

Interagency Ecological Program 2008 Work Plan to Evaluate the Decline of Pelagic Species in the Upper San Francisco Estuary

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Executive Summary

Abundance indices calculated by the Interagency Ecological Program (IEP) through 2007 suggest recent marked declines in four pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay). These fishes include delta smelt which is listed under State and federal Endangered Species acts and the longfin smelt, which has been proposed for protection under these acts. Although several species show evidence of long-term declines, the recent persistent low levels were unexpected given the high variability in winter-spring flows during the past several years.

In response to these changes, the IEP formed a Pelagic Organism Decline Management Team (POD MT) to evaluate the potential causes. The major findings through 2007 were synthesized in a recent report using two conceptual modeling approaches, a basic conceptual model, and models about species-specific responses to various stressors. The overall approach for 2008 is intended to evaluate and refine the evidence for the conceptual models and to begin to translate conceptual models into quantitative models.

The proposed 2008 studies represent an interdisciplinary, multi-agency effort including staff from DFG, DWR, USBR, USEPA, USGS, CALFED, USFWS, SFSU and UCD. Project components were selected based on their ability to refine the conceptual models, and their feasibility in terms of methods, staffing, costs, timing and data availability. The proposed work falls into three general types: 1) continuation of expanded monitoring (5 elements); 2) ongoing studies (31 elements); and 3) new studies (19 elements). None of the work will affect the mandated monitoring currently performed by IEP. The cost estimate for 2008 is \$5,862,000.

The program will be run by the POD MT to develop, direct, review and analyze the results of the effort. The program will yield a range of products and deliverables including management briefs, publications and reports, web-based monitoring data, and presentations at conferences, workshops and meetings.

Introduction

The four primary pelagic fishes of the upper estuary (delta smelt, longfin smelt *Spirinchus thaleichthys*, striped bass *Morone saxatilis*, and threadfin shad *Dorosoma petenense*), have shown substantial variability in their populations, with evidence of long-term declines for the first three of these species (Kimmerer et al. 2000; Bennett 2005; Rosenfeld and Baxter 2007). For the three declining species, a substantial portion of the abundance patterns has been associated with variation of outflow in the estuary. However, Fall Midwater Trawl abundance indices for these four pelagic fishes began to decline sharply around 2000, despite relatively moderate hydrology which historically supported at least modest fish production (Sommer et al. 2007). The situation deteriorated over the next several years; abundance indices for 2002-2007 included record lows for delta smelt, age-0 striped bass, and longfin smelt and near-record lows for threadfin shad. By 2004, these declines became widely recognized and discussed as a serious management issue, and collectively became known as the *Pelagic Organism Decline (POD)*.

In response to the POD, the Interagency Ecology Program (IEP) formed a study team in 2005 to evaluate the potential causes of the decline (Sommer et al. 2007). The team organized an interdisciplinary, multi-agency effort including staff from California Department of Fish and Game, California Department of Water Resources, Central Valley Regional Water Quality Control Board, U.S. Bureau of Reclamation, U.S. Environmental Protection Agency, U.S. Geological Survey, California Bay Delta Authority, San Francisco State University, and the University of California at Davis. The purpose of the present document is to summarize the 2008 IEP work plan to evaluate the POD.

An introduction to the POD and many of the associated management issues has been summarized in Sommer et al. (2007). Moreover, the results of the study through 2007 have been synthesized in a recent report, "Pelagic Organism Decline Progress Report: 2007 Synthesis of Results" by Baxter et al. (2008). To provide readers with a better understanding of the major factors in the POD and some of the supporting evidence, we have included text from the Basic POD Conceptual Model from Baxter et al. (2008). For more detail and a description of conceptual models for each of the POD species, readers are encouraged to review Baxter et al. (2008). As will be discussed in the "Study Approach" section, these conceptual models are used to guide the 2008 POD studies.

Goals and Objectives

The purpose of the present document is to summarize the 2008 IEP work plan to evaluate the POD. Like the 2005-2007 POD work, the 2008 POD work falls within the broader framework of the IEP whose mission is to "provide information on the factors that affect ecological resources in the Sacramento - San Joaquin Estuary that allows for more efficient management of the estuary." This mission contains the dual goals of 1) gathering and communicating scientific information about the ecology of the San Francisco Estuary and of 2) fulfilling the information needs of estuarine resource managers.

The consistent long-term monitoring surveys conducted by the IEP over nearly four decades fulfill basic information needs regarding the status and trends of estuarine resources of interest to

managers, and the relationships of different resources with each other. The IEP also has a long history of shorter-term research studies complementing its monitoring surveys. These special studies are generally designed to address additional – and often changing - information needs about the factors and mechanisms behind the observed trends, about resources not captured or captured poorly by the monitoring surveys, or about monitoring methods.

Three years after its initiation, the POD investigation stands out as the largest special research study in the history of the IEP. It is, however, firmly rooted in the monitoring and research tradition of the IEP, and, like all IEP studies, intended to fulfill the IEP mission and goals of providing sound scientific information about the ecology of the estuary and fulfilling the information needs of resource managers.

The POD investigation is taking place during a time of heightened awareness of the fragility and importance of the Delta as a unique estuarine ecosystem and a major hub for California's water, transportation and utilities infrastructure. This awareness is exemplified by the establishment of the Delta Vision Blue Ribbon Task Force through Executive Order S-17-06 by Governor Arnold Schwarzenegger and several other high profile Delta initiatives as well as an increasing number of lawsuits about Delta management issues. The common denominator of all these efforts is the need to find ways to return the Delta ecosystem and infrastructure to a more functional and resilient state and to manage it in the face of climate change, continued human population growth, etc.

With respect to the fish species at the center of the POD investigations, resource managers have to quickly find ways to return the populations of these fishes to at least pre-decline levels of the late 1990s, or else risk the local extinction of these species in the near future. To do this, managers urgently need to know what stressors, or combinations of stressors, are currently keeping the POD fishes at such alarmingly low levels, and how the effects of these stressors vary with different environmental conditions. This information is critical if managers are to find effective solutions to lessen the negative impact of these stressors on the estuarine ecosystem in general and the POD fishes in particular.

The objective for the 2008 IEP POD work is to address the following question:

What stressors, under what conditions, currently affect pelagic fish populations?

In addition to this broad study objective, we have developed specific study questions that are detailed in the Study Approach section, and in the descriptions of individual study elements. These questions were originally developed from conceptual models about the POD. They have evolved over the duration of the POD investigation based on new scientific results as well as in response to changing information needs.

Note that the broad objective has also evolved somewhat from our original focus, which was to examine: which factors may have changed around 2000; what are the mechanisms for these changes; and do these changes affect fish abundance? Part of the reason for this modification is that there appears to have been substantial variability in the timing of the decline for the different pelagic species, so the focus on changes around 2000 was considered less useful. Another

reason is that the stressors that might have been responsible for the original step declines may not be the same that are now keeping the populations down. Information about the current stressors, however, is of most interest to resource managers tasked with lessening the impacts of these stressors and thus reversing the POD fish declines.

Like the past several years of the investigation, much of the emphasis of the POD investigation will continue to be on delta smelt, and on the core region of the estuary in which they are most abundant. This priority is justified because the declining delta smelt population represents the major fisheries issue in the region, affecting water supply and many kinds of development. Remediation of the delta smelt population is one of the key objectives of several regional Delta planning processes including Delta Vision and the Bay Delta Conservation Plan. However, the work plan contains substantial work on the three other pelagic fishes and surrogate species because each has the potential to yield major insight into the causes of the recent fish declines. In particular, the results to date suggest that the causes of recent fish declines vary considerably by fish species and life stage. Similarly, we believe that comparisons between the core habitat of delta smelt and other regions (e.g. west Delta versus south Delta) can be exceptionally informative.

Basic POD Conceptual Model

The following text about the Basic POD Conceptual Model is taken directly from Baxter et al. (2008). We acknowledge that these conceptual models have many of the same limitations as earlier documents from the POD management team. Specifically, many studies initiated by the POD or initiated by others that will provide important POD information are still in progress. Preliminary results from these studies are provided whenever possible, but peer-reviewed products from these studies may not be available for some time to come. Moreover, the model may have been influenced by potential biases in the sampling programs. Several changes in the size and distribution of the target species have the potential to change our perception of trends in abundances and distributions. This, in turn, would affect our conceptual models. Throughout this discussion we use indices of abundance such as the Fall Midwater Trawl and Summer Towntnet surveys or catch-per-unit-effort as estimates of abundance. The relationship between these indices of abundance and the actual population size of any species is not known. We encourage readers to be cautious when evaluating the relative importance of the hypotheses presented in this model. However, we present them because they represent the newest thinking on POD issues, and provide useful information to guide the design of the 2008 work plan.

Finally, it is important to recognize that the recent decline in pelagic fish species is superimposed over long-term declines for several of these species and their long-term relationships with other environmental factors. Change-point analyses (Manly and Chotkowski 2006, Manly and Chotkowski, unpublished data) suggest that distinctly different statistical models might be appropriate for different time periods. As described below, a clear line divides the POD era from the years preceding it for some species. There also appear to be multiple periods within the historical record preceding the POD and the periods are not always the same across species. The conceptual models developed here explicitly focus on mechanisms that might have contributed to

the decline of pelagic fishes during the POD era. However, the historical antecedents to the POD are a crucial part of the story.

Note that these conceptual models are not intended to exclude other explanations for the observed changes in fish abundance, nor are they designed to set priorities for resource management. Instead, they are intended as examples of how the different stressors may be linked. Moreover, no single model component can explain the declines of all four species. The models will be developed and refined as additional data become available. In the meantime, we believe the new models provide a useful basis for organization of the POD study and the initial synthesis of the results.

Basic Conceptual Model

We have developed an intentionally simple basic conceptual model (Figure 1) to describe possible mechanisms by which a combination of long-term and recent changes in the ecosystem could produce the observed pelagic fish declines (Figure 2). This conceptual model is rooted in classical food web and fisheries ecology and contains four major components: (1) prior fish abundance, which posits that continued low abundance of adults leads to reduced juvenile production (i.e., stock-recruit effects); (2) habitat, which posits that estuarine water quality variables, disease, and toxic algal blooms in the estuary affect survival and reproduction; (3) top-down effects, which posits that predation and water project entrainment affect mortality rates; and (4) bottom-up effects, which posits that food web interactions affect survival and reproduction. For each model component, our working hypotheses are: (1) the component was responsible for an adverse change at the time of the POD; and (2) this change resulted in a population-level effect. The model components are described in detail in the following sections. The basic conceptual model generally does not evaluate the relative importance of the model components. Often the data are not sufficient to make such judgments. Also it is likely that the relative importance of various components changes with specific environmental conditions (e.g. river flow) within and among years. Finally, the relative importance of factors will differ among the four species.

Previous Abundance

The relationship between numbers of spawning fish and the numbers of young subsequently recruiting to the adult population is known as a stock-recruit relationship. Stock-recruit relationships have been described for many species and are a central part of the management of commercially and recreationally fished species (Myers et al. 1995). Different forms of stock-recruit relationships are possible, including density-independent, density-dependent, and density-vague types. The latter refers to situations where there is not a statistically demonstrable stock-recruit relationship observable in available data. In any form of a stock-recruit model, there is a point at which low adult stock will result in low juvenile abundance and subsequent low recruitment to future adult stocks even under favorable environmental conditions while the stock ‘rebuilds’ itself. There is evidence for a density-dependent stock-recruit relationship in San Francisco Estuary striped bass (Kimmerer et al. 2000). However, the adult striped bass stock is currently not particularly low (Figure 3), so stock size is not likely a mechanism contributing to

recent very low age-0 striped bass abundance. In other words, there appears to be enough adults in the system for the population to recover.

There is a significant stock-recruit relationship for threadfin shad (Feyrer and Sommer, in prep). Fall abundance of pre-adults is a significant predictor of young-of-year abundance the following summer (Figure 4). Similar relationships have been proposed for longfin smelt (Tina Swanson, The Bay Institute, unpublished data). However, current populations of longfin smelt and threadfin shad are similar to low populations observed in previous years (Figure 2). Threadfin shad rebounded fully from previous abundance lows in the 1970s and 1980s. Longfin smelt populations rebounded somewhat in the 1990s following previous lows during the 1987-1992 drought. Note that recovery of these species is only expected if the factors affecting recruitment have not changed substantially. If the factors affecting survival from egg to adult have changed substantially since the beginning of the POD, then recovery might not occur even though recovery from low abundance occurred in the past. The changes in the statistical relationships between outflow and population abundance indices for longfin smelt and striped bass (Figure 5) are evidence that changes in the drivers of recruitment have occurred. These changes are discussed in more detail in subsequent sections.

From a stock-recruit perspective, the present low abundance of delta smelt is of particular concern. The current population is an order of magnitude smaller than at any time previously in the record (Figure 2). The delta smelt stock-recruit relationship appears to be density vague over the entire period that data is available (Bennett 2005), meaning there is no clear relationship between the adult spawning population and the number of adult recruits expected in the following year, as measured by the Fall Midwater Trawl. There was also a historically weak statistical association between summer abundance (as measured by the Summer Towntnet Survey) and abundance a few months later during the Fall Midwater Trawl Survey, suggesting that delta smelt year-class strength was often set during late summer. However, Feyrer et al. (2007) found that the abundance of pre-adult delta smelt during fall was a statistically significant predictor of juvenile delta smelt abundance the following summer, for the time period 1987-2005. Similarly, delta smelt summer abundance is a statistically significant predictor of fall abundance. These relationships are particularly strong for the period 2000-2006 (Figure 6). The strong relationship in summer to fall survival since 2000 (Figure 6) suggests that the primary factors affecting juvenile survival recently changed and shifted to earlier in the life cycle. These observations strongly suggest that recent population trends are outside the historical realm of variability and resilience shown by these species, particularly delta smelt. Thus, recovery is likely to require changes in the stressors that have produced the current low levels of abundance and perhaps stressors that have since become more important.

Given the unprecedented low abundance of delta smelt since 2000 (Figure 6), serious consideration should be given to evaluation of Allee effects. Allee effects occur when reproductive output per fish declines at low population levels (Berec et al. 2006). In other words, below a certain threshold the individuals in a population can no longer reproduce rapidly enough to replace themselves and the population spirals to extinction. For delta smelt, possible mechanisms for Allee effects include mechanisms directly related to reproduction and genetic fitness such as difficulty finding mates, genetic drift, and inbreeding. Other mechanisms related to survival such as increased vulnerability to predation are also possible and will be briefly

discussed in the “top-down” model component section. The interactive effects of multiple Allee effects have not been well explored in ecology and may have important implications for species conservation (Berec et al. 2006).

Habitat

Aquatic habitats are the suites of physical, chemical, and biological factors that species occupy (Hayes et al. 1996). The maintenance of appropriate habitat quality is essential to the long-term health of aquatic resources (Rose 2000; Peterson 2003). For the habitat component of the model, a key point is that habitat suitability affects all other components of the model (Figure 1). Hence, changes in habitat not only affect pelagic fishes, but also their predators and prey. Although not a focus of this report, we expect that the habitats of the POD species are especially vulnerable to future climate change. Thus, any findings regarding habitat must be considered in light of expected changes in climate and changes in water management operations anticipated in response to climate change.

Pelagic Fish Habitat: Habitat for pelagic fishes is open water, largely away from shorelines and vegetated inshore areas except perhaps during spawning. This includes large embayments such as Suisun Bay and the deeper areas of many of the larger channels in the Delta. More specifically, pelagic fish habitat is water with suitable values for a variety of physical-chemical properties, including salinity, turbidity, and temperature, suitably low levels of contaminants, and suitably high levels of prey production to support growth. Thus, pelagic fish habitat suitability in the estuary can be strongly influenced by variation in freshwater flow (Jassby et al. 1995; Bennett and Moyle 1996; Kimmerer 2004). Several of the POD fishes use a variety of tidally-assisted swimming behaviors to maintain themselves within open-water areas where water quality and food resources are favorable (Bennett et al. 2002). The four POD fishes also distribute themselves at different values of salinity within the estuarine salinity gradient (Dege and Brown 2004), so at any point in time, salinity is a major factor affecting their geographic distributions. As mentioned earlier, pelagic habitat quality in the San Francisco Estuary can be characterized by changes in X2. The abundance of numerous taxa increases in years when flows into the estuary are high and the 2 psu isohaline is pushed seaward (Jassby et al. 1995), implying that the quantity or suitability of estuarine habitat increases when outflows are high.

Based on a 36-year record of concurrent midwater trawl and water quality sampling, there has been a long-term decline in fall habitat environmental quality for delta smelt and striped bass, but not for threadfin shad (Feyrer et al. 2007). The long-term environmental quality declines for delta smelt and striped bass are defined by a lowered probability of occurrence in samples based on changes in specific conductance and Secchi depth. Notably, delta smelt and striped bass environmental quality declined recently coinciding with the POD (Figure 7). The greatest changes in environmental quality occurred in Suisun Bay and the San Joaquin River upstream of Three Mile Slough and southern Delta (Figure 8). There is evidence that these habitat changes have had population-level consequences for delta smelt. The inclusion of specific conductance and Secchi depth in the delta smelt stock-recruit relationship described above improved the fit of the model, suggesting adult numbers and their habitat conditions exert important influences on recruitment.

The importance of salinity in this study was not surprising, given the relationships of population abundance indices with X2 for many species. Fall salinity has been relatively high during the POD years, with X2 positioned further upstream, despite moderate to high outflow conditions during the previous winter and spring of most years. Recent increases in fall salinity could be due to a variety of anthropogenic factors although the relative importance of different changes has not yet been fully assessed. Initial results from 2007 POD studies have identified increased duration in the closure of the Delta Cross Channel, operations of salinity gates in Suisun Marsh, and changes in export/inflow ratios (i.e. Delta exports/reservoir releases) as contributing factors.

There appeared to be a curious anomaly in the salinity distribution of delta smelt collected during the September 2007 survey of the Fall Midwater Trawl. All seven delta smelt collected during this survey were captured at statistically significant higher salinities than what would be expected based upon the relationship generated by Feyrer et al. (2007). There could be any number of reasons why this occurred, including the substantial *Microcystis* bloom which occurred further downstream than normal and may have affected the distribution of biological organisms.

The importance of Secchi depth (a measure of water clarity or, conversely, turbidity) in the long-term changes in pelagic fish environmental quality (Feyrer et al. 2007) was more surprising. Unlike salinity, interannual variation in water clarity in the Delta is not primarily a function of flow variation (Jassby et al. 2002). The primary hypotheses to explain the increasing water clarity are (1) reduced sediment supply due to dams in the watershed (Wright and Schoellhamer 2004), (2) sediment washout from very high inflows during the 1982-1983 El Nino (Jassby et al. 2005), and (3) biological filtering by submerged aquatic vegetation (Brown and Michniuk 2007; Dave Schoellhamer, USGS, unpublished data). In lakes, high densities of *Egeria densa* and similar plants can mechanically filter suspended sediments from the water column (Scheffer 1999). Vegetation has also been shown to facilitate sedimentation in marshes and estuaries (Yang 1998; Braskerud 2001; Pasternack and Brush 2001; Leonard et al. 2002). The mechanisms causing the negative associations between water clarity and delta smelt and striped bass occurrence are unknown, but based on research in other systems (e.g. Gregory and Levings 1998), Nobriga et al. (2005) hypothesized that higher water clarity increased predation risk for delta smelt, young striped bass, and other fishes typically associated with turbid water.

Initial results from a POD-funded study indicate that *E. densa*, an introduced species, is continuing to spread by expansion of existing patches and invasion of new areas (Erin Hestir et al., UC Davis, unpublished data). Areal coverage of *E. densa* increased more than 10% per year from 2004 to 2006. Light penetration and water velocity are the factors likely controlling its distribution in the Delta and salinity likely limits its penetration into the estuary (Hauenstein and Ramirez 1986). In clear water, *E. densa* can grow to depths of 6 m (Anderson and Hoshovsky 2000). If Delta clearing continues, it seems likely that *E. densa* will spread into progressively deeper water.

Trends in environmental quality for delta smelt differ during the summer period. Specific conductance, Secchi depth, and water temperature all significantly predict delta smelt occurrence in summer, suggesting they all interact to affect delta smelt distribution (Nobriga et al. 2008). However, none of the water quality variables were correlated with delta smelt abundance (as

indexed by the Summer Townt Survey) at the scale of the entire estuary (Nobriga et al. 2008). Based on these habitat variables, Nobriga et al. (2008) identified three distinct geographic regions that had similar long-term trends in the probability of delta smelt occurrence. The primary habitat region was centered on the confluence of the Sacramento and San Joaquin rivers near Sherman Island; delta smelt relative abundance was typically highest in the confluence region throughout the study period. There were two marginal habitat regions, one centered on Suisun Bay where specific conductance was highest and delta smelt relative abundance varied with specific conductance. The third region was centered on the San Joaquin River and the southern Delta. The San Joaquin River region had the warmest water temperatures and the highest water clarity. Water clarity increased strongly in this region during 1970-2004. In the San Joaquin River region, delta smelt relative abundance was correlated with water clarity; catches declined rapidly to zero from 1970-1978 and remained consistently near zero thereafter. These results support the hypothesis that basic water quality parameters are predictors of summer delta smelt relative abundance, but only at regional spatial scales. These regional differences are likely due to variability in habitat rather than differences in delta smelt responses. Water management operations are targeted on keeping the lower Sacramento and San Joaquin rivers fresh for water exports so the range in salinity is probably smaller than the range in turbidity. In the Suisun Bay region, there is a wider range of salinities relative to the other regions, so a response to that variable is possible.

Contaminants and Disease: In addition to habitat changes from salinity, turbidity and invasive aquatic vegetation such as *E. densa*, and contaminants can change ecosystem functions and productivity through numerous pathways. The trends in contaminant loadings and their ecosystem effects are not well understood. We are currently evaluating direct and indirect toxic effects on the POD fishes of both man-made contaminants and natural toxins associated with blooms of *M. aeruginosa* (a cyanobacterium or blue-green alga). The main indirect contaminant effect we are investigating is inhibition of prey production.

Concern over contaminants in the Delta is not new. There are long standing concerns related to mercury and selenium in the watershed, Delta, and Bay (Linville et al. 2002; Davis et al. 2003). Phytoplankton growth rate may occasionally be inhibited by high concentrations of herbicides (Edmunds et al. 1999). New evidence indicates that phytoplankton growth rate may at times be inhibited by ammonium concentrations in and upstream of Suisun Bay (Wilkerson et al. 2006, Dugdale et al. 2007, Dugdale et al. unpublished). Toxicity to invertebrates has been noted in water and sediments from the Delta and associated watersheds (e.g., Kuivila and Foe 1995; Giddings 2000; Werner et al. 2000; Weston et al. 2004). Undiluted drainwater from agricultural drains in the San Joaquin River watershed can be acutely toxic (quickly lethal) to fish and have chronic effects on growth (Saiki et al. 1992). Evidence for mortality of young striped bass due to discharge of agricultural drainage water containing rice herbicides into the Sacramento River (Bailey et al. 1994) led to new regulations for discharge of these waters. Bioassays using caged fish have revealed DNA strand breakage associated with runoff events in the watershed and Delta (Whitehead et al. 2004). Kuivila and Moon (2004) found that peak densities of larval and juvenile delta smelt sometimes coincided in time and space with elevated concentrations of dissolved pesticides in the spring. These periods of co-occurrence lasted for up to 2-3 weeks, but concentrations of individual pesticides were low and much less than would be expected to cause

acute mortality. However, the effects of exposure to the complex mixtures of pesticides actually present are unknown.

We initiated several studies to address the possible role of contaminants and disease in the POD. Our primary study consists of twice-monthly monitoring of ambient water toxicity at fifteen sites in the Delta and Suisun Bay. In 2005 and 2006, standard bioassays using the amphipod *Hyalella azteca* had low (<5%) frequency of occurrence of toxicity (Werner et al. unpublished data). However, preliminary results from 2007, a dry year, suggest the incidence of toxic events was higher this year. Parallel testing with the addition of piperonyl butoxide, an enzyme inhibitor, indicated that both organophosphate and pyrethroid pesticides may have contributed to the observed 2007 toxicity. Most of the tests that have been positive for *H. azteca* toxicity have come from water samples from the lower Sacramento River. Pyrethroids are of particular interest because use of these insecticides has increased (Ameg et al. 2005, Oros and Werner 2005) as use of some organophosphate insecticides has declined. Toxicity of sediment-bound pyrethroids to macroinvertebrates has also been observed in watersheds upstream of the Delta (Weston et al. 2004, 2005).

Larval delta smelt bioassays were conducted simultaneously with a subset of the invertebrate bioassays. The water samples for these tests were collected from six sites during May-August of 2006 and 2007. Results from 2006 indicate that delta smelt is highly sensitive to high levels of ammonia, low turbidity, and low salinity. There is some preliminary indication that reduced survival under low salinity conditions may be due to disease organisms (Werner, unpublished data). No significant mortality of larval delta smelt was found in the 2006 bioassays (Werner 2006), but there were two instances of significant mortality in June and July of 2007 (Werner, unpublished). In both cases, the water samples were collected from sites along the Sacramento River and had relatively low turbidity and salinity and moderate levels of ammonia. It is also important to note that no significant *H. azteca* mortality was seen in these water samples. While the *H. azteca* tests are very useful for detecting biologically relevant levels of water column toxicity, interpretation of the *H. azteca* test results with respect to fish should proceed with great caution. The relevance of the bioassay results to field conditions remains to be determined.

We have also monitored blooms of the toxic cyanobacterium *Microcystis aeruginosa*. Large blooms of *M. aeruginosa* were first noted in the Delta in 1999 (Lehman et al. 2005). Further studies (Lehman in prep.) suggest that microcystins, the toxic chemicals associated with the algae, probably do not reach concentrations directly toxic to fishes, but during blooms, the microcystin concentrations may be high enough to impair invertebrates, which could influence prey availability for fishes. The *M. aeruginosa* blooms peak in the freshwaters of the central Delta during the summer at warm temperatures (20-25°C; Lehman in prep.). Longfin smelt and delta smelt are generally not present in this region of the Delta during summer (Nobriga et al. 2008; Rosenfield and Baxter 2007) so *M. aeruginosa* toxicity is not likely a factor in their recent decline. However, large striped bass (Moyle 2002) and all life stages of threadfin shad occur widely in the central and south Delta during summer, and thus may be at higher risk. Moreover, in the low flow conditions of 2007, blooms of this cyanobacterium spread far downstream to the west Delta and beyond during summer (Lehman, unpublished data), so toxicity may have been a much broader issue than previously.

The POD investigations into potential contaminant effects also include the use of biomarkers that have been used previously to evaluate toxic effects on POD fishes (Bennett et al. 1995; Bennett 2005). The results to date have been mixed. Histopathological and viral evaluation of young longfin smelt collected in 2006 indicated no histological abnormalities associated with toxic exposure or disease (Foott et al. 2006). There was also no evidence of viral infections or high parasite loads. Similarly, young threadfin shad showed no histological evidence of contaminant effects or of viral infections (Foott et al. 2006). Parasites were noted in threadfin shad gills at a high frequency but the infections were not considered severe. Thus, both longfin smelt and threadfin shad were considered healthy in 2006. Adult delta smelt collected from the Delta during winter 2005 also were considered healthy, showing little histopathological evidence for starvation or disease (Teh et al. unpublished). However, there was some evidence of low frequency endocrine disruption. In 2005, 9 of 144 (6%) of adult delta smelt males were intersex, having immature oocytes in their testes (Teh et al. unpublished).

In contrast, preliminary histopathological analyses have found evidence of significant disease in other species and for POD species collected from other areas of the estuary. Massive intestinal infections with an unidentified myxosporean were found in yellowfin goby *Acanthogobius flavimanus* collected from Suisun Marsh (Baxa et al. in prep.). Severe viral infection was found in inland silverside *Menidia beryllina* and juvenile delta smelt collected from Suisun Bay during summer 2005 (Baxa et al. in prep.). Lastly, preliminary evidence suggests that contaminants and disease may impair striped bass. Ostrach et al. in prep.) found high occurrence and severity of parasitic infections, inflammatory conditions, and muscle degeneration in young striped bass collected in 2005; levels were lower in 2006. Several biomarkers of contaminant exposure including P450 activity (i.e., detoxification enzymes in liver), acetylcholinesterase activity (i.e., enzyme activity in brain), and vitellogenin induction (i.e., presence of egg yolk protein in blood of males) were also reported from striped bass collected in 2006 (Ostrach et al. in prep.). Further, striped bass may be especially vulnerable to contaminant effects because the long lived females can sequester contaminants bioaccumulated over several years in egg yolk, resulting in contaminant effects in developing embryos and larvae.

Habitat for Other Aquatic Organisms: Much of the previous discussion about how physical conditions and water quality affect pelagic fishes is also relevant to other aquatic organisms including plankton and the benthos. It is important to keep in mind that river flows influence estuarine salinity gradients and water residence times. The residence time of water affects both habitat suitability for benthos and the transport of pelagic plankton. High tributary flow leads to lower residence time of water in the Delta (days), which generally results in lower plankton biomass (Kimmerer 2004), but also lower cumulative entrainment effects in the Delta (Kimmerer and Nobriga 2008). In contrast, higher residence times (a month or more), which result from low tributary flows, may result in higher plankton biomass. This can increase food availability for planktivorous fishes; however, much of this production may be lost to water diversions under low flow conditions. Under extreme low flow conditions, long water residence times may also promote high biological oxygen demand when abundant phytoplankton die and decompose (Lehman et al. 2004; Jassby and Van Nieuwenhuysen 2006). Recent particle tracking modeling results for the Delta show that residence times in the southern Delta are highly variable depending on Delta inflow, exports, and particle release location (Kimmerer and Nobriga, 2008).

Very high inflow leads to short residence time. The longest residence times occur in the San Joaquin River near Stockton under conditions of low inflow and low export flow.

Salinity variation can have a major effect on the benthos, which occupy relatively “fixed” geographical positions along the gradient of the estuary. While the distributions of the benthos can undergo seasonal and annual shifts, benthic organisms cannot adjust their locations as quickly as the more mobile pelagic community. Analyses of long-term benthic data for four regions of the upper San Francisco estuary indicate that two major factors control community composition: species invasions, and salinity (Peterson et al. in prep). Specifically, the invasion of the clam *C. amurensis* in the late 1980s resulted in a fundamental shift in the benthic community; however, the center of distribution of *C. amurensis* and other benthic species varies with flow and the resulting salinity regime. So at any particular location in the estuary, the benthic community can change substantially from year to year as a result of environmental variation and species invasions (Figure 9). As will be discussed below, these changes in the benthos can have major effects on food availability to pelagic organisms.

Climate Change Effects on Habitat: There are several reasons we expect climate change will have negative long-term influences on pelagic habitat suitability for the POD fishes. First, there has been a trend toward more Sierra Nevada precipitation falling as rain earlier in the year (Roos 1987, 1991; Knowles and Cayan 2002, 2004). This increases the likelihood of winter floods and may have other effects on the hydrographs of Central Valley rivers and Delta salinity. Altered hydrographs interfere with pelagic fish reproduction, which is usually tied to historical runoff patterns (Moyle 2002). Second, sea level is rising (IPPC 2001). Sea level rise will increase salinity intrusion unless sufficient freshwater resources are available to repel the seawater. This will shift fish distributions upstream and possibly further reduce habitat area for some species. Third, climate change models project warmer temperatures in central California (Dettinger 2005). As stated above, water temperatures do not currently have a strong influence on POD fish distributions. However, summer water temperatures throughout the upper estuary are fairly high for delta smelt. Mean July water temperatures in the upper estuary are typically 21-24°C (Nobriga et al. 2008) and the lethal temperature limit for delta smelt is about 25°C (Swanson et al. 2000). Thus, if climate change resulted in summer temperatures in the upper estuary exceeding 25°C, delta smelt would have little chance of maintaining viable populations.

Top-Down

This model component proposes that the most recent fish declines can be envisioned as the result of the interactive, top-down influence of two kinds of “predators”, piscivorous fishes and water diversions. Note that predation is a common mechanism by which weakened fish are ultimately killed. Thus, increased predation can be a manifestation of other changes in the ecosystem like decreased habitat suitability, starvation, and disease. However, in the top-down section of our conceptual model, we are referring to elevated predation on healthy individuals. Thus, the top-down effects are predicated on the hypothesis that consumption or removal of healthy fish biomass by piscivores (principally striped bass and largemouth bass *Micropterus salmoides*) and water diversions (SWP/CVP exports; power plant diversions) increased around 2000. This could have occurred if one or more of the following happened: water diversions and exports increased during periods the POD fishes were vulnerable to them; piscivorous fishes became more

abundant relative to the POD fishes; pelagic fish distribution shifted to locations with higher predation risk (e.g. habitat changes); or the POD fishes became more vulnerable to predation as a consequence of their extremely low population size (i.e., predation could contribute to the Allee effect hypothesized in the “previous abundance” section) or increases in water clarity.

Predation-driven Allee effects can arise from diminished anti-predator behavior or increased predator swamping of individuals in smaller prey groups (Berec et al. 2006). They are most likely to occur with generalist predators in situations where predation is a major source of mortality, and predation refuges are limited (Gascoigne et al. 2004). In this situation individuals of depleted populations continue to be consumed even though they are at low density. More specialized predators often switch between abundant prey and consequently reduce consumption of rare prey species. As will be described below, the combination of a widely distributed pelagic piscivore (striped bass), an efficient littoral piscivore (largemouth bass), cumulative entrainment losses of multiple life stages, and decreased habitat suitability (Figure 8) suggest the conditions listed by Gascoigne et al. (2004) could apply in the Delta.

Predation Effects: This hypothesis suggests that predation effects have increased in all water year types as a result of increased populations of pelagic and inshore piscivores. In the pelagic habitat, age-1 and age-2 striped bass appear to have declined more slowly than age-0 striped bass (compare Figure 2 with Figure 12A and 12B, CDFG, unpublished data). Adult striped bass abundance increased in the latter 1990s (Figure 3) so high striped bass predation pressure on smaller pelagic fishes in recent years is probable. Further, largemouth bass abundance has increased in the Delta over the past few decades (Brown and Michniuk 2007). Analyses of fish salvage data show this increase occurred somewhat abruptly in the early 1990s and has been sustained since (Figure 11). The increase in salvage of largemouth bass occurred during the time period when *E. densa*, an introduced aquatic macrophyte was expanding its range in the Delta (Brown and Michniuk 2007). The habitat provided by beds of *E. densa* provide good habitat for largemouth bass and other species of centrarchids. Thus, the increased abundance of this introduced predator was likely caused by an increase in an introduced plant, which provided favorable habitat. The areal coverage of *E. densa* in the Delta continued to expand by more than 10% per year from 2004 to 2006, by infesting a greater portion of channels and invasion of new habitat (E. Hestir et al. U.C. Davis, unpublished data). This suggests that populations of largemouth bass and other species using submerged aquatic vegetation will continue to increase. Although none of the IEP surveys adequately tracks largemouth bass population trends, the Delta has become the top sport fishing destination in North American for largemouth bass, which illustrates the recent success of this species. Each year, lucrative fishing tournaments are held in the Delta to take advantage of the large number of trophy-sized bass in the region. Largemouth bass have a much more limited distribution in the estuary than striped bass, but a higher per capita impact on small fishes (Nobriga and Feyrer 2007). Increases in largemouth bass may have had a particularly important effect on threadfin shad and striped bass, whose earlier life stages occur in littoral habitat (Grimaldo et al. 2004; Nobriga and Feyrer 2007).

A change in predation pressure may, in part, be an effect of interactions between biotic and abiotic conditions. Natural, co-evolved piscivore-prey systems typically have an abiotic production phase and a biotic reduction phase each year (e.g., Rodriguez and Lewis 1994). Changing the magnitudes and durations of these cycles greatly alters their outcomes (e.g., Meffe

1984). Generally, the relative stability of the physical environment affects the length of time each phase dominates and thus, the importance of each. Biotic interactions like predation will have stronger community-structuring influence in physically stable systems (e.g., lakes). Historically in the estuary, the period of winter-spring high flow was the abiotic production phase, when most species reproduced. The biotic reduction phase probably encompassed the low-flow periods in summer-fall. Multi-year wet cycles probably increased (and still do) the overall 'abiotic-ness' of the estuary, allowing populations to increase. Drought cycles likely increased the estuary's 'biotic-ness' (Livingston et al. 1997) with low reproductive output and increased effect of predation on population abundance. Our managed system has reduced flow variation much of the time and in some locations more than others. This has probably affected the magnitudes and durations of abiotic and biotic phases (e.g., Nobriga et al. 2005). In other words, reduced flow variability in the estuary may have exacerbated predation effects. However, there is no clear evidence that such changes have been abrupt enough to account for the POD.

Entrainment: Major water diversions in the delta include the SWP and CVP export facilities, power plants, and agricultural diversions. Of these, the patterns of agricultural diversions are the least likely to have changed during the pelagic fish decline. A detailed study of one of these diversions found evidence that their effects on delta smelt are small (Nobriga et al. 2004). As a consequence, our discussion focuses on the power plant and export diversions.

The two power plants of concern are located in the western Delta at Antioch and Pittsburgh. Nonconsumptive water use by the power plants may reach 3200 cfs, which might be enough to create a substantial entrainment risk for fishes residing in the vicinity (Matica and Sommer, in prep.). Studies in the late 1970s indicated that losses of pelagic fishes can be very high. The recent effects of the diversions are unknown; however, the distribution of some pelagic fishes including young striped bass and delta smelt is centered near these diversions. There may also be some risk to fishes created by thermal pollution or residual chlorine from antifouling activities. The magnitude of these risks is unknown. However, operators of these facilities report that the power plants were run relatively infrequently during the POD years, so these power plants seem unlikely as a primary cause of the POD.

Because large volumes of water are drawn from the estuary, water exports and inadvertent fish entrainment at the SWP and CVP export facilities are among the best-studied top-down effects in the San Francisco Estuary (Sommer et al. 2007). The export facilities are known to entrain most species of fish in the upper Estuary (Brown et al. 1996), and are of particular concern in dry years, when the distributions of young striped bass, delta smelt, and longfin smelt shift closer to the diversions (Stevens et al. 1985; Sommer et al. 1997). As an indication of the magnitude of the effects, approximately 110 million fish were salvaged at the SWP screens and returned to the Delta over a 15-year period (Brown et al. 1996). However, this number greatly underestimates the actual number of fish entrained. It does not include losses at the CVP. Even for the SWP alone, it does not account for mortality of fish in Clifton Court Forebay and the waterways leading to the diversion facilities, larvae < 20 mm FL are not collected by fish screens, and losses of fish > 20 mm FL that are inefficiently removed by the louver system.

One piece of evidence that export diversions played a role in the POD is the substantial increases in winter CVP and SWP salvage that occurred contemporaneously with recent declines in each

of the four primary fishes (Figure 12). Increased winter entrainment of delta smelt, longfin smelt and threadfin shad represents a loss of pre-spawning adults and all their potential progeny. Similar increases in the salvage of littoral species including centrarchids and inland silverside were observed during the same period (Figure 13). The littoral species are less influenced by flow changes than the POD fishes. However, as mentioned earlier for largemouth bass, the increases in salvage for centrarchids may be at least partially a result of the range expansion of *E. densa*, which provides favored habitat. This hypothesis is supported by the observation that the greatest increases in centrarchid salvage occurred at the CVP. The intake of the CVP is located in an area with significant areas of *E. densa* nearby. Nonetheless, the increase in entrainment of both groups of fishes suggests a large change in the hydrodynamic influence of the export diversions during recent winters. Note that winter salvage levels subsequently decreased to very low levels for all POD species during the winters of 2005-2006 and 2006-2007, possibly due to the very low numbers of fish that appear to remain in the estuary.

In trying to evaluate the mechanism(s) for increased winter-time salvage, POD studies by USGS made three key observations (IEP 2005). First, there was an increase in exports during winter as compared to previous years (Figure 14). Second, the proportion of tributary inflows shifted. Specifically, San Joaquin River inflow decreased as a fraction of total inflow around 2000, while Sacramento River increased (Figure 15). Finally, there was an increase in the duration of the operation of barriers placed into south Delta channels during some months. These changes may have contributed to a shift in Delta hydrodynamics that increased fish entrainment.

These observations led to a hypothesis that the hydrodynamic change could be indexed using net flows through Old and Middle rivers (Figure 16), which integrate changes in inflow, exports, and barrier operations (Arthur et al. 1996; Monsen et al. 2007). Net or residual flow refers to the calculated flow when the effects of the tide are mathematically removed. An initial analysis revealed that there was a significant inverse relationship between net Old and Middle rivers flow and winter salvage of delta smelt at the SWP and CVP (P. Smith, unpublished). These analyses were subsequently updated and extended to other pelagic fishes (Figure 17, L. Grimaldo, in prep.). The general pattern is that POD species salvage is low when Old and Middle rivers flow are positive.

The hydrologic and statistical analyses suggest a reasonable mechanism by which winter entrainment increased during the POD years; however, the direct population-level effects of increased entrainment are less clear. As part of the POD investigation, Manly and Chotkowski (IEP 2005; Manly and Chotkowski 2006) used log-linear modeling to evaluate environmental factors that may have affected long-term trends in the Fall Midwater Trawl abundance index of delta smelt. They found that monthly or semi-monthly measures of exports or Old and Middle rivers flow had a statistically significant effect on delta smelt abundance; however, individually they explained a small portion (no more than a few percent) of the variability in the fall abundance index of delta smelt across the entire survey area and time period. Hence, there are other factors that dominate the long-term trends of delta smelt fall abundance. Similarly, Kimmerer et al. (2001) estimated that entrainment losses of young striped bass were sometimes very high (up to 99%), but they did not find evidence that entrainment losses were a major driver of long-term striped bass population dynamics.

These results do not mean, however, that direct export effects can be dismissed as contributing causes of the POD. There are two aspects of entrainment that were not addressed by Manly and Chotkowski (2006) and are not well understood: (1) the cumulative effects of entrainment of multiple life stages, and (2) larval entrainment. Larval entrainment is unknown because larvae are not diverted effectively by the louver system, nor sampled effectively at the fish screening facilities. To address this shortcoming, Kimmerer and Nobriga (2008) coupled a particle tracking modeling with survey results to estimate larval entrainment. Kimmerer and Nobriga (2008) used data from several IEP monitoring programs to estimate entrainment of delta smelt. These approaches suggest that larval delta smelt entrainment losses could exceed 50% of the population under low flow and high export conditions. Because there are few reliable larval entrainment data, it is not possible to directly address the question of how important these losses were historically.

Moreover, export effects may be subtle and operate at specific times or in specific years to disproportionately affect only one life stage of delta smelt. For example, it has been proposed that losses of larger females and their larvae may have a disproportionate effect on the delta smelt population (B. Bennett, unpublished data). Bennett (unpublished data) proposes that larger females spawn earlier in the season and produce more eggs, which are of better quality, and survivability, as has been noted for Atlantic cod and other commercially harvested species (Marteinsdottir and Steinarsson 1998; Swain et al. 2007). As a consequence, winter and early spring exports, which have continually increased (Figure 18), could have an important effect on reproductive success of early spawning female delta smelt. Bennett hypothesizes that the observed reduction in the mean size of adult delta smelt in the early 1990s (Sweetnam 1999) is a result of selective losses of earlier spawning adults and their larvae, thereby selecting for later spawned offspring (that have less time to reach maturity). Under this hypothesis, the most important result of the loss of early spawning females would manifest itself in the year following the loss, and would therefore not necessarily be detected by analyses relating fall abundance indices to same-year predictors. This hypothesis is presently being evaluated by Bennett's laboratory using otolith methods.

Bottom-Up

In the “bottom up” portion of the conceptual model, we propose that changes in the quality and availability of food have had important consequences for pelagic fishes. Here, we describe the evidence that there have been long-term and recent changes in food web function.

Food Availability: Estuaries are commonly characterized as highly-productive nursery areas for a suite of organisms. Nixon (1988) noted that there actually is a broad continuum of primary productivity levels in different estuaries, which in turn affects fish yield. Compared to other estuaries, pelagic primary productivity in the upper San Francisco estuary is poor and a low fish yield is expected (Figure 19). Moreover, there has been a significant long-term decline in phytoplankton biomass (chlorophyll *a*) and primary productivity to very low levels in the Suisun Bay region and the lower Delta (Jassby et al. 2002). Hence, low and declining primary productivity in the estuary is likely a principal cause for the long-term pattern of relatively low and declining biomass of pelagic fishes.

A major reason for the long-term phytoplankton reduction in the upper estuary was benthic grazing by the overbite clam (*Corbula amurensis*), which became abundant by the late 1980s (Kimmerer 2002). The overbite clam was first reported from San Francisco Estuary in 1986 and it was well established by 1987 (Carlton et al. 1990). Prior to *C. amurensis*' invasion, there were periods of relatively low clam biomass in the upper estuary because the Asiatic freshwater clam (*Corbicula fluminea*) colonized Suisun Bay during high flow periods and the native marine clam *Mya arenaria* (also known as *Macoma balthica*) colonized Suisun Bay during prolonged (> 14 month) low flow periods (Nichols et al. 1990). Thus, there were periods of relatively low clam grazing rates while one species was dying back and the other was colonizing. The *C. amurensis* invasion changed this formerly dynamic clam assemblage because *C. amurensis*, which is tolerant of a wide range of salinity, is always the dominant clam species in the brackish water regions of the estuary and its grazing influence extends into the Delta (Kimmerer and Orsi 1996; Jassby et al. 2002) beyond the clam's typical range, presumably due to tidal dispersion of phytoplankton-depleted water.

According to recent research, shifts in nutrient concentrations may also contribute to the phytoplankton reduction as well as to changes in algal species composition in the San Francisco Estuary. While phytoplankton production in the San Francisco Estuary is generally considered light limited and nutrient concentrations exceed production limiting levels, nutrients may affect production during times when light conditions are more favorable and also affect species composition. Dugdale et al. (2007) and Wilkerson et al. (2006) found that high ammonium concentrations prevented the formation of diatom blooms but stimulated flagellate blooms in the lower estuary. Ammonium concentrations in the Delta and Suisun Bay have significantly increased over the last few decades due to increased loading from sewage treatment plants (Jassby 2008; Mueller-Solger, in prep.). Van Nieuwenhuyse (2007), on the other hand, found that a rapid reduction in wastewater total phosphorus loads in the mid-1990s coincided with a similarly rapid drop in phytoplankton biomass at three stations in the upper estuary.

Starting in the late 1980s, a series of major changes were observed in the estuarine food web that negatively influenced pelagic fish production. Major step-declines were observed in the abundance of phytoplankton (Alpine and Cloern 1992) and the copepod *Eurytemora affinis* due to grazing by the clam (Kimmerer et al. 1994). Northern anchovy abandoned the estuary's low-salinity zone coincident with the *C. amurensis* invasion, presumably because the sharp decline in planktonic food items made occupation of low-salinity waters unprofitable for this marine fish (Kimmerer 2006). There was also a major step-decline in mysid shrimp in 1987-1988, presumably due to competition with the clam for phytoplankton (Orsi and Mecum 1996). The mysid shrimp had been an extremely important food item for larger fishes like longfin smelt and juvenile striped bass; its decline resulted in substantial changes in the diet composition of these and other fishes (Feyrer et al. 2003). As described above, the population responses of longfin smelt and juvenile striped bass to winter-spring outflows changed after the *C. amurensis* invasion. Longfin smelt relative abundance was lower per unit outflow post-clam (Kimmerer 2002b). Young striped bass relative abundance stopped responding to outflow altogether (Sommer et al. 2007). One hypothesis to explain these changes in fish population dynamics is that lower prey abundance reduced the system carrying capacity (Kimmerer et al. 2000; Sommer et al. 2007).

Several recent studies have shown that pelagic consumer production is limited by low phytoplankton productivity in the San Francisco Estuary (Sobczak et al. 2002, 2004; Mueller-Solger et al. 2002). However, in contrast to the substantial long-term declines in phytoplankton biomass and productivity (Jassby et al. 2002), phytoplankton trends for the most recent decade (1996-2005) are actually positive in the Delta and neutral in Suisun Bay (Jassby, 2008). While this does not support the hypothesis that changes in phytoplankton quantity are responsible for the recent POD, phytoplankton may nevertheless play a role in the recent POD via changes in species composition, as will be discussed in the food quality section below.

A notable finding for the POD is that *Pseudodiaptomus forbesi*, a calanoid copepod that has replaced *Eurytemora affinis* as the most common delta smelt prey during summer, continued to decline in the Suisun Marsh and confluence regions from 1995 to 2004, while its numbers increased in the southern Delta (Figure 20; Kimmerer et al. in prep., Mueller-Solger et al. in prep.). Although substantial uncertainties about mechanisms remain, this trend may be related to increasing recruitment failure and mortality in Suisun Bay and the western Delta due to competition and predation by *C. amurensis*, contaminant exposures, and entrainment of source populations in the Delta (Durand et al. in prep., Mueller-Solger et al. 2006). For example, *C. amurensis* abundance and distribution in the Suisun Bay and the western Delta during 2001-2004 was greater than during the 1995-1999 wet period, but similar to abundance indices and distribution patterns during the 1987-1992 drought (IEP 2005, Peterson et al. in prep.). Further, in the two most recent years (2005 and especially 2006), *P. forbesi* has started to rebound substantially in the western Delta (Figure 21, Mueller-Solger et al. in prep.).

There is also interest in a more recent invader, the cyclopoid copepod *Limnoithona tetraspina*, which significantly increased in the Suisun Bay region beginning in the mid-1990s. It is now the most abundant copepod species in the low-salinity zone (Bouley and Kimmerer 2006). It has been hypothesized that *L. tetraspina* is an inferior food for pelagic fishes including delta smelt because of its small size, generally sedentary behavior, and ability to detect and avoid predators (Bouley and Kimmerer 2006). Experimental studies addressing this issue are ongoing (Sullivan et al. unpublished data). *Acartiella sinensis*, a calanoid copepod species that invaded at the same time as *L. tetraspina*, also reached considerable densities in Suisun Bay and the western Delta over the last decade. Its suitability as food for pelagic fish species remains unclear, but is also being investigated (Sullivan et al. unpublished data).

Preliminary information from studies on pelagic fish growth, condition and histology provide additional evidence for food limitation in pelagic fishes in the estuary (IEP 2005). In 1999 and 2004, residual delta smelt growth was low from the Sacramento-San Joaquin confluence through Suisun Bay relative to other parts of the system. Delta smelt collected in 2005 from the Sacramento-San Joaquin confluence and Suisun Bay also had high incidence of liver glycogen depletion, a possible indicator of food limitation. Similarly, during 2003 and 2004 striped bass condition factor decreased in a seaward direction from the Delta through Suisun Bay.

Thus far, there is little evidence that the unusually poor growth rates, health, and condition of fishes from Suisun Bay and western Delta are due directly to the effects of toxic contaminants or other adverse chemical or physical habitat conditions. Therefore, our working hypothesis is that the poor fish growth and condition in the upper estuary are due to food limitation. Note,

however that contaminant episodes may be contributing to poor phytoplankton growth (Dugdale et al. 2007) and invertebrate mortality (Werner unpublished data), which could exacerbate food limitation. If fishes are food limited in Suisun Bay and west Delta during larval and/or juvenile development, then we would expect greater cumulative predation mortality, higher disease incidence, and consequently low abundance indices at later times.

Food Co-occurrence: The above patterns in fish food have generally been described at rather broad scales. Recently, interest has focused on determining patterns of co-occurrence of fish predators and their zooplankton prey. The assumption is that predators should co-occur with their prey. This idea was first explored by Nobriga (2002) who showed that delta smelt larvae with food in their guts typically co-occurred with higher calanoid copepod densities than larvae with empty guts. Recently, Kimmerer (in press), Miller and Mongan (unpublished data), and Mueller-Solger (unpublished data) used similar approaches to look at potential co-occurrence of delta smelt and their prey and its effects on survival. Kimmerer (in press) showed that there was a positive relationship between delta smelt survival from summer to fall and zooplankton biomass in the low-salinity region of the estuary (Figure 22). Miller and Mongan (unpublished data) have concluded that April and July co-occurrence is a strong predictor of juvenile delta smelt survival. Mueller-Solger (unpublished data) defined delta smelt habitat based on the environmental quality results of Nobriga et al. (2008) and prey spectrum more broadly (as all copepods) compared to Miller and Mongan (unpublished data) and found no long-term decline in the total biomass of copepods potentially available for consumption by delta smelt in midsummer, although species composition has changed considerably (Figure 21).

There are two shortcomings of co-occurrence analyses like those described above. First, it is difficult to characterize fish prey suitability. For instance, *E. affinis* and *P. forbesi* are generally believed to be preferred prey items for delta smelt (Nobriga 2002; Miller and Mongan unpublished). However, diet data show that delta smelt will actually feed on a wide variety of prey (Lott 1998; S. Slater, California Department of Fish and Game, unpublished; Figure 23). Thus, the question of prey co-occurrence involves questions of prey catchability (e.g., Meng and Orsi 1991) and profitability (energy per item consumed and nutritional quality of individual prey items). For example, *L. tetraspina* has a large biomass in the system but individual *L. tetraspina* are smaller and possibly more evasive than the larger calanoid copepods. The energy needed by an individual delta smelt to harvest a similar biomass of *L. tetraspina* compared to the energy needed to harvest a larger species could be very different, as suggested by optimal foraging theory (e.g., Stephens and Krebs 1986). Another major limitation of co-occurrence analyses is that IEP sampling programs sample fish and zooplankton at larger spatial and temporal scales than those at which predator-prey interactions occur. Both fish and copepods are likely to be patchy and the long tows required to collect sufficient numbers of organisms for counting would homogenize such patch structure. Moreover, it is unlikely that the (monthly or even twice monthly) “snapshot” of fish and prey co-occurrence in specific locations or even small regions provided by the IEP surveys is representative of feeding conditions actually experienced by fish on an hourly or daily basis.

The weight of evidence strongly supports bottom-up food limitation as a factor influencing long-term fish trends in the upper estuary. However, the bottom-up hypothesis is unlikely as a single mechanism for the recent pelagic organism decline. Specifically, it is unclear why there has

been a substantial recent decline in some Suisun Bay and western Delta calanoid copepod species, but not in phytoplankton chlorophyll *a* concentration. Also, calanoid copepod densities (especially *P. forbesi*) rebounded substantially in 2006 (Mueller-Solger, unpublished data) while the POD fish abundance indices (especially for delta smelt) remained low. Second, recent *C. amurensis* levels are not unprecedented; they are similar to those found during the 1987-92 drought years, so it is unclear if and why benthic grazing would have a greater effect on the Suisun Bay food web during the POD years than during the earlier drought years. Finally, it is possible that the hypothesis that the San Francisco Estuary is driven by phytoplankton production rather than through detrital pathways (Sobczak et al. 2002, 2004; Mueller-Solger et al. 2002) may have been accepted too strictly. Many zooplankton are omnivorous and can consume microbes utilizing dissolved and particulate organic carbon. This has recently been demonstrated for several zooplankton species in the San Francisco Estuary (Gifford et al. 2007 and references therein). Thus, shifts in availability of phytoplankton and microbial food resources for zooplankton might favor different species. It is possible that a better understanding of shifts in phytoplankton and zooplankton community composition and perhaps related changes in the microbial food web in the Suisun Bay region could explain these apparent inconsistencies.

Food Quality: Studies on food quality have been relatively limited in the San Francisco Estuary, with even less information on long-term trends. However, food quality may be another limiting factor for pelagic zooplankton and their fish predators.

At the base of the pelagic food web, food quality for consumers is determined by the relative contributions of different phytoplankton and microbial species and detritus to the overall organic particle pool available to primary consumers. For example, diatoms and cryptophytes are thought to be of good food quality for zooplankton, while the nutritional value of cyanobacteria such as *M. aeruginosa* can be very low (Brett and Müller-Navarra 1997), particularly for toxic varieties (Rohrlack et al. 2005). Lehman (1996, 2000) showed shifts in phytoplankton species composition in the San Francisco Estuary from diatom dominated to more flagellate dominated communities. Mueller-Solger et al. (2006) found that in recent years, diatoms were most abundant in the southern San Joaquin River region of the Delta, and Lehman (2007) found greater diatom and green algal contributions upstream and greater flagellate biomass downstream along the San Joaquin River. To date, the *M. aeruginosa* blooms have occurred most intensively in the central Delta, thus POD species that utilize the central Delta such as threadfin shad, striped bass, and the poorly monitored centrarchid populations (largemouth bass and sunfish) would be most likely to suffer any direct adverse effects of these blooms.

In 2007, the *M. aeruginosa* bloom year was the worst on record in the Delta (P. Lehman, in prep.). The highest cell densities were observed near Antioch, i.e. considerably west of the previous center of distribution, and may thus have affected invertebrates and fishes in the confluence and Suisun Bay regions of the upper estuary.

In general, phytoplankton carbon rather than the much more abundant detrital carbon are thought to fuel the food web in the San Francisco Estuary (Mueller-Solger et al. 2002; Sobczak et al. 2002, 2004); however, that does not mean the detrital pathways are not significant because many zooplankton are omnivorous and capable of utilizing both pathways. For example, Rollwagen-Bollens and Penry (2003) observed that while heterotrophic ciliates and flagellates were the

dominant prey of *Acartia* spp. in the bays of the San Francisco Estuary, diatoms and autotrophic ciliates and flagellates also formed an important part of their diet during phytoplankton blooms. Calanoid copepod and cladoceran growth and egg production may often be limited by low levels of phytoplankton biomass. This appears to be true even for omnivorous calanoids such as *Acartia* spp. Kimmerer et al. (2005) found a significant relationship between *Acartia* spp. egg production and chlorophyll *a* concentration in the San Francisco Estuary, suggesting that *Acartia* spp. likely also derived a large part of carbon and energy from phytoplankton. Bouley and Kimmerer (2006), on the other hand, reported that egg production rates of the cyclopoid copepod *L. tetraspina* were unrelated to chlorophyll *a* concentrations in the low salinity region of the San Francisco Estuary. *L. tetraspina* digestion rates were highest for ciliates, perhaps suggesting a greater importance of the detrital carbon pathway for this species.

In a study focusing on the nutrition and food quality of the calanoid copepods *E. affinis* and *P. forbesi*, Mueller-Solger et al. (2006) found evidence for “trophic upgrading” of essential fatty acids by *E. affinis* and *P. forbesi*, confirming their importance as high-quality food for fish. They also found that *E. affinis* gained the greatest nutritional benefits from varied food sources present in small tidal sloughs in Suisun Marsh. *P. forbesi*, on the other hand, thrived on riverine phytoplankton in the southern Delta, especially diatoms. Diatoms are likely also an important food source for other calanoid copepod species. The relative decrease in diatom contributions to the phytoplankton community in the central Delta and Suisun Bay (Lehman 1996, 2000) is thus a concern and may help explain the declines in *P. forbesi* and other calanoid copepods in these areas.

Mueller-Solger et al. (2006) concluded that areas rich in high-quality phytoplankton and other nutritious food sources such as the southern Delta and small tidal marsh sloughs may be critical “source areas” for important fish prey organisms such as *P. forbesi* and *E. affinis*. This is consistent with results by Durand et al. (unpublished data) who showed that transport from upstream was essential for maintaining the *P. forbesi* population in Suisun Bay. It is possible that the increase in *P. forbesi* densities in the western Delta in 2006 could be related to greater San Joaquin River flows during this wet year, which may have reduced entrainment of *P. forbesi* source populations in the Delta.

As noted in earlier sections, the dichotomy between phytoplankton and detrital/microbial energy pathways supporting zooplankton has probably been applied more stringently than is appropriate. Both are likely important, with the balance between them in specific areas of the estuary likely having effects on the success of particular zooplankton species. Additional research into the detrital pathway might be useful in understanding the factors controlling zooplankton populations, which are critical food resources for pelagic fishes.

Study Approach

The major objective of the 2008 POD work is to address the following question:

What stressors, under what conditions, currently affect pelagic fish populations?

This question is somewhat different than our original focus, which was to determine what stressors changed around 2002, and whether they could have substantially affected pelagic fish abundance. We altered our study focus because we have found that the species declines were not perfectly synchronous, and because it became awkward to separate short-term and long-term changes in the stressors. Stated simply, the POD team thinks the recent fish declines are due to the cumulative effects of numerous long-term and recent stressors. Moreover, the current focus on what presently affects pelagic fishes should be a more useful question for identification of the most effective management actions and thus satisfy the information needs of resource managers, fulfilling the mission of the IEP.

The study program is organized around the previously-described basic conceptual model, which provided a useful way to organize and prioritize the study elements. An important point regarding the study approach is that each of the models' components should be considered as an integrated program, not as "stand-alone" programs. As one example, much of the data on abundance and other population measures (e.g. growth, origin) collected in the first model element, "Previous Abundance and Current Abundance", will be used as part of the evaluations in all of the other narrative model elements. Similarly, the "Habitat" element will collect data on hydrology, water quality, and other habitat measures that will be used as the basis for analysis by all of the other model elements.

This Study Approach section concludes with a section on Synthesis. Much of the future POD synthesis will result from a new collaboration of the Interagency Ecological Program (IEP) with the National Center for Ecological Analysis and Synthesis (NCEAS).

Previous Abundance and Current Abundance

This element will collect a variety of monitoring data that can be used by all of the other narrative elements, and the synthesis efforts. However, the data will also be used specifically to evaluate the role of previous abundance (i.e. adult stock) on long-term population dynamics of the POD fishes. The major tasks are as follows: Two major types of data will be collected: 1) trends in fish abundance and population size; and 2) trends in other measures of population status.

Trends in fish abundance and population size will be evaluated using the following study elements:

- Summer Townet Survey (2008-007; DFG). This component provides a juvenile abundance index for striped bass and delta smelt.
- Fall Midwater Trawl Survey (2008-003; DFG). This component provides a juvenile abundance index for striped bass and longfin smelt, and adult abundance estimates for delta smelt and threadfin shad.
- Feasibility of using towed imaging systems. (2008-130; USBR, DWR). This new element will explore the use of towed imaging systems as a nonlethal alternative to conventional trawling and providing better data on the small spatial scale distribution and relative abundance of pelagic fishes.

- Use of acoustics to calculate trawl openings (2008-131; DFG). This new element will test the use of acoustics to refine estimates of volume sampled by trawls.
- Estimation of pelagic fish population sizes (2008-043; USFWS-Ken Newman). This component will continue to explore the ability of current IEP data to develop population abundance estimates for POD fishes.
- Historical population dynamics (2008-084; USBR). Consultant Bryan Manly will continue work with USBR staff on historical population dynamics to assess temporal and special trends in different fish species and communities.

Several related studies will be conducted to evaluate additional fish population metrics:

- Trends in fish biomass (2008-119; DWR). Building on previous estimates by Wim Kimmerer, long-term estimates of pelagic fish biomass trends will investigate if changes coincided with the POD years.
- Apparent growth rates of pelagic fishes (2008-051; DFG). Efforts will continue to evaluate how recent apparent growth rates compare to long term results.
- Delta smelt genetics (2008-135, UCD). A detailed genetic analysis will be conducted to examine whether stock structuring (e.g. distinct regional populations) occurs in delta smelt.
- Evaluation of delta smelt otoliths (2008-060; UCD). Dr. Bill Bennett will continue studies on temporal and spatial patterns of delta smelt growth and survival based on otolith measurements.
- Longfin smelt genetics and growth (2008-137; UCD). Similar to delta smelt investigations, otolith and genetic tools will be used to assess regional longfin smelt population structure and growth.

Habitat Effects

This study component will collect a variety of physical, chemical and biological data that can be used by all of the other conceptual model elements, and the synthesis efforts. The data will also be used specifically to evaluate several habitat-specific questions: What are the trends in basic habitat variables? How do changes in habitat quantity and quality affect pelagic fishes? What changes in habitat quantity and quality affect other organisms in the estuary? How do toxics, disease and toxic algal blooms affect the previous two groups of organisms? Although the last question is essentially a subset of the second and third, we have chosen to include it separately because we have relatively little baseline information on this issue as compared to other water quality measurements.

Trends in basic habitat variables: General patterns in estuarine habitat will be assessed with water quality and hydrological data.

- Environmental Monitoring Program (2008-072; DWR). This component provides simultaneous water quality and relevant non-fish data (e.g., zooplankton, *Corbula*) throughout the year.

- Cause of Fall Salinity Changes (2008-097; CCWD). This CALFED-funded effort will identify the relative importance of factors contributing to long-term increases in fall salinity in the Delta.
- CASCADE (2008-081; USGS). This CALFED-funded effort will identify the potential effects of climate change on estuarine habitat will be addressed through a computational assessment of scenarios.
- Turbidity sources and signals (2008-126; USGS). Turbidity is a key habitat component for pelagic fishes and an indicator of fish entrainment at the SWP and CVP. This new study element will use historical measurements of flow and turbidity to determine the likely sources of turbidity at the Delta pumping plants.

Effects of changes in habitat quantity and quality on pelagic fishes: The goal of this series of studies is to better characterize trends in pelagic fish habitat suitability. We will pursue the following questions: Has the surface area of suitable habitat changed for the POD species? Does interannual variation in estuarine hydrology influence the spatial and volumetric extent of pelagic fish habitat? What factors affect the extent of pelagic fish habitat? What are the trends in physical habitat area in the Delta versus Suisun Bay? How do flow changes alter the size and/or shape of pelagic fish habitat zones? Two study elements are proposed:

- Effects of the Cache Slough Complex on Delta Habitat (2008-132; DWR, USGS). This study element will conduct a detailed analysis of transport of sediment, phytoplankton, and zooplankton in the Cache Slough Complex, an important spawning region for delta smelt.
- SAV abundance and Distribution (2008-102; UCD). The goal of this study is to determine if temporal-spatial shifts in the habitats required by pelagic fish reduced their likelihood of finding adequate amounts of habitats needed to complete their life cycles?

Effects of habitat quantity and quality on other organisms: The approach to evaluating the effects of habitat on other organisms involves an element intended to improve our understanding of large-scale ecosystem changes.

- *Corbula* Salinity Tolerance and Grazing Rates (2008-076; SFSU). In a continuing study element, SFSU will use laboratory methods to analyze *Corbula* salinity tolerances, and the effect of salinity on clam grazing rates.

Effects of contaminants, disease, and toxic algal blooms: Studies of the effects of contaminants, disease, and toxic algal blooms will focus on answering the following questions: Is there evidence of direct toxicity to POD species in waters collected from the Delta? Is there evidence of toxicity to pelagic fish food species in waters collected from the Delta? Is there evidence of disease in POD species collected from the Delta?

- Delta smelt histopathology investigations (2008-061; UCD). Histopathology analysis of Delta smelt will be used to determine whether there is evidence of direct contaminant exposure or food limitation. Toxicity monitoring in Delta waters using the amphipod, *Hyalella azteca*, used to represent Delta smelt food species, will be used as an additional line of evidence should evidence of food limitation be observed. In addition, laboratory

studies will be conducted to compare the sensitivity of POD food species, such as *Eurytemora affinis*, to that of *H. azteca*. This work will be analyzed in conjunction with the work on “Bottom-up Effects” discussed below.

- Contaminants Studies (2008-127; UCD). Direct toxicity will be measured in laboratory exposures of Delta smelt to Delta waters collected from locations throughout the Delta. Studies to determine the potential direct toxicity produced by *Microcystis* blooms also will be conducted (2008-079; DWR).

Top-Down Effects

Elevated Predation Rates: The predation portion of the top-down study approach will focus on two major questions: What are the distributions and abundance trends of the upper estuary’s major predators? What are the effects of changing predation pressure on the POD fishes?

- Modeling Striped Bass Predation in the Delta (2008-115; DWR). Population estimates developed from the first question will be used as the basis for a bioenergetic modeling study (Fish Bioenergetics 3.0) that will evaluate trends in predation pressure in the Delta. The general approach will be to combine age-specific data on growth and abundance of striped bass with bioenergetics modeling to estimate the consumption demand of the striped bass population through time. We will try similar analyses for largemouth bass if sufficient population age structure and growth data are available.
- Effects of inshore predators (2008-133; UCD). The negative effect of SAV on native fishes in the Delta is now well-established in the literature (Grimaldo et al. 2004; Nobriga et al. 2005; Brown and Michniuk 2007). This UCD effort will provide new information into the habitat use and feeding ecology of largemouth bass in SAV.

Entrainment and other Facility Impacts: Recent work on increases in winter salvage of pelagic fishes and the “Big Mama” hypothesis (see Conceptual Model section) indicates that entrainment losses play a role in the recent population trends of some of the POD fishes, particularly delta smelt. For 2008, our overall approach to address the entrainment issue is to focus on the following two major questions: What is the mechanism for the increase in winter salvage? What are the effects of power plant diversions on pelagic fishes?

- South Delta Hydrodynamic Effects (2008-15, 16, 17). A major focus of the south Delta studies is to determine the effect of hydrodynamics and physio-chemical variables near the SWP on fish behavior and entrainment during relatively short time scale (i.e., hours and days) events.
- 3D Particle Tracking Modeling (2008-141; DWR, Consultants). Particle tracking using the newly developed 3D model will be used to evaluate particle entrainment risk for different export/inflow scenarios and historical conditions. The project will include a detailed model for Clifton Court Forebay, which should provide improved understanding of circulation patterns across this SWP facility and the corresponding effects on fish loss and residence time.

- Statistical Effects of Environmental Conditions on Salvage (2008-084; USBR). Consultant Bryan Manly's work USBR staff on historical population dynamics will include statistical analyses of factors affecting entrainment rates as indexed by salvage.

Our study approach to address the extent of power plant entrainment will be at a much more fundamental level than for the SWP and CVP. Because there have not been detailed studies on power plant entrainment since 1979, much of the focus of this study element will be to collect basic information about species loss, abundance and spatial and temporal overlap with the power plant diversions. These issues will be addressed in a single study element, "Investigation of power plant impacts" (2008-087; Consultants).

Bottom-Up Effects

The approach to address the bottom-up model component will focus on factors that may be disrupting the food web for pelagic fishes. What are the trends in plankton distribution, species composition, abundance, and biomass? What factors influence food availability for pelagic fishes? Are there regional or temporal differences in food quality for pelagic fishes?

Studies in support of the first question will be a continuation of work initiated in 2005. These include the following:

- Trends in Delta Phytoplankton. (2008-045; UCD). This ongoing UCD-study will evaluate long-term patterns and trends in phytoplankton production and biomass and other water quality variables in different Delta subregions.
- Zooplankton Trends (2008-072, DWR). As part of analyses for the IEP Environmental Monitoring Program, DWR staff will continue analyses of the zooplankton database to evaluate long-term and regional trends in zooplankton community structure.
- Zooplankton Fecundity and Population Structure (2008-044; SFSU). This continuing POD element will evaluate whether there are changes in zooplankton fecundity and population structure that may have influenced the pelagic food web.

The second question, food availability, will be addressed by evaluating food web linkages, particularly phytoplankton and zooplankton losses to clams and routing of energy through low efficiency food web pathways. Several new studies are included.

- Food Web Disruption (2008-082; SFSU). In this ongoing CALFED-funded POD element, SFSU will lead an effort to evaluate how the food web has changed in recent years.
- Benthic Biomass and Abundance (2008-065; 2008-078; DWR). This POD element will continue to develop estimates of benthic abundance and biomass.
- Fish Diet and Condition (2008-062; DFG). To further understanding of pelagic fish feeding ecology, DFG will continue with diet analyses of the primary pelagic fishes.
- Food Match/Mismatch (2008-122; DFG). This POD study element will use larval fish and zooplankton data from the 20 mm trawl survey to evaluate whether there is a mismatch between the locations of young pelagic fish and their zooplankton prey.

Synthesis for the POD

Because the POD involves multiple species in a highly variable and heavily-modified environment with multiple and often interacting stressors, we will likely rely on a *weight of evidence* approach (Burkhardt-Holm and Scheurer 2007) to interpret the results from the large number of POD studies. Using this approach, we will examine the multiple types of evidence to develop plausible linkages within our conceptual models, supplemented by quantitative approaches where they are possible. In our recent synthesis report (Baxter et al. 2008), this approach was especially important in the development of the four “species models.” As an outcome of this approach, part of the 2008 synthesis of the POD results will focus on the linkages within the conceptual models and their contributions to the overall POD phenomenon. However, the ultimate question for each of the stressors in the basic conceptual model is how they interact to produce population-level effects on the POD fishes. This question will be difficult to determine since population estimates and population vital rates (e.g., instantaneous mortality rates) are currently unknown. The gap will be addressed, in part, by one of the POD study elements to develop population estimates (see below); however, we acknowledge that the estimates may not be somewhat tenuous, particularly for rare and patchy species such as delta smelt. Hence, synthetic study elements will emphasize modeling approaches that emphasize vital rates over absolute population estimates.

- Population modeling of delta smelt and striped bass (2008-041 and 2008-038; UCD, SFSU, LSU). These projects will include both age-structured matrix models and individual-based models that will help to evaluate the effects of each of the stressors on pelagic fishes. The striped bass effort will include a dose-response model to evaluate contaminant effects.
- Statistical analyses of pelagic fish abundance data (2008-084; USBR, consultants). Statistician Bryan Manly will continue his efforts to analyze the environmental factors that affect variation in pelagic fish abundance.
- Analyses of historical abundance trends (2008-084; USBR). Consultant Bryan Manly’s work with USBR staff on historical population dynamics will include statistical analyses of environmental factors affecting abundance trends.
- Comprehensive synthesis (2008-046; USFWS, USGS, DWR, DFG). Much of the synthesis effort for the POD program will be facilitated by the National Center for Environmental Analyses and Synthesis (NCEAS), who will organize a series of work teams consisting of outside experts and IEP investigators.

Study Components

Linkages among work plan elements: All work plan elements relate to the conceptual models. Identifying these conceptual linkages ensures that all stressors are pursued; linkages among stressors and studies are identified and should help in future syntheses of the POD results. The following table allows easy identification of the justification for each work plan element

Table 1. Relationships among POD work plan elements and the basic conceptual model components: ALL (all model components); S (stock/prior abundance); H (habitat); T (top-down); B (bottom-up).

1. Expanded Monitoring		Conceptual model connection
PEN¹ #	Title	
2008-003	Fall Midwater Trawl	ALL
2008-007	Summer Townet Survey	ALL
2008-033	20mm Survey	S, H, B
2008-072	Environmental Monitoring program	S, H, B
2006-089	Directed field collections	ALL

2. On-going work

PEN #	Title	
2008-017	Larval fish behavior study	T
2008-038	Development of striped bass and longfin smelt models	ALL
2008-041	Modeling delta smelt populations in the S.F. Estuary	ALL
2008-042	Striped bass health investigations	H
2008-043	Estimation of pelagic fish population sizes	S
2008-044	Zooplankton fecundity and population structure	B
2008-045	Phytoplankton primary production and biomass	B
2008-046	Overlap/Synthetic analyses of fish and zooplankton	ALL
2008-060	Evaluation of delta smelt otoliths	ALL
2008-061	Pelagic fish liver histopathology	H, B
2008-062	Fish diet and condition	H, B
2008-065	Trends in benthic macrofauna abundance and biomass	H, B
2008-066	Evaluation of changes in pelagic fish habitat	H
2008-076	Corbula salinity tolerance	H, B
2008-078	Retrospective analysis of long-term benthic data	H, B
2008-079	Field survey of Microcystis bloom biomass and toxicity	H, B
2008-081	CASCadE	H
2008-082	Food web support for delta smelt and other estuarine fishes	B
2008-084	Analysis of historical population dynamics	ALL
2008-087	Investigation of power plant impacts	T
2008-097	Hydrologic changes and Suisun Bay increased salinity	H, T, B

2008-102	SAV abundance and distribution	H
2008-106	Estimates of fish and zooplankton biomass	T, B
2008-107	Fish facility history	T
2008-108	Delta smelt culture facility	ALL
2008-115	Striped bass bioenergetics evaluation	T
2008-119	Delta fish biomass estimation	T, B
2008-121	Endocrine disruptor study	H

3. New work

PEN #	Title	
2008-124	Contaminants synthesis	H
2008-125	Clifton court residence time	T
2008-126	Long-term sources and early warning signals in turbidity	H, T
2008-127	Contaminants and biomarkers work	H
2008-129	Upstream migration cues for Osmerids	H
2008-130	Feasibility of using towed imaging systems	S
2008-131	Use of acoustics to calculate dimensions of trawl openings	S
2008-132	Effects of the Cache Slough Complex on North Delta Habitat	H, B
2008-133	Impacts of large mouth bass on the delta ecosystem	T
2008-135	Delta smelt genetics	S
2008-136	Bioenergetics of zooplankton prey species	B
2008-137	Population genetics and otolith geochemistry of longfin smelt	H, S
2008-138	Effects of wastewater management on primary productivity	H
2008-139	Effects of <i>Microcystis aeruginosa</i> on threadfin shad	H
2008-141	3D modeling of the Delta	T, H
2008-142	Investigating lower trophic levels of Suisun Bay food web	B
2008-143	Screening to determine impacts of wastewater on delta smelt	H
2008-144	Pyrethroid pesticide monitoring	H
2008-145	Delta fish tissue selenium analysis	H

4. Transitioned elements

PEN #	Title	
2007-031	Delta and Suisun Bay particle tracking investigations	T, H
2007-063	Acute and chronic invertebrate and fish toxicity tests	S, H
2007-086	Gear Efficiency Studies	S
2007-096	Larval Fishes Survey (DSLs)	ALL
2007-118	Data mining for status and trends of predators	T

5. Completed elements

2007-036	Preliminary investigations of disease as a factor in the POD	S
2007-039	Threadfin shad data analysis and population dynamics	S, H
2007-112	Biomarkers workshop	H

6. Unaccomplished work

2007-018	Contaminant loads and disease in striped bass	S
2008-051	Apparent growth rates of pelagic fishes	S, B
2008-122	Food match-mismatch study	B, H

^{1/} Program element numbers used for tracking purposes.

I. Expanded Monitoring

Fall Midwater Trawl (FMWT)

IEP 2008-003

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What is the relative abundance (via abundance index) of striped bass, delta smelt and other pelagic fishes of the upper estuary? Can these data be used to estimate apparent growth?

Description: This survey targets age-0 striped bass and other pelagic species 30-150 mm in length using a midwater trawl towed through the water column for 12 minutes in a stepped oblique manner (Stevens and Miller 1983). Sampling takes place monthly September through December at 116 stations located from San Pablo Bay upstream through Suisun Marsh and Bay and into the Delta. This survey historically produced annual abundance indices of upper estuary pelagic fishes, which were used to identify the POD decline (Sommer et al. 2007), and more recently the survey has provided fish samples for otolith, diet, condition and histopathology studies, and collected zooplankton and mysid samples to investigate food organism presence and diet, and ranked *Microcystis* apparent densities (see below). During September 2005 and September and October 2006 and 2007, zooplankton tows were made at a subset of stations and mysid samples were collected starting in 2007 (32 sites in 2005 – 18 in 2007). Starting in 2005, delta smelt and striped bass heads and bodies were preserved separately for otolith and histopathological analyses, respectively (e.g., Bennett 2005 3a and Teh 2005 3b) or fish were preserved intact for diet and condition analyses (e.g., Gartz and Slater 2005 3c). In 2006-7, sampling continued as described above and longfin smelt, threadfin shad, and some inland silversides were collected for diet and condition. In 2008, sampling will continue separate heads and bodies of delta smelt and striped bass, and will add longfin smelt. In 2007, a mysid net was added to the zooplankton tow and the combined mysid and CB tows will again be conducted in 2008 at a subset of 10 stations positioned along a transect from the lower Sacramento River through Suisun Bay. These stations overlap the fall distributions of delta smelt and age-0 striped bass. In 2008, we will also continue the visual survey technique started in 2007, ranking the density of *Microcystis* observed at sampling stations. The same technique is also used by the Environmental Monitoring Program (EMP).

Time period: Sampling is conducted monthly from September through December and takes 2 weeks to complete.

Resources required

Cost: The 2008 FMWT budget is \$264,000 from IEP and \$30,000 from POD sources.

PI(s): Randy Baxter and Dave Contreras (DFG)

Contract needed / in place: Reimbursable contracts with DWR and USBR in place.

Contract managers: Rich Breuer (DWR) and Erwin Van Nieuwenhuysse (USBR).

Term of contract: 07/07-06/10 (DWR) and through 12/31/2009 (USBR).

Personnel: The field component of this project requires 1 boat operator, 1 biologist, and 1 scientific aide. The laboratory component requires numerous personnel for pre-season

preparation, fish identification, data validation, diet and condition procedures, stomach content analysis and zooplankton processing.

Equipment: A boat with davits and hydraulics appropriate to pull a midwater trawl net, (such as the *R/V Scrutiny*), laboratory facilities, warehouse space, formalin, ethanol, and suitable containers for sample collection and preservation.

Deliverables and dates: Survey by survey indices will be calculated and checked by the end of each month and annual indices for POD fishes will be complete by the first of the new year.

FMWT pelagic fish abundance indices are reported directly via email and as part of an article completed each spring for the Status and Trends edition of the IEP Newsletter. Also trends in distribution and abundance of jellyfish will be examined for data collected since 2001.

Zooplankton and Mysid identification has been delayed by lab staff shortages, and processing for 2006 – 2008 samples may be contracted in 2008. Once identification is complete, CPUE calculation will be completed at the end of the year, and will contribute to the fish and food-item match –mismatch analysis (2008-122).

Comments: The FMWT Survey collected delta smelt and striped bass for otolith and histopathology investigation, but did not collect sufficient numbers of either to support all the projects in 2005 - 2007, so additional field collections were necessary. Such targeted sampling may not be possible in 2008 due to smelt collection restrictions and field staff limitations. This survey currently reports annual abundance indices for 6 fishes and has collected count data on jellyfish since 2001. The ratio of same-year FMWT to TNS indices for age-0 striped bass is used as an index of summer survival (Stevens et al. 1985). This survey is mandated in the 2004 FWS OCAP Biological Opinion for delta smelt.

Summer Townet Survey

IEP 2008-007

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What is the relative abundance (via abundance index) of striped bass and delta smelt? Can these data be used to estimate apparent mortality? How are juvenile striped bass and delta smelt distributed in relation to potential food items? Is the density of food items related to fish condition, growth rate or health indices?

Description: The Summer Townet Survey (TNS) has collected juvenile fishes in the range of 20 to 50mm since 1959 (Turner and Chadwick 1972) and currently provides indices of abundance for age-0 striped bass (38mm index) and delta smelt. Samples are collected using a conical net with a 1.5 m² mouth and 12.7-mm (½ in) stretched mesh nylon lashed to a hoop frame and mounted on skis. Three, 10-minute oblique tows are made against the current at each of 32 stations located from eastern San Pablo Bay to Rio Vista on the Sacramento River and Stockton on the San Joaquin River. This survey was expanded in 2005 to include simultaneous zooplankton sampling at each station, water collections for invertebrate toxicity tests (Werner, 2005 3e) at a subset of 10 stations, and a water quality profile at every station. Since 2006, water sample collections for invertebrate toxicity were made by directed sampling, not part of this survey. Since 2006, water quality measurement were conducted with a YSI 6600 Sonde that collects temperature, depth, dissolved oxygen, turbidity, chlorophyll *a*, conductivity, salinity, pH, date, and time. Also, delta smelt and striped bass heads and bodies were preserved separately for otolith and histopathological analyses, respectively (e.g. Bennett 2005 3a and Teh 2005 3b) or were preserved for diet and condition analyses (e.g. Gartz and Slater 2005 3c). Beginning in

2007 and continuing in 2008, sampling follows methods described above, except that: water collections employed a separate boat and crew; due to time and equipment limitations, only bottom and surface water quality measures were taken because of the Sonde's slow acquisition time; longfin smelt, inland silverside and threadfin shad were collected along with delta smelt and striped bass for diet and condition; visual survey technique ranked the density of *Microcystis* observed at sampling stations, and numeric and volumetric estimation of jellyfish abundance did not begin.

Time period: Every other week from June through August.

Resources required

Cost: The 2008 TNS budget is \$211,000 from IEP and \$34,000 from POD sources.

PI(s): Randy Baxter and Virginia Afentoulis (DFG)

Contract needed / in place: Reimbursable contracts with DWR and USBR in place.

Contract managers: Rich Breuer (DWR) and Erwin Van Nieuwenhuysse (USBR).

Term of contract: 07/07-06/10 (DWR) and through 12/31/2009 (USBR).

Personnel: The field component of this project requires 1 boat operator, 1 biologist, and 1 scientific aide. The laboratory component requires numerous personnel for pre-season preparation, larval fish identification, zooplankton identification, data validation, length weight procedures, and stomach content analysis.

Equipment: A boat with an A-frame and hydraulics appropriate to pull a sled-mounted townet (such as the *R/V Scrutiny or Munson*), laboratory facilities, warehouse space, formalin, ethanol, and suitable containers for sample collection and preservation.

Deliverables and dates: Survey indices for striped bass (38-mm Index) and delta smelt will be produced by September 1 of each sampling year and reported to all Agencies through the POD Management Team. These indices will be part of any conference abundance-trend updates for CALFED Science or IEP, and will be published the following spring in the Status and Trends edition of the IEP Newsletter. Also trends in distribution and abundance of jellyfish will be examined for data collected since 2001. Zooplankton identification and CPUE calculations were delayed by lab personnel vacancies. New staff are being trained and a contract for zooplankton identification is being developed to address the backlog of unprocessed samples. Samples from 2006 and 2007 should be identified by the end of 2008, and may contribute to the fish and food-item match –mismatch analysis (2008-122).

Comments: The TNS collected delta smelt and striped bass for otolith and histopathology investigations, but did not collect sufficient numbers of either to completely support those projects in 2005, so additional field collections were necessary and were added in 2006 and 2007. A similar circumstance is expected for out years. TNS catch data are used to calculate the striped bass 38.1 mm index (Turner and Chadwick 1972) and an annual abundance index for juvenile delta smelt (Moyle et al. 1992). This survey is part of the long-term monitoring carried out by IEP and is mandated in the 2004 FWS OCAP Biological Opinion for delta smelt.

20-mm Survey

IEP 2008-033

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What is the abundance and distribution of POD fish larvae and early juveniles, particularly delta smelt and striped bass? Can catches of larval fishes and zooplankton be used to

estimate overlap and possibly recruitment success? What do POD fish larvae eat, and are diet related to availability in the environment?

Description: This survey targets late-stage larval and early juvenile fishes, particularly delta smelt and historically focused on providing near real-time information on the distribution of young delta smelt to inform water management decisions. More recently, fish and associated zooplankton data collected have become very important in the investigation of food limitation hypotheses. Starting in spring (March or April) and continuing every other week through summer (early July), three oblique tows are made at each of 48 locations in the upper estuary using a conical, 5.1 m –long plankton net composed of 1600 micron mesh with a 1.5 m² mouth, mounted on a weighted tow-frame with skids (Dege and Brown 2004). In addition, zooplankton are collected during one tow at each location with a Clarke-Bumpus (CB) net composed of 160 micron mesh attached to the top of the 20-mm net frame. General Oceanics flowmeters mounted in the mouth of each net provide estimates of volumes (m³) filtered. Fish and zooplankton samples are preserved in 10% formalin and identified in the lab. This survey has sampled annually since 1995 and provides near-real-time larval/juvenile delta smelt distribution information via the web (<http://www.delta.dfg.ca.gov/data/20mm/>) to facilitate water management decisions. Samples from 2005 and 2006 provided young delta smelt and longfin smelt for diet analyses and zooplankton data for comparison to diet data (Slater in prep.). Length data from 1995-2006 contributed to longfin smelt and delta smelt apparent growth analyses. In 2008, this survey started earlier than normal (early March) and conducted only one tow at a subset of survey stations to provide distribution information for larval and small juvenile longfin smelt. Also in March 2008, sampling commenced at six new north Delta locations to improve spatial coverage. These new locations are permanent additions to this survey. In 2009, sampling will likely commence in late January at a subset of stations for larval longfin smelt.

Time period: Every other week from early March through early July.

Resources required

Cost: The 2008 20mm budget is supplemented with \$260,000 from POD sources.

PI(s): Bob Fujimura, Julio Adib-Samii, Erin Gleason (DFG)

Contract needed / in place: Reimbursable contracts with DWR and USBR in place.

Contract managers: Rich Breuer (DWR) and Erwin Van Nieuwenhuysse (USBR).

Term of contract: 07/07-06/10 (DWR) and through 12/31/2009 (USBR).

Personnel: The field component of this project will change starting in 2008. A single early March survey targeting longfin smelt required 1 boat operator, 1 biologist and 1 scientific aide. When the full surveys starts in late March, it will run two boats for the first two days and a single boat for the remaining three days of survey and each boat requires 1 boat operator, 1 lead person (biologist, lab assistant or well trained scientific aid) and 1 scientific aide. Numerous lab personnel are associated with pre-season preparation, lab processing of samples, zooplankton and larval fish identification.

Equipment: This project requires the use of the *R/V Munson* and *R/V Scrutiny* or *RV Beowulf*. Wet lab space is required to process approximately 1300 larval fish samples and 432 zooplankton samples that are collected throughout the field season.

Deliverables and dates: larval and juvenile fish distribution data will be posted to the web within 72 hours of field sampling and a database complete with fish and environmental measurements will be available by the end of the year. A subsample of larval delta smelt in ethanol. Zooplankton identification and database will be completed as staff time allows.

Comments: The 2005 and 2006 Delta Smelt Larva surveys (DSLS) replaced the North Bay Aqueduct monitoring on a pilot basis as required by the USFWS 2005 OCAP Biological Opinion for delta smelt. The Delta Smelt Workgroup designed the DSLS as a two year trial. Protocol and methods developed in 2005 were used in 2006. Surface tows proved ineffective for larval delta smelt (DFG unpublished data) so the USFWS asked the Delta Smelt Workgroup to modify the sampling design for 2007. The timing and locations of delta smelt larva sampling in 2007 were guided by catches of ripe and spent adult delta smelt caught in the Spring Kodiak Trawl Survey (Kevin Fleming, DFG, pers. comm.). In 2008, this survey started two weeks early and conducted a single tow at a subset of 20mm Survey stations for longfin smelt, then starting in late-March, completed the full sampling panel of stations plus six additional stations added in the Cache Slough area to improve coverage in this important spawning region.

Environmental Monitoring Program

IEP 2008-072

Point person: Randy Baxter (DFG)

Lead Agency: DWR and DFG

Questions: How well is abundance (density) of microzooplankton estimated by the historical and alternative methods for common and uncommon taxa? What can be inferred about the effectiveness of historical methods and data from these results? Can microzooplankton data be used to estimate mortality rates and construct a vertical life table? What changes in protocol are recommended for the future long-term monitoring?

Description: As part of the environmental monitoring program (EMP), water quality, chlorophyll a, benthos and three types of zooplankton samples are taken monthly at up to 21 locations distributed from eastern San Pablo Bay upstream into the Sacramento and San Joaquin rivers. Since 1972, microzooplankton samples have been collected by lowering a 15 L/min pump from the surface to the bottom and back to the surface two times, capturing the discharged water in a large carboy and taking a 1.9 L subsample of this mixture preserved with formalin to examine completely for zooplankton. The accuracy and precision of resulting density estimates has been questioned, so a study commenced in fall 2005 to compare traditional methods and gear including: 1) examination of a larger sample volume collected with the same pump and 2) examination of a much larger sample volume collected using a higher capacity pump. These alternatives were tested with samples collected simultaneously in a side-by-side gear comparison in 2005 and 2006. Some of these samples were processed in 2006 and 2007 and the initial data provided showed some interesting differences between the alternative sampling methods. It also became apparent that the higher volume pump samples require a different processing technique due to the large number of organisms and occasionally large amount of detritus (see SOP section for processing specifics). Based on these initial results, the EMP started collecting 75 L with the historical pump during its monthly microzooplankton monitoring surveys starting in 2008. However, more samples need to be processed in 2008 in order to completely answer all study questions.

Time period: Sample and data analysis is ongoing and will continue in 2008.

Resources required

Cost: The 2008 EMP budget is \$3,250,000 from IEP sources.

PI(s): Karen Gehrts, Tanya Veldhuizen (DWR)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: A single laboratory assistant identifies organisms from all EMP samples. EMP staff at DWR is responsible for boat operations, field collections, and data analysis.

Equipment: Lab equipment available at the DFG lab in Stockton.

Deliverables and dates: Final study report; December 2008. Revision of the EMP zooplankton metadata.

Comments: Recommendations for changes in sampling derived from this investigation will likely be incorporated into Program protocol. This program is mandated by Water Rights Decision 1641.

Directed field collections

IEP 2008-089

Point person: Randy Baxter (DFG)

Lead Agency: DFG and DWR

Questions: There are no questions related to the Directed Fish Collections effort. Questions are listed under the project description that the fish are being collected for elements 2008-040, 2008-042, 2008-060, 2008-061, 2008-062, 2008-063 and 2008-086.

Description: Directed, short-term field collections. In 2005 and 2006 directed collections were used to increase the number of delta smelt and striped bass available for otolith analyses and histopathology, to collect threadfin shad and longfin smelt for disease and histopathological studies (e.g., Foott et al. 2006), all POD fishes for diet and condition, and to collect water from 15 locations within the upper Estuary for invertebrate and fish toxicity tests. Regular once or twice monthly sampling efforts were made to increase the numbers of target fish collected and to allow time for field examination of larval and young juvenile fishes. In 2007, delta smelt were removed as a target organism to reduce IEP's overall take of these fish. However, longfin smelt, striped bass, threadfin shad and water for both invertebrate and fish toxicity tests were still collected. In 2008, directed collections will be used to collect water for invertebrate and fish toxicity tests (see 2008-063) and they will also be used for some gear evaluation and efficiency tests.

Time period: As needed and when staff and boats are available. For water collections, sampling will take four days per month, targeted fish sampling 1 – 2 days per month and gear evaluation 4 – 10 days for the year.

Resources required

Cost: The 2008 IEP budget for Directed Field Collections is \$194,000 from POD sources.

PI(s): Inge Werner , Swee Teh, Bill Bennett , David Ostrach (UCD); Steven Slater and Randy Baxter (DFG).

Contract needed / in place: Submitted to USBR; waiting for contract to be executed.

Contract managers: Erwin Van Nieuwenhuys (USBR).

Term of contract: 1/1/08 – 12/31/08 (when executed).

Personnel: Water sampling - one boat operator and one crew member from participating research group; Fish sampling - one boat operator, one scientific aid or biologist and 1-3 researchers from participating research group. In addition, the point person contributes substantial time coordinating logistics for PIs and field crews.

Equipment: Water sampling – 20-32 ft. vessel with sufficient deck space for 8-10 large coolers. Fish sampling – 25-42 ft. vessel capable of deploying trawl gear targeting late stage larvae through juveniles; vessel and gear will change as life stage of fishes progress.

Deliverables and dates: See specific project descriptions listed above for this information.
Comments:

II. On-going Studies

Larval Fish Behavior Study

IEP 2008-017

Point person: Ted Sommer (DWR)

Lead Agency: USBR, USGS and DWR

Questions: What are the behaviors of larval fishes in the south Delta and how is behavior likely to affect entrainment risk under different hydrologic conditions?

Description: This is part of the separately-funded South Delta Hydrodynamics and Fisheries investigation that was initiated in 2004. Its goal is to develop a behavioral model of larval fish behavior to support estimation of entrainment risk in the south Delta under differing hydrologic and operations scenarios.

Time period: The second phase of field data collection was completed during spring 2005; a summary report should be available shortly. Further work will be ongoing through 2007.

Resources required

Cost: This element is not funded by POD sources.

PI(s): Lenny Grimaldo (DWR)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: Boat operators, biologists, scientific aides and non-agency laboratory staff.

Equipment: Field work for this element has been completed.

Deliverables and dates: A journal article is in review at North American Journal of Fisheries Management; another article will be submitted for publication in August 2008.

Development of Striped Bass Life Cycle Models

IEP 2008-038

Point person: Ted Sommer (DWR)

Lead Agency: UCD, SFSU-RTC, LSU, and consultants

Questions: What factors are the dominant drivers of striped bass population dynamics? What are the best management strategies for each of these species?

Description: Life cycle models are needed for both striped bass and longfin smelt, but we will pursue a model for striped bass first. Significant information exists and for striped bass some existing models may be able to be modified to meet these purposes. Synthetic modeling capabilities are a very powerful means of evaluating the interactive influences of multiple stressors on fish population dynamics (Rose 2000).

Time period: 2006-2008

Resources required

Cost: \$224,000 required to conduct this work was obtained in 2006 from POD sources.

PI(s): Frank Loge (UCD) and Kenny Rose (LSU)

Contract needed / in place: In place.

Contract manager: Ted Sommer (DWR)

Term of contract: Through February 2009.

Personnel:

Equipment:

Deliverables and dates:

February 2008- 1st progress report and IEP Workshop presentation.

October 2008 – 2nd progress report and CALFED Science Conference presentation.

January 2009 - Submission of 3 peer-reviewed manuscripts addressing description, calibration, hypothesis testing, and comparison of a) dose-structured population dynamics, b) IBM, and c) matrix models. Additionally, computer codes for each model and supporting documentation explaining use, inputs, and outputs.

Comments: Contracting was delayed, so the original schedule has been shifted with later dates for the deliverables.

Modeling the Delta Smelt Population in the San Francisco Estuary

IEP-related 2008-041

Point person: Matt Nobriga (CALFED)

Lead Agency: SFSU-RTC, LSU and UCD

Questions: What are the best management strategies for conserving this species?

Description: This element is a CALFED Science PSP grant that will develop and test three different modeling approaches for looking at delta smelt population dynamics. The modeling approaches can be generally characterized as particle tracking, matrix projection, and individual-based. The purpose of these models is to evaluate how environmental conditions influence population vital rates, which then determine how the modeled population responds.

Time period: 2006-2009

Resources required

Cost: \$332,000 per year for 3 years from CALFED Science Program. Total is \$997,000.

PI(s): Karen Edwards and Wim Kimmerer (SFSU), Bill Bennett (UCD), Kenny Rose (LSU).

Contract needed / in place: In place.

Contract manager: Steve Culberson (CALFED).

Term of contract: 3 years, beginning in 2006 and expiring 3/31/2009.

Personnel: Karen Edwards (SFSU)

Equipment: None, this is a modeling exercise.

Deliverables and dates: The project proponents expect to have final project reports and papers submitted to journals by January 2009.

Comments: The investigators have significant experience in ecological modeling and extensive experience publishing research results. This project is expected to make a major contribution to the quantitative understanding of delta smelt population dynamics.

Striped Bass Health investigations

IEP 2008-042

Point person: Rich Breuer (DWR)

Lead Agency: UCD, support from DFG

Questions: Does the condition of adult or larval striped bass suggest that contaminants and diseases could be depressing the populations of striped bass in the estuary? If present, have these effects increased in recent years? What life stages are most critical?

Description: This work will assess the health status of larval, juvenile, and adult female striped bass collected from selected locations in the Bay Delta using morphometric, histopathological, otolith (aging, growth and microgeochemical analyses) and biochemical metrics. Comparison with archived samples will allow for estimation of the contribution of this type of stressors to the long vs. short-term declines in abundance of young striped bass.

Time period: Analyses of archived samples is complete. Gravid females will start arriving on the spawning grounds in April and May, and be sampled by DFG as part of their normal operations.

Resources required

Cost: \$520,000 was obligated with 2007 funds from POD sources.

PI(s): David Ostrach (UCD)

Contract needed / in place: In place.

Contract manager: Fred Feyrer (DWR)

Term of contract: Through September 14, 2008.

Personnel: UCD personnel with fish collection support from DFG.

Equipment:

Deliverables and dates: Reports on results of the adults and larvae are due by March 30, 2008 and September 14, 2008.

Comments: The investigator has a great deal of experience and unpublished information on this topic. Transforming new and accumulated data and information into peer-reviewed literature must be an essential part of this element. All laboratory work is done. The remaining tasks will be synthesis and papers.

Estimation of Pelagic Fish Population Sizes

IEP 2008-043

Point person: Mike Chotkowski (USBR)

Lead Agency: DFG, DWR, USBR, consultants and contractors.

Questions: What are the most efficient regions (strata) for each target species sampled by the TNS, MWT and Kodiak surveys? Do fixed sampling stations in a highly tidal system approximate random distributions? What are the population sizes for each of the target pelagic species? Should strata variance be calculated based upon a normal distribution? How can long-term monitoring data be used to provide better information to managers regarding trends in biological resources? Additional questions will be developed over time.

Description: Except for adult striped bass, the status of pelagic fish populations has primarily been assessed using relative abundance indices. IEP has been reluctant to translate these data into population sizes because of sampling selectivity (i.e., non-random site selection), gear efficiencies are unknown for each of the sampling programs and fish tend to be patchy, likely adding substantial variability. Other approaches for pelagic fish population estimation are unreasonable (e.g., direct counts, mark-recapture, and change in ratio). However, the POD effort would benefit greatly from at least crude population estimates, allowing calculation of mortality rates and population modeling. The development of mean-density expansion estimators based upon stratified random trawl sampling represents the most practicable alternative. As initial steps to estimate population size, Bennett (2005) has used the TNS and MWT data, and Miller (2005) has analyzed the Kodiak trawl data. This element will:

1. Build upon earlier efforts to develop population estimates for as many of the target pelagic species as possible. Refinements of these efforts may include the use of known salinity and

temperature effects on target species distributions, updated bathymetry and the particle tracking models to: a) post-stratify survey data (i.e., set more efficient region boundaries); b) improve habitat volume estimates represented by fixed stations and regions for each of the surveys; and c) test the assumption of randomness in the data.

2. Study designs for gear evaluation including development of mesh retention probabilities, gear avoidance measures and information on vertical and lateral distributions.

3. IEP/POD statistical and analytical support – time to assist agency researchers with study design and analysis questions.

4. NCEAS participation, modeling – incorporate Delta smelt life history information, information from past and future special studies examining smelt horizontal and vertical distribution behavior and multiple long-term monitoring data sets into a single population model.

5. Develop methodology for entrainment estimation for export facilities (details to be developed).

Time period: 2008.

Resources required

Cost: \$171,000 in 2008 from POD sources.

PI(s): Ken Newman (USFWS)

Contract needed / in place: USBR contract is in process and the DWR contract is in place.

Contract manager: Erwin Van Nieuwenhuysse (USBR) and Rich Breuer (DWR).

Term of contract: Reimbursable annual contract.

Personnel: No additional personnel will be assigned, but collaboration is expected for all listed items and others developed over time.

Equipment: None.

Deliverables and dates: A journal article describing the logic, caveats, data needs and data used for estimating the sub-adult Delta smelt population size early 2008; NCEAS involvement is expected to result in one to several publications, but topics and deadlines have not been set.

Comments: Although there are substantial obstacles to measurement of population sizes, the recent efforts of Bennett (2005) and Miller (2005) provide a reasonable foundation for future work. Ken's involvement with IEP/POD is anticipated to be long-term, during which time tasks will evolve. For 2008, substantial new tasks will be reviewed by the POD management team and when approved forwarded to Ken through Kim Webb with an indication of relative priority.

Zooplankton Fecundity and Population Structure

IEP 2008-044

Point person: Anke Mueller-Solger (DWR)

Lead Agency: SFSU-RTC

Questions: Has there been a downward shift in egg production and/or nauplius survival that resulted in lowered ratios of copepodites to adults? Has there been a change in copepodite survival? What is the biomass of individual zooplankton species, and how has the zooplankton community biomass changed over time?

Description: This work plan element consists of two parts: 1. The continuation of an analysis of *Pseudodiaptomus forbesi* and *Eurytemora affinis* life stage structure and fecundity from archived zooplankton samples (1996-2005) and associated water temperature data. The goals are to determine whether the recent increase in *Corbula* abundance was associated with an increase in mortality of sub-adult (i.e., copepodite stage) *P. forbesi* and *E. affinis*, and/or a reduction in adult

P. forbesi and *E. affinis* fecundity. 2. The determination of the biomass of zooplankton species and their life stages using laboratory analysis of dry weight and carbon content of freshly collected specimens from the San Francisco estuary. The goal is to provide species-specific biomass conversion factors that will then allow for more appropriate and realistic analysis of biomass, production, and consumption trends and comparisons with other estuaries.

Time period: 2006-2008

Resources required

Cost: \$80,000 in 2008 from POD sources.

PI(s): Wim Kimmerer (SFSU)

Contract needed / in place: In place.

Contract manager: Ted Sommer

Term of contract: Through December 30, 2008.

Personnel: SFSU

Equipment:

Deliverables and dates:

- Year 1 progress report will be provided as one or more IEP Newsletter articles or manuscripts, depending on the results to date, 10/2008.
- Present preliminary results at IEP Workshop (2/2009) or CALFED Science Conference (10/2008).
- Final reports, which will comprise draft manuscripts for submission to journals or the IEP Newsletter, 10/2008.

Comments: Feasibility is high because the samples have already been collected and pilot work indicates the methods are appropriate to answer the study questions.

Phytoplankton Primary Production and Biomass in the Delta

IEP 2008-045

Point person: Anke Mueller-Solger (DWR)

Lead Agency: UCD, DWR-DES

Questions: What are the long-term and more recent patterns and trends in phytoplankton production and biomass and other water quality variables in different Delta subregions and at specific locations? How do they compare to Delta-wide trends? What factors may be responsible for these patterns and trends? How may the Delta food web be affected by these patterns and trends? Have changes in water quality, flows and exports affected phytoplankton in different Delta areas?

Description: This is an extension of a data analysis project with CALFED-ERP funding granted to Dr. Alan Jassby at UC Davis and collaborators at DWR-DES and previous IEP POD work by the same investigators. Phytoplankton production is at the base of the pelagic food web leading to the zooplankton and fish species currently experiencing rapid declines. One goal of the CALFED and subsequent POD project was to analyze available historical data on chlorophyll *a* concentrations and other water quality and biological variables in Delta sub regions or at specific long-term monitoring stations in order to determine processes underlying changes in primary production and biomass over the long term and during and just prior to the POD. Results from this project about phytoplankton biomass trends in the Delta and Suisun Bay from 1996-2005, their causes, and their trophic significance have recently been published in the San Francisco Estuary and Watershed Science journal (Jassby 2008). Additional results from this study will

help assess the relationships between phytoplankton, zooplankton, and fish production and environmental variables in the upper San Francisco Estuary.

Time period: Ongoing through 2008.

Resources required

Cost: \$25,000 was budgeted for this element however, no additional funding is needed for 2008.

PI(s): Dr. Alan Jassby (UCD), in collaboration with DWR-DES staff (Anke Mueller-Solger).

Contract needed / in place: In place

Contract manager: Ted Sommer (DWR)

Term of contract: Through June 30, 2008.

Personnel:

Equipment:

Deliverables and dates: Presentations (Jassby, CALFED 2006, and IEP Workshop 2007) and peer-reviewed publication (Jassby 2008) have already been delivered. Additional, optional deliverables include an IEP newsletter article and a final report.

Comments:

Overlap/Synthetic Analysis of POD data

IEP 2008-046

Point person: Randy Baxter (DFG), Larry Brown (USGS)

Lead Agency: USGS, DFG, DWR

Questions: NCEAS has assembled working groups to address two general questions. What is the role of contaminants in the POD? What are the direct and indirect drivers of system dynamics in the Delta ecosystem? More specific questions are being developed by sub-groups within each working group.

Description: The overall goal for the proposed NCEAS working groups is to conduct and/or guide the integration, analysis, and synthesis of POD and other relevant data and information in a more efficient, sophisticated, unbiased, and synergistic manner than would be possible with local resources alone. The NCEAS working groups on system dynamics and contaminants were formed after consultation with the POD management team and NCEAS POD steering committee indicated that these were areas where the NCEAS process could be most helpful to IEP because of lack of IEP expertise. The NCEAS effort will tie together and analyze field data, environmental data, operations information and contaminants/bioassay from POD research components and other sources. These efforts will feed directly into POD synthesis/summary reports through Larry Brown and other POD management team members participating in the NCEAS workgroups and steering committee.

Time period: Ongoing in 2008.

Resources required

Cost: \$696,000 from POD sources.

PI(s): Larry Brown (USGS), Gonzalo Castillo (USFWS), Steve Slater (DFG), Fred Feyrer (DWR).

Contract needed / in place: In place.

Contract manager: Paul Cadrett (USFWS) will manage the NCEAS-CESU contract.

Other investigators are funded through annual reimbursable contracts with USBR and DWR.

Term of contract: Scientifically sophisticated approaches and defensible conclusions require substantial time. We envision the IEP/POD-NCEAS interaction to continue beyond the term of this contract and at this time would like to establish a working relationship through May 2010, with the possibility of an extension.

Personnel: Other key staff members include Bruce Herbold (EPA) and Ted Sommer (DWR).

Equipment: None, these are data-mining efforts.

Deliverables and dates: Larry Brown (member of NCEAS work teams and POD management team) will lead the production of a 2008 synthesis report. The report will include material from POD sponsored studies and NCEAS working groups. Review will also be provided by NCEAS POD working team members and NCEAS POD steering committee. POD management team members (many involved in NCEAS efforts) and NCEAS working group members will share authorship as appropriate. A comprehensive synthesis report would follow one year later, highlighting the results from NCEAS working groups. Additionally, peer-reviewed journal articles, scientific presentations and presentations geared at lay audiences would be authored by individual POD or NCEAS working group members.

Comments: Existing staff members from the above agencies are being redirected to work closely with NCEAS to participate in the synthesis of IEP data as it relates to the POD.

Evaluate Delta Smelt Otolith Microstructure and Microchemistry

IEP 2008-060 and 2008-040

Point person: Randy Baxter (DFG)

Lead Agency: UCD

Questions: Do growth rates of delta smelt vary seasonally or geographically? When and where in the estuary are delta smelt produced?

Description: Analysis of otoliths from delta smelt to determine daily growth rate and area of origin. Analysis of otoliths that includes microchemical work can provide detailed information on fish origin and growth that can be related to histopathology analyses and potentially to ambient water toxicity for 2005 and 2006. This work has been done successfully on delta smelt (Bennett submitted). Otolith age and incremental growth measures for young fish will be derived through use of imaging software; otolith weighing and morphometric methodologies will be developed and evaluated for reliability in determining age of adult fish (>300 days post hatch). Chemical composition of otoliths at their core will be measured to provide a microchemical "signature" of natal habitat and compared via trace elements and isotopic ratios to water samples collected at various locations in the lower rivers and Delta to determine likely region of natal origin. Fish samples for this element will be collected by Spring Kodiak Trawl Survey, Summer Townet Survey, and Fall Midwater Trawl Survey, with supplemental sampling based on availability of boats and crews. In 2008, a subset of 20mm Survey samples will be preserved in ethanol for otolith analyses. In addition IEP has archived delta smelt samples from 1995 through 2005 that might be added to these analyses.

Time period: Work should be started as soon as practical and continue for at least one year.

Resources required

Cost: Estimate is \$350,000 from ERP to process approximately 500-600 samples per year for aging. \$76,000 funding for J. Hobbs (UCD) from CALFED – Sea Grant.

PI(s): Dr. Bill Bennett (UCD) and James Hobbs (UCD)

Contract needed / in place: In place

Contract manager: Steven Rodriguez (DFG) manages Bill Bennett's contract and Matt Nobriga (CALFED) manages Hobbs' contract.

Term of contract: Bennett's contract expires 6/30/2009; Hobbs' contract expires 8/1/2008.

Personnel: Field personnel are supplied by DFG's Spring Kodiak, Towntnet, Fall Midwater Trawl and 20-mm surveys, and targeted sampling.

Equipment:

Deliverables and dates: A semi-annual report date is targeted for August 20, 2008.

Comments: This work will be an extension of the delta smelt work (Bennett submitted) and striped bass work carried out by Dr. Bill Bennett and colleagues (Bennett et al. 1995). This work is part of a larger contract including a histopathological element (2008-061) and a food availability and feeding element (not listed), but similar to the Diet and Condition work (2008-062), which together provide a comprehensive view and timeline of the relative condition of the fish that we could compare to timing of potential stressors.

Delta Smelt Histopathology Investigations

IEP 2008-061

Point person: Randy Baxter (DFG)

Lead Agency: UCD

Questions: Does delta smelt histopathology suggest recent increases in toxic exposures and/or food limitation? Does the histopathological condition vary in severity by life stage within or among species and/or geographic regions? What percentage of fish is affected by environmental stressors? What are the target organs of these stressors, and can the observed effects lead to population declines? What are the stressors affecting the fish?

Description: Histopathological examination and organ anomaly rating of delta smelt caught in the wild and from bioassay testing of either ambient water samples or sub-lethal stressors, specifically food deprivation and insecticide/herbicide exposure. This work will examine mounted tissue sections of wild caught and captive-bred, bioassay-tested delta smelt for direct evidence of histological damage (e.g., cell necrosis, intersex, glycogen depletion). The bioassay fish to be examined will come from treatments involving: 1) alternating weeks of feeding and food deprivation; 2) 96 hr exposure to environmentally relevant concentrations of commonly used insecticides and/or herbicides followed by separation into fed and starved treatments for 1 week followed by normal feeding regime for four weeks; 3) fish will be starved for one week then divided into exposure treatments for 96hr followed by normal feeding for four weeks. In 2006-07 delta smelt bodies were returned preserved from several field elements (2007-003, 2007-007, 2007-089) and additional fish were available from bioassay testing (2007-063 and 2008-063). Histological damage in delta smelt from lab exposure testing will be compared to slides of field-caught fish to assess likely contaminant exposure, but it is important to keep in mind that actual exposure duration may differ between laboratory-exposed and field-collected fish, and that wild fish may additionally be exposed to natural stressors (water temperature, oxygen levels, and food depletion).

Time period: 2006-2008.

Resources required

Cost: Estimate is \$350,000 from CALFED ERP grant.

PI(s): Dr. Swee Teh (UCD)

Contract needed / in place: In place

Contract manager: Steven Rodriquez (DFG)

Term of contract: Continuation of this work is pending results of the biomarkers expert panel.

Personnel: Field personnel are supplied by DFG's Spring Kodiak, Towntnet, Fall Midwater Trawl and 20-mm surveys, and targeted sampling.

Equipment: Field sampling vessels and nets, as well as laboratory supplies needed for storage and preservation of specimens are supplied by DFG. For all trawl surveys except targeted sampling, DFG personnel collect fishes and record data. Laboratory processing and histopathological analysis are conducted at UCD. In the case of directed sampling, UCD staff will provide all storage and preservation supplies and record field data.

Deliverables and dates: Report on 2006 larvae and juveniles from targeted sampling submitted August 2007; semi-annual report due date August 20, 2008 will document additional intermediate work products.

Comments: Histopathological analysis of fish tissues can identify a variety of tissue lesions resulting from exposure to environmental stressors such as contaminants, disease, and food limitation. Histopathological lesions often manifest themselves over longer periods of time, and therefore integrate the effects of multiple stressors. It is a useful tool to identify affected organs and can help identify certain groups of contaminants with known mechanism of action (e.g. carcinogens, endocrine disruptors) and target organs (e.g. liver, gonads). Histopathological studies play an important role in directing and focusing special studies.

Quantitative Analysis of Stomach Contents and Body Weight for Pelagic Fishes

IEP 2008-062

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What is the feeding ecology of pelagic fishes in the estuary? Is there evidence of reduced feeding success during specific times of the year or in certain parts of the estuary? If so, are these changes associated with changes in growth rate, relative weight or condition?

Description: This study was conducted to investigate temporal and spatial differences in the diet composition and feeding success of age-0 delta smelt, striped bass, and threadfin shad in 2005 and 2006 that might help explain the pelagic species decline. Food habit studies have been done on many of the fish and zooplankton found in the estuary (IEP 1987; Orsi 1995; Lott 1998; Nobriga 2002; Feyrer et al. 2003); however, many of these studies were done more than 10 years ago and the feeding habits of the local inland silverside and threadfin shad populations have only been studied in a limited geographical range (Grimaldo 2004). As evidence that feeding success may be an important issue for survival, initial studies by BJ Miller suggest that delta smelt survival in different parts of the estuary was linked to whether there was co-occurrence of prey. In 2003, IEP started a study of fish length-weight relationships needed to estimate species biomass and to develop a program to monitor trends in relative weight. Work on diet and condition continued in 2006 and 2007, and was expanded to include larval fish collected by the 20mm Survey and longfin smelt among the target species and the periodic collection of all target fishes (delta smelt, striped bass, longfin smelt and threadfin shad) from Salvage. In 2008, specimens will be collected through September and will be archived for future investigations or increased sample size when staff time permits. However, work in 2008 will focus on completing lab work, analysis and initial publication. Fish collected from 2008 will be archived for future processing and analysis.

Time period: 2006 - 2008

Resources required

Cost: \$160,000 from POD sources.

PI(s): Randy Baxter and Steve Slater (DFG)

Contract needed / in place: Reimbursable contract with USBR in place.

Contract managers: Erwin Van Nieuwenhuyse (USBR).

Term of contract: Through 12/31/2008 (USBR).

Personnel: Field collection is conducted by all long-term fish monitoring surveys. Fish are retained after reaching quotas for otolith and histopathology samples; all POD fishes are retained by Bay Study for condition and diet analyses. Laboratory personnel (3 scientific aids and part time Sr. Lab Assistant) are directed in sample processing by a Biologist.

Equipment: Current long-term monitoring vessels and gear will be employed; some gear modification may occur for directed sampling. Laboratory equipment is currently available at DFG Stockton.

Deliverables and dates:

- IEP Workshop presentation, February 28, 2008.
- Draft delta smelt diet and condition manuscript, May 2008 (target journal is San Francisco Estuary and Watershed Science).
- Draft manuscript of longfin smelt, striped bass and threadfin shad diet composition, July 2008 (target journal is IEP Newsletter).
- 2005 threadfin shad diet data part of manuscript (Feyrer et al. in prep.) Threadfin shad II: Associations among environmental conditions, prey density and recruitment)

Comments: In 2006, examination of parasite load was transferred to researchers conducting histopathological investigations (2006-061, 2006-042). DFG staff will collect samples and process diet information. The IEP has extensive experience with these techniques, but lost staff leading part of this work. Lab work was delayed substantially by the loss of a biologist and long delays in hiring Scientific Aides and Senior Lab Assistants.

Trends in Benthic Macrofauna Biomass

IEP 2008-065

Point person: Anke Mueller-Solger (DWR)

Lead Agency: DWR

Questions: At central & northern Delta locations, what are the long-term trends in biomass, production, and grazing rates of benthic species? How are these changes related to physical-chemical gradients? How do changes in benthic functions such as production and grazing affect the pelagic food web?

Description: Over the past three decades, the Interagency Ecological Program (IEP) Environmental Monitoring Program (EMP) has collected benthos community composition and abundance information at 22 sites, including four long-term monitoring stations. Unfortunately the EMP monitoring did not include measurements of benthic macrofauna biomass. Biomass data are crucial in determining the role of benthic organisms in the ecosystem, especially the feeding potential of various functional groups, potential availability and transmission of contaminants bioaccumulated in benthos, and trends in production as well as the ecological significance of changes in benthic community composition and abundance. In 2006, the EMP has developed a comprehensive plan to analyze archived benthos samples dating back to 1975 which can be used for biomass estimation using a simple wet-weight method. The objective for

2006 was to measure and examine the biomass of benthic organisms collected quarterly from 1975 – 2004 at two long-term stations located in the central and northern Delta. Upon embarking on this project, it quickly became clear that the original 2006 objective was unattainable with the available staff, materials and equipment. The benthic biomass team decided to focus on obtaining clam shell length measurements from 5 sites (D4, D24, D28A, P8 and C9) during four pre- and post-POD years with different environmental conditions (1998, 2000, 2002 and 2004). This task was largely completed in 2007. In 2008, the project team will be working towards creating site specific biomass conversion factors for the length data. To accomplish the original goal of obtaining and examining complete biomass time series at two long-term stations, the Benthic Biomass project has recently received a grant from CALFED to obtain length measurements for stations D4 and D28A from 1976 to the present. Deliverables for this project are a publication and presentations at scientific conferences. Data analysis is conducted in part as part of work plan element IEP 2008-078 and other ongoing EMP data analyses. The USGS will help to characterize long term trends in biomass at the two EMP sites.

Time period: 2008

Resources required

Cost: Redirected staff from the EMP (2008-072) will be used to accomplish this work. Additional funding for an expansion of this project has recently been granted by the CALFED Science Program. This funding will likely become available by the end of 2007 or early in 2008.

PI(s): Karen Gehrts (DWR), Wayne Fields of Hydrobiology would provide identification help and Dr. Janet Thompson, USGS, would provide additional expertise.

Contract needed / in place: In place early 2008 (CALFED – DWR).

Contract manager: Karen Gehrts (DWR)

Term of contract: 2008-2010.

Personnel: Dean Messer, Karen Gehrts, Dan Riordan, Tiffany Brown, (DWR); Jan Thompson and Heather Peterson (USGS).

Equipment:

Deliverables and dates: CALFED Final Report (12/2010), CALFED Science Conference Presentation (10/2010) and other scientific presentations as dates become available.

Comments: Investigation does not depend on the availability of new field data. Special analytical techniques that are required are well-known.

Evaluation of changes in pelagic fish habitat quality using the IEP long-term monitoring data IEP 2008-066

Point person: Ted Sommer (DWR)

Lead Agency: DWR

Questions: Has the surface area of suitable striped bass and/or delta smelt habitat changed? Does interannual variation in estuarine hydrology influence the spatial extent of striped bass and/or delta smelt habitat? Have export changes affected the spatial extent of striped bass and/or delta smelt habitat? What are the trends in physical habitat area in the Delta versus Suisun Bay? Do the previous findings differ when the availability of zooplankton prey are factored into the analysis?

Description: Long-term monitoring data are being used to characterize physical habitat for delta smelt and striped bass and to test the hypothesis that there has been no long-term change in the amount of physical “habitat” for these pelagic fishes. The basic approach used in 2005 was

similar to instream flow methods (IFIM) that have been applied to rivers and streams. First, we developed habitat criteria to define the physical and chemical conditions that were suitable for striped bass and delta smelt. Second, we divided the study region into smaller area units based on the location of sampling (TNS and MWT) stations. Third, we applied the habitat criteria (step 1) to long-term water quality monitoring data for each station to determine which stations provided suitable habitat. Finally, we summed the area units (step 2) representing suitable habitat to provide an estimate of total suitable area. Note that a major difference between our approach and traditional IFIM methods is that we relied on actual water quality monitoring data at sampling stations to calculate suitable habitat, while IFIM typically uses model simulations to generate data for each station. In 2006-2008 we propose to: 1) Complete the initial analyses of habitat area for the TNS and MWT; 2) submit results to a peer-reviewed journal for publication; 3) evaluate the results based on trends in physical habitat for major geographical areas (e.g. delta vs. Suisun Bay); and 4) evaluate the feasibility of using zooplankton prey availability as an additional habitat suitability criterion. In 2008, investigators will incorporate delta smelt use from the 20mm and Spring Kodiak Trawl surveys, as well as 2005 – 2007 data into the habitat analyses. At a later date, longfin smelt from the San Francisco Bay Study may also be analyzed using the previously established techniques.

Time period: 2006-2008

Resources required

Cost: \$120,000 from POD sources.

PI(s): Fred Feyrer and Ted Sommer (DWR), Matt Nobriga (CALFED)

Contract needed / in place: Contract not needed. Existing DWR staff time will accomplish this task.

Contract manager: N/A

Term of contract: N/A

Personnel: Two Environmental Scientists at 25% time. Additional assistance of redirected IEP staff may also be needed.

Equipment: There is no field or lab component to this study.

Deliverables and dates: Two peer-reviewed journal articles will be prepared by June 30, 2008.

Comments: This study component is a continuation of the successful 2005 effort.

Corbula salinity tolerance, distribution and grazing rates

IEP 2008-076

Point person: Ted Sommer (DWR)

Lead Agency: DWR, USGS and SFSU

Questions: What is the salinity tolerance of *Corbula amurensis*? How well do salinity tolerances explain the distribution of *Corbula*? What are regional trends in benthos and grazing rates?

Description: Initial analyses of benthic abundance trends suggest that *Corbula* distribution shifted upstream around 2001, perhaps in response to recent salinity increases during autumn. To better evaluate this hypothesis, we need to develop salinity tolerance information for the clam. This will be performed in a controlled laboratory setting, likely at SFSU Romberg Tiburon Center.

Time period: Mid-2006 through 2008.

Resources required

Cost: The 2008 budget is \$65,000; however \$117,000 is the total amount for laboratory studies of salinity tolerances through the contract period. No additional costs for the field surveys and data analyses. This work is funded from POD sources.

PI(s): Jonathan Stillman and Wim Kimmerer (SFSU)

Contract needed / in place: In place

Contract manager: Ted Sommer (DWR)

Term of contract: July 2006 through December 2008

Personnel:

Equipment:

Deliverables and dates:

October 2008: Submit Year 1 progress report to IEP. This will be provided as one or more IEP Newsletter articles or manuscripts, depending on the results to date.

October 2008 or February 2009: Present preliminary results at IEP Workshop or CALFED Science Conference.

December 2008: Final reports, which will comprise draft manuscripts for submission to journals or the IEP Newsletter, as appropriate.

Comments:

Retrospective analysis of long-term benthic community data

IEP 2008-078

Point person: Anke Mueller-Solger (DWR)

Lead Agency: DWR & USGS

Questions: At the 4 core sites, how do benthic community assembly and structure change over time? How are these changes related to physical-chemical gradients? How have patterns of benthic assemblage structure changed over time, in response to invasions, and have historic relationships between benthic assemblage structure and physical-chemical gradients changed during the POD period? Can spatial or physical thresholds be identified for benthic macrofauna, especially for species of concern such as invasive species, species with important trophic effects, (e.g. *Corbicula fluminea* and *Corbula amurensis* which act as a sink for suspended organic particles), and other benthic species that are important prey items for higher trophic levels such as bird, fish and mammals? What is the environmental significance of changes in species assemblage?

Description: This is an ongoing data analysis project with IEP and CALFED-Science funding. The goal of this project is to investigate long-term trends and ecological processes involving benthic organisms from historical data collected by the IEP Environmental Monitoring Program (EMP) at its four long-term benthos monitoring stations. Specifically, this analysis seeks to uncover historical trends in community composition in relation to environmental variability, hydrology, and exotic species invasions.

Time period: Ongoing through 2008.

Resources required

Cost: \$83,000 already in place through interagency agreements.

PI(s): Key staff includes Heather Peterson and Dr. Janet Thompson (USGS).

Contract needed / in place: In place.

Contract manager: Rich Breuer (DWR)

Term of contract:

Personnel:

Equipment: No equipment is required.

Deliverables and dates: Manuscript submitted to a peer-reviewed journal for publication (Retrospective analysis of long-term data), December 12, 2008.

Report to POD MT of major findings of research to determine seasonal-scale changes in benthic assemblage patterns related to the POD, December 12, 2008.

Comments: This is a two part project which includes publication of prior research as well as new research.

Field Survey of Microcystis Aeruginosa Bloom Biomass and Toxicity

IEP-related 2008-079

Point person: Rich Breuer (DWR)

Lead Agency: DWR-DES, DFG

Questions: Is *Microcystis* biomass or toxicity increasing over time in the Delta? Does *Microcystis* bloom biomass or microcystins toxicity occur in areas important to pelagic fish species in the Delta? What are the long term trends in *Microcystis* and potential controlling factors? What are the origins of the *Microcystis* blooms? What environmental factors affect bloom development?

Description: Field surveys will be conducted to measure *Microcystis aeruginosa* bloom biomass and toxicity, determine the contribution of shallow water habitat and identify controlling factors. Sample collection at fish survey stations will help elucidate the link between *Microcystis* biomass and toxicity and its potential effect on zooplankton and fish and will be combined with previous data to develop long term trend. High frequency sampling and nutrient assays will be conducted to determine the contribution of shallow water habitat and environmental conditions on *Microcystis* biomass and toxicity. Water samples for *Microcystis* biomass and both algal tissue and dissolved microcystins toxicity will be collected biweekly and at high frequencies four times during the bloom season by DWR-DES and US Fish and Wildlife Service staff at selected stations.

Time period: Summer and fall 2006-2008.

Resources required

Cost: 250,000 from CBDA Prop 50 Science Program PSP.

PI(s): Peggy Lehman (DWR)

Contract needed / in place: In progress.

Contract manager: Ted Sommer (DWR)

Term of contract: Part of DWR-UCD large umbrella contract, still in progress.

Personnel: This work would be conducted by redirected and additional hired temporary DWR-DES staff including a boat operator; microcystins toxicity analyses by Dr. G. Boyer at State University of New York.

Equipment:

Deliverables and dates:

- Semi-annual reports submitted by December 2008, June 2009, December 2009 and June 2010. Oral progress reports to IEP project work teams by September 2009 and September 2010.
- Oral or poster presentations at the 2009 and 2010 IEP Workshop.
- Post study report to peer reviewed journal and/or published in the summer 2010 IEP Newsletter.
- Protocol for laboratory culture of threadfin shad, 8/30/2008.

Comments: Toxicity analysis will be done by Dr. G. Boyer of the State University of New York, an expert on cyanobacterial toxicity. His group has extensive experience in determination of cyanobacterial toxins and routinely analyzes samples for NOAA, CDC, and departments of health and conservation for several states. They also participated in the previous surveys. Future analyses may be possible at DFG's Water Pollution Control Laboratory.

CASCaDE Computational Assessment of Scenarios

IEP-related 2008-081

Point person: Larry Brown (USGS)

Lead Agency: USGS

Questions: This study will establish a model-based approach for placing quantitative bounds on water resource and ecosystem responses to a plausible range of future changes in the Bay-Delta Rivers and Watershed system – critical information that will allow resource agencies to anticipate changes and develop flexibility in their strategic planning to accommodate those changes before they occur. While this project has broad relevance to many goals of the CALFED Science Program, it is most directly relevant to the third priority research topic identified in the 2005 Science Program PSP, which solicits “analytical frameworks that will support assessments and refined predictions of how likely future changes such as population or climate-related hydrological shifts may affect water operations, ecosystem processes, and CALFED projects”.

Description: The goals of this project are to develop and apply a model-based approach of ecological forecasting (Clark 2001) to project future states of the Delta ecosystem under prescribed scenarios of change, and to communicate the outcomes of those scenarios to resource managers. Specific objectives include: 1) Develop/refine/calibrate/verify a set of mechanistic numerical models of climate, watershed hydrology, Bay-Delta hydrodynamics, sediments and geomorphology, and water quality; 2) Link these models to project system dynamics from prescribed forcings, beginning with the climate system (including sea level) and then cascading to the watershed (water, sediment, contaminant runoff), river system (flow, heat, sediment and contaminant transport), and Delta-Bay (hydrodynamics, water temperature, salinity, primary productivity, suspended sediments, geomorphology); 3) Compare projections under prescribed scenarios of within-Delta habitat change and catastrophic levee failures; 4) Apply model projections to assess changes in water and habitat quality, potential habitat expansion of key alien species (*Egeria*, *Corbicula*, *Potamocorbula*), incorporation of contaminants such as mercury and selenium into food webs, and qualitative population responses of native fishes, and; 5) Work in collaboration with CBDA agencies and interested stakeholders to develop flexible strategic plans based on a range of plausible, quantitative depictions of the Bay-Delta Rivers and Watershed system as it changes during the 21st century.

Time period: 2006-2008

Resources required

Cost: \$554,000 per year from a CALFED Science PSP-funded study through contract with the USGS.

PI(s): Jim Cloern (USGS)

Contract needed / in place: In place

Contract manager: Michelle Shouse (CALFED)

Term of contract: 3 years, expiring on 2/28/2009.

Personnel:

Equipment:

Deliverables and dates: A final report is required and shall be submitted by 2/28/2009. The final report must include copies of any publications or reports produced. A draft manuscript(s) will suffice for a final report. Final manuscript(s) must be submitted after publication. The CASCaDE project agrees to present project findings at the biennial CALFED Science Conference and/or other CALFED Science Program workshops and symposia.

Comments:

Food-web Support for Delta Smelt and Estuarine Fishes in Suisun Bay and Upper Estuary
IEP-related 2008-082

Point person: Matt Nobriga (CALFED)

Lead Agency: SFSU-RTC

Questions: Within the Low-Salinity Zone of the northern estuary:

1. How do benthic grazing, available solar irradiance, and the concentrations of and composition of nitrogenous nutrients interact to influence the species composition and production of phytoplankton?
2. How does bacterial production respond to changes in particulate and dissolved organic carbon (POC & DOC) delivered primarily through river flow?
3. What is the role of the microbial food-web in supporting higher trophic levels?
4. To what extent is copepod production dependent on these alternative energetic pathways (phytoplankton and bacterial production)?

Description: This is a CALFED Science Program-funded study focused on two related topics:

Topic 1: The threatened delta smelt (*Hypomesus transpacificus*) is now the principal species of concern for management of freshwater flow and diversions in the Sacramento-San Joaquin Delta, and the principal target for restoration in the upper San Francisco Estuary. The abundance of this federally-listed threatened species has been low since the early 1980s, and it has not recovered to the point where it can be considered for delisting; indeed, the 2004 abundance index was the lowest on record. Potential reasons for its low abundance are many, but evidence points to the direct and indirect effects of export pumping of freshwater in the south Delta, toxic substances, and low food supply as likely contributing factors. We believe that the feeding environment of delta smelt may be implicated in the continued low abundance of this species. Delta smelt feed for their entire lives on zooplankton, principally copepods, mainly in the brackish waters of the western Delta and Suisun Bay. As outlined in the submitted proposal, copepod abundance is depressed in this region.

Topic 2: Previous work on the responses of the estuarine ecosystem to interannual variation in freshwater flow has demonstrated a decoupling between the abundance of lower trophic levels and that of fish and shrimp (Kimmerer 2002a, b, 2004). This decoupling may imply that variability in food-web support is unimportant to variability of higher trophic levels, but there are some important pieces missing from the puzzle. Chief among these is the fact that the supply of labile organic matter from freshwater to the LSZ varies with freshwater flow, and this flux has not been accounted for in analyses of the estuarine food-web.

The funded proposal includes efforts aimed at understanding and possibly improving the food-web supporting delta smelt and other estuarine species.

Time period: 2006-2008

Resources required

Cost: \$390,000 per year from a CALFED Science PSP-funded grant.

PI(s): Wim Kimmerer (SFSU)

Contract needed / in place: This is a CALFED Science grant

Contract manager: Darcy Jones (CALFED)

Term of contract: 3 years

Personnel: Richard Dugdale, Frances Wilkerson, Edward Carpenter, Alex Parker (SFSU); Risa Cohen (Georgia Southern University); Janet Thompson, Francis Parchaso (USGS); George McManus (University of Connecticut).

Equipment: The bulk of the laboratory work will be conducted at Romberg Tiburon Lab.

Deliverables and dates: There are 5 tasks within this element: Phytoplankton (task 1), benthic grazing (task 2), bacteria (task 3), microbial foodweb (task 4), and synthesis (task 5). Tasks 1, 2, 3, and 5 will all produce at least one peer-reviewed journal article, at least one presentation at the CALFED Science Conference, and presentations at the Estuarine Ecology Team and other venues. Tasks 3 and 4 will produce a joint paper together and lastly, task 5 will produce a synthesis article. The target milestone for paper submission is December 2008.

Comments:

Analysis of historical population dynamics

IEP 2008-084

Point person: Mike Chotkowski (USBR)

Lead Agency: USBR

Questions: The examination will extend the 2005 analysis of FMWT and Bay Study data to include other fish datasets, including the FWS JFMP seine dataset. This will include the evaluation and search of, (i) long-term trends, (ii) discernable epochs in the data, (iii) notable point or short-duration events, and (iv) coordinated or contemporaneous changes in multiple species that suggest a common explanation. We will also examine relevant historical data to evaluate historical support for the two “narrative” hypotheses developed in 2005.

Description: These investigations were a component of the 2005 investigations. Based on results to date, we believe continuation is warranted to complete work already started, complete work that could not begin in 2005 due to unavailable data, and to extend the investigation in ways intended to comport with reviewer recommendations.

Time period: Ongoing through 2008.

Resources required

Cost: No additional funding is required for 2008.

PI(s): Mike Chotkowski (USBR) and Dr. Bryan Manly (West Inc.)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: Personnel other than the CO-PI's are not required.

Equipment: There is no field or lab equipment associated with this project.

Deliverables and dates: In 2006 we will submit at least two manuscripts for publication. One will be a methods paper dealing with the new regime change analysis developed by Bryan Manly; the other will be an account of the 2005 analysis of FMWT and Bay Study data, and what the findings imply.

Comments: Statistician Bryan Manly has agreed to assist. San Luis Delta Mendota Water District has generously agreed to support Dr. Manly's work. Other outside assistance may be required in the future.

Power Plant Operations

IEP 2008-087

Point person: Kelly Souza (DFG)

Lead Agency: DWR and others

Questions: What are the characteristics of the cooling water diversions associated with the Contra Costa and Pittsburg power plants, and what effects might they have on pelagic fishes? Have there been recent increases in pelagic fish entrainment?

Description: This study was previously a component of the 2005 work element, “Analysis/summary of recent changes in delta water operations”. Based on the initial data review, we believed that the issue warranted a focused study. The purpose of this element is to closely examine power plant operations to identify whether there were effects strong enough to contribute to the long-term and recent apparent step change in pelagic fish abundances.

Time period: Ongoing through 2008.

Resources required

Cost: This work is not funded from IEP sources.

PI(s): Carol Raifsnider (Tenera)

Contract needed / in place: In place.

Contract manager: Steve Bauman (Mirant)

Term of contract: Current through 2009.

Personnel: Carol Raifsnider (Tenera)

Equipment:

Deliverables and dates:

- Monthly progress reports detailing entrainment and impingement results, submitted to IEP
- Annual summary report submitted 4 months after laboratory sampling has been completed

Comments: Entrainment and impingement monitoring collections were delayed due to constraints in obtaining federal permits. Surveys have been conducted once monthly since November 2007. A full year of data is needed before analysis can begin, however a PI has not yet been identified to complete these analyses.

Hydrologic Changes and Suisun Bay Salinity

IEP-related 2008-97

Point person: Matt Nobriga (CALFED)

Lead Agency: CCWD

Questions: This work is motivated by the hypothesis that changes in reservoir operations to improve conditions for salmonid fishes (e.g., temperature control on the Sacramento River, spring flow pulses on the San Joaquin River, seasonal shifts in the timing of water exports from the Delta) have changed Delta habitat conditions and precipitated the recent delta smelt decline observed during the POD. The goals of this project are: to assess the potential consequences of actions taken to protect threatened or endangered Chinook salmon species relative to other upstream and in-Delta water management actions that have reduced flows in the Delta, potentially impacting delta smelt; and, to investigate with modeling scenarios the potential to ameliorate this trade-off with specific operational actions. The project scope includes historical data analysis, water quality and temperature modeling, salmon population modeling, and statistical analyses relating delta smelt population indices to Delta water quality and flow. These

investigations will assess the extent to which changes in reservoir and barrier operations and the timing of exports have contributed to the loss of ‘environmental quality’ in delta smelt habitat, and if changes in these actions can mitigate for the degradation of delta smelt habitat, particularly fall salinity, without harming Chinook salmon species.

Description: This project will use hydrologic data from the delta and upstream tributaries to identify changes that have occurred in water project operation leading up to and during the POD.

Time period: Ongoing in 2008.

Resources required

Cost: The 2008 estimate for CCWD is \$55,000 from CALFED funding.

PI(s): Greg Gartrell (CCWD) and consultants.

Contract needed / in place: In place.

Contract manager: Matt Nobriga. (CALFED)

Term of contract: CCWD contract is through December 2008.

Personnel: Greg Gartrell (CCWD)

Equipment: No equipment is required.

Deliverables and dates: A summary report has already been produced and a finalized report will be delivered in the second quarter of 2008.

SAV Abundance and Distribution

IEP 2008-102

Point person: Ted Sommer (DWR)

Lead Agency: USGS and UCD

Questions: Has Submerged Aquatic Vegetation (SAV) increased in the Delta? Has SAV altered the habitat to effect fish populations? Has SAV increased retention of suspended solids to create a less turbid environment, which is less hospitable to Delta Smelt?

Description: Using hyperspectral imagery, this project will provide annual acreage calculations of submerged aquatic vegetation (SAV) and quantify SAV regional distribution trends in the Delta for the past four years (2003-2006). Three tasks have been identified: 1) classify SAV in the Delta using HyMap hyperspectral imagery, 2) create SAV distribution maps in concert with SAV acreage calculations to quantify SAV distribution trends in the Delta, and 3) investigate methodology that will detect and monitor turbidity trends in the Delta using surface and aircraft hyperspectral remote sensing instruments and satellite remote sensing data.

Time period: 2006-2008

Resources required

Cost: \$90,000 for 2008 and \$80,000 for 2009 from POD sources.

PI(s): Susan Ustin (UCD)

Contract needed / in place: In progress.

Contract manager: Ted Sommer (DWR)

Term of contract: This work will be covered under the DWR-UCD umbrella contract, currently in progress.

Personnel: Erin Hestir (UCD)

Equipment:

Deliverables and dates:

- Oral presentation at CALFED Science Conference, 10/22/2008 (tasks 1 and 2).
- Oral presentation at IEP Workshop, 2/28/2009 (tasks 1, 2 and 3).
- Progress report to DWR, 2/28/2009 (tasks 1, 2 and 3).

- IEP Newsletter article and at least one written manuscript for peer-reviewed journal, 6/30/2009 (tasks 1, 2 and 3).
- Poster presentation at State of the Estuary, 10/2009 (task 3).
- Oral presentation at IEP Workshop, 2/28/2010 (task 3).
- IEP Newsletter article summarizing results of each task, 6/30/2010.
- Spatially explicit GIS layers of results, 6/30/2010.

Comments:

Fish Facility History

IEP 2008-107

Point person: Marty Gingras (DFG)

Lead Agency: DFG, USBR

Questions: What changes have occurred at the state and federal fish facilities that would change the reported number of salvaged fish?

Description: This project will identify changes that have occurred at the state and federal fish facilities from 1956 to 2006 that may have impacted the reported number of salvaged fish.

However, this investigation will not report potential items that may have impacted the retention of fish in the holding tanks (holding tank screen size changes) or survival of fish once counted (debris loads in holding tanks and impacts on released fish).

Time period: Through December 31, 2008.

Resources required

Cost: Money for this element was obligated with 2007 funds from POD sources.

PI(s): Jerry Morinaka (DFG) and Brent Bridges (USBR)

Contract needed / in place: In place.

Contract manager: Erwin Van Nieuwenhuysse (USBR)

Term of contract: This contract was extended to December 31, 2008.

Personnel: 3 months of each PI's time, spread out over 6 – 9 months.

Equipment: No equipment is required for this analysis.

Deliverables and dates: An IEP technical report will describe changes that have occurred at the state facilities; target deadline is winter 2008. The federal portion of this element may not be accomplished.

Comments:

Delta Smelt Culture Facility

IEP 2008-108

Point person: Rich Breuer (DWR)

Lead Agency: UCD

Questions: Reliable supplies of all life stages of delta smelt are valuable to management and scientific communities for a number of reasons. Cultured delta smelt provide specimens with known rearing history, required for toxicological experiments; aids research and design of fish screen efficiency, and pre-screen losses; allows investigations into basic biology with application to wild populations; and enables the development of a formal delta smelt refugia population.

Description: This program will collect sub-adult broodfish via purse seine from the wild and spawn and rear all life stages of delta smelt in the following year in accordance to the Delta Smelt Culture Manual (Baskerville-Bridges et al. 2005). Delta smelt will be housed and reared at the newly expanded Fish Conservation and Culture Laboratory (FCCL).

Time period: Continuous through June 2010

Resources required

Cost: \$390,000 in 2008 from POD sources and USBR Tracy Operations.

PI(s): Drs. Raul Piedrahita, Joan Lindberg and Brad Baskerville-Bridges (UCD)

Contract needed / in place: In place

Contract manager: Rich Breuer (DWR)

Term of contract: July 1 2007-June 30th 2010.

Personnel: UCD personnel

Equipment: Equipment to rewire the CHTR building and purchase additional chillers will be needed.

Deliverables and dates: 5,000 adults (>50mm) and 10,000 juvenile (20-50 mm) delta smelt specimens for 2008, and an annual Production Report.

Comments: In 2008, Spring Kodiak Trawl Survey personnel will experiment with artificial gamete stripping of wild-caught delta smelt and cold storage of gametes. If cold-stored gametes prove viable, this will provide a means to introduce additional genetic diversity into cultured delta smelt. These same fish will be sampled for delta smelt genetic testing (2008-135) and be preserved for otolith (2008-060) and histopathology (2008-061).

Striped Bass Bioenergetics Evaluation

IEP 2008-115

Point person: Ted Sommer (DWR)

Lead Agency: DWR, CALFED and DFG

Questions: What are the trends in estimated population consumption demand of age-1 and older striped bass? Has age-1 and older striped bass consumption demand decreased more slowly than prey relative abundance/relative biomass?

Description: This element will couple bioenergetics analyses to data provided by element 2008-116 (Adult striped bass population dynamics) to estimate the long and short-term (i.e., POD years) trends in consumption demand of striped bass.

Time period: 2008; assuming the population demographic data are available in early 2008.

Resources required:

Cost: \$72,000 in 2008 from POD sources.

PI(s): Marty Gingras (DFG), Matt Nobriga (CALFED), Gina Bengino (DWR).

Contract needed / in place: Not needed, work will be covered by agency staff.

Contract manager: N/A

Term of contract: N/A

Personnel: Matt Nobriga (CALFED) and Jason DuBois (DFG).

Equipment: None required – this is a data mining/data analyses effort.

Deliverables and dates: Draft manuscript for publication by December 2008.

Comments:

Delta Fish Biomass Estimation

IEP 2008-119

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What are the trends in fish biomass in the San Francisco estuary? Are there specific changes in biomass that coincided with the POD years?

Description: Biomass is another measure to track changes in fish communities through time. Here we use a combination of length-weight relations developed by DFG and by Kimmerer et al. (2005) to derive fish species biomass from trawl survey catch and length-frequency data. Trends in upper estuary pelagic and benthic fishes are plotted and inferences are made regarding changes observed

Time period: Ongoing in 2008.

Resources required:

Cost: Funds have already been obtained to process lab samples. Analyses will be accomplished by existing agency staff.

PI(s): Steve Slater and Randy Baxter (DFG)

Contract needed / in place: No additional funding is needed.

Contract manager: N/A

Term of contract: N/A

Personnel: Steve Slater (DFG)

Equipment: None.

Deliverables and dates: Poster presentation, October 2007 State of the Estuary Conference and IEP Newsletter article, November 2008.

Comments:

In Situ Biomarker Study

IEP 2008-121

Point person: Rich Breuer (DWR)

Lead Agency: DWR/ EPA Office of Research and Development, Cincinnati Ohio

Questions: Do fathead minnows exposed to the Sacramento and San Joaquin Rivers show evidence of endocrine disruptors?

Description: For the POD program, it is important to identify and apply biomarkers that can be applied to the fish species of concern, and help differentiate and quantify stressor groups. Not all biomarkers that are presently being explored in research labs fulfill these requirements, and careful consideration should be given to a work plan for future POD work involving biomarkers. EPA-ORD and the DWR EMP program will conduct two one-month studies in November 2007 and March 2008. Batches of Fat Head Minnows will be exposed in a flow through system to Sacramento and San Joaquin River water. The minnows will be processed and sent to ORD where they will be analyzed for endocrine disruptors. The tissue will be preserved and future biomarker work for Organo-phosphates and Pyrethroids.

Time period: Fall 2006 -winter 2008

Resources required

Cost: Funding required for this element will be absorbed from existing program costs.

PI(s): Dan Riordan (DWR)

Contract needed / in place: Not needed.

Contract manager: N/A

Term of contract: N/A

Personnel:

Equipment:

Deliverables and dates: CALFED Science Conference presentation, October 2008.

Comments:

III. New work

Contaminants Synthesis

IEP 2008-124

Point person: Rich Breuer (DWR)

Lead Agency: State and Regional Water Boards

Questions: 1) Is there evidence that contaminants contribute to the decline of pelagic organisms in the Delta? 2) Are contaminant levels sufficient to impact other aquatic species (i.e. besides the POD species)? 3) What are the potential water quality impacts from modifying Delta operations and configuration per the Vision recommended by the Governor's Blue Ribbon Task Force? 4) How should surface water monitoring programs be modified to more definitively answer the above questions?

Description: This work will synthesize available data on contaminants and toxicity into a single report to answer the above questions. The available data will be assembled by a team of graduate students from UC Davis, led by Michael Johnson and a team of subject expert PIs. An external panel of experts will be assembled to review work and develop conclusions and recommendations.

Time period: First half of 2008.

Resources required

Cost: \$150,000 from SWRCB POD.

PI(s): Karen Larsen (CVRWQCB), Michael Johnson, PhD. (UCD)

Contract needed / in place: In place.

Contract manager: Mark Gowdy and Stephanie Fong (CVRWQCB).

Term of contract: Through December 2008.

Personnel: Regional Water Board staff, UC Davis

Equipment: None

Deliverables and dates: Final report and stakeholder workshop; fall 2008.

Comments:

Clifton Court Residence Time

IEP 2008-125

Point person: Ted Sommer (DWR)

Lead Agency: USFWS, USGS, and DWR

Questions: 1) What are the circulation patterns in Clifton Court Forebay? 2) What are hydraulic residence times in CCF? 3) How do CCF circulation patterns and residence times compare to fish movements across the Forebay?

Description: Although substantial improvements have been made in estimates of fish salvaged at the SWP, the number of fish lost across Clifton Court Forebay remains a major question. Hence, the magnitude of fish losses remains unknown. Historically, some studies have been done using dye-marked salmon. In recent years, telemetry (salmon, steelhead) and pit-tagging (delta smelt) have been tested. In order to understand the sources and causes for loss, CCF circulation patterns and hydraulic residence time still need to be quantified. This issue was especially important in 2007, when operations were restricted during a period in which it was unclear whether salvaged delta smelt originated from Delta channels or from fish that had entered CCF a week or two earlier.

The present study will describe CCF circulation patterns and residence time using releases of rotamine dye. Similar methods have been used previously by USGS to evaluate flow patterns in south Delta channels. Staff still needs to meet to work out the logistics of this effort. However, we expect that dye would be placed into CCF during salmonid tracking studies planned by DWR's Bay Delta Office, and perhaps during other time periods. After the dye is released, USGS staff would conduct field measurements along a sampling grid at regular time intervals (e.g. every 2 hours). Equipment owned by DWR would be used by USGS to measure surface flow patterns. A fluorometer would be used to measure rotamine concentrations. An added benefit of this study is that it will provide valuable circulation and residence time data that could be used for verification of existing or soon-to-be-developed hydrodynamic models (RMA2, TRIM) of CCF.

Time period: 12 month pilot study.

Resources required

Cost: \$50,000

PI(s): Gonzalo Castillo (USFWS), Zaffar Eusuff and Kevin Clark (DWR) and Cathy Ruhl (USGS).

Contract needed / in place: Amendment to existing USGS contract

Contract manager: Erwin Van Nieuwenhuyse (USBR)

Term of contract:

Personnel: USGS, FWS and DWR staff.

Equipment: DWR's flow equipment will be operated by USGS and a fluorometer will be borrowed.

Deliverables and dates: Progress report, September 2008. IEP Newsletter Article draft, December 2008.

Comments: FWS, USGS, and DWR staff will meet soon to see if a pilot study could begin as soon as December 2007.

Long-term Sources and Early Warning Signals in Turbidity Monitoring Data

IEP 2008-126

Point person: Ted Sommer (DWR)

Lead Agency: USGS

Questions: 1) Do smelt move towards the water diversions because they are following specific turbidity pulses, or because their habitat has shifted towards the pumps? 2) Where are the sources of turbidity for water exported by the SWP and CVP?

Description: This study will determine the origin, movement, and extent of turbidity pulses that affect delta smelt behavior and salvage at the pumps. Recent analyses by DWR and Metropolitan Water District show that delta smelt salvage counts increase at the CVP and SWP during periods (i.e., days) immediately following the first significant storm event in the basin. Though the mechanism is unclear, water turbidity is a good measure of the storm event and the data indicate that salvage typically begins when turbidities increase over 12 ntu. As a result of a recent court ruling, this finding was recently incorporated into water project operations as a tool to help reduce fish losses. However, the sources of turbidity are not well understood. A more comprehensive source of long-term turbidity data could help elucidate the question as to whether fish are following a turbidity gradient to the salvage facilities or whether they migrating in response to a flow pulse. Data sources will focus on USGS continuous suspended-sediment

concentration time series at Rio Vista, Jersey Point, Threemile Slough, and Stockton from 1998-2005. The tasks will include:

- Finish processing 2003-2005 suspended sediment (SSC) data.
- Develop relations between turbidity and SSC from BDAT database for specific sites and seasons relevant for Delta Smelt.
- Develop statistical models of turbidity at USGS sites for 1993-1997.
- Define origin, movement, and extent of key turbidity pulses identified by Lenny Grimaldo (DWR) from 1993-2005.
- Collaborate with Lenny Grimaldo (DWR) on writing a journal article of the study results.

Time period: 12 months.

Resources required

Cost: \$92,000 from POD sources.

PI(s): David Schoellhamer and Scott Wright (USGS)

Contract needed / in place: Need to amend IEP contract, in progress.

Contract manager: Rich Breuer (DWR).

Term of contract: 12 months.

Personnel: USGS staff in collaboration with Lenny Grimaldo (DWR).

Equipment: None.

Deliverables and dates: TBD

Comments:

Contaminants and Biomarkers Work

IEP 2008-127

Point person: Rich Breuer (DWR)

Lead Agency: UC Davis

Questions: Is water in ecologically sensitive areas of the Delta toxic to delta smelt and other pelagic fish and their prey? What are the causes and sources of water column toxicity in areas of the Delta and how do they affect fish species of concern? How sensitive are Delta species to contaminants in comparison to surrogate species commonly used in toxicity testing? Is it meaningful to use surrogate species for toxicity monitoring in the Delta? Are contaminants associated with wastewater treatment effluents affecting fish species of concern? Is there a relationship between toxicity results and other POD study components such as histopathological examination of fish and Microcystis blooms?

Description: The overall goal of this study is to assess the potential for contaminated water to contribute to the observed declines of pelagic species in the Delta. The study is designed to build from the results of the 2006 and 2007 Delta-wide monitoring project which investigated toxicity of Delta water samples to invertebrates and early life stages of fish species of concern.

The 2008 – 2010 study will intensify toxicity testing in the Cache Slough, lower Sacramento, Suisun Marsh and Suisun Bay areas. Like the 2006 and 2007 study years, if toxicity is detected, toxicity identification evaluations (TIEs) and chemical analysis will be used to identify toxicant(s). *In situ* tests with delta smelt, fathead minnow or inland silversides, and *Hyalella azteca* will be conducted at Hood on the Sacramento River, and Rough and Ready Island on the San Joaquin River. This study will generate sensitivity data (in the form of 96-h LC50, EC50, no observed effect level (NOEC), and lowest observed effect level (LOEC)) and compare sensitivity of Delta species with that of standard toxicity test species for *Pseudodiaptomus forbesi*, *Eurytemora affinis*, *Ceriodaphnia dubia*, *Hyalella azteca*, delta smelt,

and fathead minnow or inland silverside for select chemicals. Lastly, molecular biomarkers developed for striped bass in 2006-07 will be used to detect and quantify stress responses in field-collected specimens from 2005-2009 to detect sublethal toxic effects and help identify the causative chemical(s) or other stressors. Biomarker development for delta smelt will continue with the immediate aim of selecting appropriate biomarkers for use in field and *in situ* studies, as well as in laboratory studies to determine cause and effect.

Time period: 2008 – 2010.

Resources required

Cost: \$1,273,000 from POD and \$25,000 from CUWA in 2008. \$1,236,000 will be needed in 2009.

PI(s): Drs. Inge Werner, Swee Teh and David Ostrach (DWR)

Contract needed / in place: Need modification of existing contract.

Contract manager: Ted Sommer (DWR)

Term of contract:

Personnel: UD Davis

Equipment:

Deliverables and dates:

- Semi-annual progress reports will be submitted to the Contract Manager will include the number of samples processed, number of samples analyzed, results and a timeline for the completion of the analyses.
- Oral progress reports will be given to the IEP project work teams by September 2008 and September 2009.
- A presentation will be given at the annual IEP workshop in February 2008 and 2009.
- A post-field progress report that describes the study and outcome to a peer-reviewed journal and/or published in the summer 2009 IEP Newsletter.

Comments: This project is dependent on the ability to obtain 5000 – 6000 delta smelt larvae aged 30 – 90 days each year for the toxicity testing and sensitivity studies, and 1000 40 – 45 day old larvae for tests with ammonia and wastewater treatment effluent from Sacramento River water.

Upstream Migration Cues for Osmerids

IEP 2008-129

Point person: Matt Nobriga (CALFED)

Lead Agency: CALFED Science Program

Questions: What are the spawning migration cues for delta smelt and longfin smelt? How do these fish migrate to and find their spawning habitats? What are delta smelt and longfin smelt spawning substrates?

Description: This is a CALFED Science Program workshop that was held on November 15, 2007. The workshop involved experts on osmerid and salmonid fish ecology from the Pacific Northwest.

Time period: November 15, 2007

Resources required: None.

Cost: No money is required for this element during 2008. Work will be accomplished by the redirection of existing staff time.

PI(s): Matt Nobriga (CALFED) and Gonzalo Castillo (USFWS)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: Gonzalo Castillo (USFWS) and Matt Nobriga (CALFED).

Equipment: None

Deliverables and dates: The deliverables are the workshop; the presentations have been posted to the Science Program website

(http://www.science.calwater.ca.gov/events/workshops/workshop_smelt.html). We anticipate a manuscript for peer-review describing the conceptual model of osmerid spawning biology that resulted from the workshop. The draft manuscript will be finished in summer 2008.

Comments:

Feasibility of Using Towed Imaging Systems

IEP 2008-130

Point person: Ted Sommer (DWR)

Lead Agency: DWR

Questions: 1) Are towed video imaging systems a feasible technique for measuring the abundance and distribution of pelagic fishes in the Sacramento-San Joaquin Delta and San Francisco Estuary? 2) If so, what species, life stages, and regions would be most suitable for this technique?

Description: Trawls presently form the foundation of IEP fish monitoring. Although these gear types have proved exceptionally useful, they are much less effective with patchy or rare species such as delta smelt. Moreover, the recent decline in delta smelt population has led to concern over lethal “take” by trawling methods. Recent progress in towed video imaging systems may provide a supplemental method that could be used to examine pelagic fish distribution and abundance. This is a pilot scale project to test the feasibility of using towed imaging systems. The first part of the study will involve identifying gear types, video speed, camera lenses, and lighting that is best suited for this application. The second part of the study will examine some of the limitations of the gear including turbidity, velocity, and variation in fish size. If technical issues can be overcome, our hope is that a more detailed study would be initiated in 2009.

Time period: 12 month pilot study.

Resources required

Cost: \$70,000 from POD sources.

PI(s): Gina Benigno (DWR) and Don Portz (USBR, Denver).

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: USBR and DWR staff.

Equipment: Waterproof camera box and filming unit, detected laptop computer (loaned by USBR for project), 75 – 150 f/s color high-speed camera, and LED lighting.

Deliverables and dates:

- Progress report, September 2008.
- IEP Newsletter Article draft, December 2008.

Comments: DWR staff will meet soon with USBR’s Denver personnel, who have expressed an interest in collaborating on this project.

Use of Acoustics to Estimate Trawl Openings

IEP 2008-131

Point person: Marty Gingras (DFG)

Lead Agency: DFG

Questions: What are the mouth dimensions of a standard midwater trawl? Do these dimensions vary based on differences in trawling depth or current direction? The information should improve the accuracy of abundance indices and abundance estimates for Delta smelt and other fishes susceptible to the trawl and may suggest appropriate alternative configurations and/or deployment of trawls.

Description: This study will employ the use of a commercially-available transmitter/transponder/computer system to calculate dimensions of a net mouth while the net is being towed during special deployments to emulate a variety of different circumstances.

Time period: January – December 2008.

Resources required

Cost: \$30,000 from POD sources for a one-time equipment purchase.

PI(s): Randy Baxter and Jennifer Messino (DFG).

Contract needed / in place: Not needed.

Contract manager: N/A

Term of contract: N/A

Personnel: One Biologist, One Mate, and one Scientific Aid would be temporarily redirected.

Equipment: Software and hardware must be purchased to complete this study.

Deliverables and dates: Not less than 5 memo-reports, each submitted the week following any deployment of the equipment and a final report with tables of pertinent trawl dimensions and recommendations.

Comments: The reported cost is limited to that required to buy the hardware and have the vendor modify software supplied with the hardware.

The Effects of the Cache Slough Complex on North Delta Pelagic Habitat: Regional Transport of Turbidity, Phytoplankton, and Zooplankton

IEP 2008-132

Point person: Ted Sommer (DWR)

Lead Agency: DWR, USGS

Questions: This study will examine the hydrodynamic “footprint” of Liberty Island in the north Delta, one of the key habitats of delta smelt. Two of the alternative hypotheses to be tested include:

Alternative 1: Liberty Island has a dominant effect on the hydrodynamics of Cache Slough Complex channels and perhaps other parts of the north Delta. Hence, we expect to see pulses of turbidity, chlorophyll a, and zooplankton coincident with tidal export from Liberty Island. Specifically, we should see these pulses on an ebb tide in lower Cache Slough (and perhaps Rio Vista) and on a flood tide in the Deep Water Ship Channel.

Alternative 2: Transport of particulates in the Cache Slough complex is determined largely by localized production (phytoplankton, zooplankton) or resuspension (sediment). For turbidity, the hypothesis is that sediments are deposited in Cache Slough Complex channels during flood events. Hence, high turbidity during other times of the year would occur in the Deep Water Ship

Channel and lower Cache Slough during 1) peak ebb and flood tides; 2) high wind periods; or 3) both conditions. Chlorophyll a in lower Cache Slough and the Deep Water Ship Channel would show diel and seasonal variation, but no tidal effects. Zooplankton would show seasonal effects, and perhaps diel effects.

Description: The Pelagic Organism Decline has created substantial interest in characterizing the habitat of pelagic fishes. This includes analyses of short term (e.g. tidal) and long-term (e.g. seasons, years) changes. Recent studies on have revealed several important observations: 1) the Cache Slough Complex represents key habitat for delta smelt; 2) turbidity is an especially important component of habitat for the Delta pelagic fishes; 3) much of the sediment and organic carbon flux in the estuary passes through the Cache Slough Complex; and 4) the Cache Slough Complex appears to be a important “food bank” for the Delta. Hence, understanding the patterns of hydrodynamics, turbidity, chlorophyll a, and zooplankton is important to describe the habitat of pelagic fishes including delta smelt. The proposed study will examine the hydrodynamic “footprint” of Liberty Island, the major body of water in the Cache Slough Complex. Flux of phytoplankton out of Liberty Island will be studied by Peggy Lehman as part of the Breach III study, providing a good opportunity to examine the fate of the exported material. We suspect that transport of biological and physical constituents from Liberty Island has a dominant effect on the channels of the Cache Slough Complex and perhaps a large area of the north Delta. The study approach will include both continuous monitoring and 24-hour flux studies:

Continuous Monitoring:

Wind: Rio Vista (existing stations)

Flow: Cache Slough, Deep Water Ship Channel, Miner Slough, and perhaps Barker & Lindsay Slough Confluence.

Turbidity: Cache Slough, Deep Water Ship Channel, Miner Slough, and perhaps Barker & Lindsay Slough Confluence, Rio Vista

24-Hour Intensive Studies (once every 3 months):

Chlorophyll *a* and zooplankton: Liberty Island, Cache Slough, Deep Water Ship Channel

Pesticides: Liberty Island, Cache Slough, Deep Water Ship Channel

Time period: 12 months (June 2008 – June 2009).

Resources required

Cost: \$322,000 from PD sources. \$407,000 will be needed in 2009

PI(s): Gina Benigno, Shawn Mayr and Ted Sommer (DWR); Cathy Ruhl, Kelly Smalling and Dave Schoellhamer (USGS).

Contract needed / in place: Needs modification of USGS contract.

Contract manager: Rich Breuer (DWR)

Term of contract: TBD.

Personnel: Identified PIs plus additional IEP staff during the 24 hour flux studies.

Equipment: ADCP for some of the locations, and turbidity sensors for all the sites, and the use of three small boats during the four 24-hour flux studies.

Deliverables and dates: TBD.

Comments:

Impacts of Largemouth Bass on the Delta Ecosystem

IEP 2008-133

Point person: Ted Sommer (DWR)

Lead Agency: UC Davis

Questions: 1) How much time do centrarchids spend foraging in pelagic habitat? 2) What is the relationship between different patch sizes of Egeria and centrarchids density? 3) What are “ballpark” estimates of centrarchid population sizes and prey requirements?

Description: Although “top-down” effects are a key part of the POD conceptual model, predation from inshore piscivores represents a relatively poorly understood source of mortality. There is good evidence that centrarchid populations have thrived as a result of the expansion of Egeria beds; however, it is unclear whether this may have contributed to the POD. Specifically, we need estimates of inshore predator abundance, and information about their effects on pelagic habitat. Four tasks comprise this element: 1) Field surveys of largemouth bass and other fish, 2) feasibility study of acoustic tracking methods for largemouth bass in the Delta, 3) Mesocosm studies on largemouth bass diets and 4) statistical models of largemouth bass abundance and impacts.

Time period: 2008-2009

Resources required

Cost: \$325,000 in 2008 from POD sources

PI(s): Drs. Andy Sih, Peter Moyle and Peter Klimley (UCD)

Contract needed / in place: This work is being included in the DWR-UCD umbrella contract, currently in progress.

Contract manager: Ted Sommer (DWR)

Term of contract: Through 6/30/2010.

Personnel: Louise Conrad, ESP, Postdoctoral scientist (UCD)

Equipment: This work requires the use of an electrofishing boat, likely borrowed from DFG.

Deliverables and dates:

- Progress report to IEP team, fall 2008 (task 1).
- IEP Newsletter submissions, fall 2009 and 2010 (task 1).
- Oral presentation at CALFED Science Conference, October 2010 (task 1, 2, and 4).
- Oral presentation at State of the Estuary Conference, October 2009 (task 2).
- Oral presentation at the California-Nevada AFS conference, spring 2010 (task 3).
- One or more manuscript for peer-reviewed journal, fall 2010 (task 1, 2, 3, and 4).

Comments:

Delta Smelt Genetics

IEP 2008-135

Point person: Randy Baxter (DFG)

Lead Agency: USFWS

Questions: What is the current population structure (microsatellite markers) of the delta smelt population? What is the mating strategy for delta smelt? What is the extent of hybridization between delta smelt and Wakasagi smelt or longfin smelt?

Description: The delta smelt abundance has declined recently to record low levels (Sommer et al. 2007), prompting petitions to “uplist” it from current “Threatened” status to “Endangered” under both the State and Federal Endangered Species Acts (The Bay Institute et al. 2006, 2007). Low abundance levels also lead to unprecedented restrictions to biological sampling in 2007 promulgated under IEP delta smelt “take” and DFG collection permit authority. Other efforts to manage delta smelt include investigations into reproductive biology and culture conducted at the

UC Davis Fish Culture and Conservation Laboratory (FCCL) located near the Skinner Fish Facility in Byron. The facility has been acquiring wild brood stock annually to produce young for experimental purposes, but these collections were restricted in 2007. As a result of the declining abundance and reduced access to wild brood stock, interest has increased to develop a refugial population. However, to effectively establish and maintain a refugial population, the genetic structure and dynamics of the population must first be determined. This study proposes to increase understanding of delta smelt population structure, hybridization, population dynamics and spawning strategies through several years of study and based on these findings to develop a breeding plan that will maintain “natural” genetic variation and population structure in closed populations.

Task 1. Microsatellite marker development (begun in July 2007 and completed in April 2008).

- Develop and optimize delta smelt specific primers to characterize microsatellite loci.
- Test cross-species microsatellites (Saint-Laurent et al. 2003, McLean and Taylor 2001, Kaukinen et al. 2004).

Task 2. Determination of the population structure of delta smelt throughout the Sacramento-San Joaquin Delta using microsatellite markers. (Initiated 2008, Expected Completion 2010)

- Genotype all individuals by PCR amplification using highly polymorphic loci lacking null alleles from already collected samples in collections held by R. Baxter and W. Bennett in addition to any wild caught during project. Estimate allele frequencies, observed (H_o) and expected (H_e) heterozygosities, and inbreeding coefficients (F_{IS}) for all populations.
- Determine the existence of genetically distinct populations of delta smelt in the Sacramento-San Joaquin Delta.

Task 3. Assessment of the extent of hybridization between delta smelt and longfin (*Spirinchus thaleichthys*) or Wakasagi smelt (*H. nipponensis*) to evaluate the role of hybridization in population abundance of delta smelt. (Initiated 2008, Expected Completion 2010)

- Genotype longfin and Wakasagi smelt by PCR amplification using polymorphic loci used for delta smelt.
- Compare to delta smelt genotypes to detect levels of hybridization and any introgression.
- Evaluate level and percentage of hybridization with delta smelt
- Examine mitochondrial DNA of hybrids to determine if hybridization is species-directional.
- Assess degree of downstream movement of Wakasagi smelt from their original introduction in reservoirs.

Task 4 Determination of spawning strategies using breeding experiments and microsatellite markers to understand delta smelt population dynamics. (Expected Initiation 2009, Expected Completion 2012)

- Conduct breeding experiments of delta smelt in a controlled environment.
- Examine progeny from tanks containing multiple individuals with different ratios of males to females.
- Use highly polymorphic microsatellite markers and computer algorithms to assign parentage to progeny.

- Assess timing and frequency of female egg release and male contribution to progeny to determine mating system (polygamous, polyandrous, or both) and spawning strategies.
- Determine effective population size from clarification of spawning strategies.

Task 5. Development of a breeding plan to maintain natural genetic variation and population structure in closed populations using information obtained on population structure, dynamics, and spawning strategies of delta smelt. (Initiated 2008, Expected Completion 2012)

- Characterize the wild BY2006 fish population structure and implications for management of potential breeding population
- Design breeding plan using information obtained from Tasks 2 and 4 to maintain natural variation in refugial population.
- Determine number of refugial populations according to wild delta smelt population structure.
- Assess natural breeding sex ratios and timing to facilitate desired crosses.
- Develop a monitoring program to assess maintenance of genetic variation in wild and closed populations.

Time period: 2008, with possible extensions and additional work funded through additional sources (see comments).

Resources required

Cost: \$134,000 from the USFWS for 2008. This element is underfunded and projects needing an additional \$50,000 per year.

PI(s): Dr. Bernie May and Katie Fisch (UCD)

Contract needed / in place: In place.

Contract manager: Kim Webb (USFWS)

Term of contract: September 2007 through March 2008

Personnel:

Equipment: Work for this element will take place at the Genomic Variation Laboratory (GVL) at UC Davis. Additional genetic work may be considered between GVL and Drs. W. Bennett and S. Cohen or between GVL and the Fish Conservation and Culture Laboratory.

Deliverables and dates:

General:

- Progress reports to agency funders as required in contracts
- Year end final contract reports
- Refereed publications
- Agency presentations (IEP February 2008, CALFED October 2008, etc. as scheduled)
- Scientific meeting presentations (e.g., AFS annual and regional meetings)

Task 1

- Microsatellite markers for use in subsequent genetic analyses
- Peer reviewed journal article (Submitted April 2008)

Task 2

- Population structure
- Peer reviewed journal article (2010)

Task 3

- Hybridization
- IEP Newsletter (2010)

Task 4

- Spawning strategy of delta smelt
- Peer reviewed journal article (2011)

Task 5

- Genetic management plan and monitoring
- Peer reviewed journal article (2012)

Project Completion/Delivery Schedule: Work will be completed within 5 years of the date of execution (June, 2012).

Comments:

Bioenergetics of Zooplankton Prey Species

IEP 2008-136

Point person: Ted Sommer (DWR)

Lead Agency: SFSU

Questions: Year 1 questions: Do larval and juvenile striped bass and delta smelt exhibit selection for different zooplankton species? How does prey selection differ among larvae and juveniles? How do light and turbidity influence prey selection? What are the underlying mechanisms that determine prey selection? Year 2 questions: What are the growth rates of larval delta smelt that are fed different prey species? What are the assimilation efficiencies of larval delta smelt feeding on different prey species? How do growth rates and assimilation efficiencies of larval delta smelt differ among diets comprised of different prey species?

Description: Videographic techniques will be used to record observations of predator-prey interactions and specific patterns of prey selection will be used to develop quantitative models of prey selection. Growth rates of larval delta smelt fed field-collected zooplankton will be measured in laboratory experiments. Length and weight measurements, combined with growth and biomass estimates of copepods will allow for calculations of assimilation and growth efficiency of larval fish feeding on copepods. Data on respiration, ingestion, growth and excretion will be used to create an energy budget for larval delta smelt, allowing for the possibility of more accurate models of population dynamic.

Time period: 2008 and 2009.

Resources required

Cost: \$82,000 for 2008 and \$82,000 for 2009 from POD sources.

PI(s): Lindsay Sullivan (SFSU)

Contract needed / in place: Requires modification of existing SFSU contract.

Contract manager: Ted Sommer (DWR)

Term of contract: Requires modification of existing contract with SFSU.

Personnel: Wim Kimmerer (SFSU)

Equipment:

Deliverables and dates:

- Presentation of results to date at CALFED Science Conference, fall 2008.
- Progress report to CALFED, winter 2008.
- Scientific paper prepared for peer-reviewed journal, winter 2008 and winter 2009.
- Presentation of results at the State of the Estuary Conference, fall 2009.

Comments: This study is dependent on the obtaining 5,000 newly hatched larvae for use in laboratory experiments.

Population Genetics and Otolith Geochemistry of Longfin smelt

IEP 2008-137

Point person: Ted Sommer (DWR)

Lead Agency: UC Davis

Questions: 1) What is the genetic population structure of longfin smelt? 2) Is there evidence of a recent change in life-history variability based on otolith chemistry and growth? 3) Have there been changes in the demographics of longfin smelt?

Description: Longfin smelt recently has been proposed for listing as an “Endangered” species. Although there is substantial concern about the status of this pelagic fish, there has been relatively little research on this species as compared to delta smelt or striped bass. Hence, the basic population structure, demographics, and life history variability are unknown. The present study seeks to address some of these data gaps using three major tasks.

Task 2. Genetic population structure of longfin smelt (PI: Israel, May) This task will identify population structuring among tissue collections from the San Francisco Bay/Delta, Klamath River, coastal Oregon, and Columbia River. Additional collection sites may be added in subsequent years based on collaborative efforts of other managing agencies. Information of genetic variation will be collected with approximately 10 microsatellite DNA markers currently being evaluated in the Genomic Variation Laboratory. Structuring will be evaluated based on clustering of genotypes among annual groups of collections at local, state, and regional scales. Traditional population differentiation analyses will be utilized for evaluating genetic structuring among tissue sample collections.

Task 1. Compare life-history variability from pre-POD to POD era. (PI: Hobbs) Using fish collected in the 1999-2001 Fall midwater trawl and the 2003 Bay Study as well as more recent collections from these sample programs, the life-history of these longfin smelt samples will be reconstructed through examination of the strontium isotope $87\text{Sr}:86\text{Sr}$ ratios to reflect salinity history. In addition we plan to expand on this tool by including the carbon isotope history $12\text{C}:13\text{C}$ as this tool has recently discovered high resolution relationships with salinity. Strontium isotopes samples are collected with laser ablation multi-collector ICP-MS and the carbon isotopes are collected by micro-milling samples from the otolith and are analyzed with GC-C_IRMS.

Task 3. Contemporary demographics of longfin smelt (PI: Israel, May) This task will evaluate multiple annual collections of longfin smelt collected pre and post POD decline to compare genetic variation in the population during these periods. This information can be insightful into demographics, effective population size, and assessing bottlenecks within a population.

Time period: 2008 and 2009.

Resources required

Cost: \$186,000 on 2008 and \$271,000 in 2009 from POD sources.

PI(s): Drs. Bernie May, Joshua Israel and James Hobbs (UCD)

Contract needed / in place: This work is being included in the DWR-UCD umbrella contract, currently in process.

Contract manager: Ted Sommer (DWR).

Term of contract: Through 6/30/2010.

Personnel: Primarily UCD staff.

Equipment:

Deliverables and dates:

- Year 1 progress report and/or IEP Newsletter article, spring 2009.
- Oral presentation at IEP Workshop, February 2009.
- Final report which will comprise draft manuscripts for submission to journals or the IEP Newsletter, spring 2010.
- Databases, as appropriate, 6/30/2010.

Comments: The project is intended to complement “data-mining” studies (e.g. Feyrer, Baxter) that will examine changes in longfin smelt habitat, abundance, and distribution.

Effects of Wastewater Management on Primary Productivity in the Delta

IEP 2008-138

Point person: Anke Mueller-Solger (DWR)

Lead Agency: SFSU, RTC

Questions: 1) Do wastewater treatment plants (WWTPs) effluents affect phytoplankton primary production and community composition in the Delta? 2) Do different wastewater treatment processes result in different phytoplankton responses?

Description: Primary production rates and standing chlorophyll levels in the Sacramento-San Joaquin Delta Estuary are among the lowest of all major estuaries in the world and may be declining further. The reason(s) for this are unclear but decreasing primary production rates are cited as a possible cause of the pelagic organism decline (IEP, 2007).

Recent work by Dugdale et al. (2007) and Wilkerson et al. (2006) has shown that elevated ammonium concentrations reduce phytoplankton production rates in San Francisco and Suisun Bays by inhibiting nitrate uptake. A recent review of ammonium concentrations in the Delta by Dr. Mueller-Solger, Department of Water Resources, has shown that median ammonium concentrations in the Sacramento River near Sacramento and in the San Joaquin River near Stockton are about an order of magnitude higher than concentrations reducing diatom growth rates by half in San Francisco Bay. Should phytoplankton production in the freshwater Delta be suppressed in the same way, this may contribute to the long-term declines in pelagic productivity and thus constitute an important "bottom-up" factor in the POD conceptual model. Furthermore, ammonium concentrations in the Sacramento and San Joaquin Rivers near the cities of Sacramento and Stockton have increased about 3% per year over the last 30 years.

The primary sources of ammonium to the Delta are sewage treatment plants, principally the Sacramento and Stockton WWTPs. Not known is whether ammonium, at concentrations measured in the Delta, inhibit freshwater diatom production rates (similar to that observed in San Francisco and Suisun Bays), and are a contributing cause to the low primary production rates in the Delta.

This work plan element is closely linked to an ongoing CALFED project (PIs: Dugdale and Wilkerson; 4/2007 - 2/2010, Agreement #1039) focusing on phytoplankton production in Suisun Bay and extends these investigations into the Delta. It will focus on the two main WWTPs in the Delta: the Sacramento Regional WWTP ("Sac Regional") and the Stockton WWTP ("Stockton"). Sac Regional employs secondary treatment and the main form of nitrogen in its effluent is ammonium. Stockton is in the process of fully implementing nitrification/de-nitrification treatment for ammonium removal. These treatment differences, along with differences in river nutrient loadings, offer a great opportunity for a comparative investigation of the effects of regional differences in river and WWTP nutrient loadings on Delta phytoplankton. Field studies will include transect surveys of nutrients and phytoplankton as well as phytoplankton "grow-out" enclosures experiments (see e.g. Dugdale et al. 2007) at or near the two WWTPs. More

controlled laboratory experiments with added effluent, ammonium, and nitrate will complement the field study.

Time period: 2008 – 2010.

Resources required

Cost: \$194,527 in 2008 and \$91,174 in 2009.

\$50,000 in place through SWRCB for focused studies on Sac Regional effluent in 2008.

\$235,701 requested from CALFED as a joint supplement to Grant Agreements No. S-05-SC-054 (PI Mueller-Solger) and No. 1039 (PI Dugdale) for comprehensive studies on the Sacramento and San Joaquin Rivers and the Delta (funding decision expected late April 2008).

The amounts budgeted for this element was \$90,000 from SWRCB POD and \$77 from DWR POD.

PI(s): Richard Dugdale, Alex Parker and Francis Wilkerson (SFSU)

Contract needed / in place: SWRCB contract is in place.

Contract manager: Mark Gowdy (SWRCB)

Term of contract:

Personnel: Above named investigators and two technicians.

Equipment: None.

Deliverables and dates: Annual reports to the SWRCB, CALFED, POD MT, IEP Newsletter articles, presentations as appropriate, and a journal article.

Comments: The feasibility and likelihood of success of this project is high because it is a direct extension of ongoing and previously published work by the PIs.

Effects of Microcystis Aeruginosa on Threadfin Shad (Dorosoma petenense)

IEP 2008-139

Point person: Ted Sommer (DWR)

Lead Agency: UC Davis

Questions: 1) What are the lethal and sublethal effects of microcystins (MCs) on growth and survival of TFS? 2) How does the accumulation and fate of MCs affect threadfin shad? The hypotheses to be tested are:

H1: Microcystis can cause lethal and sublethal toxicity to embryo, larval, and juvenile threadfin shad.

H2: Single-celled form of MC is more lethal than colonial form of MC in filter feeder such as threadfin shad.

H3: Microcystis affect the quality and quantity of *E. affinis*, and *P. forbesi* and thus lead to poor survival and growth of threadfin shad.

H4: Microcystis affects the growth and reproduction of threadfin shad.

Description: Threadfin shad (TFS) are small fresh water plankton feeders which inhabit open waters of reservoirs, lakes, and shallow water habitat in the Upper San Francisco Estuary (SFE). The purpose of this study is to examine the potential effects of the toxic alga *Microcystis*, which creates blooms that overlap substantially with the range of TFS. The working hypothesis is that TFS can be exposed to these toxins either during feeding (especially for filter feeder such as TFS) or passively when the toxins pass through gills during breathing. Work to date has successfully established culture of: 1) copepods (*Eurytemora affinis* and *Pseudodiaptomus forbesi*), 2) positive (microcystin-LR+) and negative (microcystin-LR-) strains of single-celled

forms of *Microcystis aeruginosa*, and 3) a recirculating temperature controlled fish culture system in our laboratory.

The study is divided into four tasks. Task 1 will establish laboratory culture of TFS. Task 2 will perform lethal *Microcystis* studies on TFS. The work will provide information on the sensitivity of TFS to *Microcystis*. Data will be compared to microcystis study in other fish species and copepods. The elements of this task will evaluate: 1) Acute toxicity (lethal concentration that kills 50% of the TFS) of microcystins on larval and juvenile TFS; 2) Water exposure of larval and juvenile TFS to environmentally-relevant concentrations of microcystins; and 3) Dietary exposure of larval and juvenile TFS to single-celled and colonial form of microcystis. Task 3 will focus on sublethal *Microcystis* studies on TFS including growth, histopathological, and reproductive effects of MCs. Finally, Task 4 will determine bioaccumulation and fate of microcystins in TFS.

Time period:

Resources required

Cost: \$293,000 for 2008 and \$260,000 for 2009 from POD sources.

PI(s): Drs. Swee Teh (UCD) and Peggy Lehman (DWR)

Contract needed / in place: Requires modification of existing contract.

Contract manager: Rich Breuer (DWR)

Term of contract:

Personnel: UC Davis staff; Kevin Reece and Ted Sommer (DWR)

Equipment: UCD laboratory facilities, as well as some IEP boat time to help collect threadfin shad for laboratory cultures.

Deliverables and dates:

- Progress report, presentation and protocol for laboratory culture of threadfin shad, 8/30/2008 (task 1).
- Progress reports, presentations, and publications, 6/30/2010 (tasks 2, 3 and 4).

Comments:

3D Modeling of the Delta

IEP 2008-141 (replaces 2007-031, a DWR-led effort to do particle tracking studies on the Delta).

Point person: Ted Sommer (DWR)

Lead Agency: DWR

Questions: The specific objectives of this project are:

1. Extend the geographic extent of the present UnTRIM Bay-Delta model and calibrate and validate the extended model.
2. Modify and extend existing “offline” particle tracking tool developed for the TRIM model to read UnTRIM hydrodynamic output (bathymetry, water level and three-dimensional distribution of velocity) to include appropriate delta smelt behavior and test the resulting particle tracking tool.
3. Once the tool has been adequately validated, apply the particle tracking tool to several scenarios that examine the pathways that delta smelt take through the Delta during different flow conditions (e.g. outflow, water export and tide).

Description: The UnTRIM Bay-Delta model developed for the Delta Risk Management Strategy (DRMS) project will be extended throughout portions of the Delta not included in the present UnTRIM Bay-Delta model. The resulting tool will be appropriate to predict a large range of processes including hydrodynamics, salt intrusion, movement of organisms and sediment

transport. With additional development or coupling with appropriate modules, the UnTRIM Bay-Delta model can be applied in the future to study primary productivity, contaminant transport and fate, and ecosystem dynamics (e.g. a Nutrient-Phytoplankton-Zooplankton-Detritus model).

Time period: The expected duration of the project is 13 months, assuming that funding begins on June 1, 2007.

Resources required

Cost: \$290,000 in 2008 from POD sources

PI(s): Dr. Ed Gross (URS Corporation)

Contract needed / in place: In place.

Contract manager: (DWR)

Term of contract:

Personnel: Consultants

Equipment: No equipment is needed for this modeling exercise.

Deliverables and dates:

- IEP Workshop presentation, February 2008,
- Hydrodynamic calibration report, March 2008,
- Particle tracking report, June 2008,
- Participation in POD MT meetings, as requested.

Investigating the Lower Trophic Levels of Suisun Bay Food Web: A Biomarker-specific Isotope Approach

IEP-related 2008-142

Point person: Anke Mueller-Solger (DWR)

Lead Agency: CALFED

Questions: What are the sources of organic material that support the dominant zooplankton population within Suisun Bay at different times points of the year? What changes in water management practices modify the type and magnitude of food sources available to support zooplankton production?

Description: This project is designed to obtain a coarse “time-series” of food sources being utilized by the dominant zooplankton inhabiting the central portion of the upper SFB estuary (Suisun Bay) with biomarker-specific, multiple isotopes. This project focuses on Suisun Bay because it a critical habitat for the threatened Delta Smelt, has been an area of particular concern for the pelagic organism decline investigations, and is likely to be strongly affected by changes to water project operations. While the traditional approach of using stable carbon (^{13}C) and nitrogen (^{15}N) isotopes to distinguish organic matter inputs is difficult in the San Francisco Bay estuary because of the number of potential sources and their overlapping isotopic signatures, the use of biomarkers and multiple isotope tracers can help overcome some of these limitations. Biomarkers examined in this study include specific fatty and amino acids. Multiple isotope tracers including stable carbon and nitrogen isotopes, radiocarbon, and sulfur isotopes will provide additional information. Results from this project will be used to assess the impact of particular water management strategies on zooplankton community dynamics and their potential role in the pelagic organism decline.

Time period: 09/01/07 – 08/31/10

Resources required

Cost: \$76,250 in 2008 (\$228,750 total over three years), funded by CALFED Science Fellows Program.

PI(s): Susan Lang, UC San Diego

Contract needed / in place: In place.

Contract manager: Matt Nobriga (CALFED)

Term of contract: 09/01/07 – 08/31/10

Personnel: Susan Lang

Equipment:

Deliverables and dates:

- Two completed sampling cruises, sample and data analysis, 8/31/08.
- Four completed sampling cruises, sample and data analysis, submission of one peer-reviewed publication, 8/31/09.
- Three completed sampling cruises, sample and data analysis, full synthesis of all data and final report, second paper submission, 8/31/2010.

Screening to Determine Impacts of Wastewater on Delta Smelt

IEP 2008-143

Point person: Karen Larsen (CVRWQCB)

Lead Agency: SWRCB and UCD

Questions: Is delta smelt survival negatively impacted by ambient ammonia concentration in the Sacramento River with increasing concentrations causing increased mortality? Is delta smelt survival negatively impacted by one or more contaminants that are positively correlated with ammonia from the Sacramento Regional Wastewater Treatment Plant (SRWTP)? The results of this experiment will answer these questions and refute or confirm any potential association with the SRWTP.

Description: Two delta smelt dilution series bioassay experiments using 40 – 45 day old delta smelt will be conducted. The first dilution series will consist of increasing ammonia concentrations (4.0, 2.0, 1.0, 0.5, 0.25 0 mg-N/l) amended into Sacramento River water collected upstream of the SRWTP. Controls will consist of delta smelt hatchery water and hatchery water adjusted to low EC. The second dilution series will consist of four increasing concentration of SRWTP effluent amended into the same upstream river water as was used in the ammonia dilution series. Both tests will be performed at temperatures measured in the Sacramento River during times when larval delta smelt are present.

Time period: The experiment will be performed for 7 days in 2008.

Resources required

Cost: \$20,000 from SWRCB POD.

PI(s): Inge Werner (UCD)

Contract needed / in place: In place.

Contract manager: Mark Gowdy (SWRCB), Chris Foe (CVRWQCB)

Term of contract: 12/2007 – 1/2009

Personnel: UCD, State and Regional Water Board staff.

Equipment:

Deliverables and dates: Final report and stakeholder meetings; fall 2008.

Pyrethroid Pesticide Monitoring

IEP 2008-144

Point person: Karen Larsen (CVRWQCB)

Lead Agency: CVWB, UC Berkeley

Questions: Do pyrethroids pesticides occur in toxic water column concentrations in ambient source, near-field, and Delta channel surface waters of the Sacramento-San Joaquin River Delta? What is the seasonality of pyrethroids inputs to the Delta, and are they entering in dissolved or particle-bound phases?

Description: Chemical analytes will consist of eight commonly used pyrethroid pesticides: bifenthrin, cyfluthrin, cypermethrin, esfenvalerate, lambda-cyhalothrin, deltamethrin, fenpropathrin, and permethrin. The whole water samples will be extracted by liquid:liquid extraction using dichloromethane, and then analyzed for pyrethroids. The samples for phase discrimination will be processed on a continuous flow centrifuge to separate the dissolved and particulate phases, and each phase analyzed separately by GC/ECD for the same pyrethroids. The sampling is expected to yield about 136 samples for whole water analysis (+ 36 QA = 172), 36 samples for dissolved phase pyrethroids (+ 10 QA = 46), and 36 samples for particulate phase pyrethroids (+10 QA = 46). Reporting limits for pyrethroids in water samples are anticipated to be approximately 2.5 ng/L, though may be slightly higher or lower depending on matrix effects. Total suspended solids (TSS) and total organic carbon (TOC) will be measured in each whole water sample. These data are critical to interpreting pyrethroid concentration data in the context of bioavailability.

Time period: Samples will be collected over one year, and on multiple occasions during that period to reflect dry and wet weather conditions. All sites are anticipated to be sampled at first flush (0.25 in. in Stockton and 0.50 in. in Sacramento), during two other winter rain events, and at least three times during the dry season. Agricultural discharges will be sampled at least five times during the dry season.

Resources required

Cost: \$300,000 from SWRCB POD.

PI(s): Donald Weston (UCB) and Robert Holmes (CVRWQCB)

Contract needed / in place: In place.

Contract manager: Karen Larsen (CVRWQCB).

Term of contract: Through May 2009.

Personnel: Pesticide chemical analyses will be conducted by Dr. Michael Lydy (Fisheries and Illinois Aquaculture Center, Department of Zoology, Southern Illinois University.

Whole water samples and effluent monitoring will be tested for acute toxicity by Dr. Donald Weston, Department of Integrative Biology at UC Berkeley.

Equipment:

Deliverables and dates: A final report will be prepared by Dr. Donald Weston. The report discussion will include an explanation of project context with relevant POD findings, in addition to consideration of occurrence, sources, pathways, and toxicity of pyrethroids pesticides. The target deadline for the draft report is February 2009 and the target deadline for the final report is March 2009.

Delta Fish Tissue Selenium Analysis

IEP 2008-145

Point person: Karen Larsen (CVRWQCB)

Lead Agency: SWRCB

Questions: What are the background selenium levels in fish tissue in the freshwater Delta? How do those concentrations compare with concentrations believed to harm wildlife and people? How will changing conveyance in the Delta effect selenium levels?

Description: Regional Water Board staff will work with the Contaminants Work Team to select a subset of stored fish to analyze the tissue of selenium concentrations. Funding will be used to conduct the necessary analyses.

Time period: 2008.

Resources required

Cost: \$20,000 from SWRCB POD.

PI(s): Mark Stephenson (DFG), Chris Foe (CVRWQCB))

Contract needed / in place: In place.

Contract manager: Chris Foe (CVRWQCB)

Term of contract: Unknown at this time.

Personnel: DFG lab at Moss Landing.

Equipment:

Deliverables and dates: Analyses will be conducted in 2008 and report writing during 2009. The target deadline for a final report is June 2009.

IV. Transitioned studies

Delta and Suisun Bay hydrodynamics investigations relying on particle tracking models

IEP 2007-031 (transitioned to 2008-141)

Point person: Ted Sommer (DWR)

Lead Agency: DWR and USBR

Questions: How does the spatial distribution of entrainment risk vary under different hydrologic (flows and exports) and operations (DCC, south delta barriers) scenarios? How does risk of (power plant) entrainment in Suisun Bay and environs vary with environmental conditions and power plant operations? How does risk of exposure to adverse physical or chemical conditions created by power plant operations vary with environmental conditions and power plant operations? What geographical areas do samples taken at IEP trawl stations actually represent?

Description: This is a three-pronged element. The first prong shares the goals of the South Delta Hydrodynamics and Fisheries studies: to understand the transport of fishes through the delta and to determine whether adjustments to water project operations may allow a useful reduction in entrainment of protected fish species. For the foreseeable future this work will be conducted using DSM2 and the DSM2 particle tracking model. While this part of the element is fish-oriented, we plan to adapt the investigation if possible to couple model outputs with distribution data and production models for lower trophic level organisms to assess the likelihood that water diversions could significantly influence regional productivity under certain circumstances. The second prong of the element is an investigation that will consist of particle tracking studies of Suisun Bay and surrounding waters to support the power plant operations element of the work plan. The intent will be to estimate entrainment risk and risk of exposure to high temperatures and/or chlorine produced by the Pittsburg and Contra Costa power plants. Initial work will rely on DSM2 and its PTM, but we plan to replace it with more sophisticated 3-D tools during the study period. The third prong is PTM support for development of population size estimation in the IEP field surveys. We plan to use reverse-PTM to help estimate the boundaries of sampling regions represented by fixed stations in the surveys. This work will rely on DSM2 and its PTM.

Time period: Follow-up 2005 PTM studies underway. Other applications will be ongoing through 2008.

Resources required

Cost: \$49,000 from POD sources\$49,000 to conduct this work was obligated prior to 2008. Use of 3-D technologies will require contracting with an outside entity and the cost of this is unknown at present.

PI(s): The key staff includes Mike Mierzwa, Ted Sommer and Bob Suits (DWR); Mike Chotkowski (USBR).

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: See element 2008-141.

Comments: This element was replaced by 3-D Modeling of the Delta (2008-141).

Acute and Chronic Invertebrate and Fish Toxicity Tests

IEP 2007-063 (completed and transitioned to 2008-127)

Point person: Randy Baxter (DFG)

Lead Agency: UCD

Questions: Is water in the Delta and the Napa River toxic to pelagic fish and fish food organisms? If yes, where and when? How does fish and zooplankton distribution and abundance compare to bioassay results? What is the spatial and temporal distribution of water column toxicity in relevant areas of the Delta? What are the primary toxicants?

Description: Work in 2006-07 will consist of a spatially and temporally expanded sampling and toxicity testing program. Spatial distribution of Delta sampling sites will follow the 2005 pilot program, and additional sites will be sampled in accordance with the prevalent distribution patterns of fish species of concern. The indigenous amphipod species, *Hyaella azteca*, will be used for routine toxicity testing throughout the year. This species is resident in the Delta, sensitive to contaminants, and is routinely used in toxicity testing programs throughout the Nation. Moreover, it can be used to identify the causative agents of toxicity through Toxicity Identification Evaluation (TIE) procedures. If toxicity is observed at a site through initial screening, TIEs will be initiated immediately. Adequate quantities of water will be collected to proceed with TIEs in case toxicity is observed.

Two fish species of concern (delta smelt and striped bass) will be used to test water samples from selected Delta sites, from larval to juvenile stages during periods when the respective life stages are rearing in the Delta. Fish from these tests will be preserved for biomarker and histopathological analyses. These laboratory tests will identify sites that are acutely toxic to larval/juvenile stages of delta smelt and striped bass, and help differentiate the effects of toxic contaminants from the effects of food depletion (fish will be fed during the laboratory trials), and natural stressors such as water temperature and/or oxygen depletion (laboratory tests are performed at constant temperature and water is oxygenated).

If multiple stressor effects are suspected to play a role (e.g. food limitation plus contaminants), laboratory experiments could help quantify the combined effects. Fish could be reared in the laboratory under a normal and a food-limited regime, examined for resulting histopathological lesions, then exposed to water from different Delta sites, or to specific contaminants identified as toxicants present in the Delta.

Time period: 2006-2007

Resources required

Cost: \$644,000 from POD sources.

PI(s): Inge Werner (UCD)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: Quarterly progress reports to Contract Manager; oral progress reports to IEP project work teams by September 2006 and September 2008; oral progress report at the IEP Annual Workshop in February 2006; peer-reviewed professional journal article and/or report in the summer 2008 IEP Newsletter.

Comments: In addition, information will be gathered on land use (e.g. PUR) to ascertain the potential class of toxicant(s) that could potentially be present at the sampling sites (see contaminant trends). This will aid in the TIE process, and also direct focused studies on timing and duration of potential toxic effects.

If TIE work identifies specific contaminants as toxicants of concern, focused laboratory studies should be designed and performed to expand our knowledge of the specific effects and biological effect levels of these toxicants. Specific biomarker responses can then be selected for identifying the effects of these toxicants in field studies.

Gear Efficiency Studies

IEP 2007-086 (transitioned to 2008-131)

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: What is the retention efficiency (fish in the net that remain held) of trawl nets and how does it vary by fish species and individual size? What is the capture efficiency of trawl nets for target species? With this information, can existing monitoring data be used to estimate fish population sizes?

Description: Trawl fishing gear is selective for fishes inhabiting open water or a relatively smooth bottom. In addition, trawl dimensions and mesh sizes affect the size of fishes enclosed and retained. We propose to review existing information, conduct data analyses and plan new experiments to show the effective retention size range(s) for fishes and estimated capture efficiencies of trawl nets currently used by DFG long-term fish monitoring. Review and planning will probably take most of 2006 and 2007 with field experiments commencing in 2008. One step was taken in September 2005 with the addition of a 1/8" mesh cover to the cod-end of the Fall Midwater Trawl (FMWT) net to document the sizes of fishes retained and of those that passed through the net during sampling. Concern about the additional cod-end material on the behavior of the net in the water (slower decent at deployment) lead to limited experimentation during 2005.

Two additional experiments (see elements 2008-130 and 2008-131 in the 'New Work' section for more detail) are being conducted during 2008. The first experiment involves the use of acoustic pingers that will calculate the mouth dimensions of a moving net. The other experiment will address the feasibility of using a towed imaging system to investigate the patchiness and distribution of fish captured by trawling methods.

Time period: Ongoing in 2008.

Resources required

Cost: Existing staff time would be redirected to cover these costs.

PI(s): Randy Baxter and Jennifer Messino (DFG).

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: Summary of net retention and gear behavior work for winter 2008 IEP Newsletter.

Comments: This element has been replaced by a more descriptive element, Use of Acoustics to Measure Trawl Mouth Openings, 2008-131.

Larval Fish Survey

IEP 2007-096 (transitioned to 2008-033)

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: In 2006, we addressed the question – “Can the distribution of larval delta smelt be effectively determined using surface-oriented plankton nets when compared to catches from traditional ichthyoplankton gear and methods?” – and found the answer to be no. **This element funding and effort was converted in 2008 into enhanced 20mm Survey sampling (see 2008-033).**

Description: This survey investigated whether surface-oriented, fine-mesh nets could be towed along with traditional 20mm Survey gear (IEP 1987; Rockriver 2004, Dege and Brown 2004) and improve detection of small larval delta smelt, which pass through the mesh of the 20mm Survey net. Two field seasons of data collection (2005-2006) were planned as the basis for evaluating the surface oriented nets with those towed obliquely. A third season in 2007 focused briefly (2 days) only on locations where delta smelt were believed to have spawned. If surface-oriented larva tows proved sufficient (they may not, see Rockriver 2004), then concurrent larva and 20mm Survey sampling could take place to simultaneously target larva and post-larva to small juveniles. The alternatives -- conducting two oblique tows in succession or two separate surveys for larva and 20mm fish -- are not feasible with current staff and boats. In 2005 and 2006, sampling began in January to facilitate capture of larval longfin smelt, and include concurrent collection of zooplankton samples at the 41 20-mm Survey stations plus 3 additional locations in the main channel of central and eastern San Pablo Bay. In 2007, sampling was limited to two days (April 16-17) when 10-tows during daylight and 10 after dark were made at each of two locations. At the recommendation of the Delta Smelt Working Group and the IEP Management Team, no field sampling will occur in 2008 so that staff can complete report writing based on gear evaluation data from 2005 – 2007. Some staff time and most funding for this element were redirected to conduct additional 20mm Survey sampling in the north Delta to improve spatial coverage (see 2008-033 below).

Time period: Every other week from early January through early July (2005-2006) and 2 days in April 2007.

Resources required

Cost: The 2008 DSLS budget is \$400,000.

PI(s): Bob Fujimura, Erin Gleason and Julio Adib-Samii (DFG)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A.

Deliverables and dates: Reports on 2005-2006 net comparisons for IEP Newsletter Summer 2008 and 2007 day and night sampling fall 2008.

Comments: The 2005 and 2006 Delta Smelt Larva Surveys replaced the North Bay Aqueduct monitoring on a pilot basis as required by the USFWS 2005 OCAP Biological Opinion for delta smelt. The Delta Smelt Workgroup designed this survey as a two-year trial. Protocol and methods developed in 2005 were used in 2006. Surface tows proved ineffective for larval delta smelt (unpublished DFG data) so the USFWS asked the Delta Smelt Workgroup to modify the sampling design for 2007, wherein oblique tows using standard larval sampling gear (plankton net composed of 500 micron mesh possessing a mouth 0.38m² attached to a skid mounted frame) were compared with traditional 20mm sampling. The sampling for delta smelt larva sampling in 2007 was guided by catches of ripe and spent adult delta smelt caught in the Spring Kodiak Trawl Survey (Kevin Fleming, DFG, pers. comm.). This element funding and effort was converted in 2008 into enhanced 20mm Survey sampling (see 2008-033).

Data Mining for Status and Trends of Predators

IEP 2007-118 (replaced by 2008-133)

Point person: Larry Brown (USGS)

Lead Agency: USGS

Questions: Have populations of predators that prey upon pelagic fishes increased in recent years in either a relative (in relation to populations of other fishes) or an absolute (total number) sense?

Description: The questions about population sizes will mainly be address through summarization and integration of recent analyses of IEP data sets and possible some data analysis of other pertinent existing data. These data will be used by a companion study for the construction of an individual based bioenergetics model for striped bass and then applying the model to the striped bass population.

Time period: To be determined.

Resources required:

Cost: Remaining funding in a CALFED contract to Larry Brown. Other analyses will be conducted with redirected staff effort.

PI(s): Larry Brown (USGS) and Fred Feyrer (DWR)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: Progress report by November 2007.

Comments: This element has been replaced with Impacts of Largemouth Bass in the Delta, 2008-133.

V. Completed studies

Preliminary Investigations of Disease as a Factor in the POD

IEP 2007-036 (completed)

Point person: Randy Baxter (DFG)

Lead Agency: DFG, USFWS, and UCD

Questions: What are the incidences and severities of indicators of disease or parasites for each target fish species? What can be inferred from these data about the impacts of disease and parasites on POD fish populations?

Description:

Time period: In addition to the collection of striped bass and delta smelt for histopathology in 2006, sampling will be augmented to allow collection and as needed on-board processing of fresh specimens of all four target fishes for several time periods. Sampling will be repeated in 2008 with enhanced effort for some or all target species.

Resources required

Cost:

PI(s): Scott Foott (USFWS)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: The final report has been received.

Comments:

Threadfin Shad Data Analysis and Population Dynamics

IEP 2007-039 (completed)

Point person: Ted Sommer (DWR)

Lead Agency: DWR

Questions: What are the seasonal and spatial trends in threadfin shad abundance? What factors affect their abundance and distribution? Do salvage estimates seasonally or cumulatively appear related to the longer term relative abundance of threadfin shad?

Description: In 1959, threadfin shad were introduced into reservoirs in the Sacramento and San Joaquin drainages, and from these introductions the species expanded throughout the freshwater portions of the system. Little is known about their population dynamics within the delta and until about 2002 even their abundance trends were not regularly reported (e.g., their absence IEP Newsletter 2001 (2)). We propose to continue the examination of the distribution and abundance patterns of threadfin shad within the Delta and expand analyses to include investigation of fish entering from upstream.

Time period: 2006-2008

Resources required

Cost:

PI(s): Fred Feyrer (DWR)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates:

- Poster presentation at CALFED, October 2006,
- Oral presentation at IEP Annual Workshop, February 2008.
- Draft manuscript in review at San Francisco Estuary and Watershed Science, Threadfin shad I: Population dynamics in the Sacramento-San Joaquin Delta.
- Draft manuscript in review at San Francisco Estuary and Watershed Science, Threadfin shad II: Association among environmental conditions, prey density, and recruitment.

Comments:

Biomarkers Workshop

IEP 2007-112 (completed)

Point person: Rich Breuer (DWR)

Lead Agency: CALFED

Questions: Do biomarkers currently being evaluated for the pelagic organisms indicate a population level effect from stressors? Are current biomarker analyses techniques being used for POD adequate to discern the stressor source? C

Description: For the POD program, it is important to identify and apply biomarkers appropriately to the fish species of concern, and help differentiate and quantify stressor groups. Not all biomarkers that are presently being explored in research labs fulfill these requirements, and careful consideration should be given to a work plan for future POD work involving biomarkers. A “Fish Biomarker Task Force” consisting of experts in this field would provide state-of-the-art information on biomarkers. This task force would examine and describe 1) available biomarkers according to a number of criteria including specificity and cost; 2) identify which biomarkers are applicable to Delta fish species of concern and what information they can provide; 3) identify research objectives and timelines for developing specific biomarker tools for Delta fish species of concern.

Time period: Summer 2007

Resources required: POD PI’s conducting Biomarker work and solicited experts in biomarkers. CALFED would solicit experts and organize a workshop where currently applied Biomarker analyses for POD would be discussed, as well as emerging biomarker analyses and their applicability to Delta fish.

Cost:

PI(s): Susan Anderson (S.R. Hansen and Associates), Randy Baxter (DFG) Bruce Herbold (EPA), Kathryn Kuivila (USGS) and Steve Culberson (CALFED)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Deliverables and dates: Fall, 2007: Findings from task force on biomarker applicability to discern population level effect stressors in the Delta can be found at the following link:

http://www.science.calwater.ca.gov/pdf/workshops/POD/POD_biomarker_report_022208.pdf

Comments:

VI. Unaccomplished work

Contaminant Loads in Pelagic Fish Eggs

IEP 2007-018

Point person: Randy Baxter (DWR)

Lead Agency: DFG, UCD

Questions: Has there been a change in amount and/or type of contaminants contained in striped bass eggs since 1999.

Description: Striped bass are long-lived predatory fish with the potential to accumulate toxic materials either through food or across the gill surface. Their high fat content makes eggs likely physiological targets for toxic effects of fat-soluble contaminants. Unpublished work on egg and larval health of striped bass provides strong grounds for concern. This project will assess the contaminant load of striped bass eggs collected in 2005 and compare that to work done in 1999 and 2000 following the methods developed by David Ostrach. The shorter-lived smelt and shad

are less likely to display “maternal gift” impacts, so this work focuses on striped bass. This work will complement and fit in with that described in element 2007-042.

Time period: Chemical analyses of archived samples will take place as soon as DFG water pollution lab can process the samples and analysis of the results will follow soon thereafter.

Resources required

Cost: \$10,000 from POD sources.

PI(s): David Ostrach (UCD) and Dave Crane (DFG).

Contract needed / in place:

Contract manager: Ted Sommer (DWR)

Term of contract: See Element 2007-042.

Deliverables and dates: See Element 2007-042.

Comments: This money was set aside to use at DFG’s pollution lab but the analyses were never conducted.

Apparent Growth Rates of Pelagic Fishes and Relationship to Abundance

IEP 2008-051

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: Have species’ apparent growth rates or year-end mean lengths declined, particularly those of 2001-2004 versus previous years? Are environmental factors, such as X2 position or zooplankton abundance, predictive of apparent growth rates or year-end mean size?

Description: Complete growth rate analyses based on existing length frequency data from the trawl surveys to determine if the apparent growth rates of target pelagic fishes have changed over the long-term and/or recently (2002-2004).

Time period: We are examining various data sets for these analyses and propose to complete analyses by August 2008.

Resources required

Cost: No funding is needed for this element in 2008.

PI(s): Randy Baxter (DFG)

Contract needed / in place: N/A

Contract managers: N/A

Term of contract: N/A

Personnel: Not available.

Equipment: There are no field or laboratory requirements for this project.

Deliverables and dates: Progress reports/ IEP Newsletter article, August 2008.

Comments: Personnel targeted to accomplish this work transferred from the area and it is unlikely that existing staff can accomplish the work.

Food Match Mis-match

IEP 2008-122

Point person: Randy Baxter (DFG)

Lead Agency: DFG

Questions: Are spring mesozooplankton densities and proximity to/overlap with larval delta smelt and striped bass related to feeding success, fish body condition and eventual recruitment? Do environmental factors – temperature, turbidity, and salinity – have an apparent role in feeding success?

Description: Larval growth-rate variability can influence recruitment by affecting the duration of early life stages -- those most vulnerable to predation (Houde 1996). Growth-rate in turn is influenced by feeding success (Margulies 1988), which may be mediated by the overlap of larva preferred temperature and salinity zones with areas of highest prey concentration (North and Houde 2001). Here we examine the relationships between the geographical distributions of food-sized zooplankton and larval delta smelt and larval striped bass in conjunction with water temperature, turbidity, salinity, and relate those to fish feeding success, body condition (relative weight at length) and recruitment (fall abundance indices). We use historical paired zooplankton and fish samples from tandem-fished Clark-Bumpus (CB; zooplankton) and 20 mm Survey (or Townet) nets to obtain organism densities and select fish for condition and stomach content measures.

Time period: 2007 - 2008

Resources required

Cost: No additional cost, redirected DFG staff will be used to accomplish this analysis.

PI(s): Randy Baxter (DFG)

Contract needed / in place: N/A

Contract manager: N/A

Term of contract: N/A

Personnel: Not available.

Equipment: Laboratory space, a balance and microscopes for length-weight measurements and diet examination.

Deliverables and dates: Tri-annual progress reports (April, August, December 2007); presentation Asilomar 2007, manuscript for submission to regional peer-reviewed journal summer 2007.

Comments: Personnel for this element only recently (late fall 2006) become available and then were lost to transfer in mid-2007. Sampling design and analyses have yet to be completely developed and it is unlikely that existing staff can accomplish the work.

Budget:

The initial cost estimate for 2008 funds from DWR POD, USBR POD and SWRCB POD is approximately \$5,862,000. CALFED grants that directly support various POD efforts or that will supply information useful to the POD effort are estimated at \$2,433,000. Additional elements receive funding from the USFWS, CUWA and USBR Tracy Operations totaling \$354,000. Cost estimates for individual program components are provided in Table 2 and in the previous section as part of the project summaries. In some instances, money for 2008 work was obtained in 2007, therefore not reflected in the table below.

Table 2. 2008 POD budget by element and funding source (amounts are in \$1,000).

	PEN ¹	POD Total	DWR POD	USBR POD	CALFED POD	SWRCB POD	Other
I. Existing Monitoring							
Fall Midwater Trawl	3	\$30		\$30			
Summer Townet Survey	7	\$34		\$34			
20mm Survey	33	\$260	\$145	\$115			

EMP - Water Quality Monitoring	72						
Field support for additional work	89	\$194	\$26	\$168			
TOTAL for EXISTING MONITORING		\$518	\$171	\$347	\$0	\$0	\$0

II. Ongoing Work

Larval fish behavior study	17						
Development of striped bass and longfin smelt models	38						
Modeling delta smelt in the S.F. Estuary	41	\$332			\$332		
Striped bass health investigations	42						
Estimation of pelagic fish population sizes	43	\$171	\$85	\$86			
Zooplankton fecundity and population structure	44	\$80	\$80				
Phytoplankton primary production and biomass	45	\$25	\$25				
Overlap/Synthetic analyses of fish and zooplankton	46	\$696	\$96	\$600			
Otolith analysis and microchemistry of delta smelt fish	60/40	\$426			\$426		
Liver histopathology for pelagic fish	61	\$350			\$350		
Fish diet and condition	62	\$160		\$160			
Trends in benthic macrofauna abundance and biomass	65						
Evaluation of changes in pelagic fish habitat	66	\$120	\$120				
Corbula salinity tolerance	76	\$65	\$65				
Retrospective analysis of long-term benthic data	78						
Field survey of Microcystis bloom biomass and toxicity	79	\$250			\$250		
CASCADE	81	\$554			\$554		
Food web support for delta smelt and other estuarine fishes	82	\$390			\$390		
Analysis of historical population dynamics	84						
Investigation of power plant impacts	87						
Hydrologic changes and Suisun Bay increased salinity	97	\$55			\$55		
SAV abundance and distribution	102	\$90	\$90				
Estimates of fish and zooplankton biomass	106						
Fish facility history	107						
Delta smelt culture facility	108	\$390	\$195	\$195 ^a			
Striped bass bioenergetics evaluation	115	\$72	\$72				
Delta fish biomass estimation	119						
Endocrine disruptor study	121						
TOTAL for ON-GOING STUDIES		\$4,226	\$828	\$1,041	\$2,357	\$0	\$0

III. New Work

Contaminants synthesis	124	\$150				\$150	
Clifton court residence time	125	\$50		\$50			
Long-term sources and early warning signals in turbidity	126	\$92		\$92			
Contaminants and biomarkers work	127	\$1,298		\$1,273			\$25 ^b
Upstream migration cues for Osmerids	129						
Feasibility of using towed imaging systems	130	\$70	\$41	\$29			
Use of acoustics to measure trawl openings	131	\$30		\$30			
Effects of the Cache Sl. Complex on north Delta habitat	132	\$322		\$322			

Impacts of largemouth bass on the Delta	133	\$325	\$325				
Delta smelt genetics	135	\$134					\$134 ^c
Bioenergetics of zooplankton species	136	\$82	\$82				
Population genetics and otolith geochemistry of longfin smelt	137	\$186	\$186				
Effects of wastewater management on primary productivity	138	\$167	\$77			\$90	
Effects of Microcystis on threadfin shad	139	\$293		\$293			
3D modeling of the Delta	141	\$290	\$290				
Investigating lower trophic levels of Suisun Bay food web	142	\$76			\$76		
Screening to determine impacts of wastewater on delta smelt	143	\$20				\$20	
Pyrethroid pesticide monitoring	144	\$300				\$300	
Delta fish tissue selenium analysis	145	\$20				\$20	
TOTAL for NEW WORK		\$3,905	\$1,001	\$2,089	\$76	\$580	\$159

	Overall POD	DWR POD	USBR POD	CALFED POD	SWRCB POD	Other
2008 POD TOTAL	\$8,649	\$2,000	\$3,477	\$2,433	\$580	\$159

^{a/} U.S. Bureau of Reclamation – Tracy Operations

^{b/} California Urban Water Association

^{c/} U.S. Fish and Wildlife Service

Products and Deliverables:

The monitoring and assessment program developed by this multi-institutional collaboration will yield a range of products and deliverables over a range of timelines. The POD PWT oversight team is responsible for the timely completion of all deliverables and serves as the principal contact for IEP staff and other stakeholder groups. The deliverables can be grouped into three general categories:

Monitoring Data. As in previous years, all data collected from the IEP monitoring elements used by the POD study program will be uploaded to the Bay Delta and Tributaries (BDAT) Project Site (<http://bdat.ca.gov>). BDAT contains environmental data concerning the San Francisco Bay-Delta and provides public access to that data. Over 50 organizations contribute data voluntarily to this project. The database includes biological, water quality, and meteorological data that are used to gauge the health of the estuary and to manage water and environmental resources. Also zooplankton, macroinvertebrate and fish monitoring data will be available directly via the web (<http://www.delta.dfg.ca.gov>).

Conferences and Workshops. The results of the study will be presented at special sessions at the IEP Annual Workshop during 2008 and 2009. A special CALFED workshop will also be considered to discuss the POD MT's 2008 Synthesis Report targeted for a spring 2009 deadline. Similar group presentations will be made at the CALFED Science conference (October 2008).

Publications and Reports. The researchers in this effort all place high value on the publication of peer-reviewed information. Hence, several of the key POD studies have already been published or are in review (e.g Manly and Chotkowski 2006; Feyrer et al. 2007; Sommer et al.

2007; Rosenfield and Baxter 2007; Nobriga et al. 2008). For 2008, we propose to submit a minimum of five articles to peer reviewed journals on: 1) analysis of trends in estuarine species; 2) trends in physical habitat; 3) salvage analyses; 4) pilot efforts to estimate delta smelt population size (2 articles). To the extent possible, we hope to submit an additional 4-5 articles on diverse topics including regional analysis of factors affecting primary productivity (Jassby, UCD), toxic effects (e.g. Teh and Werner UCD), predatory fish ecology, population dynamics, and food limitation (e.g. Bennett, Hobbs and Teh UCD). If appropriate, a feature article or collection of articles on the results of the overall effort will be submitted to the IEP Newsletter by winter 2008.

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