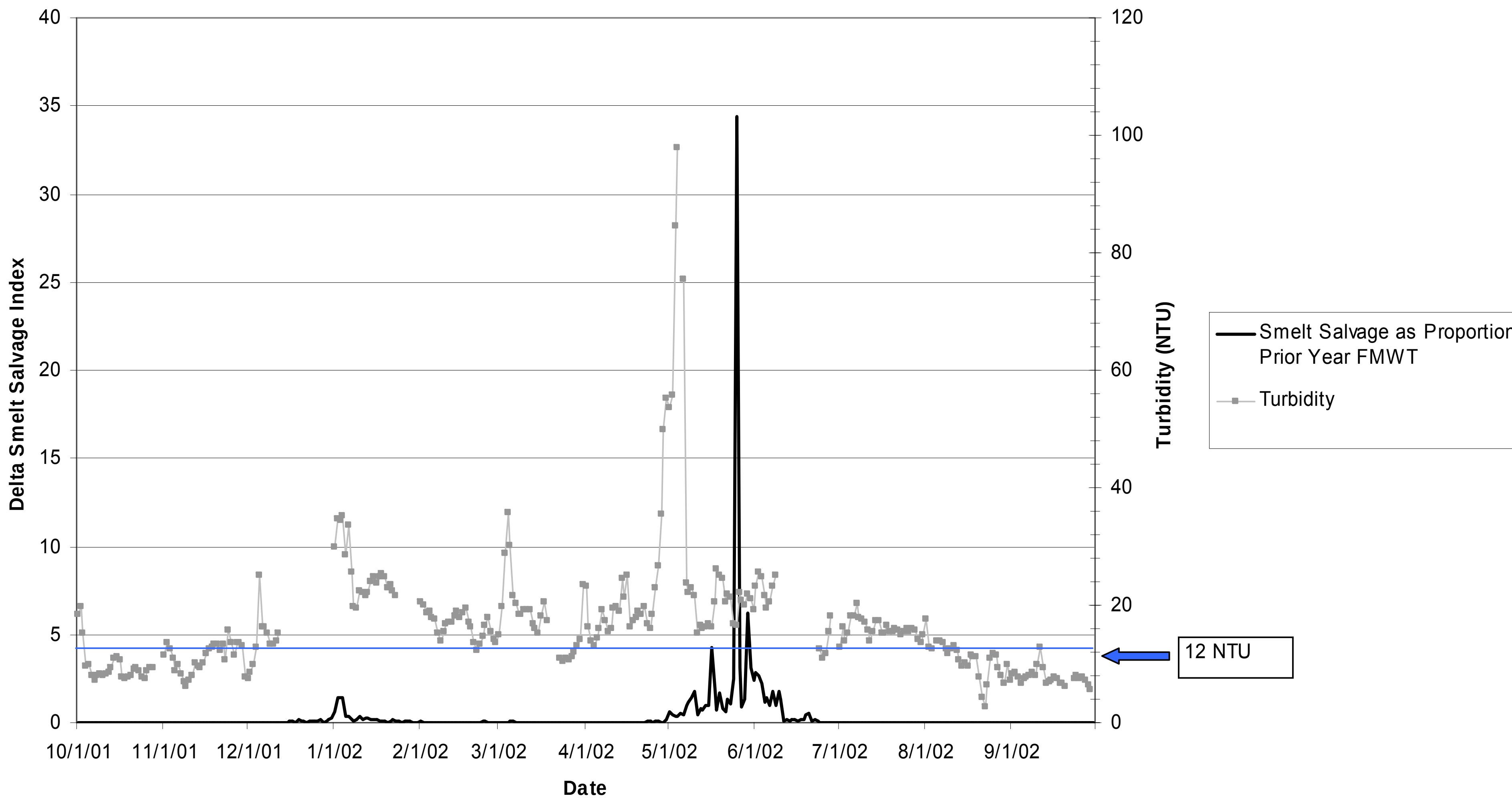
Table A-2: Total Delta Smelt Salvage by Year, including summary statistics

Year	Total Salvage	Prior Year FMWT	Total Salvage/FMWT	Amplitude	Salvage distribution	Backcasted 12 NTU Trigger Date	NTU trigger to peak salvage (days)	Total # salvaged before trigger	propn of total season salvage prior to trigger date
1993	4425	156	28.3654	2.769231	unimodal	10-Jan	12	27	0.0061
1994	398	1078	0.3692	0.076923	unimodal	4-Jan	52	100	0.25126
1995	2600	102	25.4902	1.490196	unimodal	9-Jan	16	150	0.05769
1996*	5634	899	6.26696	0.515017	unimodal	14-Feb	36	0	0
1997	1816	127	14.2992	1.11811	unimodal	20-Dec	80	12	0.00661
1998	1027	303	3.38944	0.382838	bimodal	20-Dec	10 & 94	75	0.07303
1999	2074	420	4.9381	0.4	unimodal	14-Jan	36	20	0.00964
2000	11493	864	13.3021	0.722222	unimodal	23-Jan	28	482	0.04194
2001	7991	756	10.5701	0.488095	unimodal	13-Jan	29	255	0.03191
2002	6865	603	11.3847	1.462687	unimodal	20-Dec	14	324	0.0472
2003	14323	139	103.043	5.597122	unimodal	20-Dec	17	108	0.00754
2004	8148	210	38.8	1.714286	bimodal	31-Dec	19	126	0.01546
2005	2018	74	27.2703	2.067568	unimodal	20-Dec	39	0	0

* 3 NTU sensor malfunctions most of year; date evaluated as Dec 20 using total inflow > 25,000 cfs

Review of salvage data across years for which monitoring data are available indicate some patterns which led to the development of Interim Remedies Action 1; the same logic has been used to develop the present Action 1. First, salvage data during winter generally follows a unimodal distribution, with a defined salvage peak, and short duration. Occasionally, climatic conditions and operational criteria interact to produce bimodal or diffuse salvage distributions, however these year types are the exception, as summarized in Table A-2. Peak salvage usually occurs during the month of January, however this pattern does not hold during all year types, and some years even exhibit low overall adult salvage (wet WY of 1997 and 1998, or dry years with no winter first flush as in WY 1994). Historic delta smelt salvage data and the current population status suggest a protective strategy for this period that focuses upon prevention of the attraction and subsequent entrainment of pre-spawning adults during the onset of upstream migration. While salvage itself is a useful indicator of distribution after the fact, it has serious drawbacks as a management tool when used on its own, because a large entrainment event may be inevitable by the time an increase in salvage or salvage frequency is detected

Figure A7: 2002WY Salvage Index



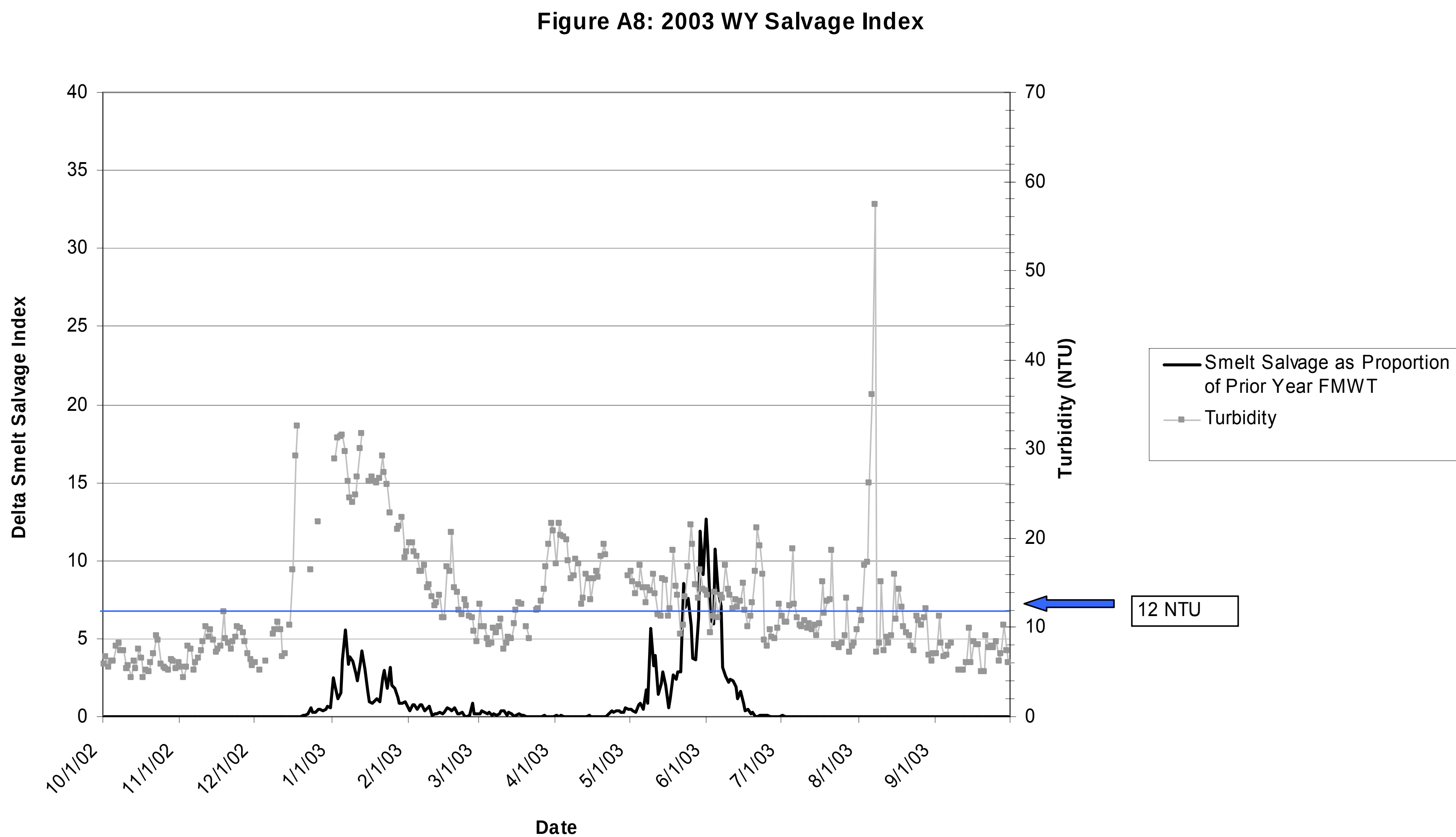


Figure A8: 2003 WY Salvage Index
Delta Smelt Salvage Index
Turbidity (NTU)
40
35
30
25
20
15
10
5
0
70
60
50
40
30
20
10
0
10/1/02
11/1/02
12/1/02
1/1/03
2/1/03
3/1/03
4/1/03
5/1/03
6/1/03
7/1/03
8/1/03
9/1/03
Date
Smelt Salvage as Proportion of Prior Year FMWT
Turbidity
12 NTU

Figure A9: 2004 WY Salvage Index

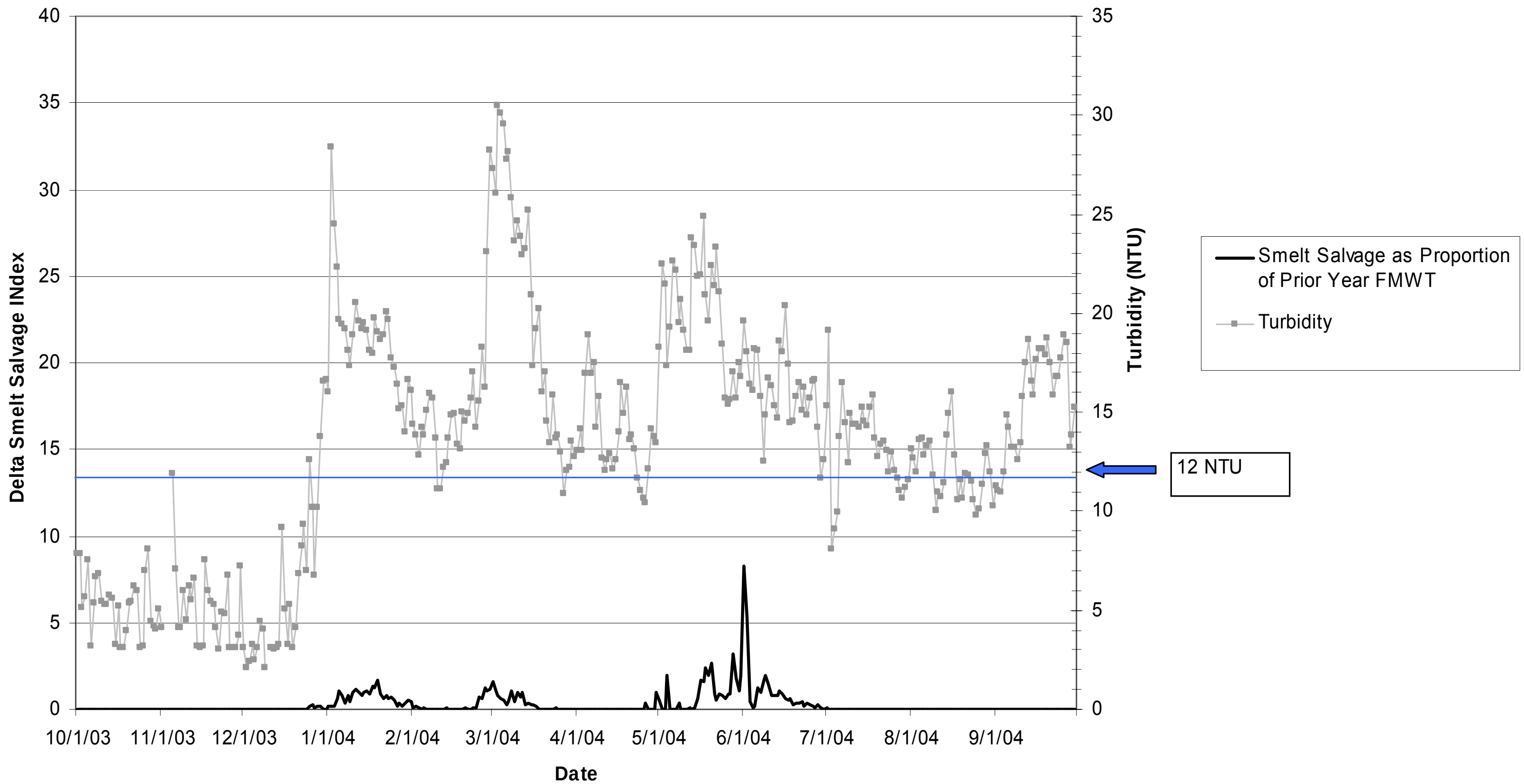


Figure A10: 2005 WY Salvage Index

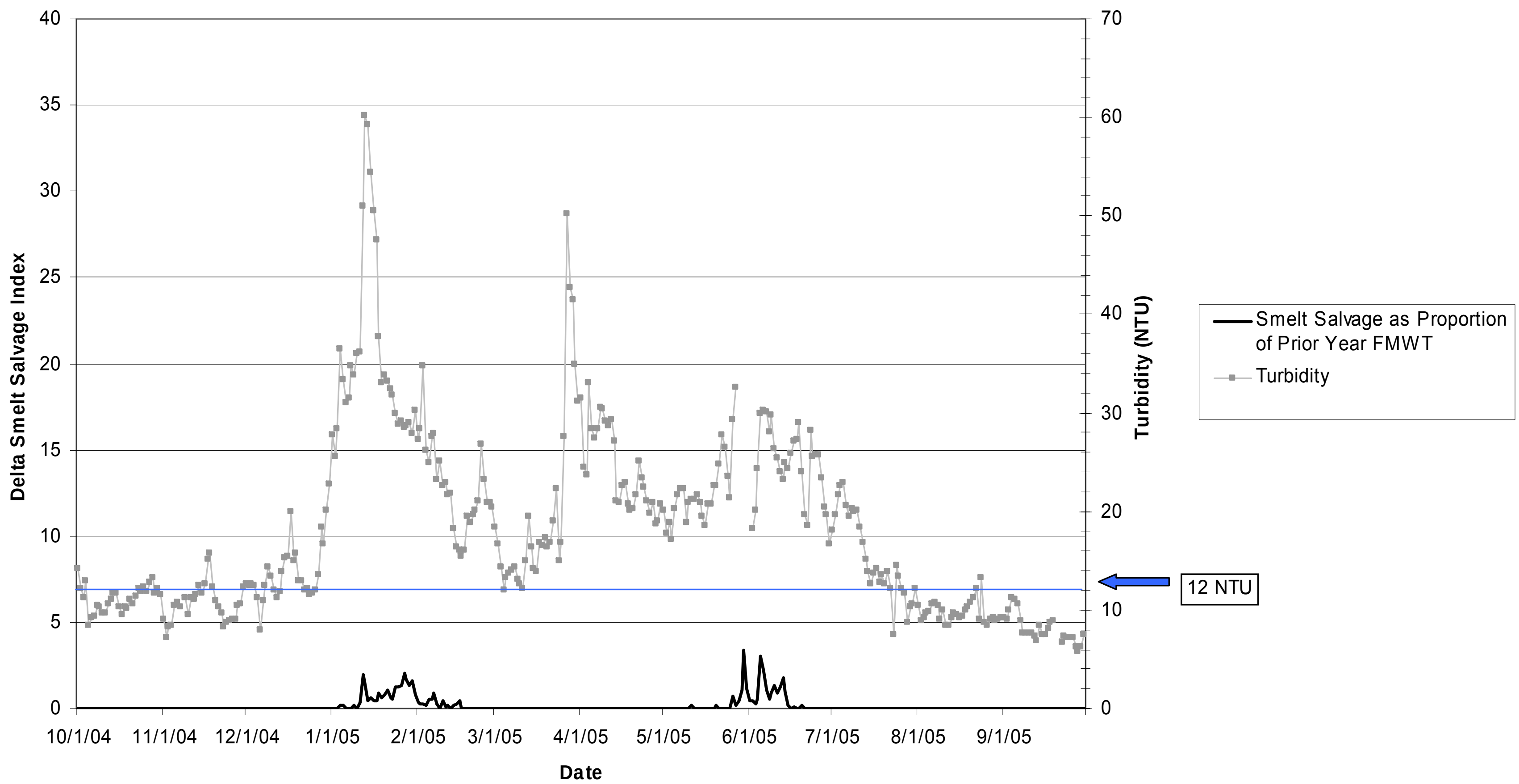
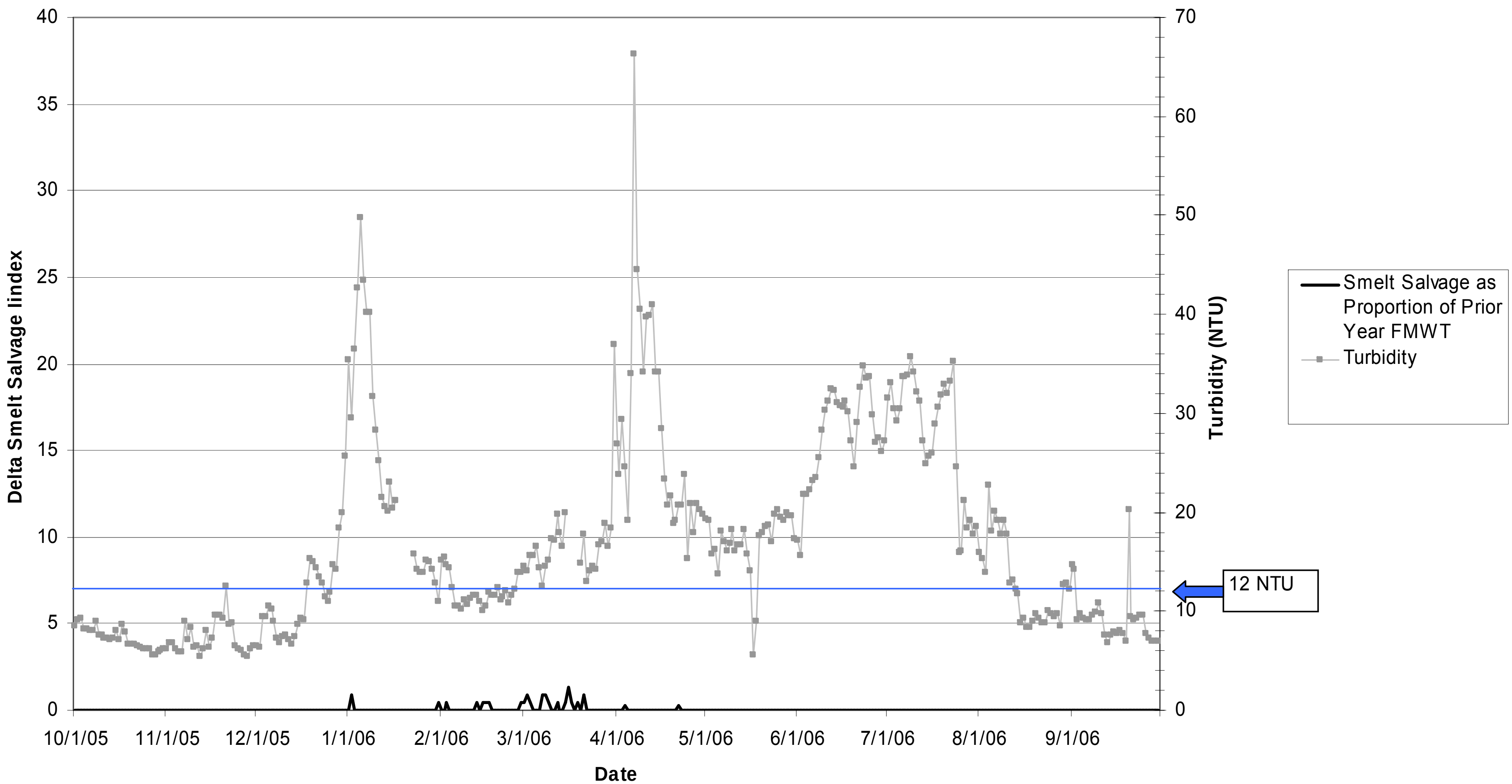


Figure A11: 2006 WY Salvage Index



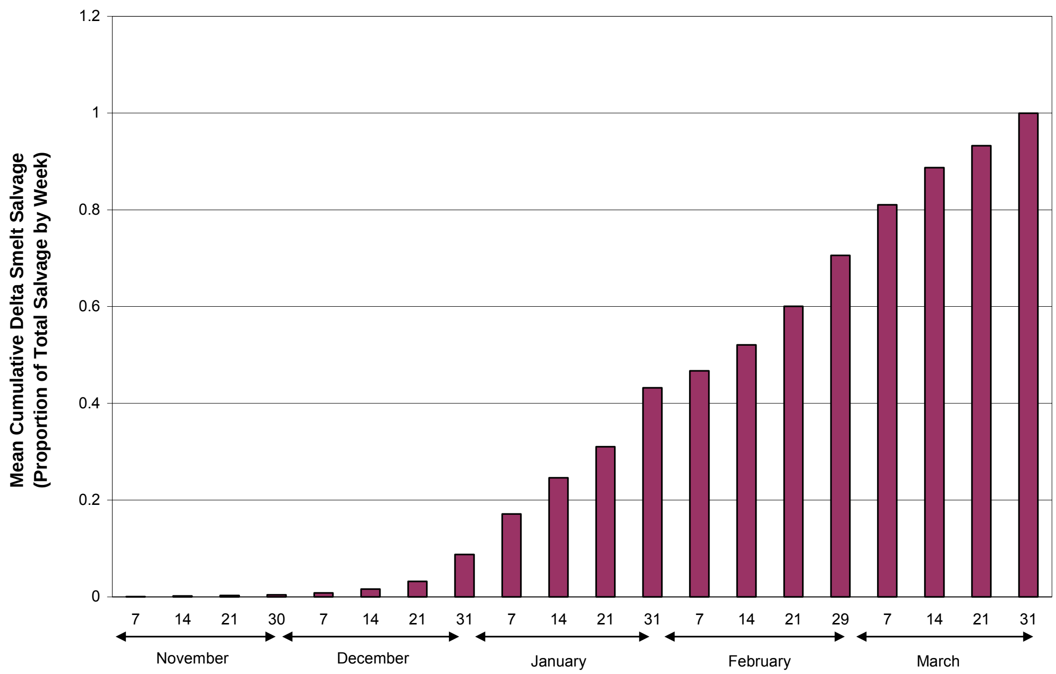
Justification for Timing of Action 1

Action 1, Part A covers the period (December 1 to December 20) when first flush salvage event were historically uncommon (Figure A-13). During this period the SWG will review conditions from week to week and may recommend to the Service that Action 1 be triggered. Part B of Action 1 (December 20 to March) covers a period when first flush salvage events have been historically more common. Part B will be triggered when turbidity increases above 12 NTU. The Service can bypass implementation of the trigger if the SWG concludes that the trigger was met by conditions (i.e., wind-induced turbidity) not likely to initiate smelt migration.

The timing of first flush salvage events is variable in any given water year. Thus, initiation of Action 1 is based on conditions (i.e., turbidity) rather than a specific month. Action 1 is, therefore, designed to provide flexibility and maximum protection for delta smelt. On average, about 1 percent of total adult delta smelt entrainment occurs during the time interval spanning December 15 through December 21 (Figure A-13). By December 31, cumulative salvage has reached 3.2 percent.

Action 1 will be shifted from December 25 (as described in the Interim Remedies) to December 20 because it better reflects the period when protection will be needed (Figure A-13). As previously mentioned, the Service will decide to initiate Action 1 before December 20 if the conditions warrant evidence smelt are migrating upstream (i.e., salvage, trawl data). Beginning in December, the SWG will review physical and biological parameters historically associated with smelt migration (i.e., precipitation, operations, turbidity, and salvage data) to make ongoing recommendations to the Service about the need to implement Action 1 at any time.

Figure A-13: Cumulative Proportional Salvage for Water Years 1993 to 2006 by Week



Duration of Action 1

The Interim Remedies Action 1 has been revised from ten to 14 days to incorporate coverage between spring and neap tidal cycles that may influence migration rate into the interior delta.

Justification for the Salvage Guideline to Trigger Action 1 (During Part A)

In many years, delta smelt have been salvaged prior to when turbidity elevates above 12 ntu (Table A-2). In the case that salvage begins prior to the trigger, the decision to implement Action 1 will be based on the following: 1) magnitude of salvage scaled to the population size (Table A-2), 2) and the amplitude which represents daily salvage divided by the prior year FMWT.

The 4th column in Table A-2 lists the cumulative seasonal salvage of adult delta smelt divided by the prior year FMWT Index (the Cumulative Salvage Index). This value ranged from a minimum of 0.37 in WY 1994 to a maximum of 103 during WY 2003. The combination of peak (amplitude or maximum daily salvage), and Cumulative Salvage Index is a general index of the magnitude of adult entrainment in a given WY.

The median value for the Cumulative Salvage Index for the years presented would be 13.3. The mean value for all years within the range presented in Table A-2 is 22.1. For peak daily salvage, the Salvage Index mean for the WY 1993 through 2005 is 1.45. The median amplitude value is 1.1. Taking these data into account, a cumulative seasonal

Salvage Index exceeding 15 appears indicative of an unacceptable risk threshold. A peak amplitude of 1.0 is adopted as an index of daily smelt salvage approaching levels suggesting that ongoing or anticipated salvage could reach unacceptable losses if exports are to increase. These values are carried forward into the prescriptions as pre-emptive triggers, and as releases from Action prescriptions to carry forward through Actions 1 and 2.

Justification for the Turbidity Criterion as a Trigger in Action 1 (Part B)

Onset of Action 1 during Part B

Turbidity associated with freshets of water is a reasonable indicator of when smelt begin to migrate upstream and become vulnerable to salvage. Though this historical trend is based on the turbidity sensor located outside the Clifton Court Forebay, there is no expectation that the relationship between increased flow and turbidity would differ from recently installed sensors identified in the Interim Remedies: Prisoners Point, Holland Cut, and Victoria Canal. It appears that the Holland Cut sensor is sensitive to localized wind conditions at times. On December 25-27, 2007, a three-day rise in turbidity at the Holland Cut monitoring station triggered Action 1. It was unlikely that a wind-associated turbidity event initiated smelt migration. Rather than rely on one of these stations to trigger Action 1 (Interim Remedies, Action 1 will be triggered when turbidities elevate over 12 NTU at all three stations. The use of three stations would better reflect a delta-wide change in turbidity than one station which may be prone to localized conditions.

Timing and the Protectiveness of the 12 NTU criterion

If the 12 NTU threshold had been used in previous years, Action 1 would likely provided early protection (i.e., less salvage) during most years. The degree to which it would have minimized the number of smelt entering the south Delta is unknown.

Justification for Flow Prescriptions in Action 1

Salvage generally increases when OMR flows decrease. To determine OMR flows that would likely minimize salvage during first flush events, winter salvage was scaled by previous FMWT and then regressed against OMR flow using piecewise polynomial regression for data from WY's 1993-2006. The change point is the location in the dataset at which the slope of the OMR-salvage relationship changes from 0 (i.e. a constant amount of salvage regardless of OMR) to positive (i.e., increasing salvage with increasingly negative OMR).

The linear-linear fit was selected because it was the analysis that required the fewest parameters to be estimated relative to the amount of variation in the salvage data accounted for by OMR. The correlation between OMR and salvage in the original dataset was -0.61 indicating that the more negative the OMR, the greater the salvage. Consequently, it was necessary to maintain the original covariance structure in the data when adding the error terms and performing the regressions.

The original covariance structure of the OMR – salvage data was maintained by adding a random error term to both parameters. The random error term was added to OMR and a correlated error term was added to salvage. The expected value of the correlated errors was -0.61. The error terms were selected from a normal distribution with a mean of 1.0 and a standard deviation of 0.25 which provided a reasonable variability in the original data. The process was repeated one hundred times, each time a new dataset was generated and a new piecewise polynomial regression was performed. The software package @Risk (© Palisade Decision Tools) was used to perform the simulations. The parameter of interest in the simulations was the change point, the value of the OMR flow at which the amount of salvage began to increase. Piecewise polynomial regressions were performed using Number Cruncher Statistical Systems (© Hintz, J., NCSS and PASS, Number Cruncher Statistical Systems, Kaysville UT).

Using the original dataset (no uncertainty), the piecewise polynomial regression analysis indicated that there was a baseline level of salvage regardless of OMR flow. The change point in OMR occurred at -1,162 cfs indicating at when flow reached -1,162 cfs, salvage began increasing. Incorporating uncertainty into the analysis moved the change point to -1,800 cfs indicating that at flows above -1,800 cfs, the baseline level of salvage occurred but with flows less than -1,800 cfs, salvage increased.

Justification for Release from Prescriptions of Action 1

Temperature

The Interim Remedies prescribed regulatory release from Action 1 once mean water temperatures at Rio Vista, Antioch, and Mossdale Stations reaches 12^{o}C. This metric is used as a surrogate to indicate time when spawning is likely to have begun based on physiological preferences. The Service has adopted this prescription.

Biological Conditions

The Interim Remedies prescribed regulatory release from Action 1 once spent females are detected in the SKT or at the salvage facilities. The Service adopted this prescription.

<u>ACTION 2: Adult Migration and Entrainment</u>

Action 2 reflects the period when OMR prescriptions for pre-spawning adult delta smelt are still required to protect parental stock prior to reproduction, however such controls may generally be relaxed because the main pulse of fish migration has occurred and adults are holding more tightly to their selected spawning areas. Action 2 may also be needed to extend protections consistent with Action 1 in years of longer spawning migration periods or changing environmental conditions. Conditions are highly variable in any given year. Rather than provide a prescription that is protective under all circumstances, a process of adaptive management based on the guidelines outlined herein is warranted. This process can most efficiently and effectively provide protections utilizing analysis of all available data and seasonal conditions.

The OMR flow prescriptions set forth during Action 2 will be based upon analysis of population status in any given year, available monitoring data from the SKT, seasonal variables such as WY type, CVP and SWP reservoir storage levels, temperature, and observed salvage during Action 1. Of these, population status and real-time salvage data are expected to be the primary driving criterion.

Justification for Salvage Guidelines in Setting Prescriptions of Action 2

The SWG will apply the following criteria to set the flow prescriptions during Action 2, to be operational until the onset of Action 3.

Zero Salvage or Extended Salvage Index of Low Amplitude

a) If salvage is zero during the final 4 days of Action 1, then increase negative OMR to no more negative than -5,000 cfs on a 7-day running average; *OR*

Decreasing Salvage or Salvage Index with Low Amplitude

b) If salvage is less in the last three days than in the preceding three days and the maximum daily salvage index is ≤1 during the prior 7 days, then limit exports to achieve OMR flows no more negative than -4,000 cfs on a 7-day running average for 7 more days (or until 4 succeeding days of zero salvage or any 5 of 7 days zero salvage); *OR*

Rising Salvage or Salvage Index with High Amplitude

c) If salvage is greater or equal in the last three days than in the preceding three days, and maximum salvage index ≥1 during any of those days, then continue OMR flow at no more negative than -2000 cfs on a 7-day running average for an additional 14 days (or until 4 succeeding days of zero salvage or any 5 of 7 days zero salvage)

Justification for Flow Prescriptions in Action 2

Flow prescriptions defined within Action 2 follow the same protectiveness criterion established during Action 1, as adjusted to reflect real-time conditions and predicted entrainment risk relative to the anticipated distribution and abundance of year-class delta smelt; and reflecting their behavioral propensity to hold in their chosen spawning habitat. These are allowed to vary based upon assessment of available data as described in the adaptive management process described in the Introductions to Actions section above.

Justification for Release from Prescriptions of Action 2

Flow

The Interim Remedies provided release from the prescription of Action 2 when the three day average Sacramento River flow at Freeport is greater than 80,000 cfs.
During WY 1982 and 1995, salvage was observed during periods when Sacramento River flows exceeded this criterion. During 1995, Sacramento River flows at Freeport exceeded 90,000 cfs while San Joaquin River flows approximated 5,000 cfs—salvage still occurred. This data suggests that adult delta smelt can still navigate the channels upstream at these flows. During 1997 and 1998, low salvage was observed while flows within both the Sacramento and San Joaquin rivers were high. For these reasons, it was determined that the offramp for prescriptions in Actions 1 and 2 should be Sacramento River flows at *Rio Vista* exceeding a three-day average of *90,000* cfs *and* San Joaquin River flows at Vernalis exceeding 10,000 cfs. It is believed that salvage under these flow conditions will be minimal.

Temperature

The Interim Remedies prescribed regulatory release from Action 1 once mean water temperatures at Rio Vista, Antioch, and Mossdale Stations reaches 12^{O}C. This metric is used as a surrogate to indicate time when spawning is likely to have begun based on physiological preferences. The Service has adopted this prescription.

Biological Conditions

The Interim Remedies prescribed regulatory release from Action 1 once spent females are detected in the SKT or at the salvage facilities. The Service adopted this prescription.

ACTION 3: Entrainment Protection of Larval Smelt

Objective: Minimize the number of larval delta smelt entrained at the facilities using Vernalis Adaptive Management Program (VAMP)-like flow levels and export reductions spanning a time sufficient for protection of larval delta smelt. Because protective OMR flow requirements vary over time (especially between years), the action is adaptive and flexible within appropriate constraints.

Action: OMR will be no more negative than -1,250 to -5,000 cfs based on a 7-day running average with a simultaneous 3-day running average within 20 percent of the applicable target OMR.[2] Depending on extant conditions (and the general guidelines below) specific OMR flows within this range are recommended by the SWG from the onset of Action 2 through its termination (see Adaptive Management Process in Introduction).[3] The SWG would provide these recommendations based upon weekly review of sampling data, from real-time salvage data at the CVP/SWP, and expertise and knowledge relating population status and predicted distribution to monitored physical variables of flow and turbidity. The Service will make the final determination.

Timing: Initiate the action within 20 days of reaching triggers below upon determination of the Service following recommendation by the SWG.

Triggers:

Temperature: When temperature reaches 12^{o}C based on a three station average at Mossdale, Antioch, and Rio Vista.

Biological: When a spent female or larva is detected.

Offramps:

Temporal: June 30, or based on the temperature below, whichever comes first.

Temperature: Water temperature reaches a three-day mean of 25^{o}C at all three stations—Mossdale, Antioch, and Rio Vista.

---

[2] The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the seven day running average described previously.

[3] During most conditions, it is expected that maximum negative OMR flows will range between -2000 and -3500. During certain years of higher or lower predicted entrainment risk, targets as low as -1,250 or -5,000 will be recommended to the Service by the SWG.

Adaptive Management Guidelines:

During the larval/juvenile entrainment risk period, the SWG will meet weekly to review available physical and biological data and develop a recommendation to the Service. The Service will determine the specific OMR target based upon the SWG recommendation and the strength of the accompanying scientific justification.

Two scenarios bookend the circumstances likely to exist during Action 3. First, the low-entrainment risk scenario. There may be a low risk of larval/juvenile entrainment because there has been no evidence of delta smelt in the South and Central Delta. In this scenario, negative OMR flow rates as high as -5,000 cfs may occur as long as entrainment risk factors permit. The second scenario, the high-entrainment risk scenario, is one in which either (a) there is evidence of delta smelt in the South and Central Delta from the SKT and/or 20mm survey, or (b) there is evidence of ongoing entrainment, regardless of other risk factors. In this case, OMR should be set to reduce entrainment and/or the risk of entrainment as the totality of circumstances warrant. Usually, if the available distributional information suggests that most delta smelt are in the North or North/Central Delta, then OMR can be chosen to minimize Central Delta entrainment. However, if the distributional information suggests there are delta smelt in the Central or South Delta, then OMR will have to be set lower to reduce entrainment of these fish. If delta smelt abundance is low, distribution cannot be reliably inferred. Therefore, the adaptive management process is extremely important. The SWG may recommend any specific running average OMR target within the specified range above.

Initiated when temperature reaches 12^{o}C based on a three station average at Mossdale, Antioch, and Rio Vista, or when spent females or larva are detected;

a) Set OMR flows to no more negative than -2,000 cfs based on a 7-day running average with a simultaneous 3-day running average within 20 percent of the applicable target OMR. The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the 7-day running average described previously;

b) The SWG will use available physical and biological real-time monitoring data to decide whether a large fraction of the delta smelt population is in the Central Delta and therefore at risk of entrainment. If a large fraction of the delta smelt population appears to be in the Central Delta, OMR flows would likely be set to no more negative than -1,250 cfs based on a 7-day running average with a simultaneous 3-day running average within 20 percent of the applicable target OMR. The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the 7-day running average described previously;

c) The SWG will use available physical and biological real-time monitoring data to decide whether the delta smelt population is at a lesser entrainment risk. In this circumstance, OMR flows would likely be set to no more negative than -3,500 cfs based on a 7-day running average with a simultaneous 3-day running average within 20 percent of the applicable target OMR. The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the 7-day running average described previously;

d) The SWG will use available physical and biological real-time monitoring data to decide whether the delta smelt population is at a low entrainment risk. In this circumstance, OMR flows to no more negative than -5,000 cfs based on a 7-day running average with a simultaneous 3-day running average within 20 percent of the applicable target OMR. The 3-day running average is calculated from actual daily OMR values, not from averaged OMR values computed using the 7-day running average described previously;

e) If circumstances existing at the initiation of Action 3 are, in the judgment of the Service, markedly different from those anticipated in (a) through (d) above, then the OMR flow prescription will be set to entrain no more than 1 percent of the particle entrainment at Station 815 (approximately no more than 10 percent of the cumulative population).

Background

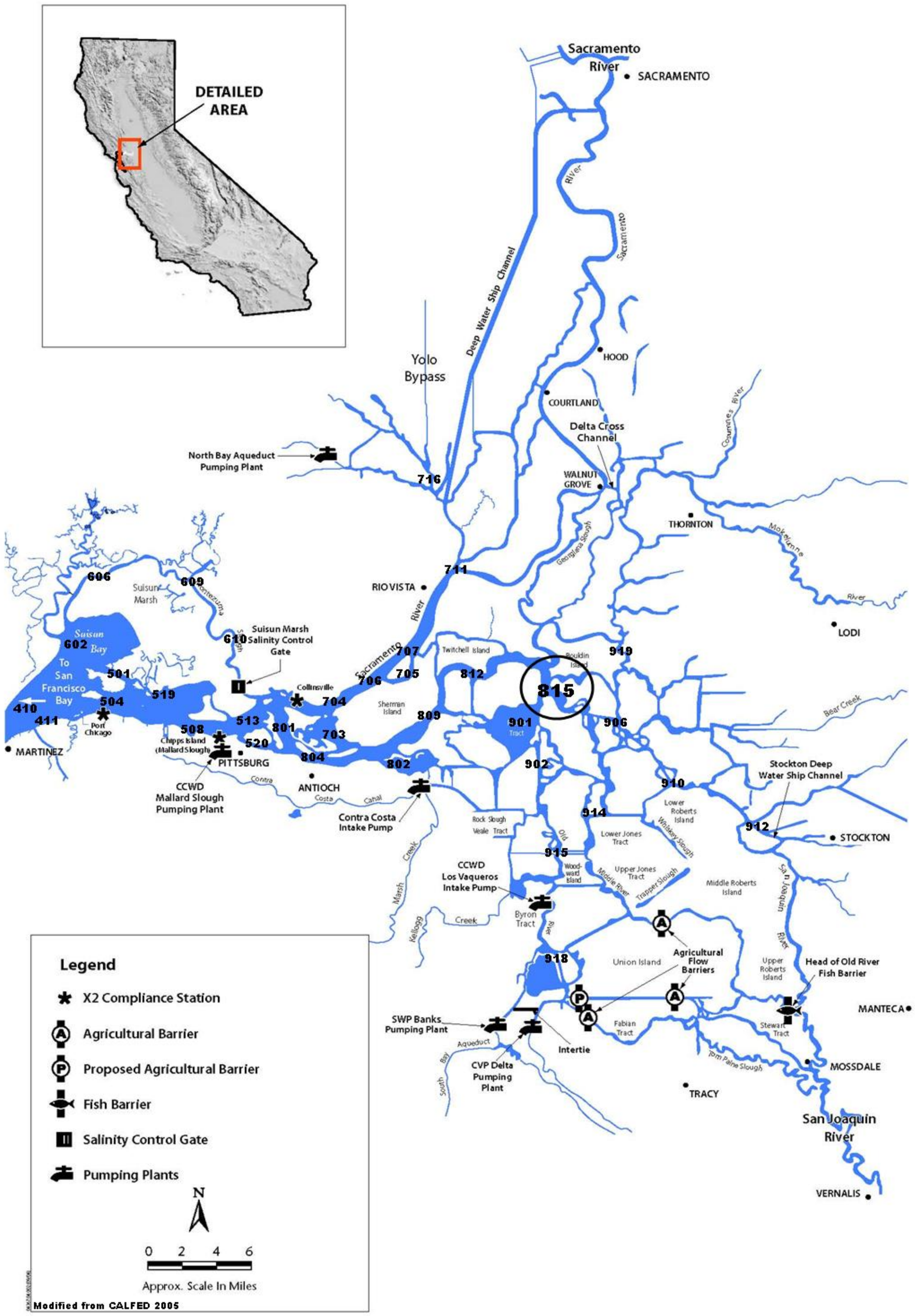
Action 3 is intended to minimize the entrainment of larval/juvenile delta smelt in the Central and South Delta. When the distribution of delta smelt is in the North or North/Central Delta, this will generally be accomplished by holding entrainment to ~1 percent of the individuals utilizing the Central and South Delta (south and east [upstream] of Station 815, see Map 2) across a 14-day particle modeling interval. Preserving larvae and juveniles that are in the Central Delta, or might be in the Central Delta in circumstances where it is difficult to ascertain the distribution of the fish, is critical to ensuring year-to-year stock-recruitment of the population and mitigating the risk of localized disturbances that might adversely affect the North Delta.

In circumstances where it is known or suspected that the Central Delta or South Delta is a principal source of emerging larvae, such as 2003, OMR restriction might be calculated using reduction of 14-day Station 815 entrainment below 1 percent, or other methods as needed to ensure protection of the larval population in conditions of such severe vulnerability. The Action utilizes OMR restrictions to achieve the desired end, as OMR is a strong predictor of geographical variation in entrainment risk in the Central and North Delta. The OMR flows associated with the protectiveness criteria defined above have been derived from particle tracking modeling with the input assumptions defined below.

These protections are directly tied to presence of vulnerable larval and juvenile delta smelt within the zone of entrainment of Banks and Jones. Therefore, Action 3 must commence no later than the time when larvae are likely to become vulnerable to entrainment, estimated to be 20 days following conclusion of Actions 1 and/or 2, or, absent other information, after average delta water temperatures rise to 12^{o}C (a time period usually from mid-March through June).

Evidence developed in the Effects Analysis of the biological opinion supports the conclusion that VAMP flow curtailments (during the years in which they have been in effect) have been instrumental in protecting delta smelt progeny. The VAMP requires San Joaquin River inflows to be no less than twice the level of exports. Examination of the OMR flow records shows that VAMP conditions generally correspond to OMR flows approximating -2,000 cfs (Figure A-14).

Protection from entrainment for larval and juvenile delta smelt will be achieved using OMR prescriptions generally ranging between -2,000 to -3,500 cfs on a 7-day running average with a simultaneous 3-day average (calculated using actual daily OMR values and not averaged daily values from the 7-day running average) not more negative by more than twenty percent of the current OMR target. However, during certain years of unusual smelt distribution (while predicted or measured larval/juvenile delta smelt distribution are either in close proximity to or far removed from the zone of entrainment), maximum negative OMR flows may be set anywhere between -1,250 to -5,000 cfs on a 7-day running average with a simultaneous 3-day average (from actual daily OMR values) not more negative than the target by more than twenty percent.



Map 2 Biological Monitoring Stations in the Delta

The following examples provide the insight on when exceptions to the ranges of OMR flows above would be used. In high risk years, when delta smelt are in the South Delta, suggesting that delta smelt are particularly sensitive to entrainment (as for example in 2003), a stricter limit on OMR flow of -1,250 cfs would be necessary to meet the defined protectiveness criterion. Alternatively, in years when sampling indicates that it appears that most adults have spawned in the Cache Slough complex and larvae may be at reduced risk of entrainment, an OMR flows around -3,500 may be possible while still meeting the protectiveness criterion. Later in the season, as more juvenile delta smelt are found seaward and while physical conditions in the Delta become less conducive to smelt larvae, OMR flow targets could relax further. Once conditions in the delta are inconsistent with smelt survival, the larval protections of Action 3 cease.

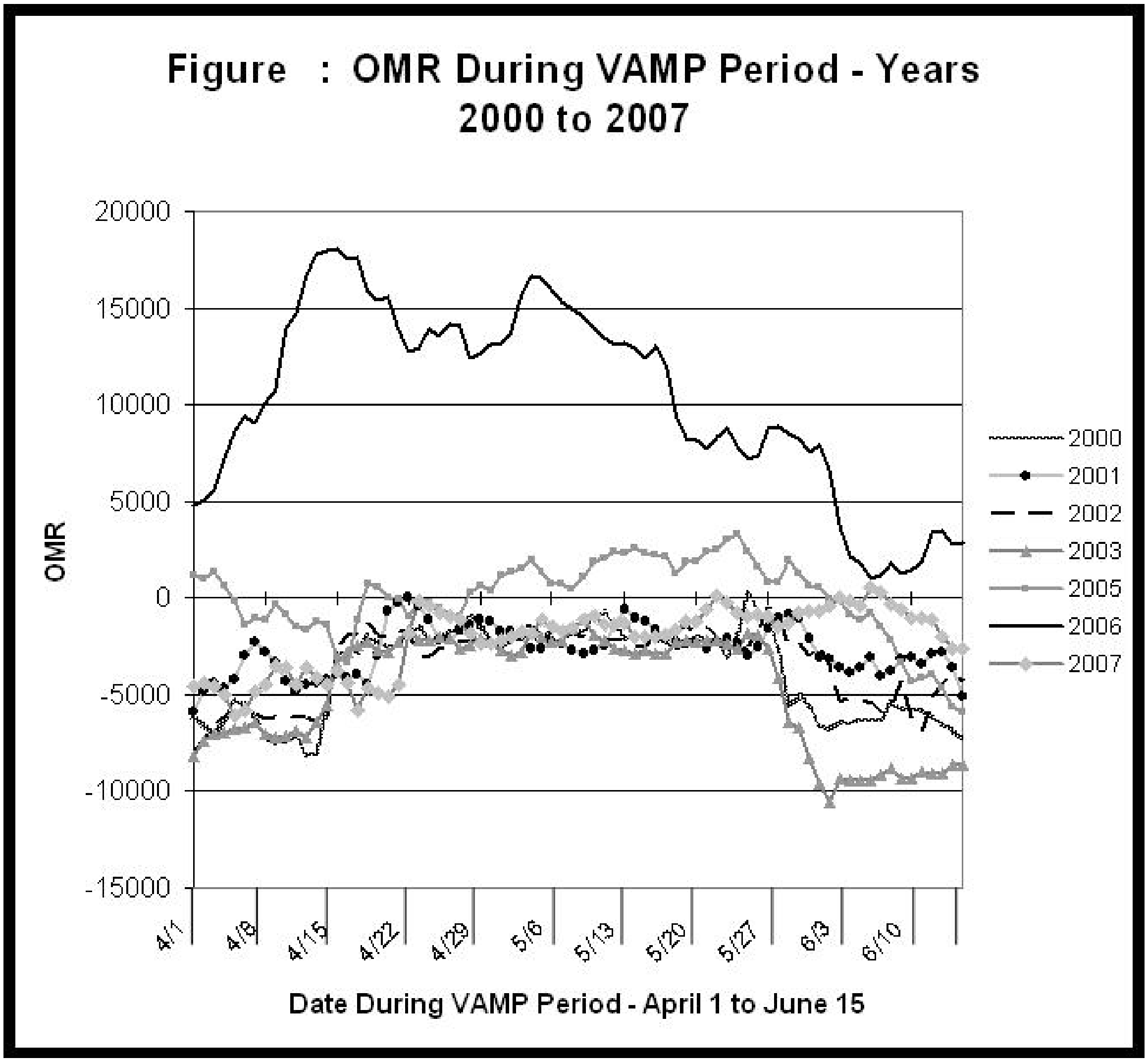


Figure A-14. OMR flows across VAMP period (usually April 15-May 15). Note that although exact VAMP conditions vary across years, the period is easily identified by OMR flows no more negative than -2000 cfs.

Justification for Timing of Action 3

The window for delta smelt spawning generally falls during February, but is variable based on seasonal conditions of flow, temperature, and physiological condition of the current year spawning cohort. Further, low adult abundances make it very difficult to discern adult spawning distribution using current monitoring methods. Lastly, protective and successful flow restrictions during the winter may reduce the discriminatory power of salvage itself as an indicator of the distribution of spawning smelt and timing to initiate Action 3.

For these reasons, it is believed that an adaptive management approach using judgment of SWG biologists in real-time is preferred to protective prescriptions that are applied regardless of variation or nuance in actual conditions. By monitoring a combination of these factors, along with tracking of important parameters in real time that are indicative of smelt presence and the timing of smelt spawning activity, utilizing the SWG is the best means to predict the appropriate time to initiate Action 3. Under most year-types and conditions, it is anticipated that Action 3 will commence within twenty days of the end of Action 2.

During Action 3 (generally March through June 30), the SWG will recommend OMR flows to the Service. These will be based upon the best-available predictive capacity of the experts within the group given available data in real-time, and will be protective of larval/juvenile delta smelt to the criteria defined above.

Justification for Different OMR Targets of Action 3

Analysis of the birth dates of delta smelt collected from the Summer Townet Survey (Bennett 2008) indicates that in 2005 the delta smelt found in the summer were almost entirely born during the VAMP period. Collection of spawned adults suggests that larvae were produced throughout much of the February-May period, but only the late produced young survived. Thus, we have determined that providing VAMP-like conditions throughout Action 3 will be beneficial to larval and juvenile delta smelt. During most year types, these OMR targets will range between a 7-day running average of -2,000 to -3,500 cfs.

If sampling, salvage, or turbidity distribution suggests that delta smelt are at high risk in the Central or South Delta, then the OMR will need to be at a 7-day running average of -1,250 cfs. If for example, based on the sampling, minimal to no salvage at the export facilities, increase in temperature, decreases in turbidity or higher San Joaquin River inflows suggest that delta smelt larvae are at lower risk in the South and Central Delta then flows may be held to no more negative than -3,500 cfs. As temperatures rise, trawl data continue to show no fish in the Central and South Delta, and salvage does not occur, OMR flows will be allowed to become as negative as -5,000 cfs. When temperature rises and turbidity drops to levels likely to be inimical to delta smelt (> 25^{o}C, turbidity <12 NTU), no further restrictions are needed as long as salvage remains at or close to zero.

The Influence-Exposure-Intensity-Response (IEIR) Analysis

On December 13, 2007, the Service requested the SWG to formulate a process to determine protective OMR flow recommendations for delta smelt larvae during the spring. The SWG agreed that a strict decision-tree approach was imprudent because it would be inflexible to real-time conditions. In such circumstances, where dynamic and interacting parameters determine delta smelt risk, static prescriptions tend to be imperfect moderators of such risk.

The process that has been developed is called "influence-exposure-intensity-response analysis" (IEIR Analysis). It involves four steps:

1) Particle tracking modeling of current and/or projected Delta conditions describes Banks and Jones' relevant hydrological influence at different flow rates.

2) Risk exposure of smelt larvae is determined by comparing Banks and Jones' relevant hydrological influence from the PTM results with current knowledge of smelt distribution using real-time data from surveys and salvage.

3) PTM runs are used to predict the probability of delta smelt entrainment at several OMR flow limits using "particle injection" points corresponding to 20mm survey sampling stations.

4) OMR flow recommendations are developed to reduce the projected entrainment risk to levels tolerable to the extant delta smelt population, as estimated by the prior-year FMWT index.

The levels of concern expressed through this analytical real-time adaptive management approach have been classified into three categories: High Concern, Medium Concern and Less Concern. These correspond generally to the following realized values of key physical, operational, and biological parameters, and were applied in 2008 as such:

Factor	***State***
• Prior Year FMWT	<40 = High Concern; >300 = Less Concern
• Salvage	high numbers = high concern; low numbers = less concern
• Distribution	south = high concern; north/northwest = less concern
• X2 Location	>80 km = high concern; <75 km = less concern
• Temperature	12°C to 25°C = high concern; >25°C = less concern

These five factors were chosen based on the following:

1. Size of spawning population: A low FMWT index indicates low abundance of potential spawners which makes population growth rate more sensitive to loss of individuals.

2. Salvage: Salvage of delta smelt indicates that larvae and juveniles are located in the central and south delta and are vulnerable to entrainment. Future entrainment becomes more demographically significant as cumulative entrainment numbers increase.

3. Fish Distribution: The hydrodynamic influence of Banks and Jones increases when larvae are closer to the intakes. Thus, smelt located in the Central and South Delta are exposed to greater intensity of entrainment risk than those located in the north or west delta.

4. X2 Location: Estimating the distribution of larval smelt and their exposure to pumping effects from existing survey data includes high inherent uncertainty, with increasing magnitude at low population abundances. However, the majority of smelt larvae and juveniles are often located just inland of X2, and so an easterly X2 would indicate that the smelt are at greater risk of entrainment at Banks and Jones

5. Water Temperature: Laboratory studies of delta smelt temperature tolerance has shown increased mortality at temperatures exceeding 25.6^{o}C. Both acclimation to water temperatures and variation in temperatures within the water column would increase water temperature tolerance as it is measured in the environment. Nevertheless, an average three-station Delta water temperature of 25^{o}C corresponds in most years to a distribution of delta smelt juveniles towards Suisun Bay, and out of the zone of entrainment risk. Most delta smelt remaining in the San Joaquin River portion of the Delta are not expected to survive as water temperatures increase above 25^{o}C, so their loss at salvage will not affect recruitment success.

The balance of conditions relative to level of concern within the IEIR analysis determines the foundation upon which a final flow recommendation may be based.

Application of IEIR Analysis: Further Guidelines to Adaptive Management within OCAP

In light of the experience in 2008, the IEIR is adjusted to make the following amendments.

As before, the SWG will evaluate data from the 20-mm survey and other parameters and make recommendations for specific timing of the more protective levels of OMR flows based upon real-time assessment of entrainment risk of larval smelt based upon their proximity to Banks and Jones, forecast operations, and particle tracking modeling run results based on a control-point method using a protectiveness criterion of 1 percent per 14-day time interval salvage threshold at Station 815.

The SWG may recommend using the less stringent level of OMR restriction based on an average Recovery Index (RI) from the preceding two years exceeding 84 (the minimum for a recovery period in the Delta Native Fishes Recovery Plan, Service 1995); however, low San Joaquin River inflows, high cross-delta flows or other conditions that degrade larval habitat in the central Delta could preclude such relaxations. During periods of intermediate concern (recovery indices from the preceding year in excess of 239), a reduction to a shorter period of restriction to the -2000 cfs level in the larval period may be supported, if the SWG determines that a large part of the larval population would not be put at risk.

The most efficient protective measure for protecting the resilience and not precluding the recovery of the delta smelt population specific to the larval/juvenile lifestage is to prevent entrainment of fish in as large a portion of the Central Delta as is practical. Results of PTM modeling focusing on protections at station 815 (Prisoner's Point) indicates that precluding entrainment of larval/juvenile delta smelt at this station would also protect fish at station 812 (Fisherman's Cut) and other stations north and west (downstream) of station 815. While the target entrainment at station 815 would ideally also be zero, there appears to be little additional entrainment protection (less than 5 percent) at OMR flows at -750 cfs (the strictest level addressed by Interim Remedies). However, entrainment risk grows exponentially at OMR flows increasingly more negative than -2000 cfs.

Figure 2 displays injection points for modeled particle tracking runs that were conducted in February 2008 with injection points at Stations 711, 809, 812, 815, 902, 915. This figure plots projected relationships for OMR flows by injection point, including entrainment probabilities for station 815 (over 30 days).

The results from these runs indicate an approximate <5 percent entrainment risk at OMR not more negative than -2000 cfs. At a target of -3,500 cfs OMR, entrainment risk at station 815 is roughly 20 percent over each 30 day interval. Assuming cumulative entrainment is additive, over a roughly four month (~120 days) interval in which Action 3 would be under effect, consistently operating at -3,500 OMR would yield a net entrainment probability placing at risk approximately 80 percent of the larval/juvenile subpopulation utilizing the South Delta at and below Station 815. If immigration of larval smelt from the Central or North Delta into the zone of entrainment during spring were to occur, the population-level risk would be even greater. Such entrainment levels are potentially a significant adverse risk to delta smelt population.

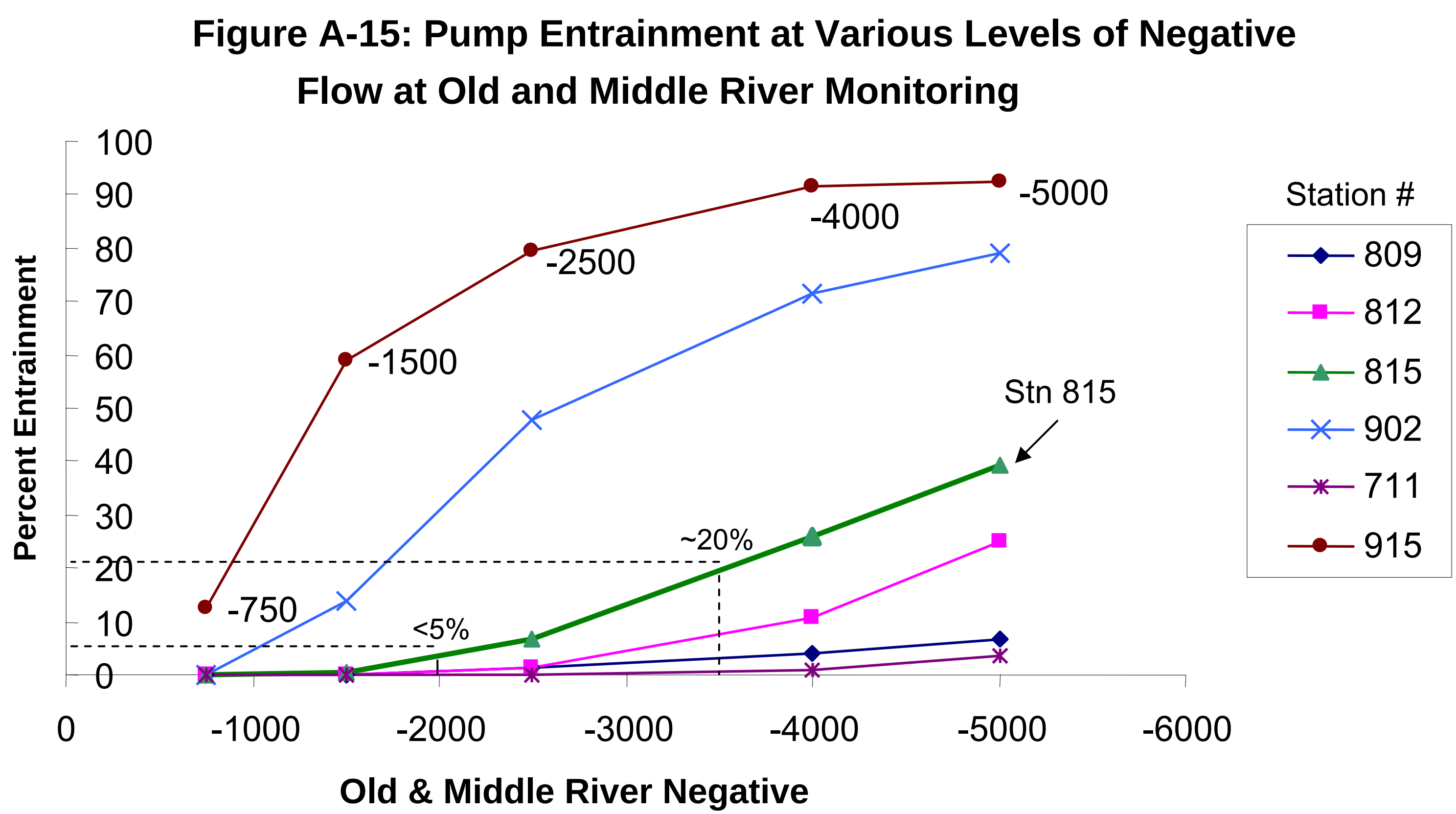


Figure A-15: Pump Entrainment at Various Levels of Negative Flow at Old and Middle River Monitoring
Percent Entrainment
100
90
80
70
60
50
40
30
20
10
0
0
-1000
-2000
-3000
-4000
-5000
-6000
Old & Middle River Negative
-750
-1500
-2500
-4000
-5000
Stn 815
~20%
<5%
Station #
809
812
815
902
711
915

Justification for Release from Prescriptions of Action 3

Calendar Date

The Interim Remedies specified the duration of Action 3 to extend to *around* June 20, or until the temperature metric below. Based upon salvage data observed during water year 2008 (see Figure A-15, above), this temporal window should be amended (extended) to June 30 in order to provide sufficient protections to late-spawned delta smelt larvae.

Temperature

The Interim Remedies specified a release from prescriptions within Action 3 when arithmetic mean temperatures at Rio Vista, Mossdale, and Antioch sampling stations reached 25^{o}C.

ACTION 4: Restore Estuarine Habitat During Fall

Objective:

Improve fall habitat for delta smelt through restoration of Delta outflow during fall when the preceding spring was classified as wet or above normal. Restoring habitat quality such that fall months resemble a more natural hydrograph will help to restore the ecological conditions of the estuary and provide direct and indirect benefits to delta smelt. Both the direct and indirect benefits to delta smelt are considered equally important to minimize adverse effects.

Action:

Provide sufficient Delta outflow to maintain average X2 for September, October, and November at no more than 15km upstream than average X2 during the preceding spring (April-June) for years in which the WY for that same spring is classified as wet or above normal. Average X2 must be maintained for each individual month and not averaged over the three month period.

Timing:

September 1 to November 30.

Triggers:

Wet and above normal water year type classification from the 1995 Water Quality Control Plan that is used to implement D-1641.

Offramps:

Not operational in below normal, dry and critical water years.

Background

Delta outflows of as much as 20,000 cfs formerly occurred in fall months of all but drought WYs; now fall outflows are always similar to what had occurred previously only during droughts. Fall Delta outflows in wet and above normal WYs from 1993-98 average 8,000-10,000 cfs, whereas after 1998 monthly averages have been 5,600 cfs across all year types and monthly variation has been very small. High inter-month variability may be important in restoring estuarine habitat conditions favoring many native species (PPIC 2007).

Habitat parameters for delta smelt have been well described for both the summer and fall seasons, as combinations of salinity, temperature, and turbidity. In winter and spring, temperature seems to be a dominant driver of habitat suitability both for adult spawning and for larval distribution Bennett . Summer habitat is controlled largely by changes in turbidity due to changes in sediment supply and in the distribution of the sediment-trapping aquatic weed, *Egeria densa*. (Nobriga et al. 2008) Fall habitat (and smelt) shifts in abundance and distribution largely due to fluctuations in X2 (Feyrer et al. 2007). X2 fluctuates mostly in response to fluctuations in outflow, although atmospheric conditions and barrier operations can also affect it.

X2 is strongly influenced by tidal cycles, moving twice daily up and downstream 6-10 km from its average daily location. For example, when the average daily X2 is near Sherman Island, delta smelt habitat can range from Chipps Island to Franks Tract. When the daily average X2 is centered on Browns Island, delta smelt habitat can range from Honker Bay to Big Break. The daily fluctuation in X2 around an upstream point such as Brown's Island exposes delta smelt juveniles to diverse stressors and degraded habitat conditions relative to a downstream X2.

Other factors can degrade the quality of smelt habitat, principally water quality degradation. In September 2007 delta smelt were found in salinities much higher than they had ever been found in before, while their usual salinity range was heavily infested with the cyanobacterium *Microcystis aurugenosa*. *Microcystis* produces toxins in its normal life, but the concentrations of these toxins in water sharply increase when the population dies, usually in September and October (Lehman pers. comm.). In September 2008 delta smelt were in their normal salinity range and *Microcystis* were less abundant than in September 2007 (pers. comm. Randy Baxter DFG and Peggy Lehman DWR). CVP/SWP operations that result in constant flow conditions every fall are among the factors associated with *Microcystis* blooms and habitat conditions with little or no variability.

Protection and restoration of habitat is an essential element in any conservation strategy where habitat has been lost or degraded. However, identifying the exact role habitat quality and volume play in the growth and survival of a species comes with some uncertainty. In the case of fall delta smelt habitat several mechanisms may operate.

1. Westward and variable locations of fall habitat move the delta smelt populations away from the risks of entrainment in the delta and distribute them more broadly throughout the Delta.

2. Variable fall flow conditions are generally inconsistent with development of dense *Microcystis* populations, thus reducing degradation of delta smelt habitat by this invasive species.

3. Constant salinity conditions in the fall since 2000 are likely to have allowed the invasive clam *Corbula amurensis* to establish year-round populations further east, thereby exacerbating whatever impacts this species has on delta smelt.

This action is designed to increase baseline monthly outflows in the fall period of wet and above normal water years to increase areas of habitat and move the habitat away from delta impacts and into broader open waters west of Sherman Island; and to increase variability of monthly habitat extent by having one or two months above the baseline. This would be expected to distribute smelt into more diverse geographic areas and impose variable salinity and flow conditions detrimental to *Microcystis* and *Corbula.*

It is believed that restoring fall Delta outflows would improve habitat area and quality, and will provide periods of population rebound necessary for maintaining the long-term viability of the delta smelt population.

Justification:

The Effects Analysis clearly indicates that there will be significant adverse impacts on X2—which is a surrogate indicator of habitat suitability and availability for delta smelt in all years (currently Figures 25 and 27 in effects analysis). However, the Service recognizes that imposing actions in all years will pose significant constraints on CVP/SWP operations. Therefore, the action is focused on wet and above normal years because these are the years in which project operations have most significantly adversely affected fall X2 relative to spring X2 (currently Figure 35 in effects analysis) and therefore, actions in these years are more likely to benefit delta smelt. Rather than setting an arbitrary stand-alone X2 criterion, the action is designed specifically around spring X2 so that it will be governed by hydrologic conditions and therefore be ecologically-based. For the purposes of implementation of this action, spring X2 is defined as the April-June average. The standard was set as a difference of 15km because that value represents a break point which was repeatedly exceeded in nine of ten possible years since 1993, with the differences in those years being exceedingly high (Figure 1). Whereas prior to 1993, it was exceeded only in 1967, and the differences were consistently much smaller than 15km and sometimes even negative.

The long-term trend in which all falls have been turned into dry or critical years matches long-term upward trends in the E:I ratio and X2 (currently Figure 30 in effects analysis). The overall effect is readily observed as a substantial divergence in the difference between fall X2 and X2 the preceding spring (April-July) (currently Figure 34 in effects analysis). Given that these conditions will persist under the proposed CVP/SWP operations, the modeling also shows they may be exacerbated under various climate change scenarios (currently Figure 33 in effects analysis).

The persistence of this significant hydrologic change to the estuary threatens the recovery and persistence of delta smelt. Outflow during fall determines the location of X2, which determines the amount of suitable abiotic habitat available to delta smelt (Feyrer et al. 2007, 2008). The long-term upstream shift in X2 during fall has caused a long-term decrease in habitat area availability for delta smelt (Feyrer et al. 2007, 2008), and the condition will persist and possibly worsen in the future. This alone is a significant adverse effect on delta smelt.

However, the problem is further complicated because there are many lines of published peer reviewed scientific research that link habitat alteration to the decline of delta smelt (Bennett 2005; Baxter et al. 2008; Feyrer et al. 2007, 2008; Nobriga et al. 2008). An important point regarding this action is that because of the current, extremely low abundance of delta smelt, it is unlikely that habitat is currently a limiting factor. However, it is clear that delta smelt have become increasingly habitat limited over time and that this has contributed to the population attaining record-low abundance levels (Bennett 2005; Baxter et al. 2008; Feyrer et al. 2007, 2008; Nobriga et al. 2008).

Therefore, the continued loss and constriction of habitat proposed under the proposed project significantly threatens the ability of the delta smelt population to recover and persist in the estuary at self-sustaining levels higher than the current record-lows.

ACTION 5: Temporary Spring Head of Old River Barrier (HORB) and the Temporary Barrier Project (TBP)

Objective: To minimize entrainment of larval and juvenile delta smelt at Banks and Jones or from being transported into the South and Central Delta, where they could later become entrained.

Action: Do not install the HORB if delta smelt entrainment is a concern. If installation of the HORB in not allowed, the agricultural barriers would be installed as described in the Project Description. If installation of the HORB is allowed, the TBP flap gates would be tied in the open position until May 15.

Timing: The timing of the action would vary depending on the conditions. The normal installation of the spring temporary HORB and the TBP is in April.

Triggers: For delta smelt, installation of the HORB will only occur when PTM results show that entrainment levels of delta smelt will not increase beyond 1 percent at Station 815 as a result of installing the HORB.

Offramps: If Action 3 ends or May 15, whichever comes first.

Justification for Action 5

The TBP change the hydraulics of the Delta, which can affect delta smelt. The HORB blocks San Joaquin River flow from entering Old River. This increases the flow toward Banks and Jones from Turner and Columbia cuts, which can increase the predicted entrainment risk of particles in the East and Central Delta by up to about 10 percent (Kimmerer and Nobriga 2008). In most instances, net flow is directed towards Banks and Jones and local agricultural diversions. Computer simulations have shown that placement of the barriers changes South Delta hydrodynamics, increasing Central Delta flows toward the export facilities (DWR 2000). In years with substantial numbers of adult delta smelt in the Central Delta, increases in negative OMR flow caused by installation of the TBP can increase entrainment. The directional flow towards Banks and Jones increases the vulnerability of fish to entrainment. Larval and juvenile delta smelt are especially susceptible to these flows.

The varying operational configurations of the TBP, natural variations in fish distribution, and a number of other physical and environmental variables limit statistical confidence in assessing fish salvage when the TBP is operational versus when it is not. In 1996, the installation of the HORB caused a sharp reversal of net flow in the South Delta to the upstream direction. Coincident with this change was a strong peak in delta smelt salvage (Nobriga et al. 2000). This observation indicates that short-term salvage can significantly increase when the HORB is installed in such a manner that it causes a sharp change or reversal of positive net daily flow in the South and Central Delta.

Many of these potential effects to delta smelt would be reduced by the OMR flows provided in Action 3. In order to determine if there will be adverse effects to delta smelt from the installation of the HORB, PTM will be completed during Action 3. The Service will use the control point method of maintaining an entrainment level at Banks and Jones below 1 percent at Station 815. If the PTM results show that entrainment would be higher than 1 percent with the installation of the HORB, then it would not be installed.

Additionally, the OMR flows provided in Action 3 or high San Joaquin River flows may provide beneficial conditions in the Delta for out-migrating salmonids and sturgeon, which would preclude the need for the HORB installation. This analysis, combined with the PTM results will provide data to help determine if listed fish would be adversely affected by the HORB. If the spring temporary HORB is not installed, the TBP would be operated as described in the Project Description.

Justification for Release from Prescriptions of Action 5

If Action 3 has ended, the entrainment concern has likely abated, and delta smelt larvae and juveniles are not likely to be present in the Central and South Delta. High flows on the San Joaquin River may also preclude the spring temporary HORB from being installed since it is not physically possible during these flows to install the HORB. The concerns for entrainment are reduced during high San Joaquin River flows.

Draft
Bureau of Reclamation and Department of Water Resources

Proposed Actions

October 16, 2008

United States Department of the Interior

BUREAU OF RECLAMATION
Central Valley Operations Office
3310 El Camino Avenue, Suite 300
Sacramento, California 95821

IN REPLY
REFER TO:

CVO-100
ENV-7.00

OCT 16 2008

MEMORANDUM

To: U.S. Fish and Wildlife Service
Attn: Susan Moore

From: Ronald Milligan
Operations Manager

Subject: Section 7 Consultation on the Continued Long-Term Operation of the Central Valley Project and State Water Project (SWP) - Transmittal of the Applicant's Potential Conservation Measures Related to SWP Operations

This memorandum transmits information provided by the California Department of Water Resources (DWR), the Applicant, which describes potential conservation actions that address effects of the continued operation of the SWP. The enclosed document identifies possible conservation measures, implementation criteria, and biological rational the Applicant would like your agency to consider during the subject consultation. The document specifically outlines three potential actions to protect delta smelt and how these actions may be implemented.

This submittal does not modify the Project Description contained in the BA which addresses how the projects will be operated under our water right permits, consistent with other regulatory requirements, absent any specific new actions that may be identified as part of this consultation.

Reclamation and DWR continue to be available to meet with you and your staff to assist in the development of the Biological Opinion. We are sensitive to the critical timing for completion of the Biological Opinion and are committed to working with your agency to finalize the consultation by the court-ordered date of December 15, 2008.

POTENTIAL ACTIONS TO REDUCE SWP IMPACTS ON DELTA SMELT AND LISTED SALMONIDS

October 14, 2008

I. INTRODUCTION

Summary

The Biological Assessment (BA) for the continued long-term operations of Central Valley Project (CVP) and State Water Project (SWP) identifies the two projects' facilities and proposed operation. The BA also describes the potential effects of those operations on delta smelt, salmonids, and green sturgeon listed under the Endangered Species Act (ESA) and on the critical habitat of those species to determine whether the proposed operation will jeopardize the continued existence of these species and adversely affect their critical habitat. The U.S. Fish and Wildlife Service (USFWS) and National Marine Fishery Service (NMFS) are reviewing the BA and other available material to determine whether the proposed operations will jeopardize the continued existence of the listed species and their critical habitat. In the event that the USFWS or NMFS determines that the proposed SWP operations are likely to jeopardize the listed species, this document describes the possible fish protection actions that could be considered by USFWS and NMFS for inclusion into the Biological Opinions as a potential Reasonable and Prudent Alternatives (RPAs) to avoid jeopardy.

This document is divided into six sections. The first is this Introduction to this document. The second describes how a Fish Protection Trigger could work. The third identifies some of the projects' potential effects on delta smelt and summarizes what is known about those effects. Most of this information is included in the BA. However, this document also includes some additional information from some more recent analyses that is particularly relevant to preparing effective and efficient actions to reduce project effects. The next two sections describe three potential actions which USFWS might consider for the protection of delta smelt and how these actions could be implemented. These actions would also provide benefits to other species, including salmonids and longfin smelt. The last section is conclusions.

Need for Holistic Approach to Fish Protection

The ecological aspects of the Bay/Delta Estuary are complex and changing. While the focus of this re-consultation process under section 7 of the ESA is focused on the effects of the SWP and CVP operations on federally listed endangered species, it cannot ignore the effects of other stressors on these species. Recent and ongoing studies suggest that these other stressors can have dramatic ecological effects. These include the effects of invasive species of both clams and zooplankton on the food web for pelagic fish species, ambient temperature effects on smelt, documented sub-lethal contaminant toxicity, unexplained mortality near sewage outfalls, predation, ammonia toxicity on important zooplankton and phytoplankton production, changes in ocean conditions and their effect on the production of salmon and many others. Simply controlling the operation of water project operations will not recover endangered fish in this estuary to the levels sought by the NMFS and USFWS. A more holistic program to address all the factors that are affecting the fish of concern and the creation of additional suitable habitat is needed.

Such a program has been formally underway since October 2006 with the signing of the Bay/Delta Conservation Plan (BDCP) Planning Agreement under both Federal ESA Section 10 and California Natural Community Conservation Plan (NCCP) provisions (see http://resources.ca.gov/bdcp/). Both the NMFS and USFWS are actively engaged in this program and sit as ex-officio members of the BDCP Steering Committee that meets every two weeks to guide the BDCP process. The BDCP Steering committee adopted Principles of Agreement in November 2007 and conducted CEQA and NEPA scoping sessions in April 2008. The Steering Committee is also actively engaged in developing a draft Conservation Strategy by the end of 2008, a draft EIR/S by the end of 2009 and the targeted adoption of the BDCP Plan and Final EIR/S by the end of 2010. Until the BDCP program is in place, the actions by the USFWS and NMFS under this re-consultation process will control just the one stressor, the SWP and CVP project operations, on endangered fish. These isolated actions will have only limited benefits to fishery abundance. Our best hope to correct the current fishery and water supply conflict in the Bay/Delta Estuary is the cooperative development and rapid implementation of the BDCP.

Need for an Adaptive Approach to Fish Protection

Prescriptive standards that are established for specific dates and fixed amounts of flows or diversions will simply not work effectively to protect the fish species in the Bay Delta Estuary. The environment is too variable. Both resident and anadromous fish that are the subject of this re-consultation move on environmental cues and become more or less susceptible to water project operations in ways that are just becoming known. Even recent court cases (e.g. the 2007 Federal District Court decision on delta smelt) have recognized this and provided for variable operational criteria within a prescribed range and a specific decision making process.

The actions described below would reduce the effects of water project operations on endangered fish at various life stages. However, because the benefits of these operational changes to these life stages and benefits to the overall fish populations are the subject of much scientific debate, they must be made within the context of an adaptive approach. The term "adaptive management" has been used in both the scientific literature and various planning processes to mean various things. It can mean the establishment of in-field "experiments" to test the benefits of actions. However, for endangered fish it is doubtful that a full range of conditions to test fish responses, especially those that could reduce the population of endangered fish, could be performed.

Therefore, the term "adaptive approach" is used here to describe specific actions with a range operational criteria that can vary, based on real time monitoring of key parameters, and within a prescribed decision making process. A key in that decision making process is the establishment of a budget to ensure the balance of the uncertainty of benefits to fish populations of water project related actions with the known water project costs. The CALFED Environmental Water Account (EWA) is an example of such a program. This program was conducted from water years 2001 through 2007 and demonstrated that the State and federal fish and water agencies can effectively work together to implement such an adaptive approach. While the Fish Protection Trigger approach described below is much simpler to implement than the CALFED EWA, it takes that experience and applies it in today's regulatory environment. Using the best available science and measures such as those described herein require that the fish and water agencies work together to analyze among themselves the rationale for the actions and expected outcomes. This approach results in a more open decision making process and allows for periodic scientific review.

Benefits to Salmonid Species

While these actions are targeted to protect delta smelt they occur at times that will also provide benefits to salmonid species. In the decision making process described above in the FPA section, these actions will be evaluated along with those in the Project Description of the BA to protect salmonid species and actions would be taken to protect both. For example, the installation of the Head of the Old River Barrier has been shown to provide some benefits to San Joaquin River salmonid species. Under the recent Federal District Court decision the installation of this salmonid protection action was not allowed in order to protect delta smelt. Under the Action 3 discussed below the OMR flow targets would be adjusted to provide the same level of protection to delta smelt with or without the Head of Old River Barrier. This will allow protection to both species where now there is conflict in the level of protection that is provided to each.

II. ESTABLISHMENT OF THE FISH PROTECTION TRIGGER

Overview and Normal Operations

The Fish Protection Trigger (FPT) is proposed as a SWP analog to the Federal b(2) account set forth in the federal Central Valley Project Improvement Act (CVPIA section (3406(b)(2)). The actions discussed below are targeted at avoiding possible peak entrainment events of endangered fish. The actions discussed below with the judicious use of the FPT and b(2) targeted at possible peak entrainment events and a decision making process to address unexpected circumstances would be sufficient to prevent jeopardy of endangered fish from water project operations in the Delta, under expected circumstances, and would be reasonable and prudent.

Unexpected Circumstances

As was seen with EWA, there can be unexpected circumstances where the b(2) and FPT assets may not be sufficient in very isolated situations to address all the water project operational impacts of the Fish Agency Directors to avoid jeopardizing the existence of specific fish species. Our knowledge about the factors that affect possible peak entrainment events has much improved over the years of implementing EWA but it is possible that even when implementing the actions discussed below unexpected circumstances could change conditions and result in a concern that project operations would have potential to cause jeopardy. In these cases, the projected or actual exceedence of the FPT or actions beyond the range called for in the actions discussed below would trigger a rapid assessment of (1) the unexpected fishery conditions that exist (2) the extent of potential impact of project operations on the listed fish, (3) the effective use of the fishery protection actions (4) the extent and nature and duration of the suggested action and (5) the operational capability to achieve the fishery related action. The decision making process discussed below would be followed and it is anticipated that the Directors of the 5 Agencies (USFWS, NMFS, DFG, USBR and DWR) would meet to address the situation on a real time basis.

Decision Making

The decision making process for implementation of the fishery actions would be made by the Fishery Agencies (USFWS, NMFS, and DFG). The Project Agencies (DWR and USBR) would be responsible for accounting for the impact of the fishery actions on SWP and CVP supplies on an ongoing basis as has been the case under the CALFED EWA since 2001. A Fishery and Operations Technical Advisory Group (FOTAG) made up of the Fishery and Water Agencies would meet weekly (or as needed) to review the real time data on fishery related conditions and water project operations and make a recommendation to carry out the actions described below and other actions set forth by the Fishery Agencies. These recommendations would be reviewed weekly by the Water and Operations Management Team (WOMT) as described in the Project Description. WOMT would provide a report each week of the decisions made. Under the normal operation of the fishery related actions, WOMT should be able to reach consensus on the actions taken. However, if consensus on the actions cannot be reached by WOMT, or unexpected circumstances exist as set forth above, then the Directors of the 5 Agencies would decide the course of action in a specially held meeting later that week. Each agency in WOMT maintains its independent decision making capabilities under its individual authorities. In the event consensus at the Director level is not achieved then the Fishery Agency with the most jurisdiction would make a decision under its regulatory authority and the Project Agency affected by that decision would decide the course of action it would take in response to that decision.

If agreed to by the 5 Agencies, the Project Agencies will fund an independent scientific peer review of the actions taken and the fishery benefits of the FPT program every two years. All the 5 Agencies would participate in this review and seek the guidance of the CALFED Science Program in the conduct of such a review. This review will inform the Fishery and Water Agencies on the efficacy of the actions taken and provide suggestions how this adaptive approach to fishery protection can be improved.

III. POTENTIAL PROJECT EFFECTS ON DELTA SMELT

Factors Affecting Delta Smelt Entrainment

One of the major factors affecting the vulnerability of delta smelt to entrainment at CVP and SWP diversions is their life stage, or more specifically where they reside in the estuary during their different stages of life. Delta smelt spend a significant portion of their juvenile and adult lives in the more brackish waters of the western Delta and eastern Suisun Bay. During this period (from about early July through mid-December or January), they have little exposure to entrainment at the CVP's and SWP's south Delta export facilities. Adult delta smelt migrate upstream to spawn in the north, central and south Delta in mid-December through March, except in years of extremely high Delta outflow when many remain in or are carried downstream into Suisun Bay or San Pablo Bay. The timing and extent of this migration varies from year to year. When the adults enter the central and south Delta, they become vulnerable to entrainment. The progeny of adults which spawned in the central and south Delta are also vulnerable to entrainment until they move downstream into the western Delta in June or early July. Delta smelt in the north Delta have a much lower risk of entrainment than those in the south and central Delta.

Delta inflow, outflow and turbidity appear to stimulate or at least are closely associated with the upstream migration of adult smelt, and thereby their susceptibility to entrainment. In most years, adult delta smelt begin moving rapidly upstream soon after the initial pulse of winter runoff and turbidity from the Delta tributaries. Peaks in adult entrainment at the water projects often coincide closely with that first pulse of freshwater runoff from Delta tributaries (Grimaldo *et al.* in review).

Flow in the south Delta has also been associated with delta smelt entrainment. Figure 1 shows the relationship between average combined flow in Old and Middle rivers (OMR) in January and February and the salvage of adult delta smelt at the CVP and SWP south Delta export facilities. The average OMR is affected by a number of factors, including San Joaquin River inflow, CVP and SWP pumping rates and other in-Delta diversions. Particle tracking modeling also suggests that OMR is associated with the entrainment of larval and early juvenile delta smelt March through May (Kimmerer and Nobriga, 2008).

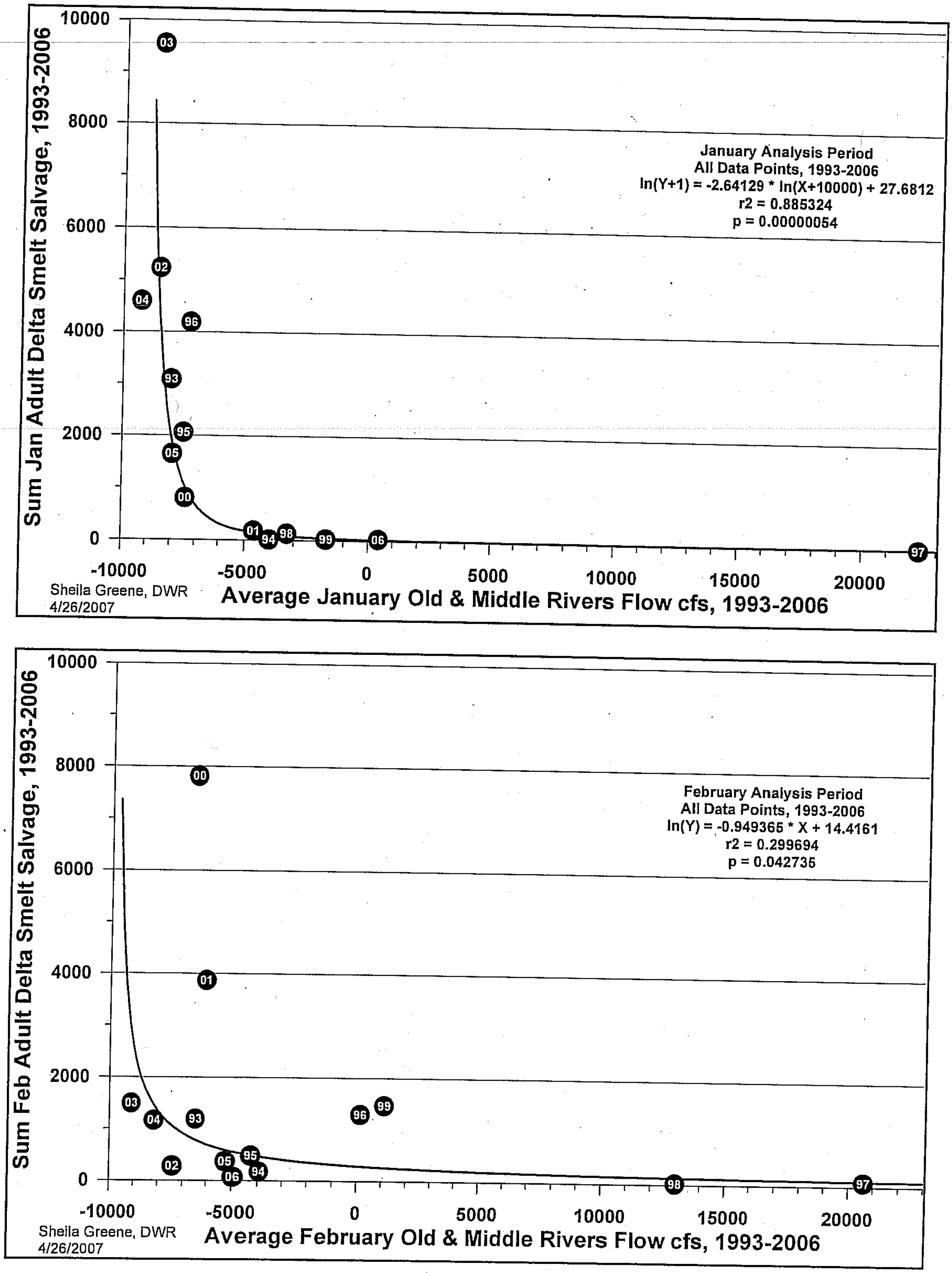


Figure 1. Relationships between average combined flow in Old and Middle rivers in January and February and the salvage of adult delta smelt at the CVP and SWP south Delta export facilities

Effect of Entrainment on Delta Smelt Population

Although the data show a relationship between OMR flow and the entrainment of adult smelt and the particle tracking model suggests a relationship between OMR flow and the entrainment of larval and perhaps juvenile smelt, the effect of this entrainment on the abundance of the adult delta smelt population is less clear. The initial results of the POD investigation found that winter entrainment of adult smelt from 1999 through 2003 was higher than in most of the previous 12 years. Because this period of higher entrainment started before and overlapped with the decline of the delta smelt population that occurred sometime during the 2002 to 2004 period, it has been suggested that high entrainment may have contributed to the subsequent decline. However, this view does not account for the fact that the entrainment was high for several years before the delta smelt population declined as might be expected of a species which rarely lives more than one year. Manly and Chotkowski (2006) also found that the OMR flow (and presumably the entrainment of delta smelt associated with it) could account for only a few percent of the long-term variation in the delta smelt adult abundance index.

Three reasons have been suggested to account for the weak relationship between the long-term trend in OMR flow or salvage and the variation in the delta smelt abundance:

First, B. Bennett (unpublished data) has suggested that variation in smelt abundance in recent years may have been affected more by the disproportional entrainment of the larger, earlier spawning females and their progeny than by the total numbers of delta smelt entrained. He has suggested that the lower survival of the larger fish and their progeny would tend to select for smaller adults that produce fewer eggs. Bennett has pointed to DFG's findings of a long-term trend to a smaller average size of the adult smelt and lower smelt abundance as evidence that this selection might be occurring.

The second reason might be that the smelt population may only be affected by episodic periods of very high entrainment which would be difficult to detect through a statistical analysis of the long-term variation of smelt abundance such as done by Manly and Chotkowski (2006). For example, a high level of entrainment in relatively few years might have a substantial effect on the population abundance but the extent of this effect would appear small when averaged out in an analysis that includes many more years when entrainment does not substantially affect smelt abundance.

The third reason might be that losses of adult, larval and juvenile smelt due to water project related effects are always small compared to other controlling factors like temperature or food availability. Kimmerer (2008) estimated that the losses of adult delta smelt from 1997 through 2005 varied between 1 and 50%, with a median of 15%. He also estimated entrainment losses of larval and juvenile delta smelt between 0 and 25%, with a median of 13%. However, Kimmerer (2008) also pointed out that the effect of these losses on the population abundance was unclear and obscured by subsequent 50-fold variability in the survival of delta smelt from summer to fall, possibly due to substantial variations in summer zooplankton abundance. This high variability in summer to fall survival could obscure episodic events of high entrainment that might have significantly affected delta smelt populations, as discussed in the preceding paragraph. Basically summer mortality might be so great that it might overwhelm the effect of entrainment earlier in the year.

Several recent analyses suggest that summer food, temperature or both may at times and perhaps usually have a substantial effect on delta smelt abundance and overwhelm any effects that entrainment effect might have on delta smelt abundance. Bennett et.al. (2008) suggest that high water temperatures in the summer of 2005 significantly contributed to the low abundance of delta smelt in the fall. Fullerton and Sitts' (personal communication) found that summer temperature changes and food supply can account for over 75% of the variation in the relative abundance of delta smelt from fall to summer over the period of record since 1971. They also found that changes in temperature and food supply can account for about 75% of the variation in the relative abundance of delta smelt from summer to fall since 1988. Their more recent work, to be presented at the CALFED Science Conference in late October 2008, suggests that ammonia in local discharges can dramatically affect smelt abundance. Similar results were found by a more comprehensive statistical analysis of a host of possible factors done by Manly (Attachment 1. Manly found that declines in rotifer zooplankton abundance were most closely related to the declines in delta smelt abundance fall to summer. Manly's analysis also found that both rotifers and *Eurytemora* abundance are highly and positively correlated. Both are considered good food sources. Manly also found that increases in the zooplankton *Limnoithona* are most closely associated with the declines in delta smelt abundance from the summer to fall. *Limnoithona* is an evasive species that significantly increased in the Bay-Delta Estuary in mid-1990s. It is thought to be an inferior food source for smelt and is now the most dominant zooplankton in the estuary displacing more valuable food sources like rotifers and *Eurytemora*. While Manly's analysis differs in some respects from Fullerton and Sitts', their results both suggest that the changes in temperature and valuable food sources are significant contributors to the decline in delta smelt abundance. Neither Fullerton and Sitts nor Manly found a negative population effect of exports, export-related mechanisms salvage or fall salinities on the abundance of delta smelt. In fact, Manly found a positive correlation between delta smelt abundance and salvage of delta smelt, indicating that salvage of delta smelt may be more an indicator of relative abundance than a factor adversely affecting the abundance of delta smelt. These findings suggest that summer temperatures which approach the upper range suitable for delta smelt survival and decreases in valuable food sources maybe major contributors to the 50-fold variability of the summer to fall survival found by Kimmerer (2008).

IV. POTENTIAL ACTIONS TO PROTECT DELTA SMELT

During the last few years, we have made substantial progress in improving our understanding of the CVP/SWP and other factors effects on delta smelt. This improved understanding has been reflected in improvements in CVP and SWP operations to reduce entrainment of adult and young delta smelt. If USFWS determines that actions beyond those set forth in the BA's Project Description are necessary to avoid jeopardizing of the survival of delta smelt, USFWS should consider allocating the State FPA and federal b(2) assets discussed above to implement the three actions described below to reduce entrainment of adult, larval and juvenile delta smelt.

Although the full extent of the projects on delta smelt is still not entirely understood, the actions identified below would address the entrainment of the adults and their progeny and the episodic entrainment events that may have an effect on delta smelt abundance. The first action could help reduce the movement of adult delta smelt into the central and south Delta, and thereby reduce the entrainment of those adults and their progeny. The second action would reduce the entrainment of adults which have entered the central or south Delta, The third action would reduce the entrainment of larval and juvenile smelt in the spring. The first and second actions are refinements in the actions implemented in 2008 under Federal District Court Order. The third action provides a tool for that can be used to better tailor operations to reduce or avoid the episodic entrainment events that have occurred in the past and which may have an effect on delta smelt abundance.

We are not proposing an action to further manage fall X2 location. There are several factors unrelated to salinity that correlate with changes in summer to fall abundance of delta smelt (See Attachment 1 and the discussion in the "Effects of Entrainment on Delta Smelt Populations" above). Until more is known about these factors and the likely actual cause for changes in the summer to fall abundance, it is not prudent to establish a fall X2 action. Also, fall X2 actions for the protection of delta smelt could severely impact project water supply and the projects' ability to maintain sufficient cold water in their upstream reservoirs to protect listed salmonids. For these reasons we do not believe that the current state of the science is sufficient to establish a fall X2 action to protect delta smelt.

Action 1 – Pulse Flow Action

This action would control flows in the Central Delta during the first pulse of fresh water into the Delta to reduce the number of adult smelt migrating upstream into the central and south Delta. Reducing the number of adults entering the central and south Delta will reduce the number adults and their progeny likely to be entrainment at the CVP and SWP facilities later in the year.

Trigger - On or after December 20 when the 3-day average Freeport flow is between 25,000 and 80,000 cfs, and the average turbidity exceeds 12 NTU for 2 consecutive days at each of three monitoring stations: False River, Prisoners Point, and Holland Cut

Action – Achieve an average net upstream Old and Middle River (OMR) flow between 2,000 and 5,000 cfs over a 10-day period, commencing within two calendar days of the trigger (one time action). The OMR target would be set to minimize the turbidity plume into Central and Southern Delta.

End of Action – The action would end after (1) ten days, or (2) the 3-day Sacramento River flow at Freeport increases to greater than 80,000 cfs, or (3) the onset of spawning, which ever occurs first

We propose that this action be highly adaptive and modified as data indicates appropriate. Its effectiveness should be reviewed each year by the FOTAG and WOMT to help guide its implementation in subsequent years. The review needs to include its effectiveness to reduce fish movement into the central or south Delta and evaluation alternative triggers to begin and end the action.

Rationale for Action - In recent years, river flow or turbidity were used to trigger CVP and SWP operational changes when delta smelt were likely to begin their upstream migration into the interior Delta in response to the first pulse of winter runoff. Recent DWR analyses indicate that together Sacramento River flow and turbidity within in the Delta are better predictors of when this upstream migration is going to occur than when only flow or turbidity is used alone. The triggering criteria therefore include both. It also uses the recently installed False River turbidity station rather than the Victoria Canal station which was used in 2008. We feel that turbidity in False River better reflects the conditions in the central Delta which might trigger smelt migration into the south Delta. It is also more likely to be on the smelt migration route and it is further away from the CVP and SWP pumps than the Victoria Canal station.

Figure 2 overlays the proposed triggering criteria on the historical salvage, turbidity and Sacramento flow during the 1993-2005. It shows that the criteria would have triggered export reductions within days of delta smelt salvage in 10 of 12 years, excluding 1996 because of suspect turbidity data. (The turbidity data used in this analysis was from the station located outside the Clifton Court Forebay since it provides data going back to 1993, and the data from the three turbidity stations used in proposed criteria only go back a few years.) The trigger did not work well in 1997 and 1999; both of these years had very high flow events. In 1997 that action would have been stopped after seven days when Freeport flow exceeded 80,000 cubic feet per second (cfs). In 1998, the proposed trigger would have resulted in action would have reduced the initial entrainment of smelt, but would have missed the much larger entrainment event of fish in late March. Figure 2 shows that in 1996 and 2001 a trigger which includes both Freeport flow and Delta turbidity was significantly better than one which only relied on that flow or turbidity; in other years using the flow and turbidity in the trigger was good or slightly better than using the flow or turbidity.

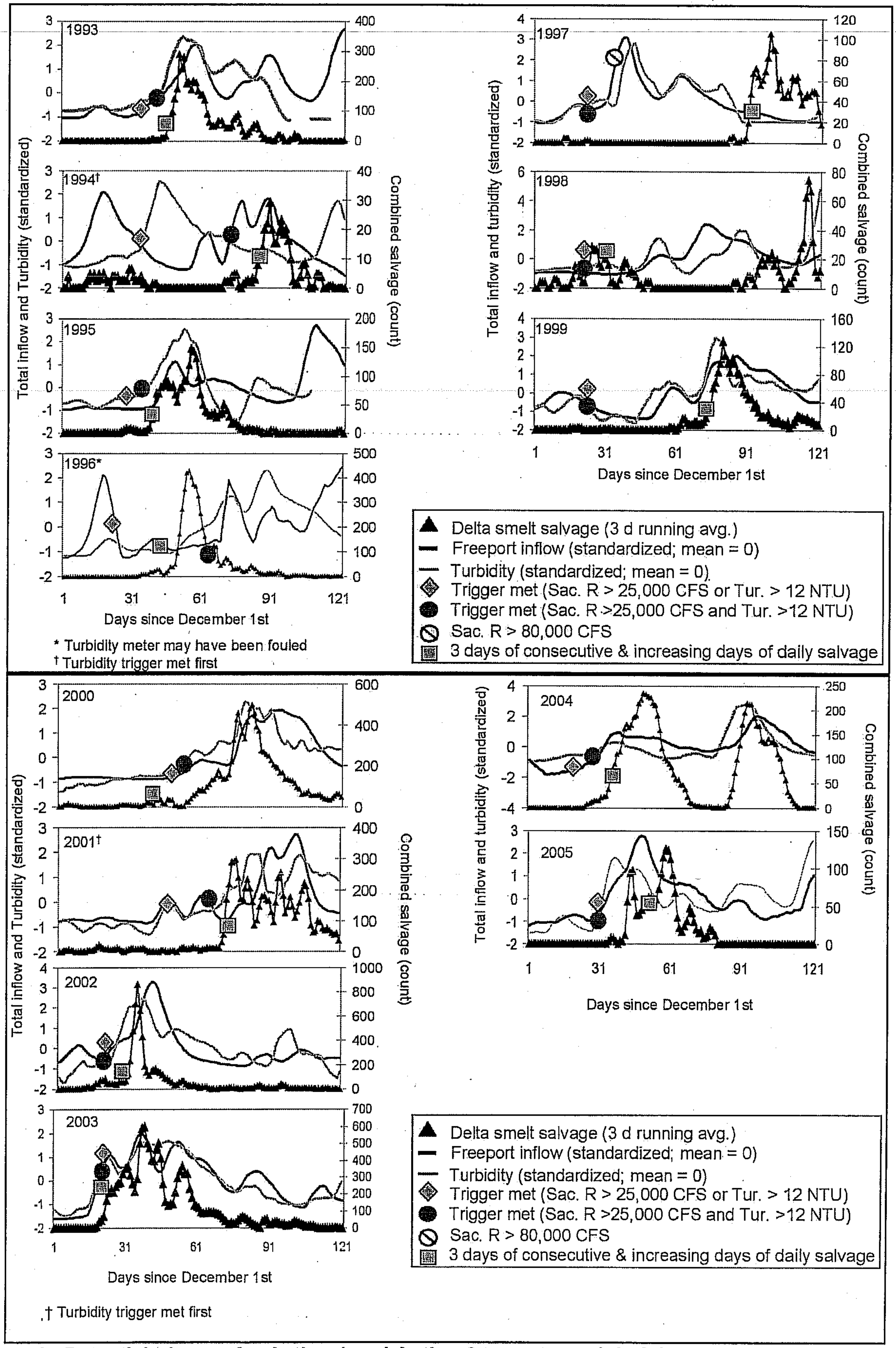


Figure 2. Potential triggers for Action 1 and Action 2 to protect adult delta smelt.

The action itself and the criteria for the termination of the action are similar to what the Federal District Court required in 2008. The primary difference its that we suggest USFWS provide itself the flexibility to consider actions ranging between -2000 and -5000 OMR, instead of only -2000 cfs. This would provide USFWS the opportunity to adaptively manage this action and assess the effects of different flows on turbidity distribution and delta smelt migration.

Action 2 – Adult Smelt Action

This action is designed to reduce entrainment of adult smelt that have entered the central and south Delta.

Trigger - The combined salvage of delta smelt at the CVP and SWP increases steadily over three consecutive days, unless the 3-day average Sacramento River flow at Freeport is greater than 80,000 cfs. OR if Delta Smelt Surveys show a significant number or delta smelt in the Central or Southern Delta.

Action – Net upstream OMR flow maintained at 5000 cfs. The flow will be a 14-day running average. Simultaneously, the 7-day running average shall be within 1,000 cfs of the applicable 14-day running average. (The running average is calculated taking the current day's value plus the appropriate number of previous days in the averaging period (14 or 7) and the average for these days calculated. The running average for the next day simply moves forward by one day and is recalculated as set forth above. The first day of compliance with the action is based on all the days in the averaging period. For example, if the 14-day mean starts on January 15, compliance is determined based on the 14-day average that begins on the 15th and ends 14 days later on January 29th.)

End of Action – This Action will end when the delta smelt start to spawn. The onset of spawning is indicated by spent females in Spring Kodiak Trawl, or in salvage at the SWP or CVP, or when the daily three-station average water temperature at the Mossdale, Antioch and Rio Vista monitoring stations exceeds 12 degrees Celsius.

Rationale for Action – The trigger for this action differs from that used in 2008. Rather than following immediately after the pulse flow action or on January 15th, it begins on seeing increasing salvage at the SWP and CVP south Delta fish salvage facilities. This refinement is designed to avoid implementation of this costly action in years such as 1997 and 1999 (see Figure 1) and as happened in 2008 when it probably has little or no benefit to delta smelt.

Figure 2 shows that the proposed trigger would better align the CVP and SWP operational action to an actual increased risk entrainment to delta smelt. In 8 of the 12 years the proposed action, like the 2008 action, would have been triggered during or soon after the first pulse flow action. In 2000, it would have triggered it before the pulse flow action. However, in years where the smelt do respond to the initial pulse of freshwater, the proposed trigger would delay the initiation of Action 2 until there is evidence that the fish migration and entrainment risk is increasing. It would also delay the initiation of Action 2 if Action 1 was effective in inhibiting the movement of adult smelt to areas where they are at risk of entrainment. However, if the salvage showed that Action 1 failed to substantially reduce the risk of adult smelt entrainment, Action 2 would be triggered during or immediately following Action 1.

Action 2 is similar to the adult protective action that was implemented in 2008, except for the averaging period for meeting the OMR criterion. There we propose to use the 14-day and 7-day running averages that FWS, USBR, DFG, and DWR previously agreed to and proposed in our remedy proposal to the Federal District Court. The 14-day averaging period provides SWP and CVP operators with the flexibility they need to deal with tides and barometric conditions outside their direct control. Old and Middle river are highly affected by the tides and can typically have a daily tide range of flow of plus or minus 30,000 cfs during a single day. This makes measuring the net daily flow difficult. In addition, the lunar tide cycle causes the "filling and draining" of the Delta twice each month. Due to 28-day lunar tidal cycles (two spring and two neap cycles), a 28-day running average would therefore be appropriately consistent with the monthly averaging periods shown in these graphs. However, due to concerns expressed in the past by USFWS related to the possible effects peak OMR flow conditions, a 14-day averaging period which would allow for one neap and spring tide cycle to occur within the averaging period would be acceptable. Therefore, the OMR flow target would be a 14-day running average. Simultaneously, the 7-day running average is proposed to be within 1,000 cfs of the applicable 14-day running average.

Figure 1 indicates that keeping average net upstream OMR flow from exceed 5,000 cfs will keep entrainment of adult delta smelt at reasonable levels. That was the reason it was used in 2008 and we see no reason to change it in this proposal. The criteria for the termination of this action would remain as they were in 2008.

<u>Action 3 - Larval and Juvenile Delta Smelt Action</u>

While Action 1 and Action 2 are designed to avoid or reduce entrainment of adult delta smelt, Action 3 is designed to reduce entrainment of larval and juvenile delta smelt.

Trigger - The action will begin when there is evidence that delta smelt may beginning to spawn. The onset of spawning is indicated by spent females in Spring Kodiak Trawl, or in salvage at the SWP or CVP, or when the daily three-station average water temperature at the Mossdale, Antioch and Rio Vista monitoring stations exceeds 12 degrees Celsius.

Action – Net upstream OMR flow not to exceed the targets as determined using the latest fish distribution and abundance survey data and the Particle Tracking Model. To eliminate potential peak entrainment events that have occurred in the past, the Potential Entrainment Index (PEI) target determined by the PTM is not to exceed 5% in any 20-day period. The documentation of the Potential Entrainment Index is discussed in Attachment 2. The flow will be a 14-day running average. Simultaneously, the 7-day running average shall be within 1000 cfs of the applicable 14-day running average. The range of the upstream OMR flows expected from this action is between 2,000 cfs to 8,000 cfs based on the actual distribution of delta smelt except under unexpected conditions discussed above.

End of Action – The action would end on June 20th.

Rationale for Action – This action has many similarities to the action implemented in 2008 to protect larval and juvenile smelt. It would be triggered by evidence of delta smelt spawning as specifically described in the Action 2 above. Once it is triggered the CVP and SWP would be operated to maintain an OMR flow target that would vary through the season depending on the most recent delta smelt distribution and abundance data from DFG's 20-mm and Kodiak surveys and the results of the Particle Tracking Model (PTM).

DWR proposes that USFWS use a more defined and systematic approach to integrate the fish survey results and the PTM to develop the OMR operational criteria. Under this approach the distribution and relative distribution of larval delta smelt through the Bay-Delta will continue to be determined based on the results of DFG's latest 20-mm Delta Smelt Survey. This survey is conducted every two weeks from mid-March through mid-July. If temperatures trigger the Action 3 before delta smelt larvae are detected in a 20-mm Survey, the distribution of larval delta smelt will be assumed to be similar to the distribution of the adults in DFG's latest Kodiak Trawl Survey. After each fish survey, a preliminary OMR operational criterion will be determined using a PTM regression relationship based on historical data Attachment 2 provides a detailed description of the development of the PTM regression relationships and how they could be used to develop operating criteria for the water projects. It also describes how well relationships correlate to historical salvage and compare to Kimmerer's (2008) estimates of historical entrainment. Based on our analyses, DWR proposes that the regressions be used to estimate preliminary OMR criterion that would keep the Potential Entrainment Index of juvenile delta smelt over the following 20 days at or below 5%. Figure 11 of Attachment 2 shows that this PEI goal will usually keep the annual PEI below 10% and well below the historical levels. The projects will begin operating to this preliminary criterion within 4 working days of receiving the fish survey data from DFG. This preliminary OMR criterion will be replaced with a refined OMR flow criterion calculated using a full PTM run a few days later. This cycle of revising and operating to the preliminary and refined OMR criterion will be repeated after each fish survey until the action is ended on June 20. A specific description of the methods used to determine the preliminary and refined OMR flows are described in the following section.

We recommend that the USFWS, in consultation with USBR, DWR and DFG, allow for the modification of this method in the future to incorporate improvements in monitoring, modeling, or analytical methods. If the fish population falls below levels that can be detected at both the Kodiak and the 20mm surveys, the target OMR could be calculated using the PTM to keep the entrainment of injected particles in the central Delta (such as the 20mm station 815) below some specific percentage.

The use of the proposed PEI approach has a couple of substantial advantages over tools that have been used in the past to protect larval and juvenile delta smelt. First and foremost is that it clearly ties the operational criteria to the proportion of the fish population at risk of entrainment. The greater the proportion of the smelt population exposed to entrainment, the greater the operational response will be to reduce that risk. Second, the proposed method is similar to that used by Kimmerer (2008) in that it estimates the percentage of the smelt larvae and juveniles entrained by the CVP and SWP. However, rather than using the fish survey results and OMR flow to estimate the proportion of the larval and juvenile population entrained in the past, as Kimmerer did, the proposed method would use the PTM model to calculated the OMR needed to keep the future entrainment of the larvae and juveniles below some predetermined portion of the smelt population.

The target OMR flow would also be based on 14-day and 7-day running averages, rather than only the 7-day average used in 2008. The 14-day average provides the necessary operational flexibility of the CVP and SWP needed to deal with the substantial variation in OMR flow due to the lunar tidal cycle. Simultaneously, the 7-day running average shall be within 1000 cfs of the applicable 14-day running average. This assures that the daily pumping occurring within a 14-day averaging period does not increase to levels which might be harmful to delta smelt. The action would continue through June 20, as it did in 2008.

V. METHOD TO IMPLEMENT ACTION 3

Following are the specific steps that would be taken to determine and adjust OMR target flows through the spring to levels that would keep the annual Potential Entrainment Index (PEI) of larval/juvenile delta smelt at the CVP and SWP south Delta facilities at less than 5% in any 20-day period:

1. After the action is triggered, determine the preliminary target OMR needed to achieve the calculated 20-day PEI. This preliminary target OMR will be determined using DFG's most recent 20-mm delta smelt larval survey results and the PTM regression equations. (The development and application of the PTM regression equations are described in Attachment 4.) The preliminary target OMR will be determined within a day of the triggering of the action and receipt of the most recent fish survey data from DFG. If 20-mm Survey results are not available or did not detect delta smelt, the latest Kodiak Survey will be used as an indication of larval/juvenile delta smelt distribution and abundance.
2. The Water Operations Management Team (WOMT) confirms the action trigger has been met and reviews and adopts the preliminary target OMR flow.
3. The adopted OMR target will be implemented within 2 days of its adoption by WOMT, and will remain in effect until it is replaced by a refined OMR target based on a full PTM run using the most recent 20-mm or Kodiak survey results.
4. Determine the refined target OMR using the fish survey data and a full PTM run within 4 days of receiving the fish survey data from DFG. Adjust operations to the refined OMR target within a day of its determination. This target OMR will be used until it is readjusted based on new fish survey information.
5. The previous four steps will be repeated after each fish survey until the action ends on June 20.

Example of Application of Action 3 using the PEI

As an example, if this method was used in 2008 the following would have been the dates for the adjustment of the OMR flow targets.

OMR Target 1 - February 21 to March 26 - Action 3 would have been triggered by the detection of spent female at the CVP's salvage facility on February 17. The February Kodak Trawl (that was conducted February 4-8) would have been selected as the most recent fish survey available to use to estimate the distribution and relative geographical abundance of delta smelt. A preliminary target OMR to achieve the 20-day PEI of 5% would have been calculated using the February Kodiak Trawl survey results and the PTM regression equations for 20-days. The full PTM would have also been started to refine the preliminary OMR target. All the above tasks would have occurred by February 18.

On February 19, the WOMT would have confirmed the triggering event and adopted the preliminary target OMR. The preliminary OMR flow target would have gone into effect February 21st and operations begin to achieve the flow target. Within a day or two the refined OMR target would have been determined using the full PTM and operations would be immediately adjusted to meet that refined target. The 14-day mean would have been achieved 14 days later (March 5th) and the running average would have been kept at or below the OMR target flows. Furthermore, the 7-day mean after the first 7 days (February 27) would have been kept within 1000 cfs of the 14-day mean target flows. The CVP and SWP would have operated to this initial OMR target until March 26, when it would have been replaced by a new target based on the fish distribution and abundance data from the March Kodiak Trawl.

OMR Target 2 - March 27–April 23 - The March Kodak Trawl was conducted March 10–14, and its data was available on March 18. The 2nd preliminary OMR target would have been calculated using this data. WOMT would have considered and adopted the 2nd preliminary OMR target on March 25, which would have been implemented on March 27. Within a couple of days the refined target would be available and the projects would modify their operations to meet that target.

The first and second 20-mm surveys were conducted March 17-21 and March 31-April 4 respective. Their results were available by March 28 and April 11, respectively. These results would have been reviewed, but since neither detected delta smelt, they would not have been used to revise the OMR target. Therefore, the 2nd OMR target would have been left in place until April 23, when it would have be revised based on the April Kodiak results.

OMR Target 3, April 24–April 30 - The April Kodiak Trawl was conducted April 4 -11, and the results became available on April 15. This information would have been used to calculate a new preliminary target OMR which the WOMT would have considered at its April 22 meeting and begun to implement on April 24. This target would have been in effect for a few day until it was replaced by the refined target. The refined target would have been in place until May 1, when it would have been revised based on the results of the 3rd 20-mm Survey.

OMR Block 4, May 1- May 14 - The 3rd 20-mm Survey was conducted April 14-19, and its results became available on April 25. These results would have been used to calculated the 4th preliminary OMR target for adoption at the April 29 WOMT meeting. The project would have begun operating to the new target OMR on May 1. It would have been maintained as the target until it was replace by the refined target, which would have been in place until May 14, when it would have been modified based on the result of the 4th 20-mm Survey.

OMR Target 5, May 15-May 28 - The 4th 20-mm trawl was conducted April 28 to May 2, and its results were available on May 9. These results would have been used to calculate a new preliminary OMR target for WOMT approval on May 13th and implementation on May 15. It would have been maintained as the target until it was replaced by the revised target a couple of days later. The revised target would have remained in place until May 14, when it would have been modified based on the results of the 5th 20-mm Survey. (The May Kodiak Trawl was conducted May 5 – 9, and its data became available on about May 13. However, because the 20-mm Survey data was now available and showing delta smelt distributions, the Kodiak trawl data would no longer be used during the rest of the year to set OMR flows).

OMR Target 6, May 29-June 11 - The 5th 20-mm survey was conducted May 12–16, and its results were available May 23. Based on these results a new preliminary OMR target would have calculated for approval by WOMT on May 27 and implementation on May 29. This preliminary target OMR would have been replaced within a couple of day with the refined target, which would have been maintained through May 14, when it would have been modified based on the results of the 6th 20-mm Survey.

OMR Target 7, June 12–June 20 - The 6th 20-mm survey was conducted May 26 – 30, and its results were available June 6. Based on these results a new preliminary OMR target would have calculated for approval by WOMT on June 10 and implementation on June 12. This target OMR would have been replaced by the refined target within a couple of days, which would have been maintained through June 20 when Action 3 ended.

Key Logistical Assumptions

The schedule described above assumes the following:

1. DFG's Kodiak Survey results are available within 2 working days of the completion of the survey.
2. DFG's 20-mm Survey results of the first tow are available estuary wide within four working days and the most significant of the results of 2nd and 3rd tows are available within five working days of the last day of the survey. (For the 2nd and 3rd tows of a survey, the most significant stations for the modeling might be those (1) where smelt are found in the 1st tow, (2) which are adjacent to stations where smelt are found in the 1st tow, and (3) between the pumps and where smelt are found in the previous tows.)
3. PTM regressions can be used to calculate the preliminary target OMR flow within a day of receiving DFG's fish survey data. The full particle tracking runs can determine the refined target OMR in 4 days..
4. The WOMT can consider the preliminary OMR target the day after it is calculated.
5. The projects can begin operating to a new OMR target within two days of its adoption by WOMT.

VI. Conclusion

DWR believes these refinements to the triggers and actions as described above would both make the actions more effective at protecting delta smelt while minimizing the adverse effects on CVP and SWP water supply. These refinements are based on the latest analysis of the historical entrainment, flow and turbidity data and substantial improvements in the application of the Particle Tracking Model. While the effect of entrainment losses on the delta smelt population is still unclear, these actions would reduce the entrainment of early spawning adults and their progeny that Bennett has suggested may be adversely affecting delta smelt abundance and size. It would also avoid the higher levels of entrainment identified by Kimmerer (2008) in some years. If implemented in the past, Actions 2 and 3 would have prevented peak entrainment events, especially in 1996, 2002 and 2003, and significantly reduced annual losses to the population. Kimmerer (2008) opined that, although there is not a significant statistical relationship between salvage and delta smelt population, the effects of entrainment events on the population may have been episodic. While Manly and Chotkowski (2006) found a significant relationship between combined export volume in certain months and FMWT abundance in historical analyses, exports accounted for at most a few percent of the variation in FMWT catches.

REFERENCES

Bennett, W.A., J.A. Hobbs, and S.J Teh. 2008. Interplay of Environmental Forcing and Growth-Selective Mortality in the Poor Year-Class Success of Delta Smelt in 2005. Final Report "Fish Otolith and Condition Study 2005"

Kimmerer, W. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta San Francisco Estuary and Watershed Science. Vol. 6, Issue 2.

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

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

Attachment 1

Statistical Analyses of Variables Possibly Influencing Delta Smelt Abundance from Fall to Summer

Bryan F.J. Manly
Western EcoSystems Technology Inc.
Cheyenne, Wyoming
bmanly@west-inc.com

Contents

1. Introduction

This report describes statistical analyses of variables that have either been found in the past to be related to the abundance of delta smelt in the summer, have been suggested as possibly important in this respect, or where it is plausible that a relationship exists. These variables and their sources are described by Miller (2008), with the reasons for including them in the analyses reported here. The sources and reasons for including the variables are not repeated here.

The report examines changes between the abundance of delta smelt as measured by the Fall Midwater Trawl index (FMWT), based on results of surveys carried out in the Sacramento-San-Joaquin Delta from September to December, and the abundance in the summer as calculated from the Summer Townet surveys carried out in June to August. Two summer abundance indices are considered for this purpose. One is the standard Summer Townet index (STN), while the other is an index of the July abundance (STN1) that is described by Miller (2008).

The basic approach used involves starting with equations relating the summer abundances to the fall abundance and then seeing which other variables can be added into these equations to better account for the changes in the summer abundances that have been observed from 1972 to 2006.

The results of the analyses indicate that the summer abundance as measured by the standard STN index is related positively to the abundance of Eurytemora and Pseudodiaptomus from April to June, negatively related to the number of spawning days in a year (a temperature relationship), and has a non-linear relationship with Secchi. The variables are different for the July abundance index STN1, and involve a negative temperature effect, a positive prey effect, and a positive Secchi effect.

The variables considered in this report display some quite high positive and negative correlations. This means that although the equations for predicting the summer abundance of delta smelt work quite well the determination of what are causal effects and what are due to confounding effects is not straightforward.

A separate report is being prepared using similar methods to those described here to examine the change in delta smelt abundance from the summer to fall.

2. Methods

The approach adopted to investigate the possible effects of the variables described by Miller (2008) on changes in the delta smelt abundance between summer and the previous fall involved first finding the equation that best relates the STN summer abundance index to the previous FMWT abundance index (FMWT) using regressions involving either the indices themselves of their natural logarithms. Similarly, the July abundance index STN1 was investigated in terms of whether the best relationship is obtained using the indices themselves or their natural logarithms. Here the description "best" in both cases refers to having the largest coefficient of determination (R^2).

The reason for adopting this approach as a first step in the analysis was that it is anticipated that the summer abundance will naturally be related to the previous fall abundance. Also, including the previous fall abundance in an equation should take into account all of the effects on delta smelt abundance that occurred before that previous fall.

There is one previous fall midwater trawl abundance estimate and two summer townet abundance estimates, with all of these indices being available for the years from 1972 to 2006, except for 1975 and 1980. In the past the abundance estimates have been related by regression either directly or after taking logarithms. This then leads to four possible equations that might be considered to relate these variables by simple linear regressions, namely

$$\text{STN} = \text{A} + \text{B.FMWT} \quad (2.1)$$
$$\text{Ln(STN)} = \text{A} + \text{B.Ln(FMWT)} \quad (2.2)$$
$$\text{STN1} = \text{A} + \text{B.FMWT} \quad (2.3)$$

and

$$\text{Ln(STN1)} = \text{A} + \text{B.Ln(FMWT)}. \quad (2.4)$$

The equations (2.1) and (2.3) are obvious possibilities for a relationship between the fall and summer abundance, implying that an increase in the fall abundance leads to an expected linear increase in the summer abundance. Equations (2.2) and (2.4) are, however, also sensible because it is reasonable to expect the values of STN and STN1 to be approximately proportional to FMWT. A slight generalization then suggests a relationship like

$$\text{STN . a.(FMWT)}^{b},$$

or

$$\text{Ln(STN) . Ln(a) + b.Ln(FMWT)},$$

which is the form for equations (2.2) and (2.4).

Following the choice of the best fitting equations for STN and STN1, the residuals from these equations have been plotted against each of the variables that STN may be related to. The purpose of this step was just to get some insight into which variables seem useful for adding into the equations. The correlations between these variables are also provided as this gives insight into which variables are measuring more or less the same thing, so that at most one of these variables should be considered for entry into the equations.

The next part of the analysis involved considering all of the potential predictor variables that are available for the years 1972 to 2006 other than 1975 and 1980. These variables were considered first in order to avoid reducing the data because of missing values. They were added into the equation one at a time using a stepwise process that allowed the squares of variables to be entered, using the following steps first for the equation with STN as the dependent variables, and then for the equation with STN1 as the dependent variable:

(a) The equation predicting the Summer Townet abundance using just the Fall Midwater Trawl abundance was fitted to the data.

(b) The variables without missing values were considered one at a time for being added into the equation. The most significant variable in this respect was then added into the equation providing that it produced a significant improvement in fit at the 5% level.

(c) Having added a variable into the equation the process described in (b) was repeated to see whether a second variable could be added into the equation, but with one modification. In addition to considering each of the variables not already in the equation, the square of the variable already in the equation was also considered for entry. If the square term produced a significant improvement in fit at the 5% level then it was added. Otherwise, the most significant other variable was added providing this produced a significant improvement in the fit of the equation at the 5% level.

(d) Step (c) was repeated until there was no significant variable to add to the equation, always giving preference to adding significant squared terms into the equation rather than adding a new variable.

This process resulted in an equation for STN and an equation for STN1 based on some of the variables with no missing values.

At that point consideration was given to whether the residuals from the selected equations display significant serial correlation. If so, the equations could be re-estimated with an allowance for this serial correlation.

Having developed equations based on variables with no missing values other than for 1975 and 1980, consideration was given to whether any of the variables with missing values should be added into the equations, or should replace variables already in the equations. These variables were examined in another stepwise process. First the equations determined from the full set of data were re-estimated using the years with data available for a set of the variables with missing values. For example, the ammonia variables are only available for 1975 onwards. The equations already chosen were therefore re-estimated based only on data from 1975 onwards. The variables with missing values were then examined one at a time for entry into the equation, with squared terms also considered. This showed whether for the reduced data one or more of the variables with missing values would significantly improve the fit of the equations already chosen from the full set of data. There was also the possibility that entering a new variable would make one of the variables already in the equation non-significant, in which case it would be removed.

This process does give precedence to the variables already in the equation with no missing values. This is considered to be appropriate because of the desire to have equations that predict the Summer Townet abundance for as many years as possible.

The intended outcome of this rather complicated selection process were equations for STN and STN1 that give a good fit to the data, ideally for all of the years from 1972 to 2006 except 1975 and 1980.

3. Results

Table 3.1 shows the proportion of the variation in the data (R^2) accounted for by each of the equations (2.1) to (2.4), when fitted to data for the summer townet survey years of 1972 to 2006. The best fitting equation is (2.2), with R^2 = 0.418, followed by equation (2.4) with R^2 = 0.294.

Given the clearly superior fit of the equations using logarithms and the lack of significance for the equations not using logarithms there seems little point in considering the equations that do not use logarithms any further. Figures 3.1 and 3.2 show how the observed and expected summer indices compare for equations (2.2) and (2.4).

Table 3.1 Comparative fits for equations (2.1) to (2.4).

Dependent	Predictor	R^2	Significance
STN	FMWT	0.106	0.065
Ln(STN)	Ln(FMWT)	0.418	0
STN1	FMWT	0.105	0.066
Ln(STN1)	Ln(FMWT)	0.295	0.001

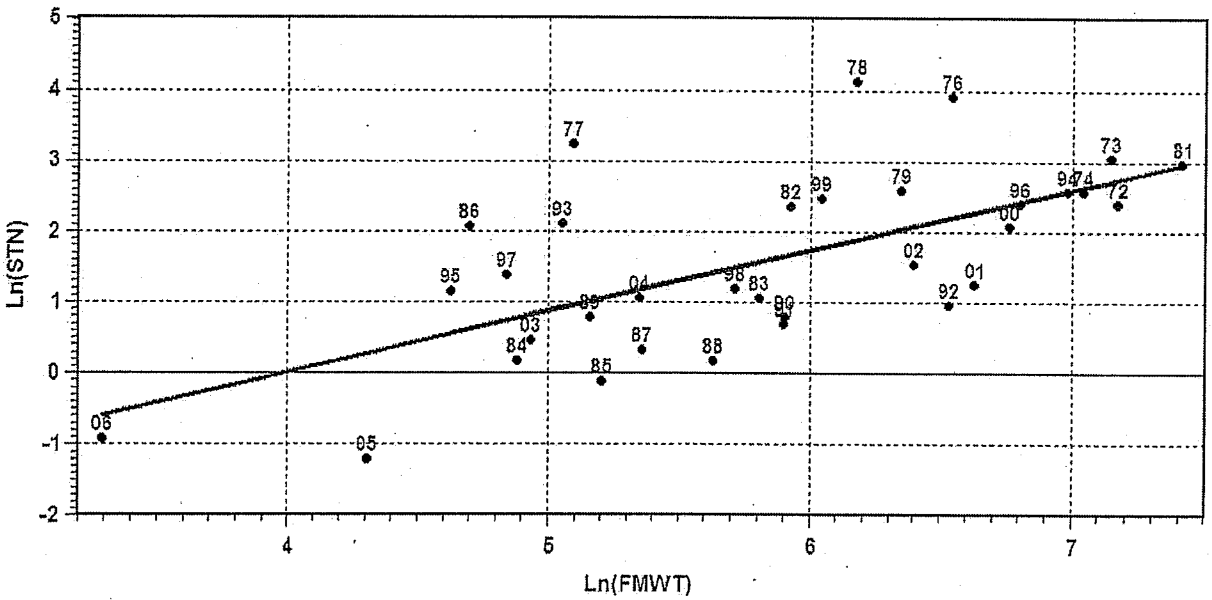


Figure 3.1 The observed (•) and predicted (–) values for Ln(STN) for 1972 to 2006 with the years for observations indicated. The equation used here gives an R^2 value of 0.418.

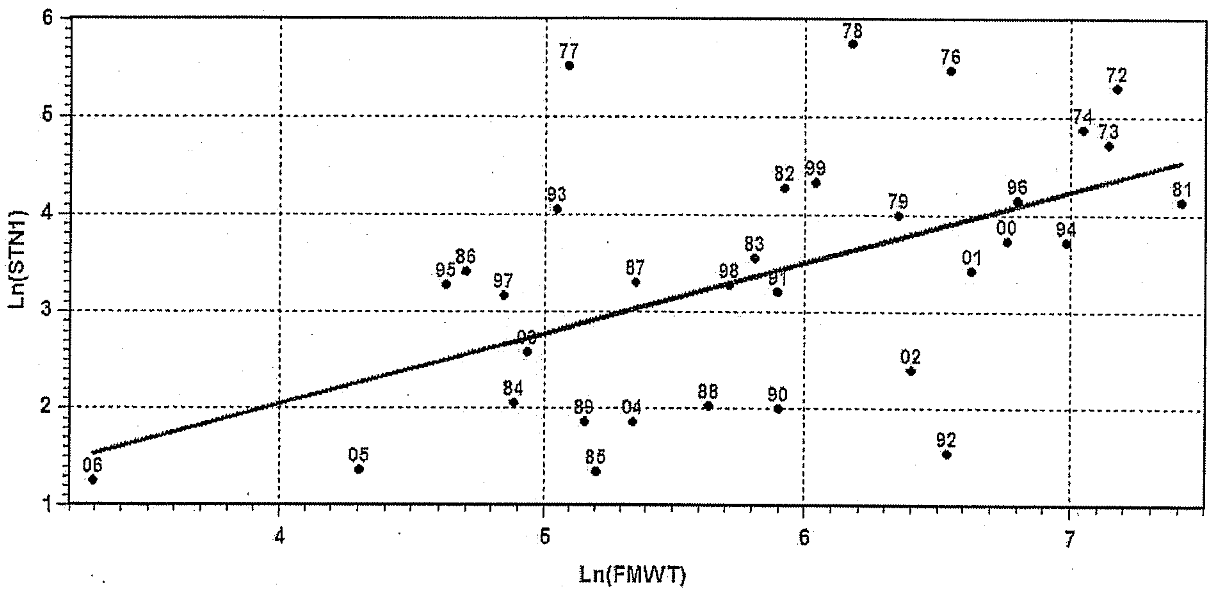


Figure 3.1 The observed (•) and predicted (–) values for Ln(STN1) for 1972 to 2006 with the years for observations indicated. The equation used here gives an R^2 value of 0.294.

Variables Considered for Adding Into the Equations

The variables that are available for adding to the equations relating the STN abundance to the FMWT abundance are listed below, with the abbreviated names that will be used for the remainder of this report. Miller (2008) gives details of why these variables were chosen for inclusion in the analysis, and how the values were calculated.

Davis	The average July air temperature at Davis (EC) in the STN year.
DavisM	The maximum Davis summer temperature (EC) in the STN year.
Spawn	The number of spawning days in the STN year.
LarvalM	The maximum temperature during larval development (EC) in the STN year.
EC	The September to December Conductivity (micro-siemens/cm) in the Delta the year before the STN year.
X2	The September to December average distance to the 2 ppt line from Golden Gate the year before the STN year.
Secchi	The average September to December Secchi depth in the Delta the year before the STN year (cm).
Secchi1	The April to May Secchi depth weighted by the percentage of delta smelt in different parts of the Delta in the STN year (cm).
Eury	The average Eurytemora density in the Delta in late April in the STN year (numbers/m^3).
Calanoid	The average April to June calanoid copepod density in the STN year

	(numbers/m^3).
MinEP	The minimum April to June Eurytemora + Pseudo-diaptomus density in the STN year (numbers/m^3).
Rotifers	The average rotifer density in late April in the STN year (numbers/m^3).
Limno	average Limnoithona density in late April in the STN year (numbers/m^3).
Ammon1	The average September to December ammonia measured at Hood the year before the STN year (mg/l).
Ammon2	The maximum average monthly ammonia at Hood for September to December the year before the STN year (mg/l).
Ammon3	The average monthly ammonia at Hood in April in the STN year (mg/l).
Ammon4	The average monthly ammonia at Hood in March in the STN year (mg/l).
Ammon5	The discharge of ammonia from the Sacramento Regional Wastewater Treatment Plant, March to May in the STN year (tons).
Ammon6	The discharge of ammonia from the Sacramento Regional Wastewater Treatment Plant, August to October the year before the STN year (tons).
AdSal	The adult salvage December to March before the STN surveys.
JuSal	The juvenile salvage in the STN year.
AdFrac1	The calculated variable AdSal/FMWT the year before the STN year.
JuFrac1	The calculated variable JuSal/FMWT in the year before the STN year.
Index1	The calculated value AdFrac1/Exports1.
Exports1	The export rate for December to March before the STN surveys (cfs).
Exports2	The export rate for April to May in the STN year (cfs).
DIn1	The average Delta inflow October to April before the STN surveys (cfs).
DIn2	The average Delta inflow in April in the STN year (cfs).
DOut1	The average Delta outflow October to April before the STN surveys (cfs).
DOut2	The average Delta outflow in April in the STN year (cfs).
PDO	The average Pacific decadal oscillation for October to March before the STN surveys.

Most of the above variables have known values for 1972 to 2006, although the lack of values for the previous FMWT index means that the data for 1975 and 1980 cannot be used anyway. The variables with some missing data for years other than 1975 and

1980 are Secchi 1 (22 missing years), Ammon1 to Ammon6 (2 missing years), and the salvage variables AdSal to Index1 (6 or 7 missing years).

Plots of Regression Residuals Against the Other Variables

To examine whether any of these variables can account for some of the variation in the summer townet abundances that is not accounted for by the fall midwater trawl abundance, these variables were first standardized to have means of zero and standard deviations of one. The standardized residuals from the fitted equations (2.2) and (2.4) were then plotted against these standardized variables, as shown in Figure 3.3.

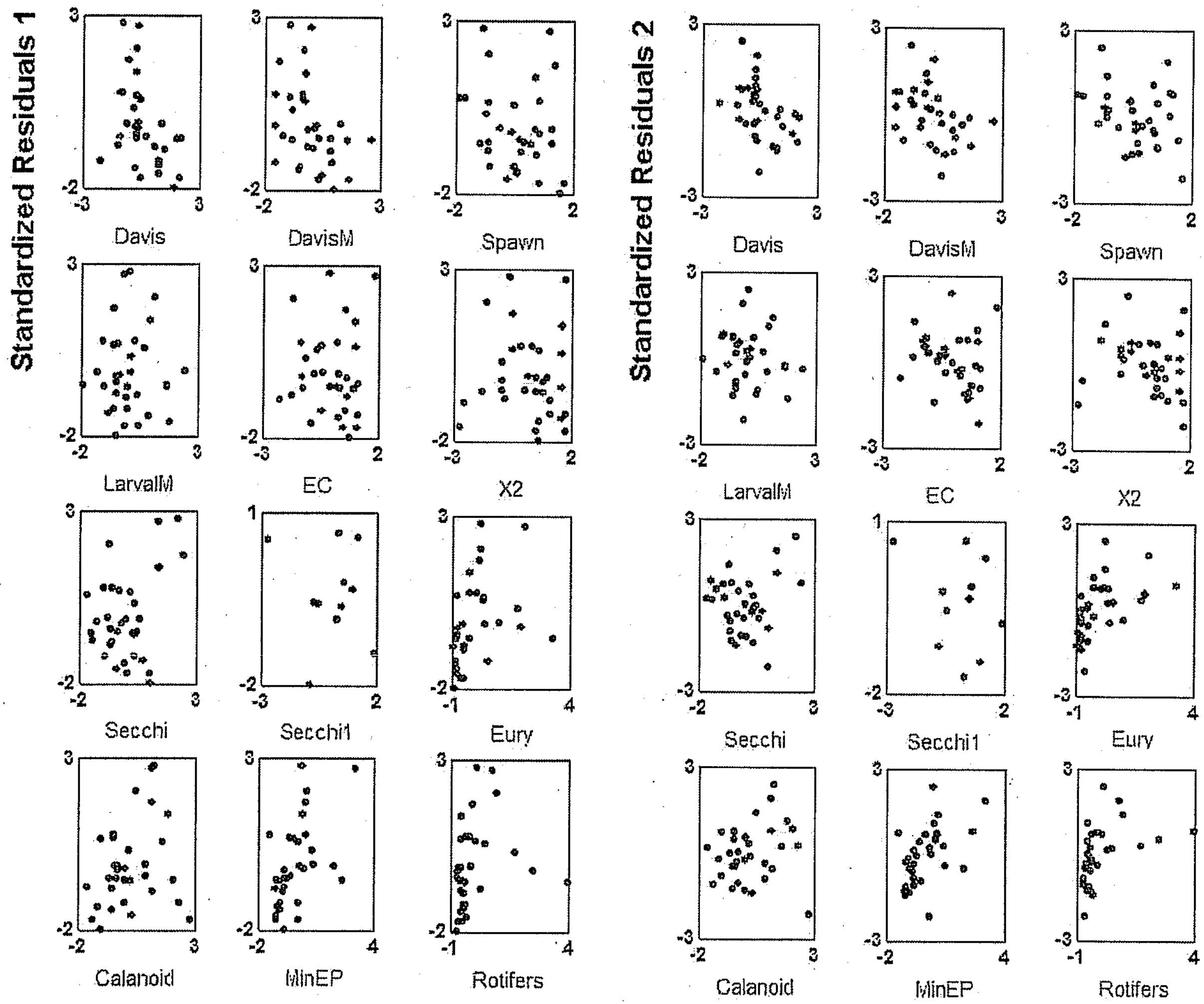


Figure 3.3 Standardized residuals from equation (2.2) are shown on the left-hand side, and the standardized residuals from equation (2.4) are shown on the right-hand side. These residuals are plotted against standardized values of the average July temperature at Davis, the maximum summer temperature at Davis, etc., to see whether there is any indication that the residuals from the equations can be accounted for by variation in the variables considered.

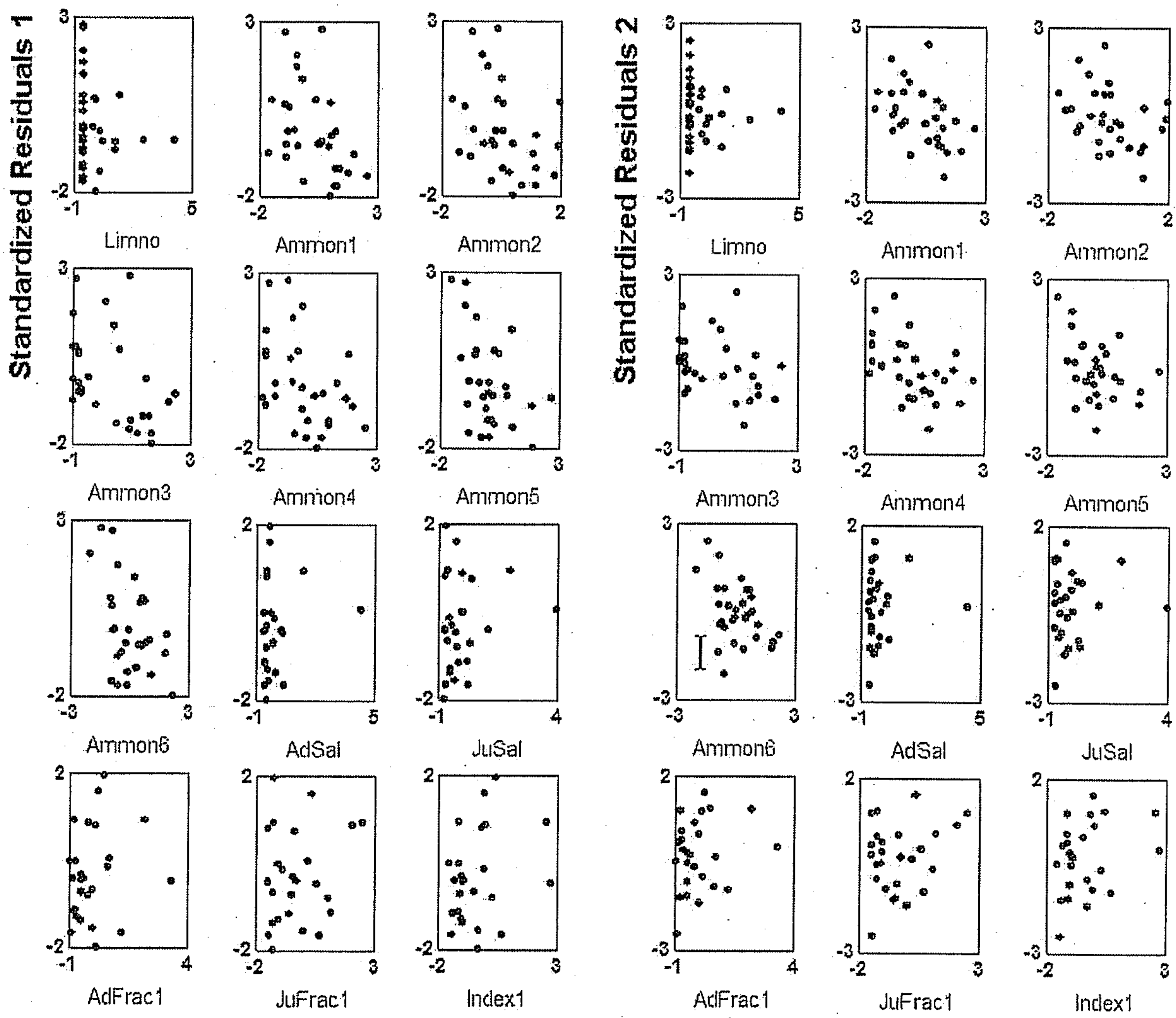


Figure 3.3, Continued.

The residuals are often similar for equations (2.2) and (2.4) in terms of apparent relationships with the variables listed above. In summary the most obvious effects suggested by the plots in Figure 3.3 are that:

! Low residuals tend to occur with high values of Davis and DavisM, i.e. the summer townet abundance tends to be lower than the equations predict when the temperature at Davis is high.

! Low residuals also tend to occur when the number of spawning days is high, but this is clearer for equation (2.4) than for equation (2.2).

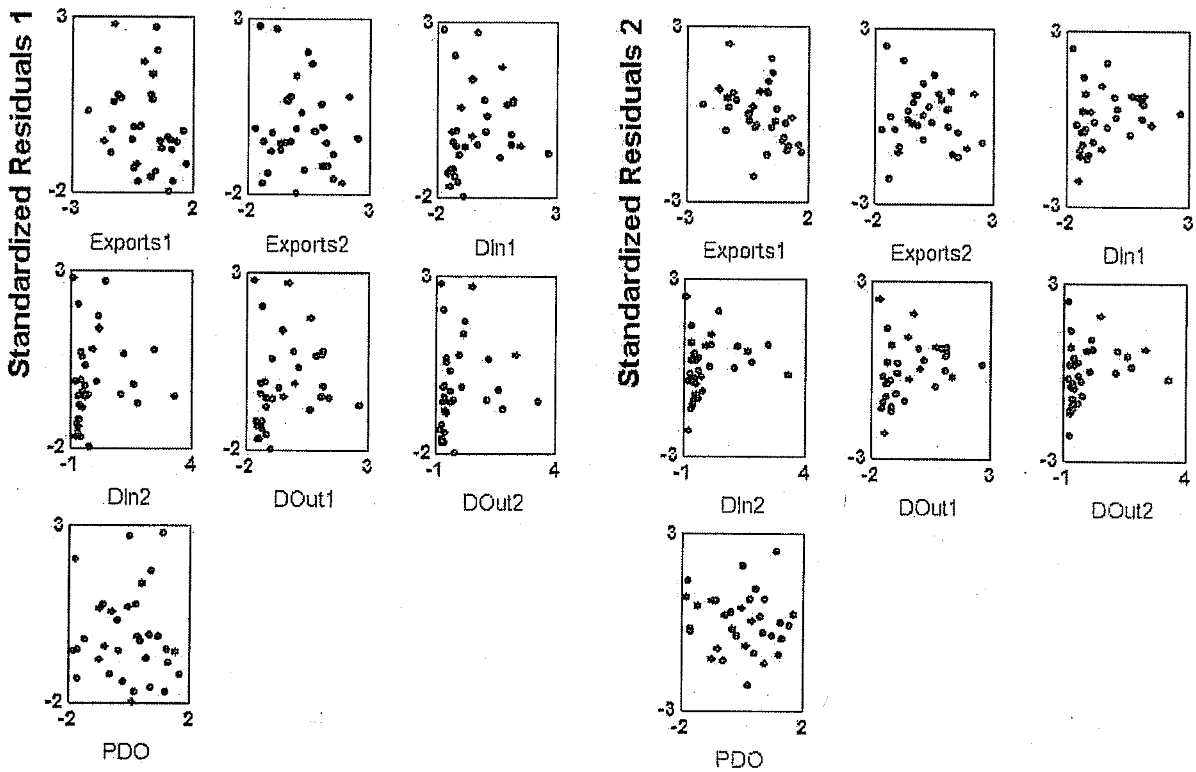


Figure 3.3, Continued.

- Low residuals tend to occur with low values of Eury, i.e. the summer townet abundance tends to be lower than the equations predict when the Eurytemora density is low.

- Low residuals tend to occur with high values for all of the ammonia variables, i.e. the summer townet abundance tends to be lower than the equations predict when ammonia levels are high.

- Low residuals tend to occur with high values for Exports1, i.e., the summer townet abundance tends to be lower than expected when December to March exports are high.

Correlations Between the Other Variables

Figure 3.3 suggests that part of the residual variation in the equations relating logarithms of the Summer Townet abundance indices to logarithms of the Fall Midwater Trawl abundance indices may be accounted for by one or more of the variables described above. However, a possible complication in assessing the importance of different variables in terms of their effects on delta smelt abundance is the correlations that are present between some of the variables.

	Davis	DavisM	Spawn	LarvalM	EC	X2	Secchi	Secchi1	Eury	Calanoid	MinEP	Rotifers	Limno	Ammon1	Ammon2	Ammon3	Ammon4	Ammon5	Ammon6	AdSal	JuSal	AdFrac1	JuFrac1	Index1	Exports1	Exports2	DIn1	DIn2	DOut1	DOut2	PDO
Davis																															
DavisM	0.71																														
Spawn	0.57	0.25																													
LarvalM	-0.32	-0.18	0.14																												
EC	0.42	0.37	0.29	-0.08																											
X2	0.62	0.22	0.21	-0.21	0.54																										
Secchi	0.70	0.62	0.42	-0.50	0.52	0.29																									
Secchi1	-0.05	-0.22	0.32	0.32	-0.35	0.03	-0.35																								
Eury	-0.38	-0.38	-0.64	-0.10	-0.23	-0.07	-0.25	-0.55																							
Calanoid	0.15	0.30	0.18	0.31	-0.10	-0.00	-0.26	0.57	-0.36																						
MinEP	-0.33	-0.33	-0.40	-0.13	-0.72	-0.34	-0.28	-0.22	0.76	-0.19																					
Rotifers	-0.18	-0.16	-0.67	-0.18	0.12	0.06	-0.08	-0.62	0.82	-0.20	0.37																				
Limno	-0.23	0.38	-0.47	-0.19	-0.13	-0.43	-0.02	-0.19	-0.19	0.09	-0.12	0.00																			
Ammon1	0.00	-0.18	0.28	0.49	0.22	0.26	-0.22	0.65	-0.55	0.19	-0.64	-0.47	-0.28																		
Ammon2	0.13	-0.16	0.41	0.30	0.34	0.20	-0.08	0.60	-0.47	0.45	-0.60	-0.24	-0.42	0.76																	
Ammon3	0.66	0.41	0.39	0.09	0.50	0.48	0.27	0.20	-0.54	0.20	-0.68	-0.20	-0.21	0.61	0.61																
Ammon4	0.11	-0.08	0.32	0.47	0.20	0.13	-0.16	0.65	-0.62	0.34	-0.67	-0.40	-0.21	0.92	0.86	0.73															
Ammon5	0.60	0.60	0.45	0.24	0.45	0.38	0.25	0.33	-0.68	0.43	-0.71	-0.44	-0.04	0.64	0.56	0.88	0.71														
Ammon6	0.35	0.05	0.27	-0.28	0.42	0.61	0.26	0.14	-0.35	-0.32	-0.46	-0.39	-0.27	0.54	0.27	0.50	0.34	0.46													
AdSal	0.09	0.34	0.29	0.64	0.36	0.07	-0.11	0.33	-0.41	0.75	-0.52	-0.18	0.03	0.39	0.51	0.30	0.45	0.55	-0.22												
JuSal	-0.53	-0.23	-0.40	0.57	-0.64	-0.52	-0.79	0.17	0.24	0.24	0.42	0.00	0.18	0.07	-0.16	-0.20	0.07	-0.07	-0.37	0.10											
AdFrac1	0.53	0.55	0.27	-0.03	0.55	0.34	0.34	0.04	-0.19	0.59	-0.38	0.10	-0.17	0.14	0.54	0.54	0.28	0.63	0.08	0.59	-0.26										
JuFrac1	-0.30	-0.29	-0.22	0.21	-0.56	-0.45	-0.60	0.34	0.13	0.36	0.34	0.02	-0.06	0.17	0.28	0.09	0.30	0.07	-0.20	-0.03	0.71	0.10									
Index1	0.50	0.45	0.27	-0.06	0.48	0.26	0.31	0.05	-0.15	0.56	-0.32	0.15	-0.23	0.12	0.59	0.54	0.30	0.57	0.03	0.51	-0.25	0.98	0.21								
Exports1	0.34	0.44	0.43	0.26	0.83	0.49	0.27	-0.05	-0.41	0.20	-0.72	-0.24	-0.11	0.40	0.35	0.44	0.29	0.61	0.42	0.65	-0.32	0.54	-0.46	0.41							
Exports2	0.10	0.03	0.27	0.29	-0.26	-0.30	0.05	-0.29	0.35	-0.14	0.54	0.06	-0.42	-0.32	-0.25	-0.11	-0.26	-0.12	-0.33	-0.11	0.34	-0.01	0.27	0.05	-0.19						
DIn1	-0.30	-0.29	-0.36	-0.57	-0.33	-0.50	-0.00	-0.41	0.45	-0.28	0.53	0.44	0.25	-0.74	-0.39	-0.55	-0.59	-0.74	-0.44	-0.59	-0.07	-0.29	0.16	-0.17	-0.67	0.09					
DIn2	-0.06	0.12	-0.51	-0.61	0.04	-0.07	0.33	-0.79	0.60	-0.47	0.43	0.65	0.37	-0.86	-0.74	-0.52	-0.85	-0.63	-0.30	-0.50	-0.28	-0.21	-0.40	-0.21	-0.30	-0.01	0.67				
DOut1	-0.29	-0.29	-0.37	-0.58	-0.35	-0.49	-0.00	-0.41	0.46	-0.29	0.55	0.45	0.24	-0.74	-0.41	-0.55	-0.60	-0.75	-0.45	-0.61	-0.06	-0.30	0.16	-0.18	-0.69	0.10	1.00	0.68			
DOut2	-0.06	0.13	-0.52	-0.62	0.04	-0.06	0.34	-0.77	0.58	-0.46	0.41	0.65	0.39	-0.85	-0.73	-0.52	-0.84	-0.63	-0.30	-0.50	-0.30	-0.20	-0.40	-0.20	-0.30	-0.03	0.67	1.00	0.68		
PDO	0.63	0.53	0.25	-0.63	0.10	0.33	0.57	0.25	-0.36	0.38	-0.16	-0.18	0.10	-0.13	0.16	0.24	-0.01	0.30	0.17	0.02	-0.55	0.51	-0.13	0.50	0.01	-0.33	0.06	0.09	0.06	0.11	

Figure 3.4 Correlations between the 31 predictor variables being considered for the change in delta smelt abundance from fall to the following summer, with the correlations that are significant at the 5% level highlighted.

Figure 3.4 shows the correlations for the 31 variables described above, based, for each pair of variables, on the data for the years where values for both variables exist.

Correlations that are significantly different from zero are highlighted. There are 68 significant correlations out of the 465 correlations shown in the figure.

The significant correlation shown in Figure 3.4 are sometimes expected, such as the positive correlations between most of the ammonia variables and between the Delta inflow and outflow variables. In other cases the correlations are perhaps surprising, such as the high positive correlations between the Davis temperature and X2, the Davis temperature and Secchi, and the high negative correlation between EC and Juvenile salvage. It seems clear that some of the correlations between variables will make it difficult to determine which variables are responsible for changes in delta smelt abundance and which variables are indirectly associated with changes in delta smelt abundance through their correlation with other variables.

Trying Adding Variables with No Missing Values Into the Equations

Data on the STN abundances and the previous FMWT abundances are available for the years 1972 to 2006, excluding 1975 and 1980. For these years values are also available for most of the 31 variables listed above. The exceptions are the Secchi1 variable, all of the ammonia variables, and the salvage related variables. These variables with missing data were therefore temporarily put aside and the other variables were considered for adding to equations (2.2) and (2.4) using the stepwise approach defined in the Methods section. Earlier analyses had suggested that the prey densities might be better expressed as logarithms. For this reason the selection of variables to enter equations included the logarithms Ln(Eury), Ln(Calanoid), Ln(MinEP) and Ln(Rotifers). Zero values for Limno did not permit logarithms to be used with this variable.

First the equation relating Ln(STN) to Ln(FMWT) was estimated. The stepwise selection of variables then led to MinEP, Spawn, Secchi and Secchi^2 being added into the equation. Details of the final equation are shown in Table 3.2, together with details of the equation with the Secchi variables removed. For this equation the Secchi variables are only borderline significant. Just adding Secchi into the equation including MinEP and Spawn does not quite give a significant effect at the 5% level. Adding Secchi^2 into the equation also does not give a significant effect. However, if both Secchi and Secchi^2 are added into the equation together then the effect is significant ($p = 0.029$).

Figure 3.5 shows the observed and the predicted values of Ln(STN) from the estimated equations, together with the standardized residuals. Overall the fit of the equations is good, with the broad trends in the values of Ln(STN) captured, including most of the decline since 1999. The standardized residuals are all within the range from -2 to +2, as expected, but nevertheless indicate systematic deviations between the observed and predicted Ln(STN) values. In particular, the observed values are higher than expected from 1976 to 1979, and are usually lower than expected from 1983 to 1992. No patterns are apparent, however, since 1993.

Table 3.2 Variables selected for the equation relating Ln(STN) to Ln(FMWT), with and without Secchi and $Secchi^2$ included, with t-values, significance levels for coefficients (Sig) and R^2 values.

	Model with Secchi Variables					Model Without Secchi Variables				
	Est	SE	t	Sig	R^2	Est	SE	t	Sig	R^2
Constant	2.643	2.972			0.759	-0.718	1.094			0.687
LnFMWT	0.735	0.160	4.60	0.000		0.537	0.155	3.47	0.002	
	2.136	0.635	3.37	0.002		2.934	0.621	4.72	0.000	
Spawn	-0.029	0.009	-3.23	0.003		-0.025	0.009	-2.65	0.013	
Secchi	-0.162	0.096	-1.68	0.104						
$Secchi^2$	0.002	0.001	1.96	0.060						

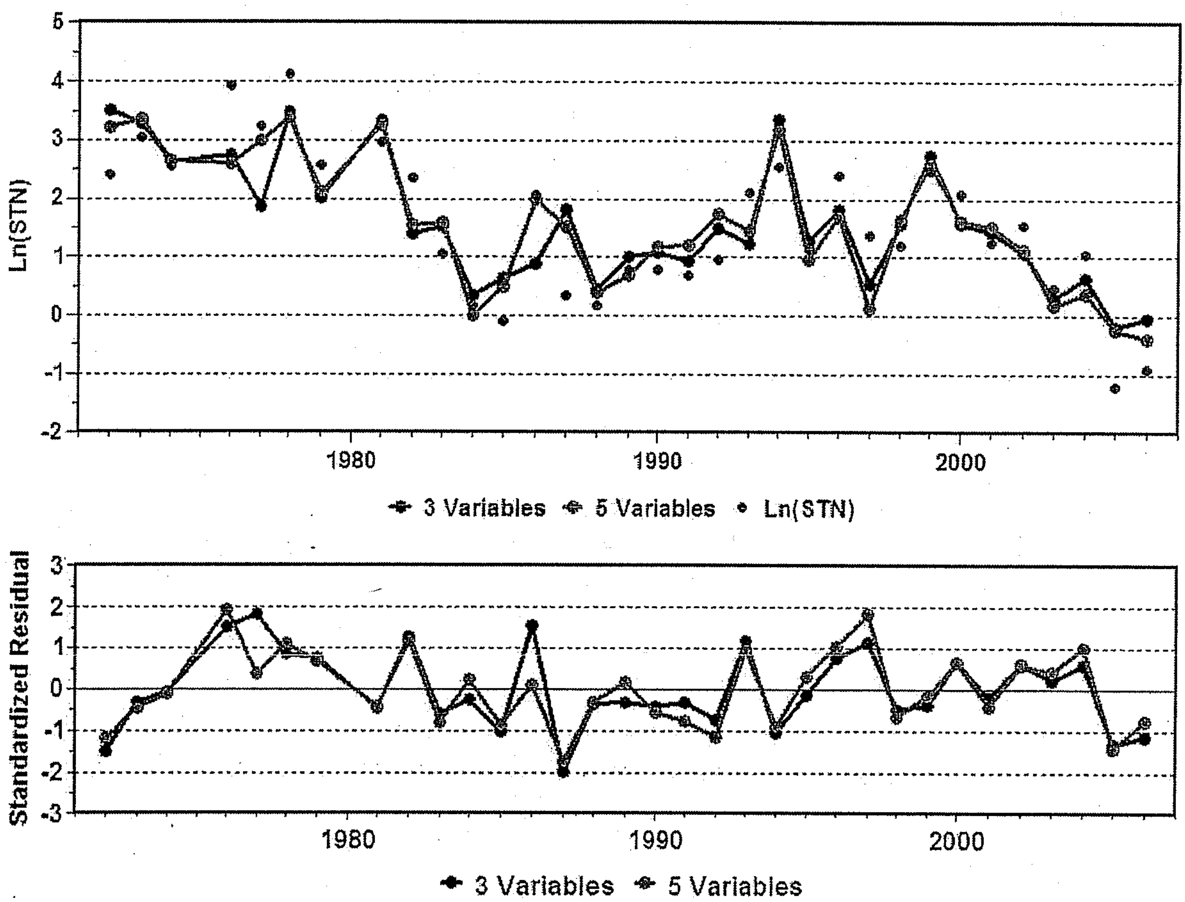


Figure 3.5 The top plot shows the observed values of Ln(STN) and the values predicted from the regression equations of Ln(STN) against Ln(FMWT) and three or five other variables as shown in Table 3.2. The lower plot shows the standardized residuals from the regression equations.

For the equation relating Ln(STN1) to Ln(FMWT) the stepwise selection process led to the equation including the added variables Davis, Ln(Rotifers) and Secchi. Details of the final equation are shown in Table 3.3, while Figure 3.6 shows how the observed and predicted values of Ln(STN1) compare, and the standardized residuals from the estimated equation.

Table 3.3 The variables selected to enter the equation relating Ln(STN1) to Ln(FMWT).

	Est	SE	t	Sig	R^2
Constant	0.077	3.676			0.747
LnFMWT	0.425	0.149	2.85	0.008	
Davis	-0.403	0.114	-3.53	0.001	
	0.845	0.155	5.46	0.000	
Secchi	0.029	0.012	2.46	0.020	

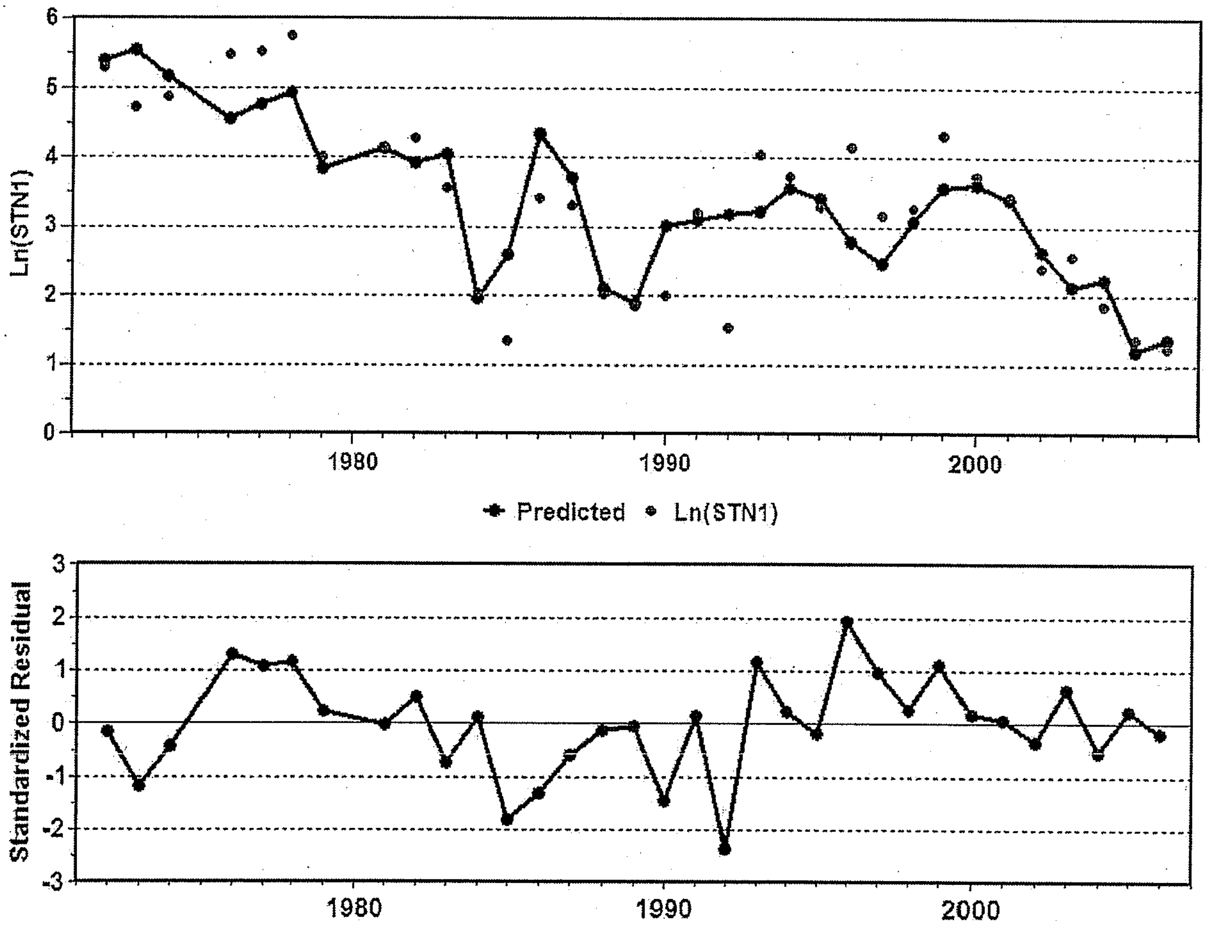


Figure 3.6 The observed and predicted values on Ln(STN1) above, with standardized residuals shown below.

Figure 3.6 shows that again the predicted equation has captured the overall trends in the values of Ln(STN1) since 1972, with the decline since 1999 captured very well. There are, however, distinct patterns in the residuals from the equation, with positive values 1976 to 1979, mostly negative values from 1983 to 1992, and then mostly positive values from 1993 to 1999.

The patterns in residuals shown in Figures 3.5 and 3.6 suggest that these residuals may be serially correlated. This is not the case with the equations for Ln(STN). The three variable equation gives a correlation of zero to two decimal places between the residual for one year and the residual for the next year, and the five variable equation gives a correlation of only 0.02.

The serial correlation between successive residuals is higher with the equation for Ln(STN1) at 0.17. A regression with correlated residuals was therefore considered for this equation, where the residual at time i assumed to be related to the residual at time i - 1 by an equation of the form

$$E_i = \alpha E_{i-1} + U_i$$

where U_1, U_2, etc., are independent random variables with mean zero and the same variance. From this model the estimate of α is $\hat{\alpha} = 0.202$ with standard error 0.196. This is far from being significantly different from zero at the 5% level, so the model with correlated residuals was not considered further.

Trying Adding Ammonia Variables to the Equations

The ammonia variables listed above have values available for the years 1976 to 2006. To investigate whether these variables are important in the relationship between the summer and fall abundances the equations shown in Tables 2.2 and 2.3 were refitted just using the data for 1976 to 2006. The effect of adding each of the variables Ammon1 to Ammon6 into the equations was then examined.

None of the equations were improved significantly or near significantly at the 5% level by adding in any ammonia variable. Hence it was concluded that none of the ammonia variables listed above gives a clear improvement to any of the equations relating the summer delta smelt abundance to the previous fall abundance and other variables.

Trying Adding the Salvage Variables to the Equations

There are five salvage related variables listed above, all with data available for the years 1981 to 2006. These were examined in terms of the value in adding them into the equations relating the summer and fall abundances using a similar approach to the one used for the ammonia variables, but starting with the fall to summer abundance equations estimated using data for the years 1981 to 2006 only.

For the five variable equation relating Ln(STN) to Ln(FMWT) it was found that Index1 made the most significant contribution to this equation, although not significant at the 5% level ($p = 0.061$). Also, the estimated coefficient is positive, indicating that the summer abundance tends to be higher in years where this index of salvage is high.

The three variable equation relating Ln(STN) to Ln(FMWT) gave a similar result, with Index1 making the most significant contribution, this time with the result being significant at the 5% level ($p = 0.037$). The estimated coefficient is still positive.

For the equation relating Ln(STN1) to Ln(FMWT) none of the salvage variables make anything approaching a significant contribution when added to the equation. Overall, therefore the conclusion regarding the salvage variables is that they have little predictive ability in addition to the variables already selected to be in the equations and, if anything just suggest that salvage indices may tend to be high in years of high delta smelt abundance.

The Second Secchi Variable

There are two Secchi variables listed above. The first is the average September to December Secchi depth in the Delta in the year before the Summer Townet surveys. This variable is available for 1972 to 2006 and has been chosen to enter the equations for the summer abundance. The second Secchi variable is an average April to May Secchi depth weighted by delta smelt percentages in different parts of the Delta. This variable is only available for 1995 to 2005, which is considered to be too few years to make it worth analyzing.

4. Conclusions

Two equation for the summer delta smelt abundance have been considered. The first related logarithm of the usual Summer Townet abundance index (STN) to the logarithm of the usual Fall Midwater Trawl abundance index (FMWT), with other variables added to improve the fit of the equation for the available years of data. The final equation found in this case based on variables with no missing years of data includes the minimum April to June Eurytemora plus Pseudo-diaptomus density (MinEP), the number of spawning days (Spawn, based on suitable temperatures), and possibly a quadratic relationship with the average September to December Secchi depth in the Delta.

For this equation the relationship between Ln(STN) and MinEP is positive, as expected, indicating that the summer delta smelt abundance increases with the available amount of food. The relationship with Spawn is, however, negative, which is not expected since more spawning days should be associated with higher abundance.

The negative association of abundance with Spawn may be due to confounding between variables. Figure 3.4 shows that the Spawn variable has significant negative correlations with Eury (the Eurytemora density) and Rotifers (the Rotifer density), plus quite large positive and negative correlations with many other variables, including a correlation of +0.51 with the Davis temperature. Hence high values for the Spawn variable tend to occur when conditions are not expected to be suitable for delta smelt (low food and high temperature). This suggests that the equation found from the analyses described in this report needs to be considered further in terms of what the actual causal factors may be for delta smelt summer abundance.

The Secchi relationship also needs further consideration. The residuals shown in Figure 3.3 tend to decrease as the standardized Secchi value increases from -2, but there are four relatively large positive residuals with high standardized Secchi values. There is therefore some suggestion that high Ln(STN) values are associated with both low and high Secchi values, but this is dependent very much on the four large positive residuals.

Some evidence was found that the equation relating Ln(STN) to Ln(FMWT) is improved by including an index of the delta smelt adult salvage, Index1 = (Adult Salvage)/FMWT/(December to March Exports). However, the estimated coefficient of the index is positive, indicating that the summer delta smelt abundance tend to be higher when the index is high. This may just be because the index is a measure of the summer abundance of delta smelt for the given level of the fall abundance. Also, the Index1 variable involves the FMWT variable, which is already present in the equation through the term Ln(FMWT). This alone makes the apparent effect of Index1 difficult to interpret.

The second summer abundance variable considered was the July Summer Townet abundance index (STN1) calculated by B.J. Miller. Starting with the equation relating Ln(STN1) to Ln(FMWT) it was found that this is improved by adding the Davis temperature, Ln(Rotifers) and Secchi variables. Given these variables in the equation there was no evidence that any other variable is important. As expected the relationship between Ln(STN) and the Davis temperature is negative (high temperatures are unsuitable for delta smelt), and the relationship with Ln(Rotifers) is positive (abundant food is good for delta smelt).

The relationship with Secchi is also positive, which is perhaps not expected. As was the case with the other equation this seems to be due to some extent to four relatively high Ln(STN1) values occurring with the four highest Secchi values (Figure 3.3). A further complication is the high positive and significant correlation of +0.70 between the Secchi variable and the Davis temperature. Both variables are in the equation, with the nature of their effects confounded because of this correlation.

Reference

Miller, W.J.(2008). *Statistical Comparison of Factors Affecting Delta Smelt Abundance.*

Statistical Analyses of Variables Possibly Influencing Delta Smelt Abundance from Summer to Fall

Bryan F.J. Manly
Western EcoSystems Technology Inc.
Cheyenne, Wyoming
bmanly@west-inc.com

Contents

1. Introduction

This report describes statistical analyses of variables that have either been found in the past to be related to the abundance of delta smelt in the fall, have been suggested as possibly important in this respect, or where it is plausible that a relationship exists. These variables and their sources are described by Miller (2008), with the reasons for including them in the analyses reported there. The sources and reasons for including the variables are not repeated here.

A previous report (Manly, 2008) examined changes between the abundance of delta smelt as measured by the Fall Midwater Trawl index (FMWT), based on results of surveys carried out in the Sacramento-San-Joaquin Delta from September to December, and the abundance in the summer as calculated from the Summer Townet surveys carried out in June to August. Two summer abundance indices were considered for this purpose. One is the standard Summer Townet index (STN), while the other is an index of the July abundance (STN1) that is described by Miller (2008). The basic approach used involved starting with equations relating the summer abundances to the fall abundance and then seeing which other variables can be added into these equations to better account for the changes in the summer abundances that have been observed from 1972 to 2006.

The present report uses similar methods but examines changes between the summer abundance of delta smelt as measured by the STN and STN1 indices and the abundance in the fall of the same year as measured by the FMWT index. In this case the analysis begins with two equations relating the fall abundance to STN and STN1 and then sees whether other variables can be added into these equations to better account for the changes in the summer abundances that have been observed from 1972 to 2006.

For the equation that relates the fall abundance to the STN abundance the only variable that is added is the Limnoithona density in August, with a negative effect. Miller (2008) suggests that this may be the result of Limnoithona being a poor source of food with a high abundance making it difficult for delta smelt to find more desirable prey.

For the equation that relates the fall abundance to the STN1 abundance the variables that appear to be most important are the average Eurytemora plus Pseudodiaptomus density in August, with a positive effect, and again the Limnoithona density in August appears with a negative effect.

2. Methods

The analysis begins with an examination of which of the equations

$$\text{FMWT} = A + B.\text{STN} \quad (2.1)$$
$$\text{Ln(FMWT)} = A + B.\text{Ln(STN)} \quad (2.2)$$
$$\text{FMWT} = A + B.\text{STN1} \quad (2.3)$$

and

$$\text{Ln(FMWT)} = A + B.\text{Ln(STN1)} \quad (2.4)$$

best account for the variation in the Fall Midwater Trawl abundance, where the Summer Townet abundance estimates are in the same calendar year as the Fall Midwater Trawl abundance. Equations involving STN and STN1 were considered for further analysis because of the possibility that the better of these two variables in the equations above is not the best when other variables enter the equations.

Following the choice of the best fitting equations involving STN and STN1, the residuals from these equations are plotted against each of the variables that FMWT may be related to. The purpose of this step is just to get some insight into which variables seem useful for adding into the equations. The correlations between these variables are also provided as this gives insight into which variables are measuring more or less the same thing, so that at most one of these variables should be considered for entry into the equations.

The next part of the analysis involved considering all of the potential predictor variables that are available for the years 1972 to 2006 other than 1974 and 1979 (for which there are no FMWT values). These variables were considered first in order to avoid reducing the data because of missing values. They were added into the equation one at a time using a stepwise process that allowed the squares of variables to be entered, using the following steps first for the equation involving STN, and then for the equation involving STN1:

(a) The equation predicting the fall abundance using just the summer abundance was fitted to the data.

(b) The variables without missing values were considered one at a time for being added into the equation. The most significant variable in this respect was then added into the equation providing that it produced a significant improvement in fit at the 5% level.

(c) Having added a variable into the equation the process described in (b) was repeated to see whether a second variable could be added into the equation, but with one modification. In addition to considering each of the variables not already in the equation, the square of the variable already in the equation was also considered for entry. If the square term produced a significant improvement in fit at the 5% level then it was added. Otherwise, the most significant other variable was added providing this produced a significant improvement in the fit of the equation at the 5% level.

(d) Step (c) was repeated until there was no significant variable to add to the equation, always giving preference to adding significant squared terms into the equation rather than adding a new variable.

This process resulted in an equation for FMWT involving STN and another equation for FMWT involving STN1, with both of these equations also including some of the variables with no missing values.

At that point consideration was given to whether the residuals from the selected equations display significant serial correlation. If so, the equations were re-estimated with an allowance for this serial correlation.

Having developed equations based on variables with no missing values other than for 1974 and 1979, consideration was given to whether any of the variables with missing values should be added into the equations, or should replace variables already in the equations. These variables were examined in another stepwise process. First the equations determined from the full set of data were re-estimated using the years with data available for a set of the variables with missing values. For example, the ammonia variables are only available for 1975 onwards. The equations already chosen were therefore re-estimated based only on data from 1975 onwards. The ammonia variables were then examined one at a time for entry into the equation, with squared terms also considered. This showed whether for the reduced data one or more of the ammonia variables would significantly improve the fit of the equations already chosen from the full set of data. There was also the possibility that entering a new variable would make one of the variables already in the equation non-significant, in which case it would be removed.

This process does give precedence to the variables already in the equation with no missing values. This is considered to be appropriate because of the desire to have equations that predict the fall delta smelt abundance for as many years as possible.

The intended outcome of this rather complicated selection process were equations for the fall abundance using either STN or STN1 that give a good fit to the data, ideally for all of the years from 1972 to 2006 except 1974 and 1979.

Table 3.1 shows the proportion of the variation in the data (R^2) accounted for by each of the equation (2.1) to (2.4)., when fitted to the FMWT values for 1972 to 2006. The best fitting equation is (2.4) which relates Ln(FMWT) to Ln(STN1), with R^2 = 0.383. Both equations with logarithms give much better results than those without using logarithms, so there is little point in considering the equations without logarithms any further.

Table 3.1 Comparative fits of equations (2.1) to (2.4)

Dependent	Predictor	R^2	Significance
FMWT	STN	0.036	0.292
Ln(FMWT	Ln(STN)	0.302	0.001
FMWT	STN1	0.103	0.068
Ln(FMWT)	Ln(STN1)	0.383	0.000

Figure 3.1 shows the observed and predicted values of Ln(FMWT) based on equation (2.2). The relationship between Ln(FMWT) and Ln(STN) is clear but it is interesting to note that the observed values of Ln(FMWT) in 2004, 2005 and 2006 are quite low in comparison to the predicted values.

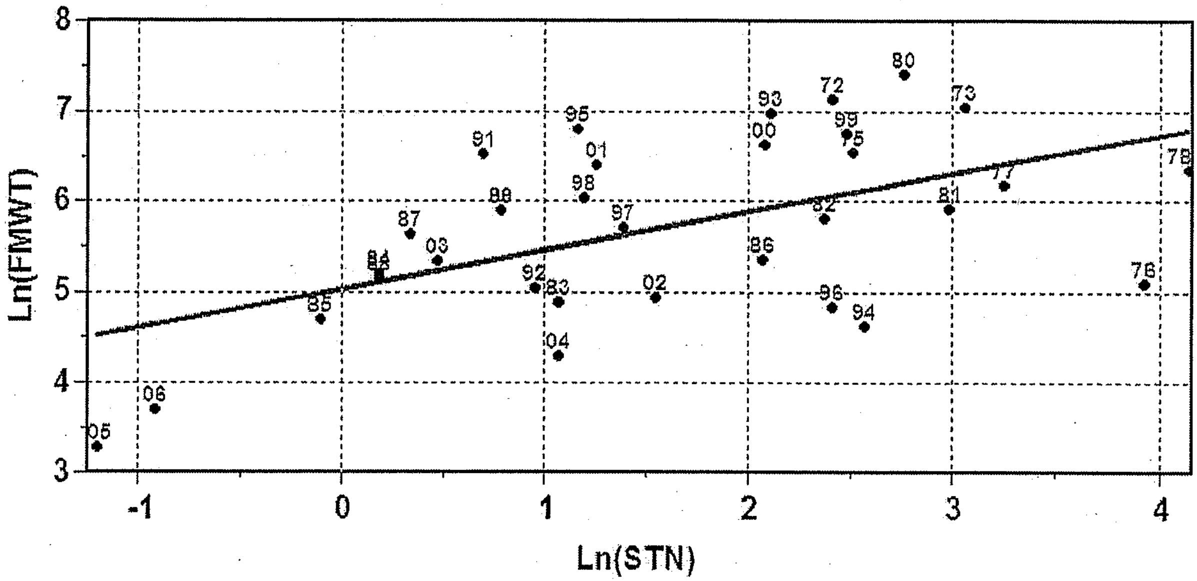


Figure 3.1 The observed (•) and predicted (—) values of Ln(FMWT) plotted against the observed Ln(STN) values for equation (2.2) with $R^2 = 0.302$. The years are also shown for the observed values of Ln(FMWT).

Figure 3.2 is similar to Figure 3.1 but is for equation (2.4) relating Ln(FMWT) to Ln(STN1). The fit is better for this equation but the observed Ln(FMWT) values for 2004, 2005 and 2006 are still lower that the values predicted from the equation.

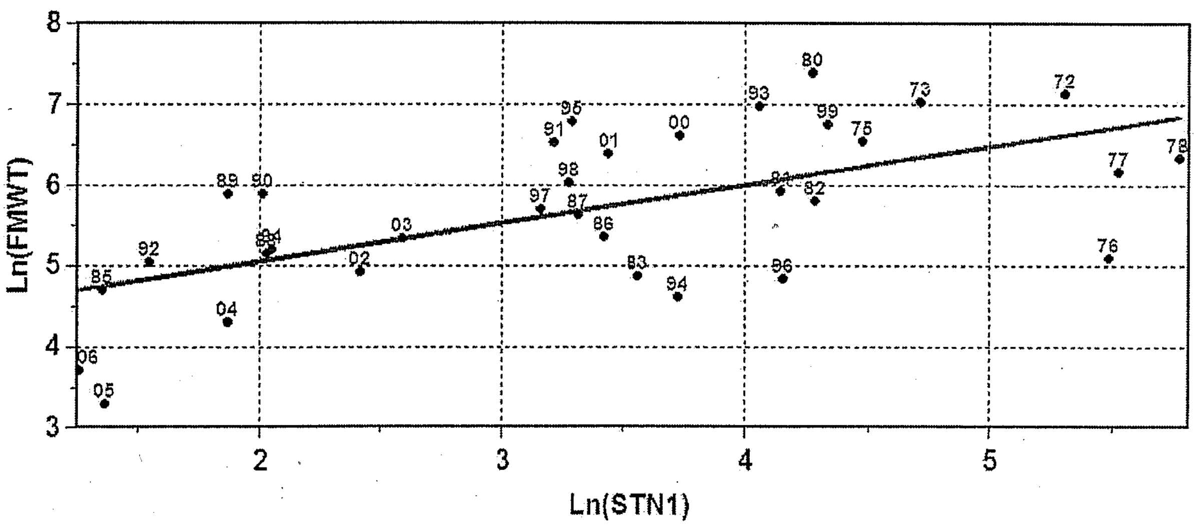


Figure 3.2 The observed (•) and predicted (—) values of Ln(FMWT) plotted against the observed Ln(STN1) values for equation (2.4) with $R^2 = 0.383$. The years are also shown for the observed values of Ln(FMWT).

Variables Considered for Adding Into the Equations

The variables that are available for adding to the equation relating the FMWT abundance to the summer abundances are listed below, with the abbreviated names that will be used in the remainder of this report. Miller (2008) gives details of why these variables have been selected for use, and how the values for the variables were obtained.

EC	The September to December Electro-conductivity (micro-siemens/cm).
X2	The September to December average distance of the 2 ppt line from Golden Gate (km).
Secchi	The average September to December Secchi depth (cm).
AvgEPJ	The average Eurytemora + Pseudo-diaptomus density in July (number/m^3).
AvgEPA	The average Eurytemora + Pseudo-diaptomus density in August (number/m^3).
AvgLimJ	The average Limnoithona density in July (number/m^3).
AvgLimA	The average Limnoithona density in August (number/m^3).
AvgCalJ	The average calanoid copepod density in July (number/m^3).
AvgCalA	The average calanoid copepod density in August (number/m^3).
AvgZooJ	The average zooplankton biomass density in July (mcg of carbon/m^3).
AvgZooA	The average zooplankton biomass density in August (mcg of carbon/m^3).
MaxDavis	The maximum 15-day back average air temperature at Davis in July or August (EC).
AvgDavis	The average 15-day back average air temperature at Davis for July to August (EC).
AvgHood	The average September to December ammonia at Hood (mg/L).
MaxHood	The maximum average monthly ammonia at Hood for September to December (mg/L).
Discharge	The discharge of ammonia from the Sacramento Regional Wastewater Treatment Plant from August to October (tons).

Most of these variables have values for all the years 1972 to 2006, although the absence of the FMWT index in 1974 and 1979 means that these years cannot be considered anyway. For the years with FMWT values there are missing values for the ammonia variables for 1972, 1973 and 1974, and missing values in 1988 for AvgEPJ, AvgLimJ, AvgCalJ and AvhZooJ.

Plots of Regression Residuals Against the Other Variables

To examine whether any of the variables listed above can account for some of the variation in Ln(FMWT) remaining after allowing for the summer abundance these variables were first standardized to have means of zero and standard deviations of one for 1972 to 2006. The standardized residuals from equations (2.2) and (2.4) were then plotted against these standardized variables, as shown in Figure 3.3.

There are no very clear relationships between the regression residuals and the other variables but the following patterns can be noted:

- The residuals tend to be positive for low values of EC and Secchi, suggesting that low values of EC and Secchi are associated with fall abundances that are higher than would otherwise be expected.

- The residuals tend to be positive for high values of AvgEPA and AvgCalA suggesting that high values of these potential food variables are associated with fall abundances that are higher than would otherwise be expected.

Correlations Between the Other Variables

A possible complication with assessing the importance of different variables in terms of their effects on delta smelt abundance is the correlations that are present between some of these variables. Figure 3.4 shows these correlations for the 16 variables listed above, with significant correlations highlighted.

There are 120 correlations shown in Figure 3.4, with 44 of these significantly different from zero at the 5% level. There are significant positive correlations between EC and X2, Secchi, AvgHood and MaxHood, many significant positive and negative correlations between the potential food variables, significant positive correlations between the Davis temperature variables and some of the potential food variables, and Discharge has significant positive correlations with the Hood ammonia variables and the Limnoithona variables and a significant negative correlation with AvgCalJ.

The many high positive and negative correlations indicate that separating the effects of different variables on delta smelt abundance is not simple, with many potential confounding effects being possible.

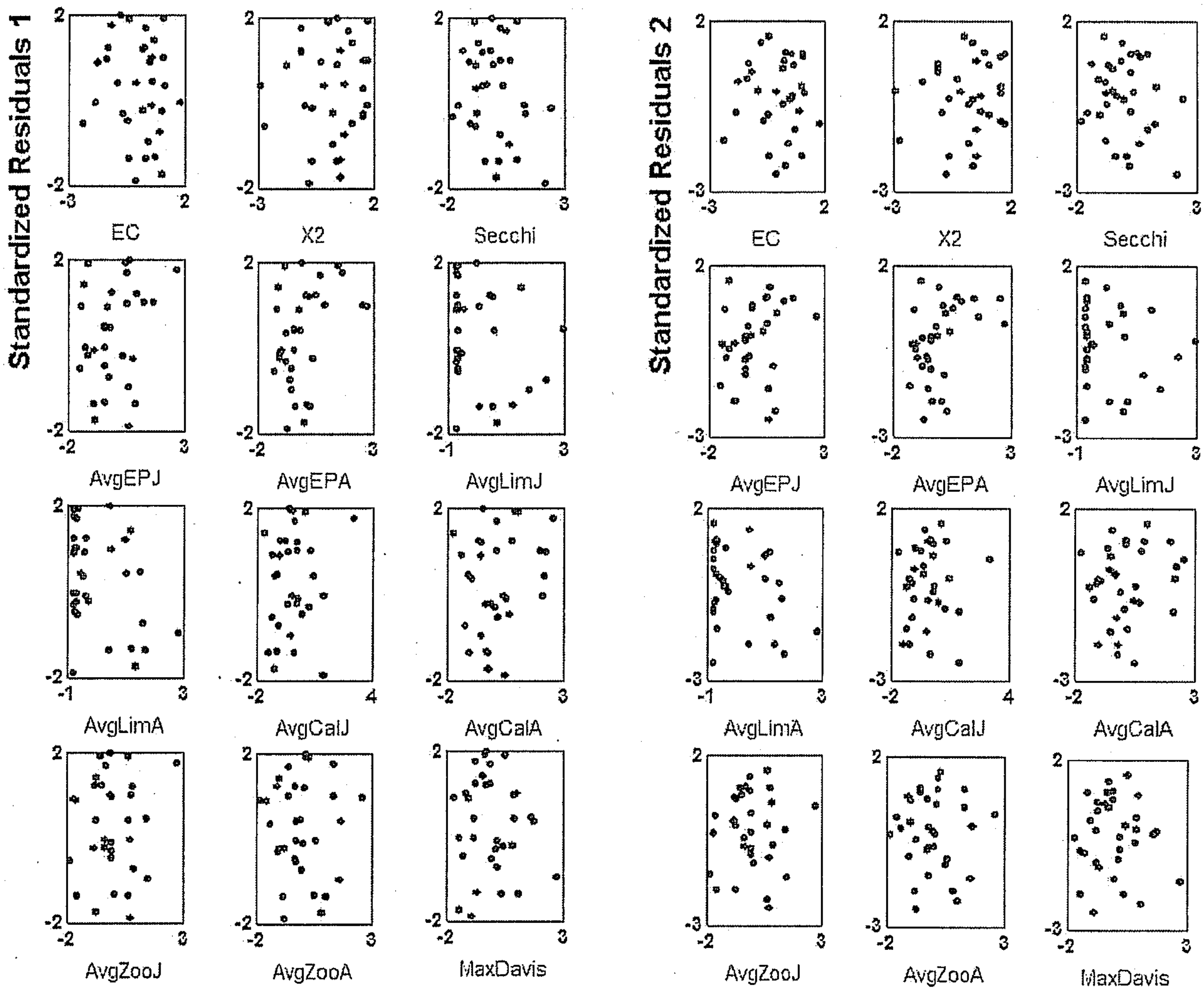


Figure 3.3 Standardized residuals from equations (2.2) are shown on the left-hand side and standardized residuals from equation (2.4) are shown on the right-hand side. These standardized residuals are plotted against standardized values of the variables listed above in the text to see whether there is any indication that some of the variation in the fall abundance can be accounted for by one or more of the variables.

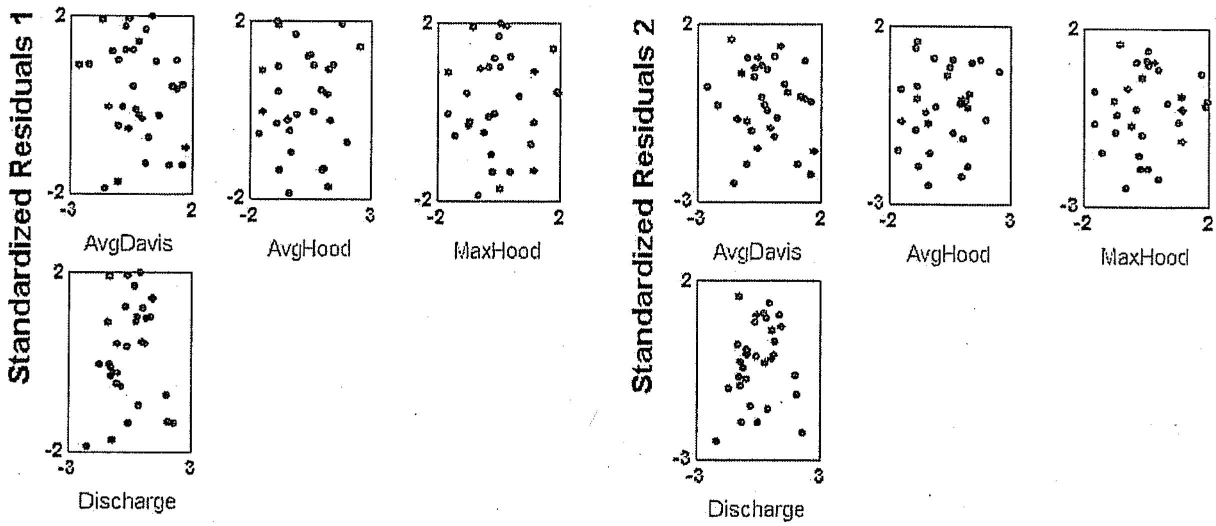


Figure 3.3, Continued.

	EC	X2	Secchi	AvgEPJ	AvgEPA	AvgLimJ	AvgLimA	AvgCalJ	AvgCalA	AvgZooJ	AvgZooA	MaxDavis	AvgDavis	AvgHood	MaxHood	Discharge
EC																
X2	0.72															
Secchi	0.62	0.23														
AvgEPJ	0.22	0.35	0.23													
AvgEPA	0.16	0.31	0.11	0.70												
AvgLimJ	0.30	0.12	0.02	-0.04	-0.09											
AvgLimA	0.24	0.04	0.04	0.04	-0.03	0.88										
AvgCalJ	0.09	0.10	0.22	0.46	0.15	-0.52	-0.47									
AvgCalA	-0.12	-0.07	0.05	0.28	0.47	-0.56	-0.48	0.74								
AvgZooJ	0.34	0.20	0.21	0.47	0.16	0.39	0.35	0.56	0.30							
AvgZooA	0.01	-0.09	0.05	0.32	0.51	0.19	0.38	0.28	0.61	0.56						
MaxDavis	0.07	-0.04	0.02	0.25	0.07	0.36	0.41	0.04	-0.01	0.44	0.36					
AvgDavis	0.22	0.15	0.11	0.32	0.19	0.44	0.49	-0.08	-0.07	0.35	0.39	0.80				
AvgHood	0.83	0.61	0.41	0.11	0.17	0.47	0.36	-0.28	-0.36	0.12	-0.07	-0.06	0.17			
MaxHood	0.64	0.49	0.33	-0.00	0.04	0.64	0.51	-0.47	-0.55	0.09	-0.12	0.04	0.30	0.83		
Discharge	0.23	0.22	-0.03	0.26	0.34	0.63	0.66	-0.45	-0.35	0.18	0.29	0.24	0.46	0.50	0.59	

Figure 3.4 Correlations between the 19 predictor variables being considered for the change in delta smelt abundance between the summer and fall, with correlations that are significant at the 5% level highlighted.

Trying Adding Variables with No Missing Values Into Equations

The variables EC, X2, Secchi, the August food variables (AvgEPA, AvgLimA, AvgCalA, and Avg ZooA), and the Davis temperature variables either have values available for all years 1972 to 2006, or are only missing values in 1974 and 1979 when no FMWT values are available. These nine variables are therefore the ones with no missing values as far as the equations relating the fall abundance to the summer abundances are concerned.

The stepwise process labeled (a) to (d) that is described above was applied with these nine variables, first starting with the equation relating Ln(FMWT) to Ln(STN), and then starting with the equation relating Ln(FMWT) to Ln(STN1).

The equation relating Ln(FMWT) to Ln(STN) has R^2 = 0.302 (Table 3.1). The stepwise selection of variables with no missing values first selected AvgLimA for entry into the equation, raising R^2 to 0.408. Next AvgEPA was considered for entry, but this did not significantly improve the equation. Therefore, only AvgLimA was added into this equation. Details of the final equation are shown in Table 3.2.

Table 3.2 The equation relating Ln(FMWT) to Ln(STN) after the stepwise process for adding variables with no missing values.

Coefficient for	Est	SE	t	Sig	R^2
Constant	5.528	0.308			0.408
Ln(STN)	0.303	0.122	2.49	0.019	
AvgLimA/1000	-0.380	0.164	-2.32	0.027	

The equation relating Ln(FMWT) to Ln(STN1) has R^2 = 0.383 (Table 3.1). In this case the stepwise selection of variables led first to AvgEPA entering the equation, increasing R^2 to 0.477, and then AvgLimA entering, increasing R^2 to 0.542. The effect of AvgLimA is not quite significant at the 5% level, and no other variable could be added into the equation to give a further significant improvement in the fit. Table 3.3 shows the final equation. AvGLimA is retained in the equation because it is so close to being significant at the 5% level.

Table 3.3 The equation relating Ln(FMWT) to Ln(STN1) after the stepwise process for adding variables with no missing values.

Coefficient for	Est	SE	t	Sig	R^2
Constant	4.186	0.514			0.542
Ln(STN1)	0.407	0.109	3.73	0.001	
AvgEPA/1000	0.311	0.147	2.12	0.043	
AvgLimA/1000	-0.297	0.147	-2.02	0.053	

Figure 3.5 shows the observed and predicted values of Ln(FMWT) from the estimated equations, together with the standardized regression residuals. Overall the fit of the equations is reasonable, with the broad trends in Ln(FMWT) captured, and it is interesting to note that the equation including Ln(STN1) gives almost exactly the observed Ln(FMWT) values for the first and last years of observations (1972 and 2006).

The standardized regression residuals are within the range from -2 to +2, with one exception, which is what is desirable for regression equations that fit well. There are, however, some patterns in the residuals that indicate the possibility of an important variable being missing from the equations. In particular the residuals are mostly negative from 1981 to 1989, mostly positive from 1997 to 2001, and negative since 2004.

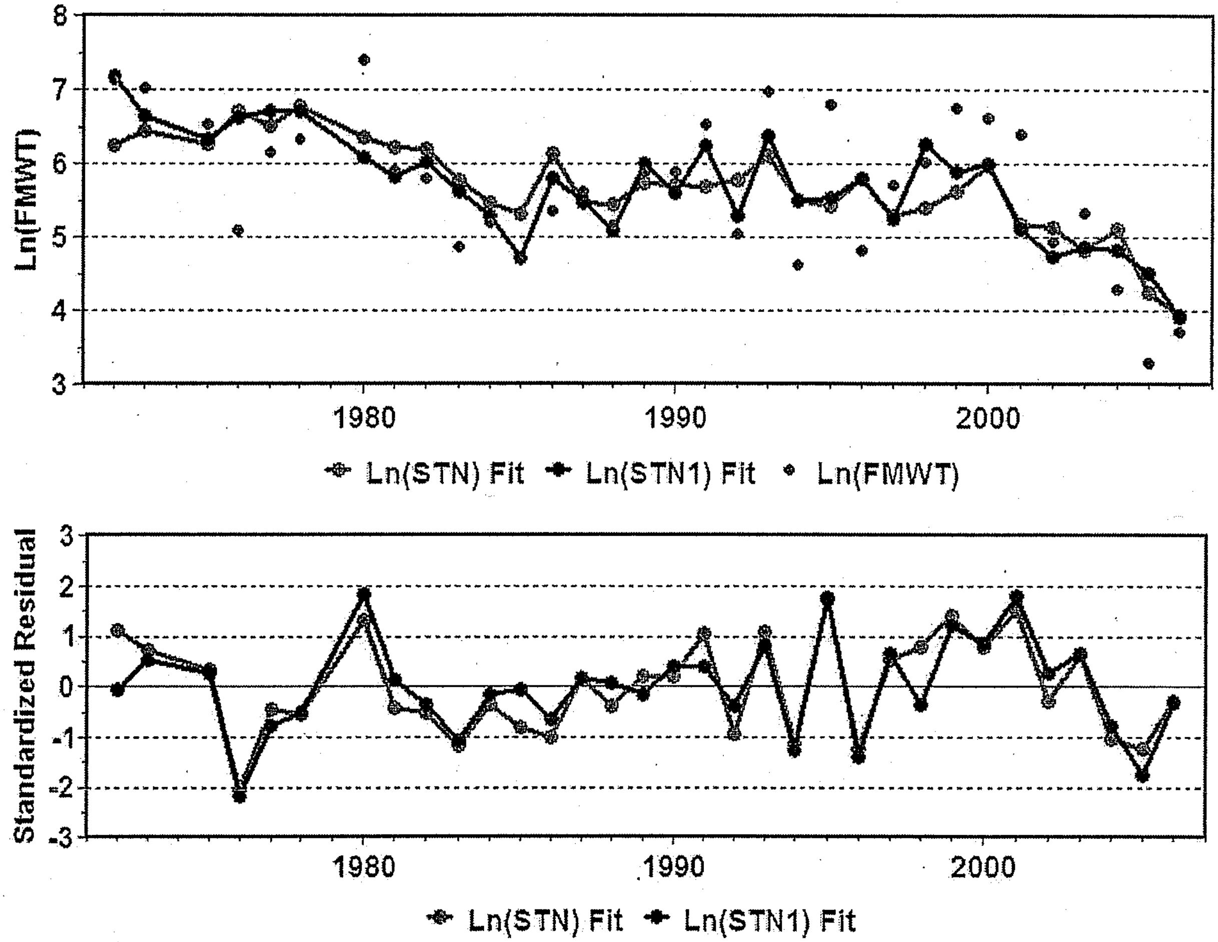


Figure 3.5 The top plot shows the observed values of Ln(FMWT) and the values predicted from the equation including Ln(STN) and the equation including Ln(STN1). The lower plot shows the standardized regression residuals from these equations.

Serial correlation between successive regression residuals is not the cause of these patterns. The observed correlation between each regression residual and the one in the following year is only 0.03 for both equations.

Trying Adding July Food Variables Into the Equation

The variables AvgEPJ, AvgLimJ, AvgCalJ and AvgZooJ represent potential delta smelt food in July. Values for these variables are available for all years except 1988. To examine possible effects of these variables the equations relating the fall to summer delta smelt abundances shown in Tables 3.2 and 3.3 were re-estimated with data for 1988 removed and consideration was given to adding one of the July food variables into the equation.

For the equation relating Ln(FMWT) to Ln(STN) the variable AvgEPJ gave the best improvement in fit but this is far from significant at the 5% level ($p = 0.242$). No variable was therefore added to this equation. For the equation relating Ln(FMWT) to Ln(STN1) the variable AvgLinJ gave the best improvement in fit but this was not significant at the 5% level (p = 0.095). No variable was therefore added to this equation either.

It was concluded that there is no point in adding any of the July food variables into either of the equations already obtained for relating the fall abundance to summer abundances.

Trying Adding Ammonia Variables Into the Equation

The ammonia variables AvgHood, MaxHood and Discharge have known values for all years except 1972 to 1974. The equations relating the fall to summer delta smelt abundances shown in Tables 3.2 and 3.3 were therefore re-estimated with data for these three years removed, and consideration given to adding ammonia variables into the equations.

For the equation relating Ln(FMWT) to Ln(STN) the variable Discharge gave the best improvement in fit but this is not significant at the 5% level (p = 0.066). This variables was therefore not added into the equation, although there might be considered borderline evidence that the variable is important. The estimated coefficient of Discharge is, however, positive, suggesting that higher discharges of ammonia tend to increase delta smelt numbers, which is perhaps unlikely.

For the equation relating Ln(FMWT) to Ln(STN1) the variable Discharge again gave the best improvement in fit but this was again not significant at the 5% level (p = 0.099), and again has a positive estimated coefficient. No variable was therefore added to this equation either.

It was concluded that there is little point in adding any of the ammonia variables into either of the equations already obtained for relating the fall abundance to summer abundances.

4. Conclusions

The equations shown in Table 3.2 and 3.3 appear to be the best based on the variables available, and conditional on the logarithm of the summer delta smelt abundance being included in equations.

The equation including Ln(STN) shown in Table 3.2 includes the variable AvgLimA, which is the average Limnoithona density in August, but with a negative coefficient. Miller (2008) suggests that the negative effect may be due to Limnoithona being a poor source of food for delta smelt and the recent high abundance of this species making it difficult for delta smelt to find alternative prey species.

The equation including Ln(STN1) shown in Table 3.3 also includes the variable AvgEPA, which is the August density of Eurytemora plus Pseudodiaptomus, with a positive coefficient, indicating that the abundance of delta smelt is related to the abundance of these prey species. The equation also includes the August density of Limnoithona density with a negative sign, again suggesting an undesirable effect when this species is very abundant.

References

Manly, B.F.J. (2008). *Statistical Analyses of Variables Possibly Influencing Delta Smelt Abundance from Fall to Summer.* Western EcoSystems Technology Inc. report dated 31 July 2008 (FMWT-STN.pdf).

Miller, W.J.(2008). *Statistical Comparison of Factors Affecting Delta Smelt Abundance.*

Attachment 2

DOCUMENTATION OF POTENTIAL ENTRAINMENT INDEX

Potential Entrainment Index

The Potential Entrainment Index (PEI) is a methodology developed by California Department of Water Resources (DWR) to predict larval and juvenile delta smelt entrainment. The PEI value represents an estimated percentage of the total population of delta smelt that would be entrained over a given time period. This approach improves upon previous applications of the PTM because it attempts to quantify the effects of export operations on the delta smelt population. The PEI values are derived from near real-time hydrodynamic conditions and delta smelt distribution. Relationships between particle entrainment and hydrodynamics at various geographic locations derived from PTM runs are the basis for calculating the PEI. Simulations with the PEI have successfully reconstructed historical salvage seasonal patterns and peaks, suggesting it can be a useful tool to determine effective water management actions such as maintaining larval and juvenile delta smelt entrainment below a specified level or estimating the effects of water management actions on larval and juvenile delta smelt entrainment.

Particle Tracking Model

The PTM is a model developed by DWR to simulate the transport and fate of individual "particles" traveling throughout the Delta. The PTM uses velocity, flow, and depth output from DWR's one-dimensional hydrodynamic model for the Delta, Delta Simulation Model 2 (DSM2) as input. More information on the PTM and DSM2 can be found at DWR's Delta Modeling Section website (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/index.cfm).

To track the fate of particles in PTM, a group of particles is injected during a simulation at any node in the DSM2 grid. These particles are tracked individually through each time step, with their ultimate fate recorded. Ultimate particle fates could include entrainment through CVP/SWP export pumps, entrainment through other in-Delta diversions, or transit beyond the DSM2 grid boundary as outflow. Particles are assumed to be neutrally buoyant. For this application the PTM to fish species, phenomenon such as behavior, predation, and mortality are not simulated.

20-mm Survey

The 20-mm survey is a fish monitoring study conducted by DFG, beginning in 1995 and continuing through the present. The 20-mm survey monitors postlarval-juvenile delta smelt distribution and relative abundance throughout their historical spring range in the Delta.

The 20-mm survey occurs from 8 to 10 times a year, at a frequency of every two weeks. Survey stations are sampled throughout the Delta and downstream to the eastern portion of San Pablo Bay and Napa River (Figure 1). Samples are collected using an egg and larval rigid opening net, constructed of 1,600 μm mesh. The survey reports sampling results within 72 hours, including the distribution and relative abundance of delta smelt throughout the delta.

PEI Development

The first step to develop the PEI was to determine relationships between hydrodynamics and particle entrainment at the CVP/SWP export pumps for several of the 20mm Survey sampling sites. This was accomplished by running the PTM using historical DSM2 simulation as input and injecting particles at 20-mm survey stations. The historical DSM2 simulation is a DSM2 simulation using historical Delta inflows, Delta exports, and barrier/gate operations as input, with the intention of reflecting actual Delta hydrodynamic conditions.

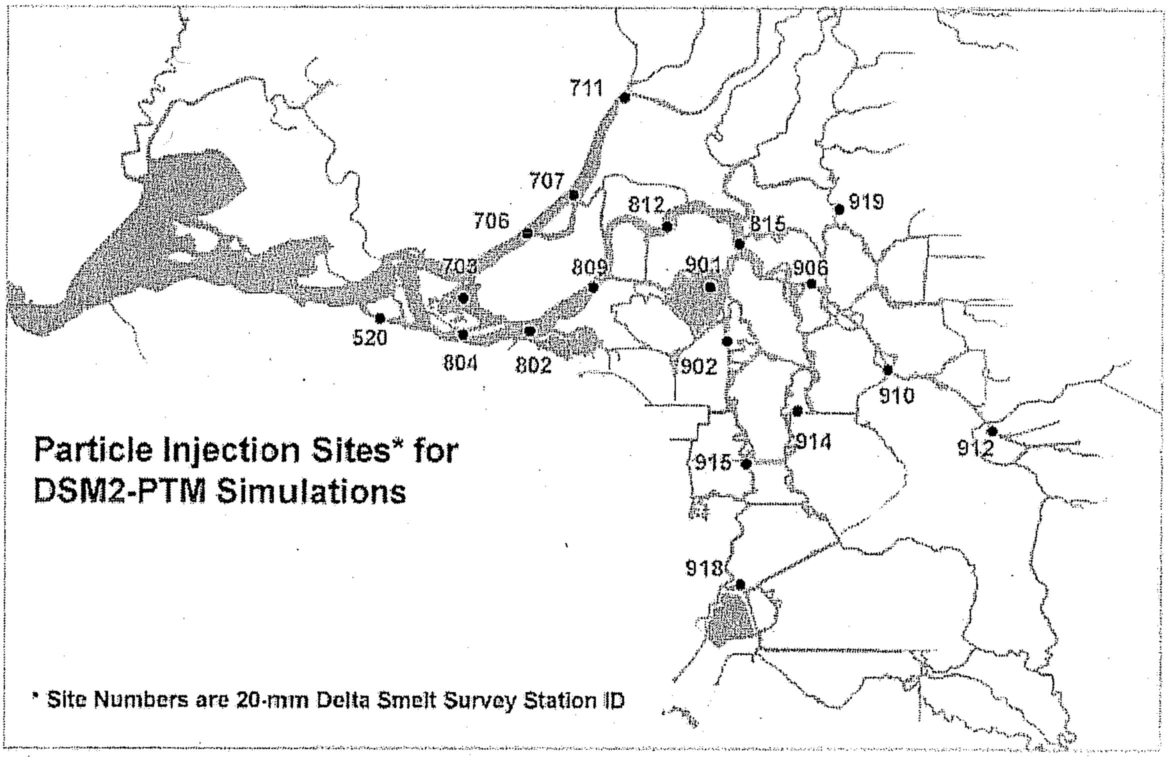


Figure 1. . Select 20-mm survey locations and particle injection sites.

One thousand particles were injected at 20-mm survey stations on the midpoint date of each historical 20-mm survey from 1995 to 2005 (**Table 1**). Surveys initiated after the end of June were not included in the analysis. Additionally, survey stations that have not detected delta smelt were omitted (**Table 2**). The source and fate of each particle was tracked over simulations lasting for10, 20, 30, and 40 days

Table 1. Start and end dates of historical 20-mm surveys

Year	Survey	Start Date	End Date	Year	Survey	Start Date	End Date
1995	1	4/24/95	4/28/95	2001	1	3/19/01	3/24/01
	2	5/8/95	5/12/95		2	4/2/01	4/7/01
	3	5/22/95	5/26/95		3	4/16/01	4/21/01
	4	6/5/95	6/9/95		4	4/30/01	5/7/01
	5	6/19/95	6/24/95		5	5/14/01	5/19/01
1996	1	4/10/96	4/17/96		6	5/29/01	6/4/01
	2	4/24/96	4/30/96		7	6/11/01	6/16/01
	3	5/9/96	5/14/96		8	6/25/01	6/30/01
	4	5/21/96	5/29/96	2002	1	3/18/02	3/23/02
	5	6/8/96	6/14/96		2	4/2/02	4/7/02
	6	6/24/96	6/29/96		3	4/15/02	4/20/02
1997	1	3/31/97	4/5/97		4	4/29/02	5/4/02
	2	4/14/97	4/19/97		5	5/13/02	5/18/02
	3	4/28/97	5/3/97		6	5/28/02	6/2/02

Year	Survey	Start Date	End Date	Year	Survey	Start Date	End Date
	4	5/12/97	5/17/97		7	6/10/02	6/15/02
	5	5/27/97	6/1/97		8	6/24/02	6/29/02
	6	6/9/97	6/14/97	2003	1	3/24/03	3/29/03
	7	6/24/97	6/29/97		2	4/7/03	4/12/03
1998	1	4/6/98	4/11/98		3	4/21/03	4/26/03
	2	4/21/98	4/25/98		4	5/5/03	5/10/03
	3	5/4/98	5/9/98		5	5/19/03	5/24/03
	4	5/18/98	5/23/98		6	6/2/03	6/7/03
	5	6/1/98	6/6/98		7	6/16/03	6/21/03
	6	6/15/98	6/20/98		8	6/30/03	7/3/03
	7	6/28/98	7/3/98	2004	1	3/29/04	4/3/04
1999	1	4/12/99	4/17/99		2	4/12/04	4/17/04
	2	4/26/99	5/1/99		3	4/26/04	4/30/04
	3	5/10/99	5/15/99		4	5/10/04	5/15/04
	4	5/23/99	5/28/99		5	5/24/04	5/28/04
	5	6/7/99	6/12/99		6	6/7/04	6/12/04
	6	6/21/99	6/26/99		7	6/21/04	6/25/04
2000	1	3/20/00	3/25/00	2005	1	3/14/05	3/19/05
	2	4/3/00	4/8/00		2	3/28/05	4/2/05
	3	4/17/00	4/22/00		3	4/11/05	4/16/05
	4	5/1/00	5/5/00		4	4/25/05	4/29/05
	5	5/15/00	5/19/00		5	5/9/05	5/13/05
	6	5/29/00	6/2/00		6	5/23/05	5/27/05
	7	6/12/00	6/17/00		7	6/6/05	6/11/05
	8	6/26/00	6/30/00		8	6/20/05	6/24/05

For each sampling station and simulation duration, regression models were used to describe the relationship between the percentage of particles entrained and either OMR flow or QWEST (**Figure 2**, **Figure 3**, and **Figure 4**). Potential entrainment was better predicted based on Qwest for survey stations west of the confluence of the San Joaquin and Sacramento rivers (see **Figure 5**).

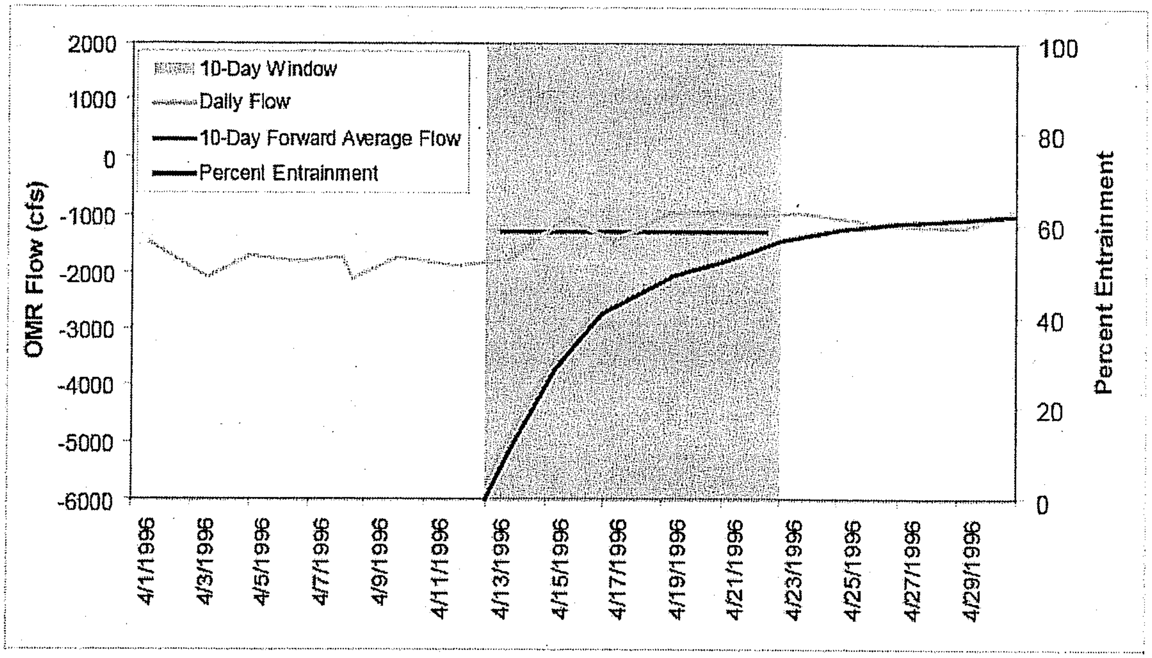


Figure 2. . Example of cumulative PEI calculation and averaged hydrology.

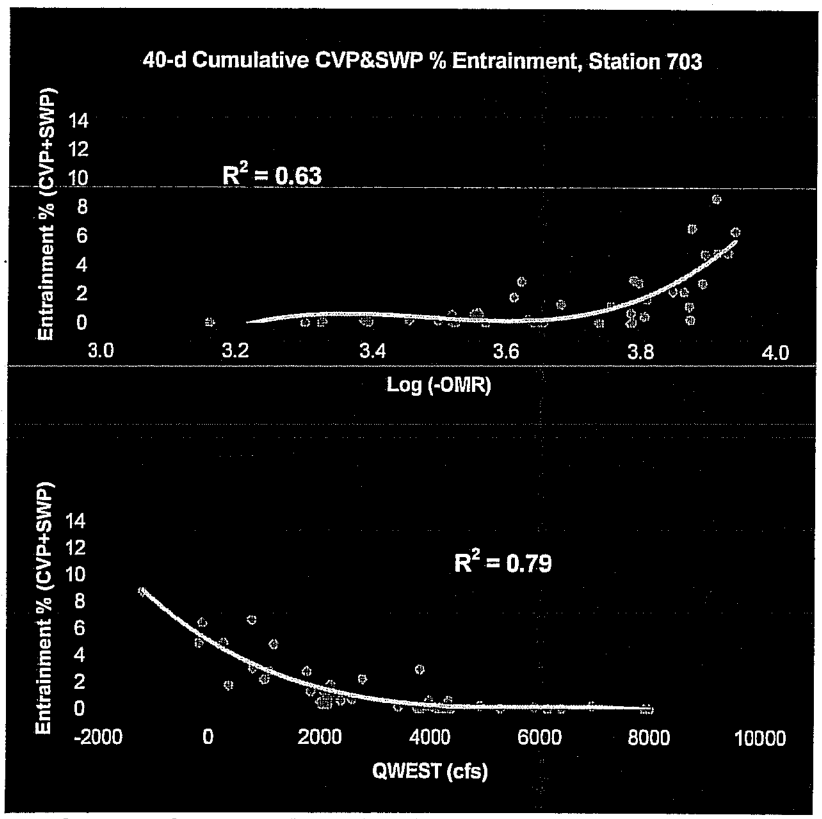


Figure 3. Examples of regression equations developed for percent entrainment versus OMR and Qwest, with better Qwest regression.

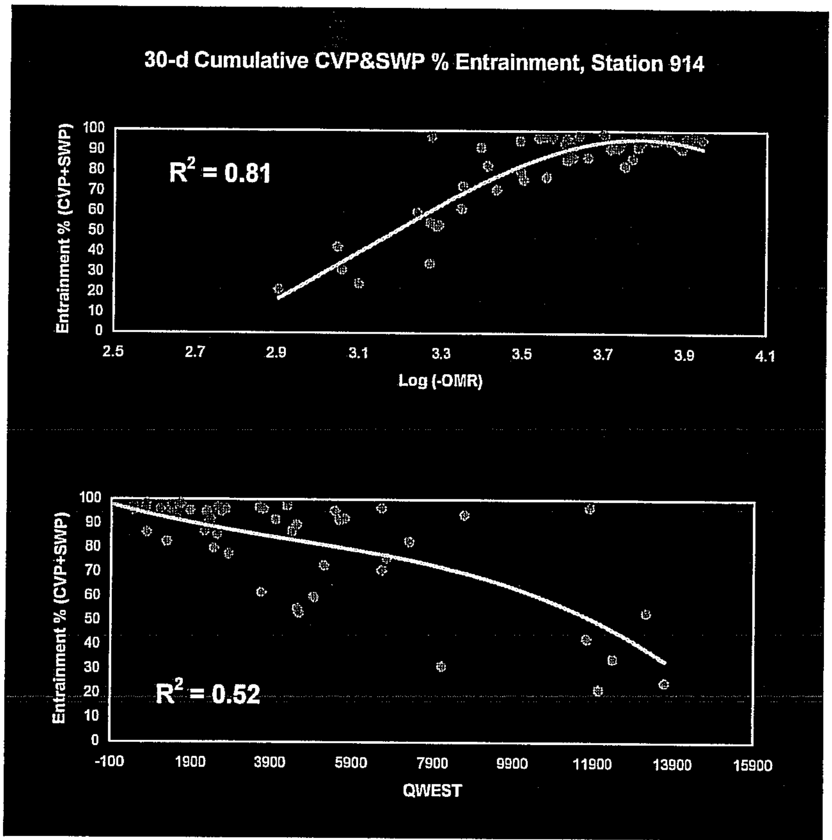


Figure 4. Examples of regression equations developed for percent entrainment versus OMR and Qwest, with better OMR flow regression.

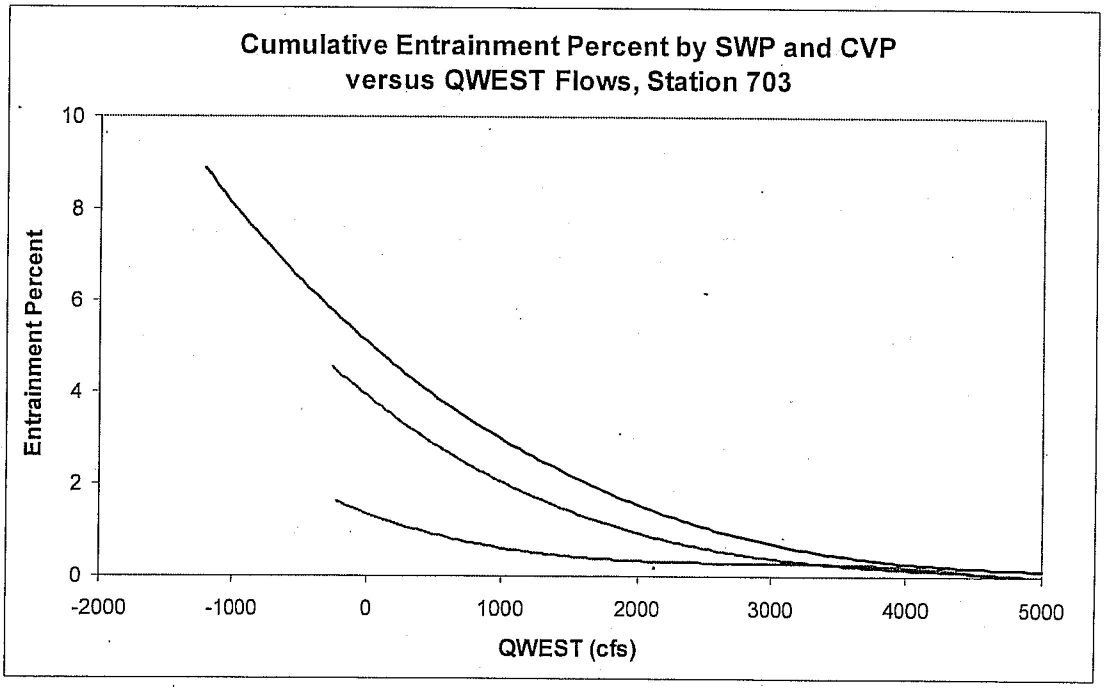


Figure 5. Example regression equations of potential entrainment versus flow for 10-day (Green), 30-day (Red), and 40-day (Blue) time periods.

The resulting regression models were then applied to data on delta smelt distribution to determine the percentage of delta smelt likely to be entrained for each station. Values from each station are summed to calculate the Potential Entrainment Index (PEI), which represents the total percentage of the delta smelt population likely to be entrained given their distribution and the hydrodynamic conditions for the given time period. The PEI is calculated as follows:

$$PEI = \sum_{i=1}^{N}(PP_i * RA_i)$$

Where:

- PP is the PTM % entrained particles to the CVP/SWP export pumps over a period of time for each survey station;
- N is the total number of survey stations;
- RA is the relative abundance of Delta Smelt at each station.

The relative abundance of delta smelt at a given survey station is calculated as the density of delta smelt at a station, reported as Catch per Unit Effort (CPUE) from the 20-mm survey, multiplied by the volume of water associated with each survey station (Table 2)

$$RA = D * V$$

Where:

- RA is the relative abundance of Delta Smelt at each station
- D is surveyed fish density at a station
- V is the representative volume of water associated with the survey station (B.J. Miller, 2005)

The PEI methodology was initially developed using regressions for select 20 mm survey stations in Suisun Bay and the interior Delta. However, the 20 mm survey includes additional stations west of Suisun Bay, in the Suisun Bay and Marsh area, and the Cache Slough area that were not included in the regression development. To more accurately represent the delta smelt abundance, an effort was made to represent all fish detected in the 20 mm surveys and the volumes associated with all survey stations in the PEI methodology. The CPUE and volumes associated with 20 mm survey stations that did not have a PEI regression were assigned to the nearest 20 mm survey station that did have a regression equation, resulting in adjusted CPUE values and adjusted volumes for select 20 mm survey stations (**Table 2**). This assumption may lead to higher than actual PEI values, since a proportion of the relative abundance is assumed to be closer to the export pumps than actually detected in the 20 mm survey.

Table 2. Water volumes associated with 20-mm survey stations

20-mm Survey Station ID	Actual Volume (AF)[1]	Adjusted Volume (AF)[2]
508	42240	42240
513	45410	45410
520	12260	12260
703	42460	42460
704	10830	10830
705	10830	10830
706	24540	24540
707	32600	32600
711	43200	43200
716	22720	22720
801	30580	30580

20-mm Survey Station ID	Actual Volume (AF)[1]	Adjusted Volume (AF)[2]
802	35000	27720
804	64670	64670
809	35740	35740
812	41130	41130
815	40380	40380
901	45290	45290
902	15450	15450
906	75540	75540
910	17130	17130
912	14960	14960
914	37810	37810
915	12010	12010
918	12030	12030
919	17950	17950
519	30000	1150484
606	3000	85510
609	3000	24010
719	10000	10000

1 - Source: B.J. Miller, 2005
2 - Source: B.J. Miller, 2005 except as modified through assignment of station volumes for 20-mm surveys outside of the PEI methodology to the nearest station within the PEI methodology.

Assumptions

The PEI methodology is based on the assumption that the predicted entrainment is applicable to fish that act as particles, meaning the fish do not exhibit any behavior and act as neutrally buoyant particles. Since adult and juvenile delta smelt are known to exhibit behavior, including diurnal vertical movements in the water column and lateral movement through channels triggered by environmental cues such as food abundance and turbidity, this analysis only predicts PEI values for larval delta smelt. The adult and juvenile delta smelt abundance determined by the 20-mm survey is assumed to be representative of larval delta smelt abundance. The abundance was assumed not to change over time, so that mortality and recruitment were not accounted for over the cumulative period.

The PEI methodology was also developed based on the historical and current Delta configuration. If the Delta configuration changes, the regression equations based on the historical conditions would no longer be applicable. Potential changes in Delta configuration could include activities such as island flooding, dredging, or barrier/gate installation, to name a few.

Another key assumption of the PEI methodology was the volume of water attributed to each 20-mm survey location and the subsequent abundance calculation. There is still much debate about how the abundance of delta smelt should be calculated. The values used in this methodology are best estimates that are likely more representative of the relative volumes of fish habitat, instead of absolute volumes. Therefore, the PEI is proposed to be used as a relative index as opposed to an absolute predictor.

Finally, the PEI methodology assumed that hydrology was stable over the cumulative period being analyzed. Since an average was used for OMR and Qwest flow, large fluctuations in hydrology and subsequent fluctuations in potential entrainment were masked. This fluctuating hydrology is the cause for much if not all of the variation in the PEI regressions. If the proposed method is used in the future and the system is in balanced conditions, then these variations in hydrology will be much reduced and the equations more predictive.

Given the simplifying assumptions described above, the PEI was developed to be a relative index and used as a tool to compare potential entrainment under various CVP/SWP operational criteria.

PEI and Historical Salvage

To evaluate the ability of the PEI to accurately estimate entrainment, the PEI methodology was modified to simulate historical delta smelt salvage. To perform the analysis, historical 20-mm survey data and historical hydrology was used to predict the PEI for each historical 20-mm survey. The PEI was then related to salvage on a seasonal basis to simulate seasonal historical delta smelt salvage.

There are several difficulties in relating PEI to salvage. PEI is calculated as potential entrainment at the entrance to Clifton Court Forebay (CCFB). However, salvage is determined by measuring the number of delta smelt counted at the Skinner Fish Facility at the intake to Banks Pumping Plant (Error! Reference source not found.6). The number of fish counted at the Skinner Fish Facility likely would not be represented by the PEI calculated at the CCFB entrance due to many reasons, including unknown predation within CCFB and non-continuous monitoring and counting at the Skinner Fish Facility.

Figure 6. Comparison of locations for measurement of salvage and calculation of PEI.

Due to these concerns, an additional adjustment to the relationship between PEI and salvage was included as follows, adding a factor for antecedent salvage:

$$PS = C1*PEI + C2*AS$$

Where:

- PS is predicted salvage
- PEI is the entrainment index
- AS is the antecedent salvage
- C1 and C2 are coefficients

This equation was used to simulate seasonal historical salvage using the PEI based on a 10-day and 20-day cumulative period. The comparisons with actual historical salvage can be seen in **Figure 7** and **Figure 8**. As seen in these figures, the pattern of peaks in historical salvage is generally predicted using the PEI versus salvage relationship. The magnitude of the peaks is occasionally not as accurate, most likely due to one or a combination of the simplifying assumptions made in the development of the PEI and the PEI versus salvage relationship and the "dilution and delay" effects caused by Clifton Court Forebay.

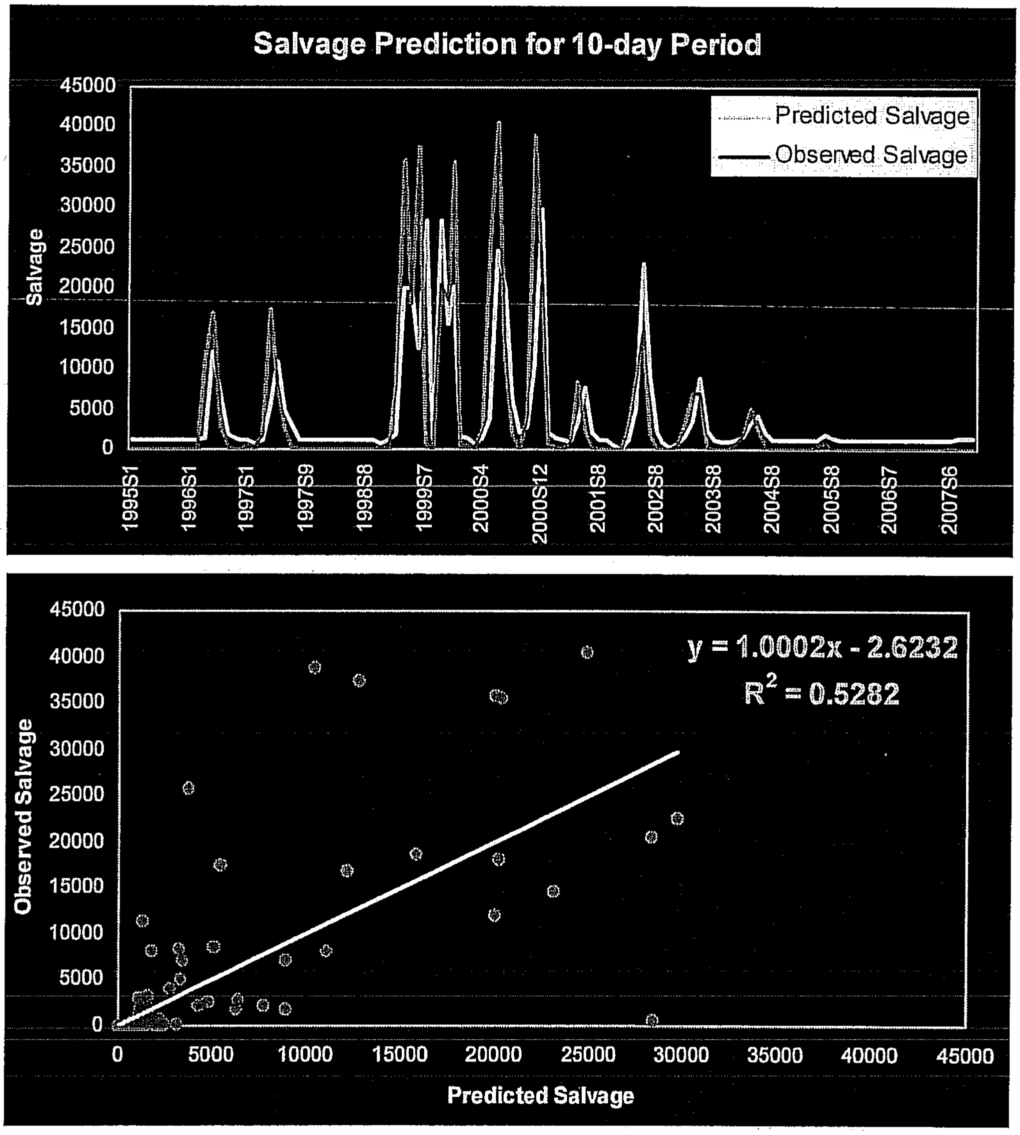
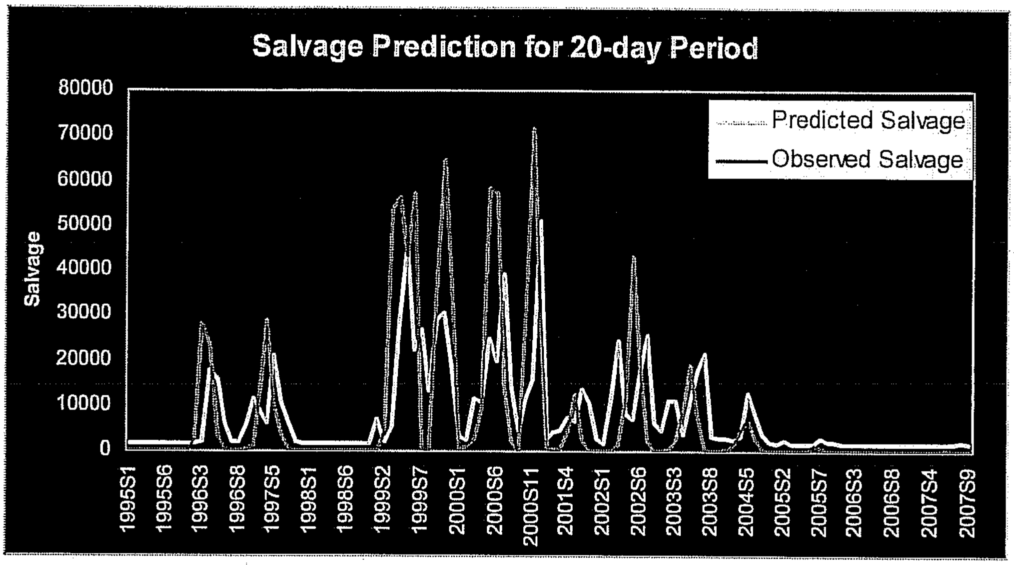


Figure 7. Comparison of 10-day PEI-based salvage prediction versus historical salvage.



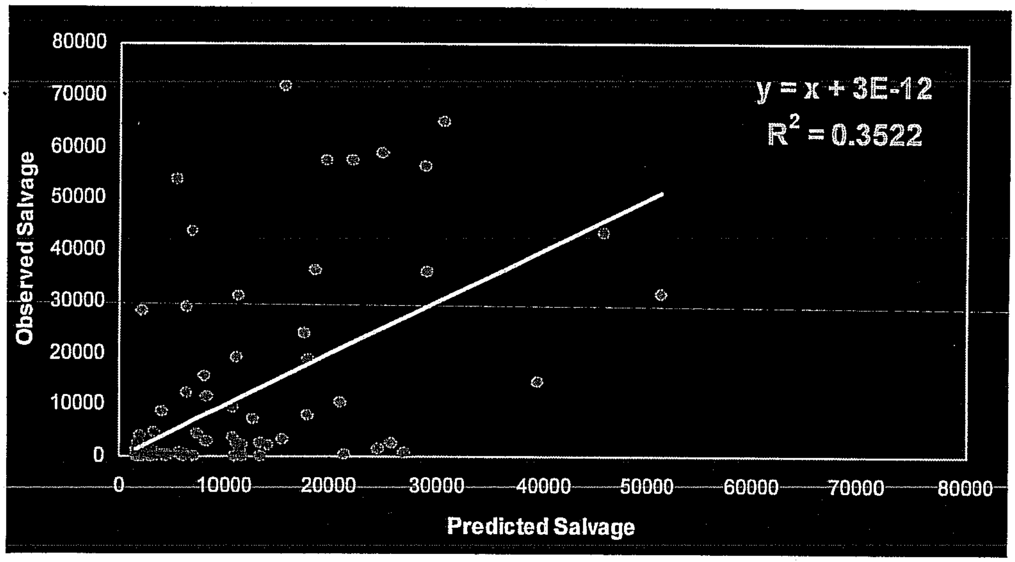


Figure 8 Comparison of 20-day PEI-based salvage prediction versus historical salvage.

PEI and Real-time Operations

Potentially, the PEI could be used in real-time management of the CVP/SWP export operations and OMR flow to keep delta smelt entrainment below a pre-determined target level. To determine the OMR flow that would result in a PEI less than a pre-determined target and the associated water costs, the PEI methodology could be used with historical 20-mm survey data as input, but with modified hydrology (OMR flow and Qwest). For each historical 20-mm survey and for a given cumulative time period, the average OMR flow and Qwest flow over the same cumulative time period could be iteratively adjusted until the maximum target PEI was not exceeded. This exercise would quantify how the hydrology and exports relate to affect PEI and what a maximum PEI target means in terms of water supply costs.

Potential PEI Application for CVP/SWP Export Operations Management

As an illustrative example of applying a maximum PEI target, an analysis of historical and adjusted historical PEI estimates was conducted. For this analysis, the 20-day cumulative PEI regressions and 20-day averaged input hydrology were used. For each historical 20-mm survey, the PEI was calculated using historical hydrology and adjusted historical hydrology, with OMR flow between -500 cfs and -5,000 cfs in 500 cfs increments. The Qwest and change in exports associated with each increment of adjusted OMR flow was also calculated over the 20-day period. The OMR and associated change in exports was determined for two potential maximum target PEI levels: 3.2%, and 5%. (**Figure 9** and **Figure 10**).

In this analysis, if the historical PEI was already less than the maximum target PEI, the historical PEI and hydrology was maintained. This means exports did not increase to meet the maximum target PEI value. Also, in some cases, the historical PEI was higher than the maximum target PEI value, even when OMR flows were more positive than -500 cfs. In those cases, the minimum PEI attainable through modification of OMR flows was targeted.

This analysis shows that as the maximum target PEI value decreases, the required export reductions to reach the maximum target PEI increases. Also, there are some occasions where the maximum target PEI could not be met historically with export reductions. This type of historical analysis could be used with other historical population indicators such as the Fall Midwater Trawl (FMWT) index to determine if the effects of potential entrainment are related to changes in the subsequent abundance of delta smelt. So far, the work by Kimmerer (2008) and Manly and Chotkowski (2006) have not been able to see such an effect.

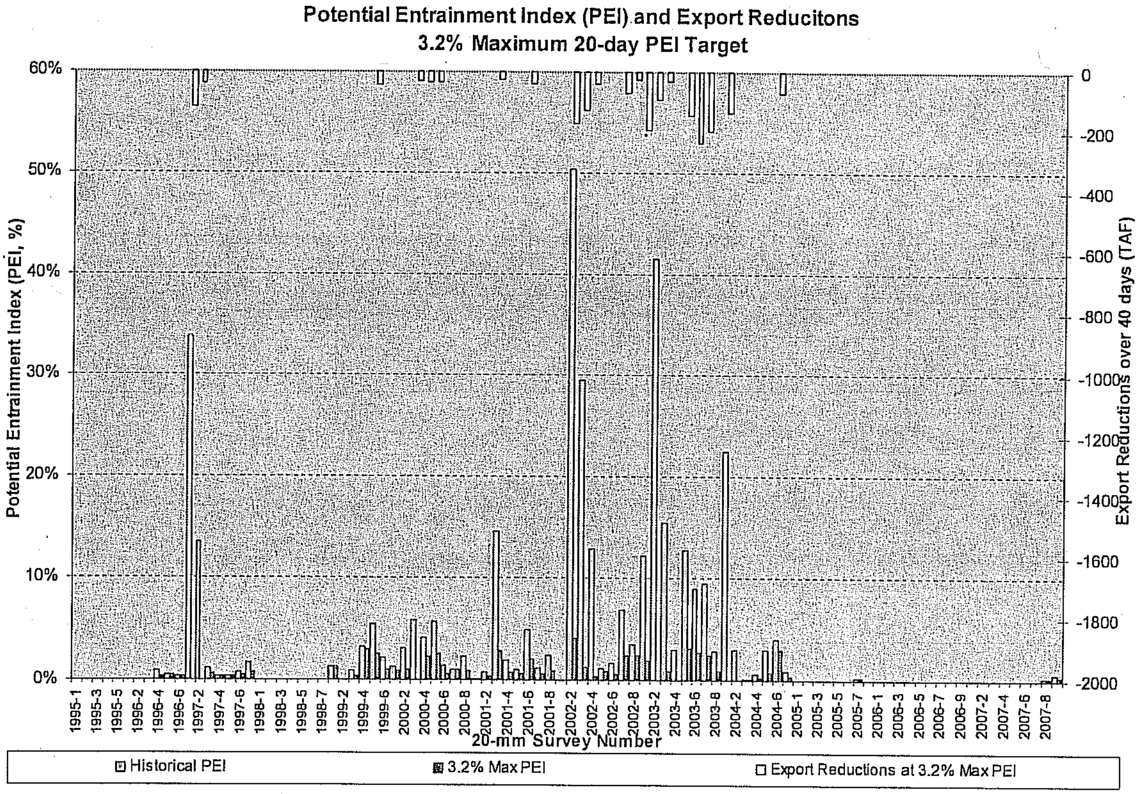


Figure 9. Comparison of historical PEI and 3.2% maximum target PEI.

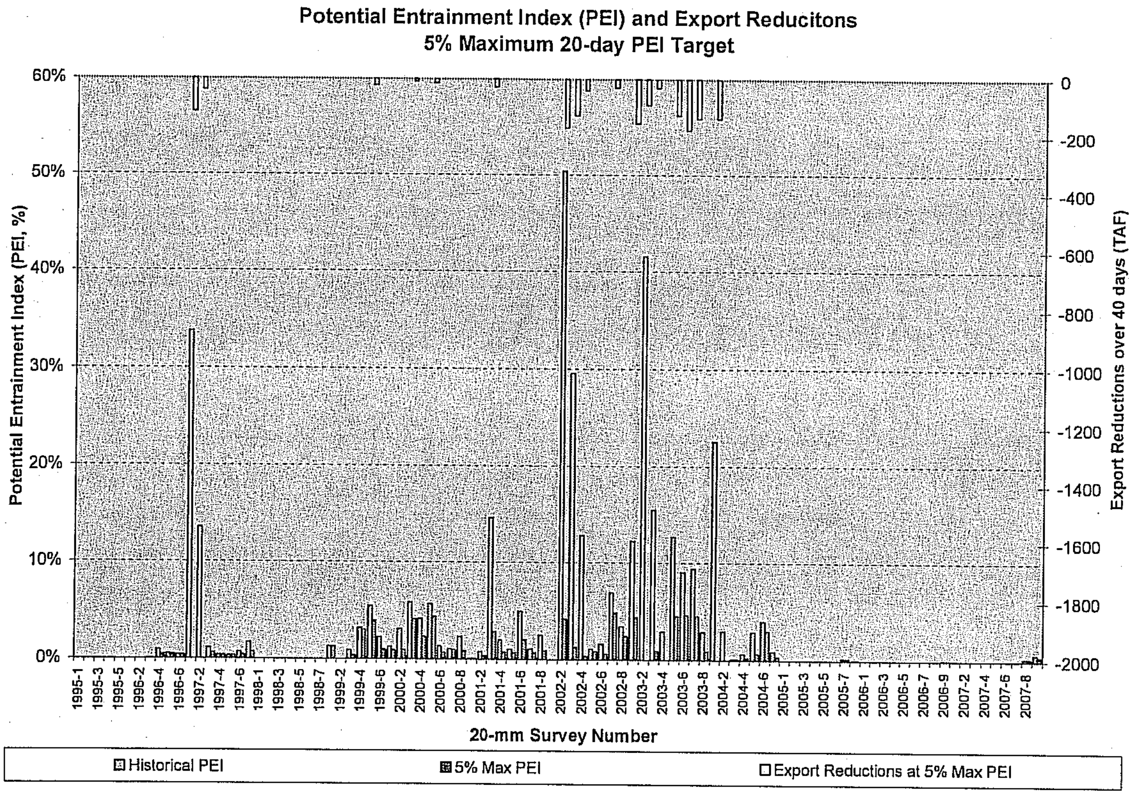


Figure 10. Comparison of historical PEI and 5% maximum target PEI.

Managing CVP/SWP export operations to meet a maximum PEI target was shown to successfully reduce potential entrainment over individual 20-day periods. To compare the PEI methodology with annual estimates of potential entrainment from Kimmerer (2008), annual PEI estimates were calculated. Annual PEI estimates were calculated by assuming a constant rate of potential entrainment over the period, a constant rate of population introduced at the beginning of each period, and no natural mortality. Population was introduced at a constant rate beginning with the first detection of delta smelt a single survey location in a 20-mm survey.

First, the annual total population introduced (TPI) was calculated, assuming no entrainment or mortality:

$$TPI = \sum_{i}^{N} (TP_{i-1} + CP)$$

Next, the annual total population remaining (TPR) after accounting for potential entrainment was calculated:

$$TPR = \sum_{i=1}^{N} \left[(P_{i-1} + CP) * (1 - PEI_i) \right]$$

Finally, the annual potential entrainment index (APEI) was calculated as the percent of total population not remaining:

$$APEI = 1 - \frac{TPR}{TPI}$$

Where:

- i is the period.

- N is the total number of periods in a year.
- PEI is the potential entrainment for a period.
- CP is a constant population introduced at the beginning of each period.
- TP is the total introduced population without entrainment in a period.
- P is the population in a period, calculated as:

$$P_i = (P_c + P_{i-1}) * (1 - PEI_i)$$

The APEI values for both historical and a maximum PEI target of 5% were plotted with Kimmerer's annual values (2008) for comparison (**Figure 11**). Historical APEI values were generally lower than Kimmerer's estimates with no mortality, but followed the same general patterns. Implementation of a maximum PEI target of 5% reduced APEI in years such as 1997 and 2002, when historical APEI values were high.

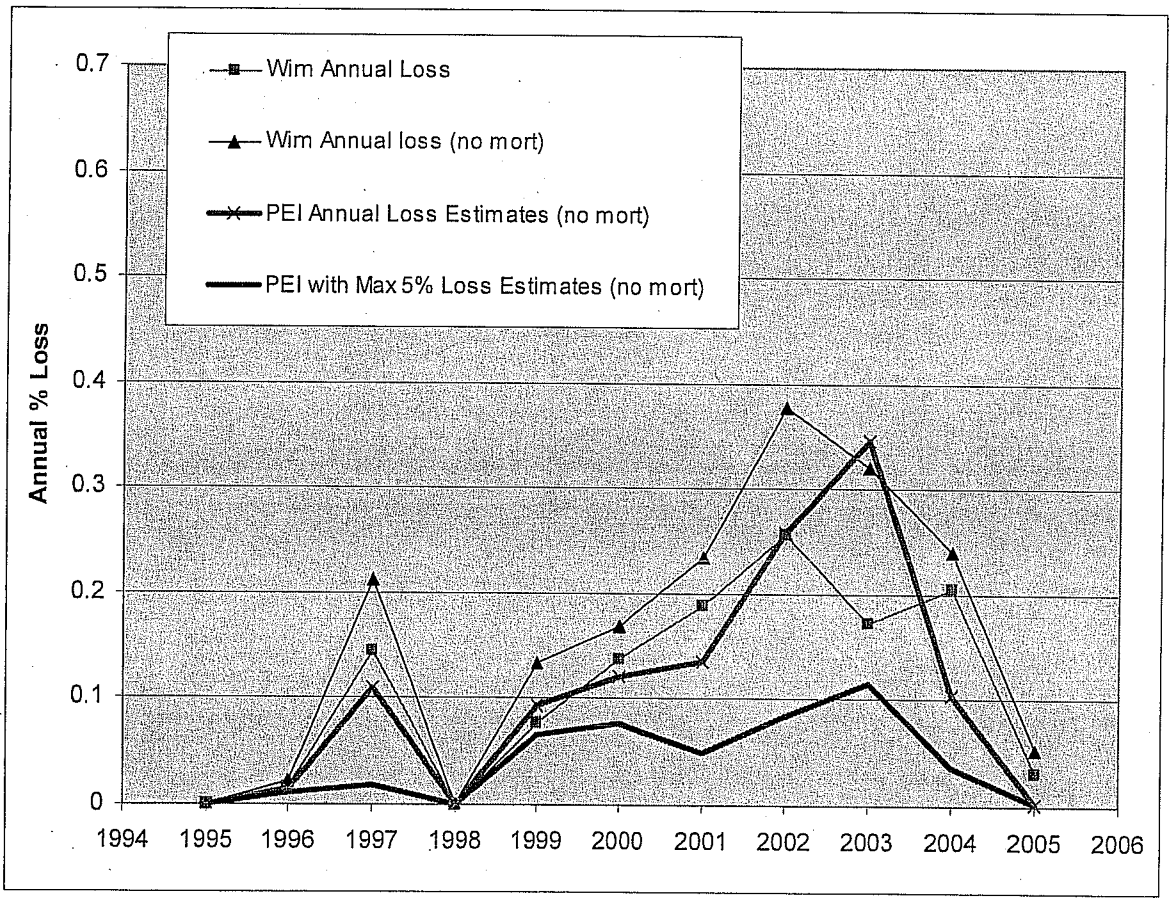


Figure 11. Estimated historical annual losses by Kimmerer and by the PEI method compared to projected losses using a 20-day PEI of 5%.

Potential PEI Improvements

The PEI methodology could be improved in several ways. Regressions for PEI versus hydrology could be developed for other time periods besides the 10-, 20-, 30-, and 40-day cumulative time period. Additionally, regression equations could be developed for the "far field" stations that were not developed for this analysis. In the PEI method presented here, the next closest station regressions were used which results in an over estimate of the PEI. Once behavior simulation is implemented in the PTM, the PEI methodology could be applied to other life stages of delta smelt or other species.

References

Kimmerer, W. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta San Francisco Estuary and Watershed Science. Vol. 6, Issue 2.

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

Miller W.J. 2005. Estimating the population of delta smelt using the Spring Kodiak Trawl data, paper prepared for the December 2005 Workshop on the Environmental Water Account, November 2005.