Interagency Ecological Program Synthesis of 2005 Work to Evaluate the Pelagic Organism Decline (POD) in the Upper San Francisco Estuary

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Executive Summary

Abundance indices calculated by the Interagency Ecological Program (IEP) suggest recent marked declines in numerous pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay). Although several species show evidence of long-term declines, the recent low levels were unexpected given the relatively moderate winter-spring flows of the past several years.

Our initial conceptual model included three general factors that may be acting individually or in concert to lower pelagic productivity: toxins, invasive species, and water project operations. The overall approach for 2005 was based on a "triage" model to identify the most likely causes, and to assign priorities to projects on the basis of where funds and resources can be best used. The 2005 work fell into four general types: an expansion of existing monitoring (four expanded surveys); analyses of existing data (nine studies); new studies (six studies); and ongoing studies (four studies). This document represents a progress report for the 2005 work completed to date. Because most of the studies are still in progress, the 2005 findings should be considered tentative and this report will be updated as input and information becomes available.

Highlights of the 2005 results included the following initial results:

Pelagic fishes. 1) Higher outflow conditions in 2005 failed to improve fish abundance; 2) there was no evidence of a recent decrease in the amount of "physical habitat" for delta smelt or juvenile striped bass; 3) there was no evidence of a recent major decline in growth rates for delta and longfin smelt, or striped bass; 4) in 1999 and 2004, delta smelt in Cache Slough had higher residual growth/condition than other locations; 5) striped bass age-fecundity relationships in 2005 did not appear to differ substantially from relationships developed in the 1970s and 1980s; and 6) otolith analyses indicated that in 1999 delta smelt spawned throughout the upper estuary recruited to the adult population, whereas in 2004, only fish spawned in the Delta recruited.

Food web/exotic species. 1) Reanalysis of the zooplankton data revealed that there was no recent step-change in calanoid copepods; however, we are still determining whether regional e.g. Suisun Bay, declines occurred; 2) there has been no recent major decline in chlorophyll *a* (an index of phytoplankton biomass); 3) the toxic blue-green alga *Microcystis* was present throughout the Delta at substantially higher levels in 2005 than 2004; 4) although there has been a recent expansion in the range of the clam *Corbula*, recent occurrence is comparable to the late

1987-1992 drought; and 4) changes in sediment composition and benthic assemblages occurred estuary-wide in 1999-2000.

Toxics. 1) Although studies on contaminants found that there have been changes in the patterns of use for herbicides and pyrethroid pesticides, it is unclear if these changes pose serious risks for aquatic species; 2) significant acute or chronic toxicity to the amphipod, *Hyalella azteca*, was detected at four out of ten sampling sites, however the cause was not identified; 3) no significant toxicity to the cladoceran, *Ceriodaphnia dubia*, the delta smelt or the juvenile striped bass was observed during the study period; 4) delta smelt are more sensitive to copper than previously reported and are 10-12 times more sensitive than juvenile striped bass; and 5) delta smelt from 2003 and 2005 (limited) showed more liver lesions at two locations representing general regions in Suisun Marsh (near and in Nurse Slough) and the Sacramento River at Cache Slough and the Sacramento Deepwater Ship Channel.

Water Project Operations. 1) There have been changes in the input flows to the Delta in recent years, including a slight increase in average Sacramento River flow since 2001 and a substantial reduction in peak San Joaquin flows since 1999; 2) there was no evidence of a recent major change in residence time, consistent with the lack of change in chlorophyll *a;* 3) increases in the pattern of wintertime salvage are consistent with hydrodynamic changes occurring each winter since 2001. These changes correspond closely with reductions in the abundance of several pelagic species. 4) nonconsumptive water use by Contra Costa and Pittsburg power plants may reach 3200 cfs (both facilities combined). The fish population impacts of these diversions have not been evaluated since the early 1980s, but given their location and the potentially large cooling water flux through them, the impacts could be substantial.

Although the 2005 conceptual model was a useful tool to implement the triage study design, we chose to develop new models because of new information about trends in zooplankton, and to reflect spatial and temporal variation in the stressors and the pelagic organisms. As an alternative, the initial results were synthesized in two general ways. First, we developed a matrix to depict when and where each stressor is most likely to be important and which were supported by the preliminary 2005 results. Secondly, we constructed narrative explanations for the recent step decline in abundance of pelagic species in the context of their long term trends or previous patterns. Note that these narratives are not exclusive of other explanations for the observed changes in fish abundance. The narratives presented here were chosen because they (1) include logical and plausible mechanisms for which there is at least some supporting evidence and (2) have broad explanatory power extending to multiple pelagic fish species (though no narrative claims to cover all the species). They also serve as examples of how the various stressors may be regionally linked. Moreover, neither of these narratives explains the declines of all four species. In the meantime, we believe that the two initial narrative models provide a useful basis for the development of more detailed hypotheses and studies for 2006 and beyond. The proposed 2006 work plan will be distributed as a separate document.

Introduction

In the last few years, the abundance indices calculated by the Interagency Ecological Program (IEP) Fall Midwater Trawl survey (FMWT) and Summer Townet Survey (TNS) show marked declines in numerous pelagic fishes in the upper San Francisco Estuary (the Delta and Suisun Bay) (IEP 2005). The abundance indices for 2002-2004 include record lows for delta smelt and age-0 striped bass and near-record lows for longfin smelt and threadfin shad. In contrast, the San Francisco Bay Study did not show significant declines in its catches of marine/lower estuary species. Based on these findings, the problem appears to be limited to fish dependent on the upper estuary.

In addition to the declines in fish species, initial IEP monitoring suggested declining abundance trends for zooplankton with a substantial drop in calanoid copepod abundance in 2004 (IEP 2005). Calanoid copepods such as *Eurytemora affinis* and *Pseudodiaptomus forbesi* are the primary food for larval pelagic fishes in the upper estuary (Meng and Orsi 1991; Nobriga 2002) as well as older life stages of planktivorous species such as delta smelt (Lott 1998). Conversely, the invasive cyclopoid copepod *Limnoithona tetraspina*, was hypothesized to be a poor food source for some fish and an intraguild predator of calanoid copepods. It was also thought to be the most abundant copepod in the estuary and increasing in abundance.

While several of these declining species - including longfin smelt, juvenile striped bass and calanoid copepods have shown evidence of long-term declines - there appears to have been a precipitous “step-change” to very low abundance during 2002-2004 (IEP 2005). Moreover, the record or near-record low abundance levels are remarkable in that winter-spring river flows into the San Francisco Estuary were moderate during this period. Many estuarine organisms including longfin smelt and striped bass typically produce poor year classes in dry years (Jassby et al. 1995); delta smelt abundance is generally lowest in very wet or very dry years (Moyle et al. 1992). Thus, we expected the moderate hydrology during the past three years to support modest production.

In response to these changes, the IEP formed a Pelagic Organism Decline (“POD”) work team to evaluate the potential causes. The product of this effort was a 2005 work plan, which provides an overview of the problem, a conceptual model, and description of a “screening level” study to examine some of the major causal factors (IEP 2005).

The following report summarizes the initial 2005 results and provides an initial synthesis how the stressors may interact with the target organisms in time and space. This document is intended as a progress report to provide the basis for suggested work in 2006. Neither this report nor the 2005 study were intended to “prove” which stressor(s) is responsible for the observed trends. Instead, this synthesis report represents a working document that will evolve over the next several years as studies are completed

Conceptual Model

Initial Conceptual Model: Based on the initial hypothesis that fish abundance declined abruptly after 2001, we developed an initial conceptual model (IEP 2005). Specifically, we proposed at least three general factors that may have been acting individually or in concert to lower pelagic productivity: 1) toxic effects; 2) exotic species effects; and 3) water project effects (Figure 1). The conceptual model used these categories to illustrate the potential pathways by which pelagic species in the Delta could be affected (Figure 1). For each group of "boxes" shown in the model, one or more examples are provided in italics. The arrows represent the potential mechanisms for changes. Note that not all of the organisms shown in each box are necessarily responsible for each of the mechanisms. Some of the rationale for these components is described below.

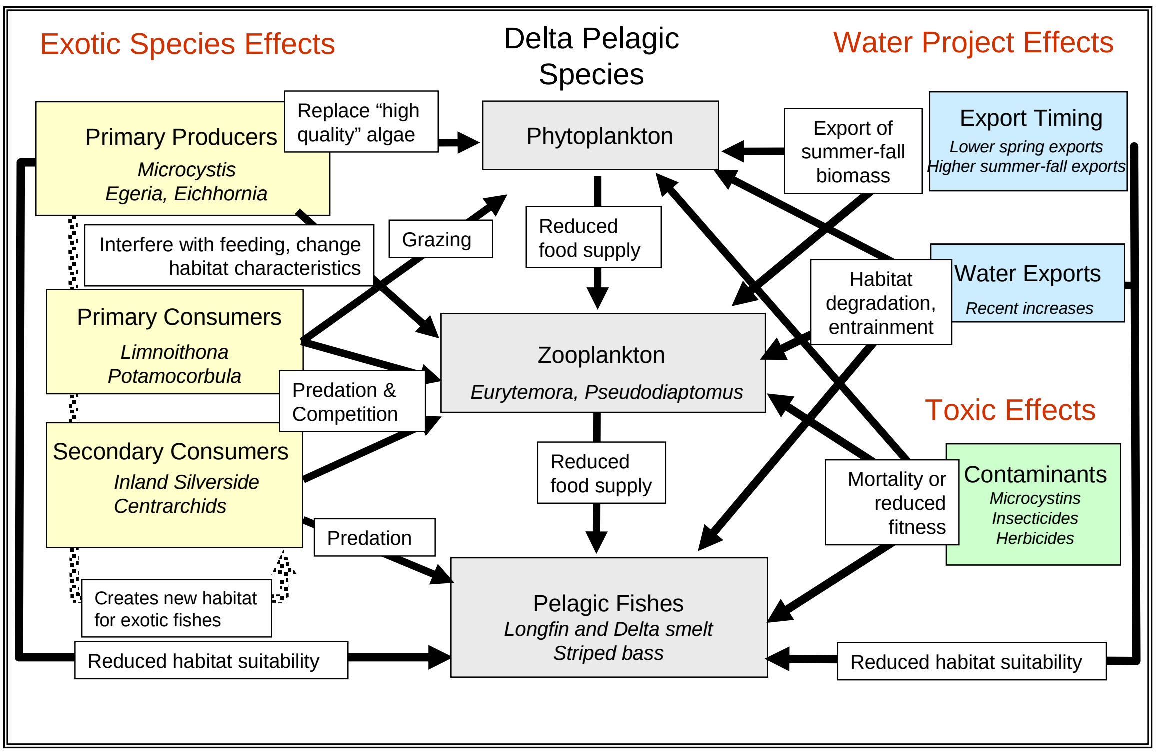
Toxins could affect fishes directly or indirectly by reducing lower trophic level quantity or quality. Herbicides could directly affect phytoplankton, zooplankton and fishes, while insecticides are most likely to affect zooplankton and fish. Toxic effects at lower trophic levels may reduce food supply for fishes and/or their invertebrate prey. Blooms of the blue-green alga (cyanobacteria) *Microcystis aeruginosa* have been observed in the Delta since 1999 (Lehman and Waller 2003, Lehman et al. 2005). This species complex often produces toxic metabolites collectively known as microcystins. Microcystins are cancer-causing to humans and wildlife, including fish (Carmichael 1995), and reduce feeding success in zooplankton (Rohrlack et al. 2005). Microcystins have been found in Delta zooplankton and clam tissue and could impact organisms at higher trophic levels through bioaccumulation (Lehman et al. 2005). The switch from organophosphate to pyrethroid pesticides increased substantially through the 1990s (see Oros and Werner report in Attachment A). Pyrethroid pesticides have been shown to be less harmful to humans and terrestrial wildlife but more harmful to aquatic organisms. The rising use of organic herbicides and copper-based compounds to control nuisance aquatic weeds and algal blooms in the Delta may also pose a threat to desirable aquatic organisms.

The negative effects of invasive exotic species in the estuary have been well-established. Some notable examples were the substantial declines in lower trophic level productivity that followed the introduction of *Corbula amurensis* (Nichols et al. 1990; Kimmerer and Orsi 1996; Jassby et al 2002, Kimmerer submitted) and the reduced abundance of native nearshore fishes associated with proliferation of *Egeria densa* and centrarchid fishes along Delta shorelines (Brown and Michniuk in review; Nobriga et al. 2005). At this time, we have limited information about quantitative aspects of the estuarine food web needed to estimate *Corbula* grazing rates or predict whether nearshore and pelagic food webs are coupled in ways relevant to the production of pelagic fishes.

Kimmerer (2002a) showed that water project operations have resulted in lower winter/spring inflow and higher summer inflow to the Delta. As noted previously, the actions by the CALFED implementing agencies have restored some spring inflow, but have also increased summer inflows to meet increasing summer export demands. This shift was implemented based on the assumption that it would be more protective to sensitive early life stages of key estuarine fishes and invertebrates. However, it is possible that high export during summer-winter months has unanticipated food web effects by exporting biomass that would otherwise support the estuarine food web. Other possible mechanisms include increased entrainment of fishes during the summer-winter months, or a reduction in habitat quality downstream (e.g. less area of the appropriate salinity). Total annual exports have continued to increase. It is also possible that the total volume diverted on an annual basis influences estuarine productivity (Livingston et al. 1997, Jassby et al 2002).

Revision of 2005 Conceptual Model: As will be discussed in further detail, the currently available 2005 results suggest that this conceptual model needed to be revised to incorporate consideration of spatial and temporal variation in potential fishery impacts. As a consequence, while the model provided a useful basis to design a rapid response 2005 study program, we relied on a different approach to synthesize the initial results and begin the process of developing 2006 study elements.

Delta Pelagic Species Conceptual Model



Study Approach

Details of the 2005 study were described in IEP (2005). The overall approach for 2005 was a "triage" model to better define the degree to which toxics, exotic species and water project operations may be responsible individually, in sequence, or in concert for the apparent long-term abundance declines and step-changes. Much of the rationale for the study design was based on *temporal*, *spatial* and *species* contrasts for selected fish and zooplankton. For each contrast, the variables to be evaluated were abundance, growth rate, fecundity, feeding success, condition factor, parasite load and histopathology (fish only). Note that much of the 2005 data needed to make these contrasts is still pending.

Temporal Contrasts. Temporal contrasts will be made seasonally and interannually. Analyses of monitoring data and additional samples were collected to help identify whether there are specific times of the year in which stressors are most pronounced. Much of this year's emphasis was on the summer growth season, which is extremely important to fishery production dynamics in temperate zone ecosystems. To the extent possible, these results were contrasted with historical data or samples to determine if current observations are consistent with earlier years. The hydrology in 2005 provided an excellent opportunity for a "natural experiment"—flow conditions have been consistently wet throughout the winter and spring, which typically results in good abundance levels for many pelagic species (Jassby et al. 1995).

Working Hypotheses for 2005:

- Stressor effects on pelagic populations are highest during the summer.
- Wet year hydrology in 2005 will result in substantial increases in the abundance of pelagic fish and calanoid copepods.
- Stressor effects have increased during the summer relative to historical data.

Spatial Contrasts: Monitoring data and new samples were evaluated to determine whether there was a specific region(s) of the estuary where stressor effects were strongest and to the extent possible, whether regional effects have changed in recent years.

Working Hypotheses for 2005:

- Pelagic species will show the strongest responses to stressors in specific regions of the estuary.
- Stressor effects have increased in specific regions of the estuary relative to historical data.

Species Contrasts: Three fish species (delta smelt, striped bass, inland silverside) and three zooplankton species (*Eurytemora affinis, Pseudodiaptomus forbesi, and Limnoithona tetraspina*) formed the focus of much of the 2005 effort. These species were selected because they provided convenient contrasts: for each list, the first two are declining in abundance, while the third is increasing.

Working Hypotheses for 2005:

- The more recent invaders (inland silverside, *Limnoithona*) will show less response to stressors.

Study Results

The 2005 work fell into four general types: 1) an expansion of existing monitoring; 2) analyses of existing data; 3) new studies; and 4) ongoing studies relevant to the POD. Several issues were not addressed in the 2005 study plan, most notably oceanic conditions. Ocean conditions were excluded because they are unlikely to be responsible for upstream effects in the Delta, the focus of the present study. The only possible exceptions are striped bass and longfin smelt, but not at the early larval and juvenile stages that are being examined. Climate change was also not explicitly evaluated in 2005, although two key responses (flow, temperature) were included in the analyses.

This following summary represents a progress report for the 2005 work completed to date. Because most of the studies are still in progress, the 2005 findings should be considered highly tentative. More detailed descriptions of most of the studies and preliminary results are provided as Attachment A.

1. Expanded Monitoring

The IEP currently has an extensive monitoring program. IEP fish, zooplankton and water quality monitoring programs were the source of most of the data and samples used for the present effort. However, we augmented certain sampling programs to ensure adequate collection of all life stages of pelagic fish. Abundance trends for zooplankton and fishes were updated through 2005 for surveys completed at the time of reporting (see Baxter et al. and Hieb et al in Appendix A). Survey specific results were also presented in appropriate sections below.

a. Delta Smelt Larvae Survey

Lead agency: DFG

What: This survey was designed to compare catch of delta smelt larvae in surface-oriented nets and in nets retrieved in the traditional oblique manner. Sampling with both methods took place simultaneously during the 2005 season at 19 of the 41 stations historically sampled by the 20mm Survey. All stations sampled in 2005 were within the legal Delta.

Questions Addressed: Can the distribution of larval delta smelt be more effectively determined from sampling with surface-oriented, bow-mounted plankton nets than by the historically used ichthyoplankton gear and methods (IEP 1987)? If current surface gear proves effective for larval delta smelt, what are the trends in seasonal abundance and distribution of smelt and other surface-orientated larvae?

Status: Field sampling was successfully completed and larvae have been identified. Complete net comparison analyses are pending.

Major Findings: 1) Surface oriented nets were successfully deployed and fished, and did not substantially add to survey duration; 2) Delta smelt larva numbers were low in all nets and insufficient to discriminate among nets. Most delta smelt larva captured in the fore-mounted surface nets (206 of 209) were collected later in the season during the 20mm survey, after oblique tows with the ichthyoplankton net was discontinued.

Future Direction: This sampling methodology proved feasible and efficient (all nets were deployed from a single vessel). The survey will be expanded into January-March and down estuary to improve capture of longfin smelt.

b. Summer Townet Survey
Lead agency: DFG

What: The Summer Townet Survey (TNS) has collected juvenile fishes in the range of 20 - 50 mm since 1959 (Turner and Chadwick 1972). Samples are collected using a conical net with a 1.5 m^2 mouth and 12.7-mm (½ inch) 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 to include four additional tasks: a water quality profile, a simultaneous zooplankton sample, collection of juvenile striped bass and delta smelt for histopathology and otolith growth analyses, and collection of water samples for ambient toxicity.

Questions Addressed: What is the relative abundance (via abundance index) of juvenile striped bass and delta smelt? Did higher outflow conditions in 2005 result in higher abundance? How are juvenile striped bass and delta smelt distributed within the upper estuary during summer?
Status: Sampling was completed and fish and zooplankton samples processed. Fish and water samples collected were transferred to other researchers. Fish abundance indices were calculated. Zooplankton densities have not been calculated or associated with fish data.

Major Findings: Despite higher April-June flow conditions in 2005 compared to 2001-2004, juvenile striped bass abundance was essentially the same at 0.9 as the record low of 0.8 in 2004 (Figure 2). Delta smelt relative abundance was at a record low at 0.3 (Figure 3). Historically, both juvenile striped bass and delta smelt abundance has been highest at intermediate spring outflows.

Future Direction: Continue to collect zooplankton samples as part of this survey as well as collect and preserve fishes of interest for other researchers. Relate fish and zooplankton densities to one-another to look for match-mismatches. Use diet information to suggest the most important comparisons and condition factor information to suggest an outcome.

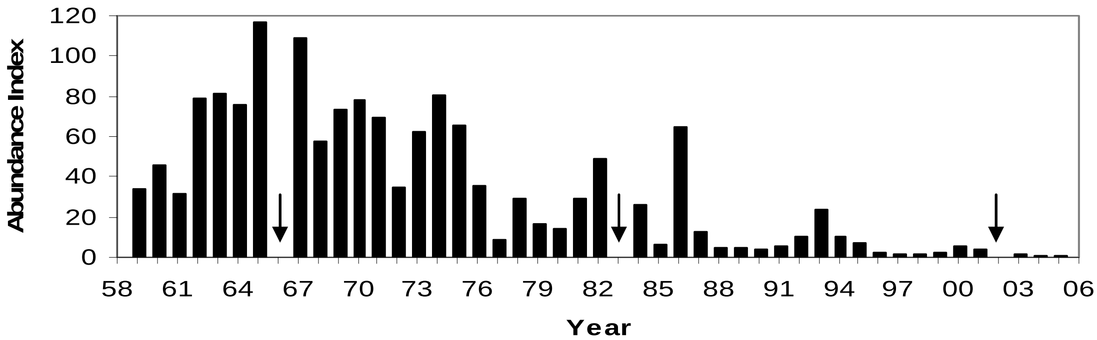


Figure 2. Summer Townet Survey juvenile striped bass annual abundance indices, 1959-2005. Arrows indicate years when an index could not be calculated.

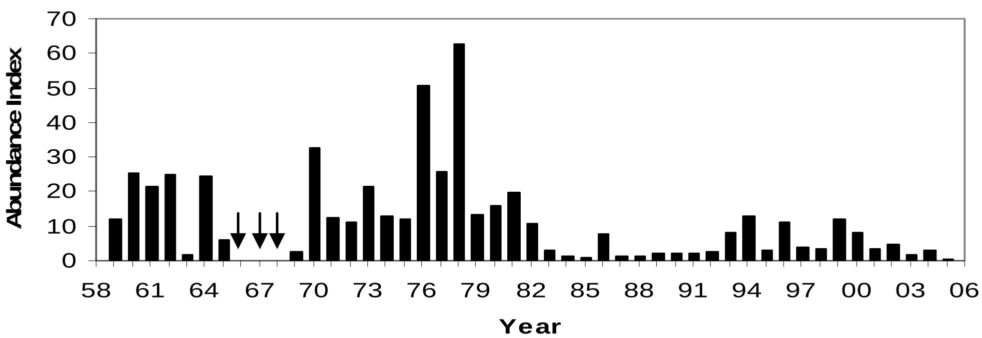


Figure 3. Summer Townet Survey delta smelt annual abundance, 1959-2005. Arrows indicate years when an index could not be calculated.

c. Fall Midwater Trawl

Lead agency: DFG

What: This survey targets age-0 striped bass and other pelagic species approximately 30-150 mm in length using a midwater trawl towed through the water column for 12 minutes in a stepped manner (Stevens and Miller 1983). Fishes are collected monthly (September – December) from 116 stations located from San Pablo Bay upstream through Suisun Bay/Marsh and into the Delta. Additional work for 2005 included: taking a water quality profile at each site with an YSI meter, a zooplankton tow at selected sites during the September survey, collection and preservation of juvenile striped bass and delta smelt for histopathology and otolith aging, and collecting a water sample at selected sites for ambient water toxicity testing. In addition, an outer bag of smaller mesh was attached to the cod-end of the midwater trawl to capture fishes passing through the current mesh to document its size retention capabilities.

Questions Addressed: What is the relative abundance (via abundance index) of juvenile striped bass, delta smelt and other pelagic fishes of the upper estuary? Did abundance improve in 2005 as a result of higher outflow conditions?

Status: Fish, zooplankton, water measurements and water collections were completed for September. Zooplankton samples are being identified and YSI measurements are being processed and summarized.

Major Findings: 2005 survey will not be completed until mid December.

Future Direction: Most of the additional field sampling work added to this survey was incompatible with safe and efficient collection of fish data. Collection and preservation of fishes for other study elements was the exception. Water collections for ambient toxicity and sampling to document mesh retention will also be done independently of survey sampling in the future. Data from histopathology, otolith growth and condition factor need to be linked to one another and placed into temporal and geographic context to look for potential linkages to mechanisms for decline.

d. Other focused sample collections

Lead Agencies: DFG, DWR

What: Focused, short-term field collections were undertaken where gaps appeared in the sampling grid or when particular species were needed for laboratory analysis that weren't evvectively captured using the existing monitoring work.

Questions Addressed: Specified in the original task.

Status: focused sampling was conducted and completed. Samples were provided for feeding habits and condition, histopathology and *Microcystis* studies.

Major Findings: Not applicable.

Future Direction: Continue as needed.

2. Analyses of Existing Data

a. Summarize the spatial and seasonal presence of early life-stages of pelagic fishes and zooplankton

Lead agency: DFG

What: A brief life history of each species emphasizing how it uses the estuary and a graphical description of the seasonal occurrence of early life-stages of the target fishes and zooplankton, and when each is collected by the Delta Smelt Larvae Survey, Summer Townet Survey, Fall

Midwater Trawl, the 20 mm Survey, and the Neomysis/zooplankton component of the Environmental Monitoring Program.

Questions Addressed: When and where are potentially vulnerable species life stages available to be affected by stressors? This basic summary of when and where different life stages of target species are present was used as a resource for other program components.

Status: Completed June 15, 2005.

Major Findings: Descriptive table and species life histories were prepared (See Appendix A).

Future Directions: Revise information as needed to keep data relevant to the investigation.

b. Apparent growth rates of pelagic fishes and relationship to abundance
Lead agency: DFG

What: Apparent growth is a term used when growth rate is based on changes in length frequencies through time from sample data. It may or may not accurately represent true growth depending on the importance of factors such as gear effectiveness and size –selective mortality. In general, fish growth rates can be an indicator of toxic exposure or food limitation (Bennett 2005). We examined fish length data collected by 20mm, Summer Townet, Fall Midwater Trawl Bay Study and Suisun Marsh surveys to determine: 1.) whether apparent growth rates of selected fishes changed over time, particularly between 2002-2004 and previous years; 2) whether mean year-end lengths during fall changed abruptly during 2002-2004 (Sweetnam 1999. No additional length analysis has been conducted on Summer Townet or Fall Midwater Trawl data. We also compared length at date data with abundance to evaluate whether apparent growth rate influences abundance and made use of recently collected length-weight data and compare it to similar historical information derived from sampling in the upper estuary (e.g., Kimmerer et al. 2005).

Questions addressed: Have species apparent growth rates changed over time, particularly during the period from 2002-2004 versus previous years? Have species' year-end mean lengths declined, particularly 2002-2004 versus previous years?

Status: In progress. A subset of possible length data have been processed to develop apparent growth rates for delta smelt and longfin smelt from 20mm (juvenile striped bass data were not suitable), and juvenile striped bass data from Bay Study and Suisun Marsh surveys. Year-end mean lengths have been calculated for all targeted fishes from the Fall Midwater Trawl.

Major Findings: Apparent growth rates for delta and longfin smelt post-larvae/small juveniles from the 20mm survey ranged from 2.2-3.7 mm/day for delta smelt and 1.2-2.4 mm/day for longfin smelt (Baxter et al. Appendix A). Apparent growth rates of both species was as high or higher in 2002-2004 than in previous years (1995 – 2001) Apparent growth rates for juvenile striped bass from Bay Study and Suisun Marsh sampling were well correlated (r=0.775) and also were higher in 2002-2004 than in previous years. Trends in mean size in the Fall Midwater

Trawl varied by species: striped bass mean size increased from 1967 – 2004; 2002-2004 striped bass lengths were among the highest for the period of record; mean delta smelt lengths have not recovered to pre-1990 levels, so the step –change reported by Sweetnam (1999) persists; mean longfin smelt lengths show no long-term trend, but were fairly high during 2002-2004; threadfin shad mean lengths show a persistent step-decline around 1993.

Future Direction: We will also compare length at date data with abundance to evaluate whether apparent growth rate influences abundance. The apparent growth data will be compared to food availability, condition factor, otolith growth and histopathology data.

c. Zooplankton fecundity and population structure
Lead agencies: DFG and USBR

What: This is an analysis of existing data to evaluate changes in the number and frequency of nauplii present per adult calanoid copepod, and eggs and embryos present per female mysid shrimp. Some of these analyses will be conducted as part of Bryan Manly's ongoing fish and zooplankton data analyses in collaboration with DFG zooplankton survey staff. Additionally, patterns in mysid fecundity will be examined looking for time trends. These population parameters may indicate the presence of environmental stressors for zooplankton including toxins, exotic species invasions, and habitat degradation. Decreased reproductive fitness can lead to population declines. Currently, egg/embryo numbers are determined only for mysids. We will evaluate the benefit:cost ratio for similar analyses of copepods by contrasting information gained versus sample process time using preserved archived samples

Questions addressed: What are the monthly and spatial patterns and annual trends in calanoid copepod population age structure and mysid shrimp fecundity? Do patterns and trends coincide with any known environmental events or the presence of specific stressors? Did fecundity decrease over time or in certain regions, indicating worsening environmental conditions? Was there a step change in the last few years?

Status: Summaries of mysid fecundity were completed (Mecum, Appendix A). We detected errors in the 2004 zooplankton data during analyses which lead to a quality check of historical data, and subsequent correction and revision during summer 2005. For this reason, population structure analyses did not begin until fall 2005. We also found historical raw zooplankton fecundity data during data organization and these data are being prepared for analyses. No new copepod fecundity studies were conducted in summer 2005, but this work may occur in late 2005 or early 2006.

Major Findings: The number of mysid females available for fecundity declined in steps from low thousands through the late 1980s, to less than 10 per year 2002-2004 (Mecum Appendix A). During this period the relative number of large females (>14 mm) available diminished to zero leading to a loss in population fecundity. No change was observed over time in length-adjusted number of egg/embryos per fecund female. Fecundity maxima have shifted from Suisun Bay to the Delta.

Future Directions: Complete work as planned comparing zooplankton life stage dynamics (Bryan Manly). Collect data on 2005 copepod fecundity and decide if examination of archived samples is warranted and if so, proceed. Compare any time-trend relationships observed to potential causative factors.

d. Toxic and other harmful effects of Microcystis aeruginosa blooms
Lead agency: DWR

What: This is a literature review on *Microcystis aeruginosa*. *Microcystis aeruginosa* blooms may be an important new stressor for pelagic species in the Delta. Many basic questions about ecological effects of *Microcystis aeruginosa* blooms can be answered from existing literature. Answers to these questions will provide important background information for *Microcystis* studies (see element 3d below) and data analysis and interpretation.

Questions addressed: What are the main *Microcystis* toxins? How do they act on fish and zooplankton? What concentrations are known to have lethal or sublethal effects on fish and zooplankton? What are other harmful effects of *Microcystis* blooms on pelagic species? How do blooms form? How variable is the production and toxicity of microcystins among blooms of *M. aeruginosa*?

Status: Completed

Major Findings: The most common microcystin in the Delta is the highly toxic microcystin-LR. *Microcystis* can have a wide variety of ecological impacts. It can limit zooplankton food intake and reproduction. For fish, *Microcystis* is indigestible but the toxins can be taken incidentally with food and bioaccumulated. Based on work elsewhere, *Microcystis* is likely to shift ecological communities toward species tolerant or resistant. However temperature can be a significant limiter on *Microcystis* growth in temperate areas. Most data on *Microcystis aeruginosa* blooms are in lacustrine environments, making it unclear if it is relevant to estuarine habitat.

Future Direction: Integration of literature review results with field data is the primary next step.

e. Use and toxicity of pyrethroid pesticides
Lead agencies: SFEI

What: This is a literature review and data analysis of pyrethroid pesticide use and toxicity. Pyrethroid pesticides are used in increasing amounts by agriculture and vector control as other pesticides are withdrawn from use. Pyrethroid pesticides are more toxic to aquatic organisms than some other classes of pesticides. A review of the available literature and data on pyrethroid use in the Delta watershed and potential pyrethroid toxicity to estuarine organisms provided information regarding the need for, and scope of, future studies of pyrethroid toxicity.

Questions addressed: What are the basic chemical and toxicological characteristics of pyrethroid pesticides? For which purposes and how much are pyrethroid pesticides used in the Delta watershed, and how has the use changed over time? What are the most likely pathways for these pesticides to enter the Estuary? What factors influence the transport and toxicity of these pesticides in the Estuary? What is known about pyrethroid toxicity to estuarine organisms? What concentrations are known to have lethal or sublethal effects on fish and zooplankton? Are there particular groups of estuarine organisms that are most sensitive to pyrethroids?

Status: Completed and reviewed by satellite contaminants work team; no peer or stakeholder review.

Major Findings: As organophosphate insecticide use declines due to increased regulation, pyrethroid insecticides have replaced the organophosphate pesticides for both urban and agricultural uses. Pyrethroid use in the Central Valley in 2000-2003 was nearly double that in 1991-1995. Pyrethroid insecticides are hydrophobic compounds that have a strong tendency to adsorb to particulates like sediments rather than remain dissolved in the water column. As such, pyrethroid transport likely occurs with mass transport of sediment and particulates during storm and irrigation runoff events. In addition, pyrethroids are most likely to cause toxicity to benthic organisms. Pyrethroids are very toxic to both fish and invertebrates. However, the environmental pyrethroid concentration (exposure) data is needed to determine the risk to aquatic organisms in the Delta system. Although pyrethroids are relative insoluble in water, all are sufficiently soluble to cause adverse biological effects. Amphipods and copepods are among the taxa most sensitive to pyrethroids insecticides. Pyrethroid insecticides have been detected in sediments from Central Valley agricultural and urban drainage dominated water bodies at concentrations high enough to contribute to toxicity to sensitive aquatic species. In agricultural drainage dominated water bodies the highest concentrations are detected shortly after their peak use in July through November. Pyrethroid and toxicity monitoring in Sacramento area creeks shows that pyrethroids are transported into urban streams via storm drains and cause toxicity to benthic organisms a short distance downstream of the drains. A one box model indicates that surface sediment concentrations in the 1-2 ng/g dry weight range are probable in Suisun Bay based on estimated pyrethroid concentrations resulting from loads from Central Valley runoff. These values are sufficient to cause toxicity to benthic organisms such as *H. azteca* (Weston et al. 2004).

Future Direction: Pyrethroid insecticides are among the list of several contaminants that have the potential to cause toxicity to aquatic organisms in the Delta. Rather than focusing on pyrethroids a priori, future toxicity studies should rely on toxicity identification evaluations (TIEs) and chemical analysis to determine whether pyrethroids play a role in the observed toxicity. POD investigators also should stay abreast of findings of studies being conducted by outside entities. The Sacramento River Watershed Program and the San Francisco Estuary Institute currently are developing TIE and chemical analysis techniques for pyrethroid insecticides, and conducting pesticide model runs for two pyrethroids to determine the potential edge-of-field exposure concentrations.

f. Use and toxicity of aquatic herbicides

Lead agencies: DWR in cooperation with DBW

What: This is a literature review and data analysis for copper-based and other aquatic herbicides used to control nuisance aquatic plants in the Delta. Some of the data collected during and after herbicide applications by the California Department of Boating and Waterways (DBW) has been published in reports, while other data need to be entered into electronic databases to be analyzed. Additional reviews and data analyses are needed to assess the potential for these compounds to contribute to declines of pelagic species in the Delta and to help decide if additional studies are necessary. This work will also help us understand exotic plant dynamics in the Delta.

Questions addressed: What are the basic chemical and toxicological characteristics of the herbicides used to control aquatic nuisance species in the Delta? What is their use history? How and when are they applied? What is their toxicity to estuarine organisms and other effects on the aquatic environment? What concentrations, if any, have lethal or sublethal effects on fish and zooplankton? Is there evidence of or potential for toxicity to zooplankton or fishes in the upper estuary based on current application practices? Are any groups of estuarine organisms more sensitive to these herbicides than others?

Status: The literature review has been completed. The key entry of the DBW data has not begun.
Major Findings: Impacts of aquatic herbicides on pelagic organisms in the Delta are not likely to be significant for most herbicides used for aquatic weed control. However, surfactants and other adjuvants applied with the herbicides may contribute to pelagic organism declines.

Future Direction: Assess monitoring data collected under the NPDES permit (i.e., herbicide analysis and toxicity tests) in the context of other POD study data. Additional information on surfactant toxicity to pelagic organisms would be useful, but likely of low priority. POD investigators also should examine agricultural practices of rice farming as it accounts for 93% of the copper sulfate applied in Sacramento County (CDPR 2003).

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

Lead agencies: DWR and DFG

What: Long-term monitoring data were used to characterize physical habitat for young-of –the –year 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 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 juvenile striped bass and delta smelt. Second, we divided the study region into smaller area units based on the location of TNS stations. Third, we applied the habitat criteria (step 1) to long-term water quality monitoring data for each TNS 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.

Questions addressed: Has the surface area of suitable juvenile striped bass and/or delta smelt habitat changed? Does interannual variation in estuarine hydrology influence the spatial extent of juvenile striped bass and/or delta smelt habitat? Have export changes affected the spatial extent of juvenile striped bass and/or delta smelt habitat?

Status: Initial study completed for both FMWT and townet survey.

Major Findings: Based on the data available to define "habitat" (Nobriga et al. and Fryrer et al. Appendix A):

- There is no evidence that delta smelt and juvenile striped bass, physical habitat quantity has decreased since 1970.
- There is no evidence that variation in physical habitat quantity significantly influences delta smelt population dynamics.
- The relationship between delta smelt physical habitat area and hydrodynamic conditions indexed by X2, is uncertain because the relationship varied substantially depending on which habitat definition was considered.

Future Directions: The results of this study indicate that basic physical habitat for delta smelt and juvenile striped bass has not changed. However, we would like to re-do the analysis by developing the habitat criteria using the top 50% of years with highest delta smelt abundance, then testing the probability that the 50% of years with lowest delta smelt abundance come from the same multivariate distribution of habitat variables. This would provide further assurance that our results are robust by testing the probability that pooling all years for analysis was an appropriate choice. In addition, we would like to use GIS software to examine the distribution of predicted 'optimal' habitat and the empirical distribution of the population. This might provide insight into other distribution-constraining variables that we have not accounted for (zooplankton abundance, water depth, etc.).

h. Analysis/summary of recent changes in delta water operations
Lead agency: USGS, DWR, EPA and USBR

What: Since the mid-1990s, more water has been exported during the summer (July-September) than before, in part to compensate for conservation-driven export reductions in spring (April and May). There have been other changes in water project operations, which may also have had unexpected biological side-effects (e.g. export of more primary production). The purpose of this element is to closely examine recent changes in water project operations to identify effects potentially strong enough to account for the apparent step change in pelagic fish abundances since 2001. Other historical changes in water project operations will also be studied to support the "Analysis of historical population dynamics" study element and advance our knowledge of the role of water project operations in the long-term decline of certain pelagic fish species. However, long-term analyses will be secondary to the investigation of recent changes.

Questions addressed: (1) How have the major inflows and outflow from the Delta, and how have they changed in recent years? (2) What are the major outflows from the Delta changed in recent years? (3) How have barrier operations in the Delta changed in recent years? (4) 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 (5) Have there been recent increases in pelagic fish entrainment?

Status: Four draft reports completed. Filenames for the reports in Appendix A are:

(a) "Delta hydrology summary 1985-2004.pdf"
(b) "Power plants evaluation.pdf"
(c) "Historical patterns in salvage data.pdf
(d) "Particle tracking model results.pdf

Major findings:

(1) There have been changes in the input flows to the Delta in recent years, including a slight increase in average Sacramento River flow since 2001 and a substantial reduction in peak San Joaquin flows since 2001. There are some methodological issues with the hydrology report that will have to be addressed.
(2) Coincident with an increase in winter exports, there have been substantial increases in salvage rates (a measure of water project entrainment) of pelagic fishes. Moreover, the high winter salvage levels have occurred at a time when pelagic fish year class strength was at record or near-record lows.
(3) Nonconsumptive water use by the power plants may reach 3200 cfs, which may be enough to create a substantial entrainment risk for fishes residing in that region of the estuary. 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.

Future directions: Investigation of the effects of water project operations during the winter and spring months have become a priority of the POD investigation for reasons explained in the "synthesis" portion of this document. We believe next steps should include model-based investigations of Delta circulation and zone of entrainment dynamics to find out why there have been recent increases in salvage density of several of the species showing the strongest index declines since 2001. We also believe the potential effects of the Pittsburg and Contra Costa power plants should be investigated using modeling approaches and examination of available data.

i. Analysis of historical population dynamics

Lead agency: USBR

What: These investigations were begun with the observation that there appears to be a downward step change in several pelagic fish species indices after 2001. This element is a general review of historical fish population dynamics in the estuary. Zooplankton and benthic invertebrate population density and biomass dynamics will also be explored where data series exist that have not been analyzed (for historical dynamics) elsewhere (for benthos biomass, see 3f). Several historical analyses of fish, plankton, or benthic invertebrate populations have been published, and their findings were (or will be) reviewed and incorporated into this investigation; however, there will be a de novo examination of pelagic and nearshore fish populations. Results from these analyses will be integrated with the ongoing data analyses studies described in 4c and 4d.

Questions addressed: The examination included, first, a review of historical IEP monitoring data to describe historical fluctuations. This included the evaluation of, or search for, (1) long-term trends, (2) discernable epochs in the data, (3) notable point or short-duration events, and (4) coordinated or contemporaneous changes in multiple species that suggest a common explanation. A simple model will be used at this stage to account for the known effects of gross hydrology. Second, the power of various hypotheses raised in the POD PWT investigation to explain historical fluctuations in pelagic and nearshore fish indexes will be investigated. Nearshore fishes (e.g., inland silversides) are included because of the expected contrast in their responses to some possible stressors. In connection with hypotheses involving stressors imposed during a specific time period, the effort will focus particularly on determining whether the timing of response onset is plausible. As with other parts of the POD PWT investigation, the central focus will be on changes that may have occurred since 2001. However, the scope of the investigation will be wide, because a full explanation for recent changes may be complicated and reach much farther into the past.

Questions addressed: What are the long-term patterns in individual pelagic species catches, including trends, step changes, and changes in distribution among sampling stations? What are the joint patterns in the catch of pelagic species, and, with particular attention to 2001-2002, to what extent do trends and step changes coincide among species? What are the long-term patterns in common littoral fish species catches, and are there contrasts in trajectory among some of the species? What do factors known to affect catch of some species, such as seasonal pulses in river discharge, and also factors hypothesized to affect trawl catch, such as SWP and CVP exports, contribute to models of FMWT catch?

Status: In progress. Results may be presented at the November 14th meeting. A manuscript in preparation will be submitted for journal publication by the end of the year or shortly thereafter. Progress summary and draft report ("DRAFT progress report on analysis of historical fish and zooplankton populations dynamics" by – Bryan Manly and Mike Chotkowski) is included as part of Attachment A.

Major findings: Work to date has focused on methods development. Analyses expected before 14 November.

Future direction: adaptation of these methods to other species of interest to the POD investigation to provide step change and trends analyses of all species using consistent methods; additional statistical modeling to support the POD investigation.

3. New Studies

a. Evaluation of delta smelt otolith microstructure and microchemistry
Lead agency: UC Davis

What: The original study proposed to evaluate delta smelt, juvenile striped bass, and inland silverside otolith microstructure and microchemistry to evaluate pelagic fish growth rates and natal origin. The 2005 study was restricted to delta smelt. The 2005 results are not currently available. Rather, we report on a detailed comparison of delta smelt otolith microstructure (growth rates) and microchemistry (natal origins) of 1999 versus 2004.

Questions addressed: Does interannual variation in spawning and rearing conditions contribute to interannual abundance differences?

Status: the 2005 analyses are ongoing.

Major findings: The 15-20ºC index of the spawning temperature window was about 2 weeks longer in 1999 than 2004. This could have contributed to differences in abundance between 1999 and 2004 because the 15-20ºC index of the spawning temperature window may be correlated with the Fall Midwater Trawl index. However, the statistical relationship between the 15-20ºC index of the spawning temperature window and the Fall Midwater Trawl index is weak and the empirical otolith hatch date distributions were substantially longer and more similar among year than the 15-20ºC index indicated, suggesting the 15-20ºC index underestimates the actual spawning window and over-predicted the difference among years. Average delta smelt growth rate was faster in 1999. Faster growth rates are often associated with higher recruitment success in fishes. Thus, this factor also could have contributed to higher abundance in 1999. There was a tendency for faster growing fish to have higher condition and/or longer length at age. In both years, the Cache Slough station had higher residual growth/condition than other locations. Likewise, in both years Suisun Bay and the Sacramento-San Joaquin River confluence had low residual growth/condition. Otolith microchemical analysis indicated that in 1999 delta smelt spawned throughout the upper estuary (Napa River and the Delta) recruited to the adult population, whereas in 2004, only fish spawned in the Delta recruited. This also could have contributed to higher abundance in 1999 since more of the estuary was available for spawning.

b. Liver histopathology and general pathobiology (starvation disease, and toxic exposures) for pelagic fishes
Lead Agency: UC Davis

What: Histopathological examination of larval and juvenile delta smelt, juvenile striped bass and inland silverside and additional pathobiological evaluation of young striped bass. The relative quantity of glycogen and liver lesions in fish provides a good indication of their health (Bennett et al. 1995; Bennett 2005). Low glycogen levels can be indicative of indicates low feeding success, thus implicating food availability as a stressor. However, glycogen levels also can be influenced by rapid growth periods and exposure to contaminants. Liver lesions other than glycogen depletion also suggest sublethal exposure to toxic compounds. It is hoped this diagnostic tool will help pinpoint if, when, and where significant toxic exposure and/or food limitation occurs.

Questions addressed: Does histopathological information support hypotheses of recent increases in toxic exposures and/or food limitation? Do target fishes from the same locale exhibit similar responses? Does the histopathological condition vary in severity by life stage within or among species and/or geographic regions?

Status: The 2005 field work has been completed. Laboratory processing of fish collected in summer 2005 is ongoing. Progress reports provided in Attachment A by Teh and Ostrach.

Major Findings: For 2005 only subsets of the delta smelt and juvenile striped bass data are currently available. For delta smelt, some comparisons with results from 2003 were made. Liver glycogen depletion is the most common liver lesion observed to date. Infiltration of inflammatory cells is the second most frequent lesion. Samples show similar incidence of liver lesions at the Sacramento-San Joaquin confluence in March 2003 and similar liver lesion scores. The available data suggest the delta smelt population is subject to chronic glycogen depletion and other liver disorders. For juvenile striped bass, liver glycogen depletion was also noted for fish collected at station 703. Numerous other pathobiologic indicators, including microscopic parasites not observable in section 3c (below), were reported. The general conclusion of the pathological reports was that findings were not out of the ordinary for wild fish populations. However, the PI speculated that incidence of disease and infection could interact with other stressors to depress population abundance.

Future Direction: Complete 2005 sample analysis. Preserve surviving toxicity test fish from both toxic and non-toxic samples for histopathology analysis. Need to determine whether the major liver lesions are due to contaminants, reduced food supply, infection or combinations of these factors. Analyze gut content in fish with low liver glycogen levels. Link otolith investigation to histopathology, for example, those sites where growth rates are lower based on otolith analysis to reduced liver glycogen levels. Seek fish necropsy pathologists expertise to expand organ sampling (i.e., kidneys, gill, and gonads).

3c. Analysis of stomach contents, weight and parasites
Lead agency: DFG

What: Feeding success during early life history can contribute to fish recruitment success (Ludsin and DeVries 1997; Limburg et al. 1999). 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 ten years ago and the feeding habits of the local inland silverside and threadfin shad populations have only been studied in a limited geographical location (Grimaldo 2004). The only previous evaluation of parasite load was an evaluation of cestode infection in juvenile striped bass (Arnold and Yue 1997). However, information on gut parasites can be collected quickly during the processing for stomach contents analysis. Parasite load can influence susceptibility to other stressors (Moles 1980). The IEP started a study of fish length-weight relationships needed to develop a program to monitor relative weight.

Questions addressed: What is the diet composition of the target species. For juvenile striped bass, delta smelt and threadfin shad, is there evidence of reduced feeding success or increased macroscopic parasite load at 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 liver condition? For inland silverside, a species not in decline, is their condition or feeding success better than that of declining species? Is their a difference in condition between fish collected in pelagic environments and those collected in near-shore environments?

Status: Age-0 fishes were collected in 2005 by the Summer Townet Survey, Fall Midwater Trawl Survey, San Francisco Bay Study, and beach seine supplemental field sampling. To date 400 delta smelt, inland silverside and striped bass have been weighted and measured and 116 have had their stomach contents examined. Condition comparisons were also made between 2005 specimens and specimens collected in previous years in other programs.

Major findings: Preliminary results suggest feeding incidence is higher for delta smelt and inland silverside (100% and 95%, respectively) than for striped bass (48%) (Slater et al. Appendix A). By volume, delta smelt stomach contents were dominated by Calanoid copepods of the genus Acartiella (31%) and the species *Pseudodiaptomus forbesi* (24%). By volume, striped bass stomach contents were dominated by the introduced Mysid shrimp *Acanthomysis bowmani* (19%) and *P. forbesi* (14%). By volume, inland silverside stomach contents were dominated by the cyclopoid copepods of the introduced genus *Limnoithona* (25%) and *P. forbesi* (14%). Inland silverside also made substantial use (7% by volume) of terrestrial invertebrates, that were not found in striped bass and delta smelt stomachs. The relative weight of striped bass decreased in a seaward direction from the Delta to western Suisun Bay, suggesting striped bass rearing in Suisun Bay have relatively poor body condition.

Future direction: Complete the processing of stomachs obtained from 2005 specimens and convert the diet data into feeding success metrics. Integrate the 2005 stomach content information with the yet-to-be completed 2005 histopathology studies and growth/apparent growth studies. Compare 2005 food habits results with results from earlier (pre-decline) studies.

d. *Field survey of Microcystis aeruginosa bloom biomass and toxicity*
Lead agencies: DWR and DFG

What: A new field survey to measure *Microcystis aeruginosa* bloom distribution, biomass and toxicity. A single day study in 2003 and a seasonal study in 2004 indicated that a *Microcystis aeruginosa* bloom was widespread throughout the Delta (Lehman et al. 2005). Furthermore, microcystins in tissue of zooplankton, amphipods, clams, and other benthic organisms collected in 2003 and 2004 indicated that the base of the food web contained microcystins that could impact organisms at higher trophic levels through bioaccumulation (Lehman et al. 2005). This survey built on the 2004 survey in time and space. Moreover, the study was closely coordinated with the 2005 fish surveys (Summer Townet Survey, Fall Midwater Trawl) and toxicity assays. Sample collection at fish survey stations will help elucidate the link between *Microcystis* biomass and toxicity and its direct effect on zooplankton and fish.

Questions addressed: Is *Microcystis* biomass or toxicity increasing over time in the Delta? Does *Microcystis* bloom biomass or microcystins toxicity overlap in time and space with pelagic fish species in the upper estuary? Is there a relationship between bloom biomass and toxicity with zooplankton and fish abundance? Is there a relationship between the bloom biomass, microcystins in algal tissue or microcystins dissolved in the water column, and microcystins toxicity in zooplankton, benthic, epibenthic and fish tissue? Do regions of high zooplankton and benthic tissue microcystins toxicity coincide with high microcystin tissue content, lower density and poor health of planktonic feeding fish?

Status: Field work completed.

Major Findings: Blooms of *Microcystis aeruginosa* appeared to expanded and intensified in the Delta, especially at the San Joaquin River stations (Antioch, Frank's Tract, Old River and San Joaquin River Ship Channel). *Microcystis aeruginosa* was not found downstream of the low salinity zone and its bloom in the Delta was apparently delayed by the cooler water temperatures in 2005 relative to earlier years.

Future Direction: The results to date have focused on the levels of microcystins in the algal biomass, but have not yet evaluated the degree of toxicity to the target organisms. Hence laboratory studies on the effects of *Microcystis aeruginosa* on the growth and survival of common copepods in the Delta would allow evaluation of *Microcystis aeruginosa* impacts in the field. *Microcystis* bloom distribution and toxicity data should be integrated with spatial-temporal analyses of zooplankton abundance and fish condition/histopathology status.

e. Acute and chronic invertebrate and fish toxicity tests
Lead agencies: UC Davis

What: This is a study to investigate toxicity of Delta water samples to invertebrates and fish in laboratory bioassays. The 2005 work was a pilot-level study intended to assess the potential for contaminated water to contribute to the observed declines of pelagic species in the Delta and to help decide if additional studies, including studies to chemically identify toxins, are warranted. Monthly water samples were collected twice a month at selected fish survey sites in the Delta and the Napa River from June through September 2005 during the *Microcystis aeruginosa* sample collections. Sampling took place approximately simultaneously with fish sampling at sites characterizing primary inflows to the Delta as well as geographic regions important to pelagic fish of interest or known to receive agricultural runoff or herbicide treatments for aquatic weed control, and sites used for toxicity testing in 1993-1995 (Werner et al. 2000). Test organisms included the invertebrates *Ceriodaphnia dubia*, *Pseudodiaptomus forbesi*, *Hyalella azteca*, as well as juveniles of the Delta fish species delta smelt (*Hypomesus transpacificus*) and juvenile striped bass (*Morone saxatilis*). Seven day and ten day bioassays were conducted under standardized laboratory conditions. Mortality after 96 hours and invertebrate egg production and fish growth after seven or ten days were used as measures of acute and chronic toxicity, respectively.

Questions addressed: Is water in the Delta and the Napa River toxic to pelagic fish and fish food organisms? If yes, where and when? Is there a relationship between toxicity results and fish and zooplankton abundances? Is there a relationship between *Microcystis* blooms and results of the toxicity assays?

Status: Toxicity testing is complete. Samples for stress protein analysis are waiting processing.

Major Findings: Significant acute and chronic toxicity to the amphipod, *H. azteca*, was detected at five out of ten sampling sites: the Napa River, the Old River, the San Joaquin River, and the Sacramento River. No TIEs were conducted on the samples exhibiting toxicity so the cause was not identified. Toxicity to the copepod *P. forbesi* was detected in the San Joaquin River. No significant toxicity to the cladoceran, *C. dubia*, delta smelt or striped bass was observed during the study period (delta smelt and striped bass were tested only once). While no significant toxicity to the cladoceran was detected, anecdotal evidence shows the potential for microcystin toxicity to the cladoceran. Spiking studies show that delta smelt are more sensitive to copper than previously reported and are 10-12 times more sensitive than juvenile striped bass.

Future Direction: Complete stress protein, acetylcholinesterase and vitellogenin assays. Continue toxicity testing to determine temporal and spatial distribution of toxicity in the Delta. Number of sites and sampling events (i.e., beginning in winter) should be increased and spring sampling should include at least two storm water runoff events. Ensure that TIEs are conducted on samples showing observed toxicity, with particular attention to possible copper toxicity when copper-based herbicides are applied. Include analysis of biomarkers such as stress protein and endocrine disruption in future toxicity studies. Bioassay results should continue to be integrated with *Microcystis*, zooplankton abundance, fish growth/condition and histopathological data.

f. Striped bass and delta smelt fecundity estimates
Lead agency: DFG

What: Observed declines in fall juvenile fish abundance could result from poor survival of larval and early juvenile life stages, or could simply result from declining egg production. Declining egg production could result from a decline in the average size, age or total number of spawning females, or a reduction in individual female fecundity caused by degraded environmental conditions (e.g. exposure to contaminants or poor food availability). The specific purpose of this work plan action was to develop up-to-date relationships between female size/age and fecundity for striped bass and delta smelt. For both species, the goal was to compare current and historical fecundity relationships for indications of any significant change. Fecundity relationships were most recently developed for San Francisco Estuary striped bass and delta smelt in the mid 1980s and late 1990s, respectively (Knudsen and Urquhart 1988). For striped bass, fecundity relationships can be used in combination with adult population estimates to improve current estimates of overall egg production (Steven's et al. 1985; Kimmerer et al. 2000: 2001).

Questions addressed: Has there been a recent decrease in the fecundity of striped bass or delta smelt? How do recent striped bass egg supply levels compare with historical levels?

Status: Thirty adult striped bass collected during the spring 2005 spawning migration have been processed. Ovaries from the 30 adult bass were visually examined for general health. Delta smelt data have not been processed.

Major findings: The overall condition of the ovaries appeared to be excellent with only one fish having noticeable parasites. Size -fecundity relationships in 2005 did not appear to differ substantially from relationships developed in the 1970s and 1980s

Future direction: Update estimates of total striped bass egg supply by integrating age-fecundity relationships with current age-specific estimates of adult female abundance. Analyze contaminant levels in retained ovary samples for the purpose of assessing viability impairment. Develop and implement a program in 2006 to retain adult female delta smelt from the IEP's Spring Kodiak Trawl Survey for laboratory assessments of general fish condition, ovary condition, and fecundity. Investigate relationships between health parameters and fecundity.

g. Trends in benthic macrofauna biomass

Lead agency: DWR

What: Over the past three decades, the Interagency Ecological Program (IEP) Environmental Monitoring Program (EMP) has collected benthos community composition and relative abundance information at 22 sites, including four long-term monitoring stations. Biomass data are crucial in quantifying the role of benthic organisms in the ecosystem and the ecological significance of changes in benthic community composition and abundance. Specifically, knowledge of bivalve biomass is needed to improve our understanding of lower trophic level food web pathways in the estuary. The EMP has archived benthos samples dating back to 1975 which can be used for biomass estimation using a simple wet-weight method. The objective for 2005 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. Data analysis was conducted as part of the ongoing study *4 d*.

Questions addressed: 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?

Status: The laboratory work for this project in still underway. No report was submitted.

4. Ongoing Studies

a. Learning from the DSM-2 particle tracking model

Lead agencies: DWR

What: The original study plan component was based on the IEP-funded project "Learning from the DSM-2 particle tracking model", led by SFSU and DWR. After the completion of the study plan, DWR offered to perform modeling that was better-suited to the POD study questions. Hence, the following is somewhat different than described in the original study plan. In the present study, the Delta Simulation Model-2 Particle Tracking Model (PTM: Culberson et al. 2004) was the analysis tool. We assessed the sensitivity of water source and timing on entrainment risk and residence time during March-October 1990-2004. Model scenarios were based on neutrally buoyant particles that we hoped would provide insight into potential water project effects on phytoplankton, zooplankton and larval fish inputs from the Sacramento and San Joaquin rivers. The analyses were based on daily particle "injections" at Vernalis and Freeport and actual flows and water project operations.

Questions addressed: Has there been a reduction in residence time in the Delta? Have recent changes in operations had a disproportional effect on inflow from the San Joaquin River? Is there evidence that recent operations have increased entrainment risk for pelagic species?

Status: Model runs and draft report completed.

Major Findings: The model runs did not provide evidence of a major shift in residence time during the past 3-4 years. However, the Sacramento River runs provided evidence that residence time tended to be longer prior to the Bay-Delta Accord. This effect may have been strongly influenced by hydrology as residence time was typically longer in drier years. The second study question was related to the assumption that operations typically have a stronger effect on inflow from the San Joaquin River than the Sacramento River. This idea is supported by the model runs that showed that residence times tend to be shorter for particles released in the San Joaquin River than the Sacramento River due to their higher likelihood of entrainment. Model runs also suggest that entrainment risk during late-winter through early-summer (March-June) has been somewhat higher during the past 3-4 years. This observation is relevant to the third study question although additional analyses are needed (e.g. fish salvage data). The model results may partially be related to hydrology as entrainment risk appeared to be somewhat inversely correlated with hydrology for March-May. Moreover, the model suggested that entrainment risk tended to be lower during drier June-October before 1994. The most interesting change in San Joaquin River entrainment in the model output is the reduction in frequency of low-San Joaquin River-entrainment events occurring in winter or spring since 1998. The annual profile has been almost invariant since 1999, in contrast with the substantial winter or spring reductions in San Joaquin River entrainment that occurred between 1990 and 1998

Future Directions: The model runs did not support the hypothesis that gross residence time in the Delta has decreased, one of the key mechanisms suspected to influence the food web in the original conceptual model. However, additional model studies could provide insight into whether residence time has changed for specific regions of the Delta. Recommended new studies include (1) model the remaining months (November through February), and (2) reprocess the residence time studies to separately calculate residence time for fractions of particles according to outcome (i.e., whether they were entrained or exited the Delta at Chipps Island).

b. South Delta Fisheries-Hydrodynamics Studies
Lead agencies: USBR, USGS and DWR

What: This is an externally-funded (South Delta Barriers Project and USBR) IEP special study that was initiated in 2004. Its goal is to develop a theoretical baseline for understanding how physical transport processes and larval fish behavior affects entrainment risk in the south Delta under differing hydrologic and operations scenarios. This report represents one element of the investigation. The basic 2005 study design for the element was:

- Zooplankton and fish larvae were to be collected each hour for 48 hours straight at a near-field (first 24 hours) and far-field (second 24 hours) location.
- Three habitats were sampled each hour; edge, channel surface, and channel mid-depth.
- In situ chlorophyll and DOC measurements were to be made every 4 hours at each location.
- Hydrodynamic profiles measured by USGS to examine flow and velocity contours across the channel.
- Hydroacoustic profiles were to be measured by USBR to examine fish mass movements in relation to fish and hydrodynamic sampling.
- Other variables were to be measured each hour using a Sonde profiler: temperature, specific conductance, chlorophyll, DO, and turbidity

Questions addressed: What are the behaviors of larval fishes in the south Delta and how does behavior affect entrainment risk vary under different hydrologic (flows and exports) and operations (DCC, south Delta barriers) scenarios? Do recent year summertime water operations have the potential to significantly increase mortality rates?

Status: 2005 field work was completed. Delta smelt samples are being used for otolith and diet analysis. Data analysis is ongoing.

Major Findings: Prickly sculpin is the most abundant species collected thus far; centrarchids are a close second. However, native fishes also were collected (e.g. delta smelt, splittail and blackfish). Pilot results show that velocity profiles in the Old River Channel can be measured. Larval fish composition varies by habitat and time of day.

Future Directions: Continued laboratory and data analyses.

c. Phytoplankton primary production and biomass in the Delta
Lead agencies: UCD and DWR

What: This is an ongoing data analysis project with CALFED-ERP funding granted to Dr. Alan Jassby at UC Davis (ERP-02-P33) and collaborators at DWR-DES. The full title is “Primary Production in the Delta: Monitoring Design, Data Analysis and Forecasting.” 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 this ongoing project was to analyze available historical data on chlorophyll *a* concentrations and other water quality variables in Delta sub regions or at specific long-term monitoring stations in order to determine processes underlying changes in primary production and biomass. This was an extension of similar analyses conducted at the Delta-wide scale (Jassby and Cloern 2000; Jassby et al 2002). Results from this study were intended to assess the potential for sub-regional and local bottom-up food web effects on pelagic zooplankton and fish, effects of changed export patterns on phytoplankton production in different Delta areas, etc.

Questions addressed: What are long-term patterns and trends in phytoplankton production and biomass and other water quality variables in different Delta sub regions 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 exports affected phytoplankton in different Delta areas?

Status: Initial analyses of chlorophyll *a* and general species trends have been completed, although no report is available yet.

Major Findings: While earlier studies by Jassby et al. (2002) showed that chlorophyll a levels declined substantially during the late 1980s, preliminary results indicate no obvious recent downward trend during 1996-2004. Of the 16 “good” monitoring sites that he analyzed, Jassby found that three stations in the San Joaquin River actually showed increases in chlorophyll *a*. The rather coarse species data provide no evidence that there has been a major decrease in diatoms (“good algae”) or a corresponding increase in the amount of blue green algae (“bad algae”). However, the existing monitoring program does not adequately address patchy “blooms” such as Microcystis.

Future Directions: The preliminary results do not support the original conceptual model that a decrease in phytoplankton had recent and substantial food web effects for pelagic species. However, additional analyses could provide important insight into processes affecting lower trophic levels. Specifically, additional work is needed to assess trends in species composition. Also, nutrient data could potentially be used to evaluate grazing rates.

d. Retrospective analysis of long-term benthic community data
Lead agencies: DWR and USGS

What: 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 describe historical trends in community composition in relation to environmental variability, hydrology, and exotic species invasions. The goals were to determine whether there was any change in the benthos that predated or matched the step decline in pelagic fish abundance and to relate any recent changes to changes that occurred during the 1987-1992 drought.

Questions addressed: What re the long-term and short-term trends in benthos, sediment composition and water quality parameters.

Major Findings: Changes in sediment composition and benthic assemblages occurred estuary-wide in 1999-2000. The changes in community composition were much less pronounced than changes occurring in 1987-1989 following the *Corbula amurensis* invasion. In San Pablo Bay, the most significant increase of a grazer organism was of the amphipod *Ampelisca abdita*. Since 2001, *C. amurensis* has rebounded to former high abundance levels observed during the 1987-1992 drought. Brackish water organisms, including *C. amurensis*, have also increased in abundance at the Sacramento-San Joaquin River confluence to 1987-1992 levels. Based on previous studies, it is presumed this resurgence could depress lower trophic level productivity in Suisun Bay and the western Delta (Kimmerer and Orsi 1996; Kimmerer submitted). Total bivalve abundance was lower in recent years than during wetter conditions in the 1990s. However, this was mainly due to reduced abundance of the freshwater bivalve *Corbicula fluminea*. In Old River, *C. fluminea* numbers have dropped recently relative to the latter 1990s. Though *C. amurensis* has never been detected in Old River, lower chlorophyll a levels also became more prevalent in the Delta after 1988. This was despite an increase in water clarity that should have favored phytoplankton production. There are indications that phytoplankton production capacity might have been higher prior to the late 1980s. Thus, other phenomena in addition to bivalves might be contributing to depressed phytoplankton abundance (Jassby et al. 2002).

Synthesis of 2005 Results:

Our triage approach in 2005 was used to better refine the major issues that need to be examined in greater detail in 2006 and beyond. While we anticipated that valuable information would be collected, we did not expect to be able to identify "the problem" at the end of 2005 because environmental stressors are typically multiple and synergistic (Bennett and Moyle 1996; Rose 2000). Hence, the goal of the 2005 effort was to provide basic information about the: 1) the relative potential importance of each potential causal link; and 2) the degree of evidence for and uncertainty surrounding each.

We had planned to use the initial conceptual model (Figure 1) as the basis of the synthesis. However, this conceptual model was based on earlier data showing a system-wide decline in calanoid copepods, which a re-examination of the data in 2005 did not support. Moreover, we found that the model did not adequately reflect spatial and temporal variation in the stressors on pelagic organisms. Initial results from 2005 also suggested that some stressors might act independently of the estuarine food-web that was central to our conceptual model. Though the model provided a useful basis to design the 2005 study program, we chose a somewhat different approach to synthesize the 2005 elements results.

The ultimate goal of this effort continues to be development of species and ecosystem models with links to stressors, in order to compare the relative effects of different stressors on fish populations. We expect initial modeling efforts to be a central part of the 2006 effort (to be described in a separate document). In the meantime, we have chosen to maintain our focus on the development of conceptual models. Because much of the 2005 data is preliminary or unavailable at this writing and has not yet been peer-reviewed, these models should be considered equally preliminary.

Relationship of Models to Long-Term Trends

The recent step decline in pelagic fish species is superimposed over long term declines for several of them and long term relationships of these fish with other environmental factors. The relationship between longfin smelt and outflow has weakened in the last three years. Delta smelt was showing an apparent increase in abundance and distribution until the last 4 years. Striped bass survival from egg to young of year has in the past shown a relationship to outflow. Threadfin shad have long been an abundant species in the Delta with a large range of variability across years until recently when abundances have remained low over the last 4 years.

Importance of Sampling Programs

Several changes in the size and distribution of the target species have the potential to change our perceptions of trends in abundances and distributions. This, in turn, has the potential to affect the synthesis of the 2005 data. For example, Sweetnam (1999) showed that by the early 1990s, there had been a step-change in the size of adult delta smelt, potentially affecting their vulnerability to sampling. Moreover, recent studies outside of the standard stations of the Fall Midwater Trawl have found delta smelt occupying areas of the Sacramento Deepwater Ship Channel and northern Delta where they were not previously thought to be common. Applications of smaller meshed nets around the end of the Fall Midwater Trawl net have found that the smaller sizes at which delta smelt have been occurring in recent years are better sampled by the smaller mesh. Finally, the abundances of the target species are at record low abundances. Therefore, our ability to detect changes from year to year is greatly reduced. These changes in the vulnerability of the target populations to our sampling program are an ongoing area of research and concern. Studies of these issues must continue to be pursued.

Synthesis Models

The major results were synthesized in two general ways. First, we developed species matrices to examine which stressors were most likely to be important and which were supported by the preliminary 2005 results or which could not be ruled out because we had no data to base such a conclusion. Secondly, we constructed explanations for the recent step decline in abundance of pelagic species in the context of their long term trends or previous patterns. Note that both types of models were specifically developed for the purposes of designing the work plan for 2006 and beyond—they were <u>not</u> intended to be the basis of setting resource management priorities.

Matrix Model for Species and Stressors: Matrix models were developed for the four target fish species (delta smelt, longfin smelt, threadfin shad and juvenile striped bass) to summarize the potential role of various stressors in the recent decline. The matrices depict our current consensus of whether or not each stressor impacted each species-life stage during 2002-2004, possibly influencing the decline. The level of information used to support our consensus is also ranked. Though we attempted to develop information on most of the stressors listed, there are numerous cases where data are unavailable or have not been analyzed. In such instances we indicate no information, but have an expectation that information will be available soon to refine the models. The stressors evaluated are listed below:

- Mismatch of larvae and food. This stressor focuses on the separation of larval fish and food items in time and geographical space. If young fish are not co-located with food, they will starve or have increased vulnerability to predation (Cushing 1990). For the purposes of the matrices, the stressor is considered to apply only to larvae—it is considered separate from fish that can actively swim to locate food.

- Reduced habitat space. Amount of open-water habitat as defined by physical and chemical parameters that limit the distribution of species.

- Adverse water movement/transport. Changes in Delta hydrodynamics that direct fish to unsuitable area due to water project operations. Transport refers to movement of a life stage as influenced by Delta hydrodynamics which can be altered by water project operations (i.e. exports, gate operations, reservoir releases, barriers). Delta hydrodynamics affects transport through its effects on migratory cues, habitat quality or hydrologic resident times. This stressor specifically excludes entrainment, but may include thermal effects of power plant effluent.

- Entrainment. Mortality of pelagic fishes caused by loss to water diversions for exports, in-Delta uses, and power plant cooling.

- Toxic effects on fish: Acute and chronic effects sufficient to increase mortality and/or reduce fecundity of pelagic fishes.

- Toxic effects on fish food items. Acute and chronic effects sufficient to increase mortality and/or reduce fecundity of pelagic fish food items.

- Harmful Microcystis blooms. Acute and chronic effects of Microcystis sufficient to result in one or more of the following in pelagic fishes: increase mortality; reduce fecundity, reduced feeding; or habitat avoidance.

- *Corbula* effects on food availability. Corbula decreases phytoplankton and zooplankton, which are reflected in the production of larger zooplankton, invertebrates or fish especially in early lifestages.

- Disease and parasites. Disease or parasites that result in reduced survival or fecundity of pelagic fishes.

The species matrices are included as Figures 6-9. Annotations for the matrices are provided in Appendix B. Columns represent key times of the year, with reference to the corresponding life stages. The rows describe the relationships between life stages and the major stressors. Within each cell is an idealized "map" containing sub-cells to represent the major regions of the upper estuary (Figure 4). The various regions of the Delta have been described differently by different authors. For aquatic organisms, we believe the tidal nature of the estuary overrides many of the geographic features. Thus, in our discussion of the areas of the Delta, we intentionally use overlapping areas to better account for the fact that water frequently moves from area to area while still bearing in mind that the stressors and processes in different areas are different. This overlap is most pronounced in discussing "Suisun Bay" and the "Northern Delta" (i.e. the blue and green areas in Figure 1). Marine influences, including X2 position can have impacts up the axis of the estuary as far as Decker Island, while significant factors, such as sediment plumes from the Yolo Bypass are at times prominent downstream to at least Chipps Island. Similarly, the San Joaquin River is not representative of a single area's influences but rather the southern limit of Central Delta processes and the northern limit of South Delta processes. Therefore, we have included the San Joaquin River within both areas in our delimitation of the Delta. The actual areas of overlap may also be taken to represent the tidal excursions in each area, such that areas of overlap are much longer in the western regions than in the more upstream locales. Overall, we are concerned with identifying the areas where stressors and processes originate and less concerned with their exact locations of impact.

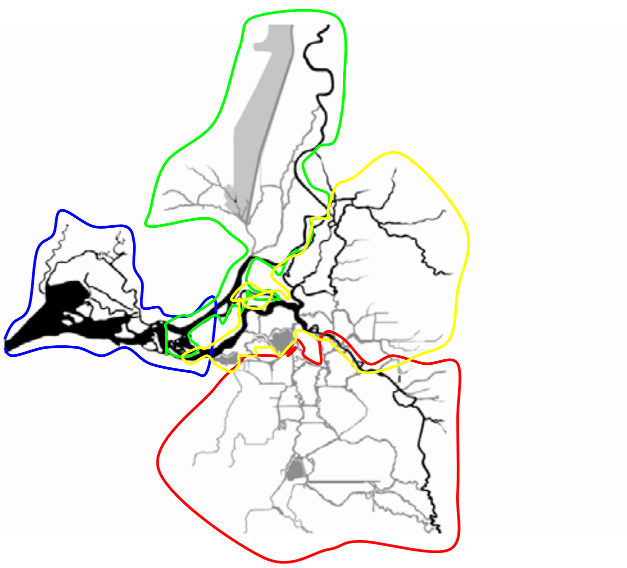


Figure 4. Map of the Delta to identify the regions specified in the matrix.

The geographic boundaries roughly correspond to: Suisun Bay (Suisun Bay, river confluence area downstream of Decker Island and Big Break); Central Delta (South of Rio Vista, North of Franks Tract): North Delta/Lower Sacramento River; South Delta/San Joaquin River (Franks Tract and south/east Delta). The symbols within the "map" are designed to reflect a binary potential for the impact of each stressor (described below) and the degree to which available data support our assertions. Additional details about the logic for each symbol are provided as annotations in Appendix B.

Impact

Plausible Impact = The factor (stressor) is likely to have a substantial influence on lifestage survival (*Large Symbol*).

No Likely Impact = The factor (stressor) is unlikely to have a substantial influence on lifestage survival (*Small Symbol*).

Information

Strong = Substantial information exists for directly addressing the stressor influence on lifestage (*Dark Symbol*)

Limited = Either available information or current data analysis is too limited to support strong conclusions regarding stressor) influence on lifestage (*Grey Symbol*).

None = Either information is not available, or no available data have been appropriately analyzed, to address stressor influence on lifestage (*Clear Symbol*).

Figure 5. Matrix Legend

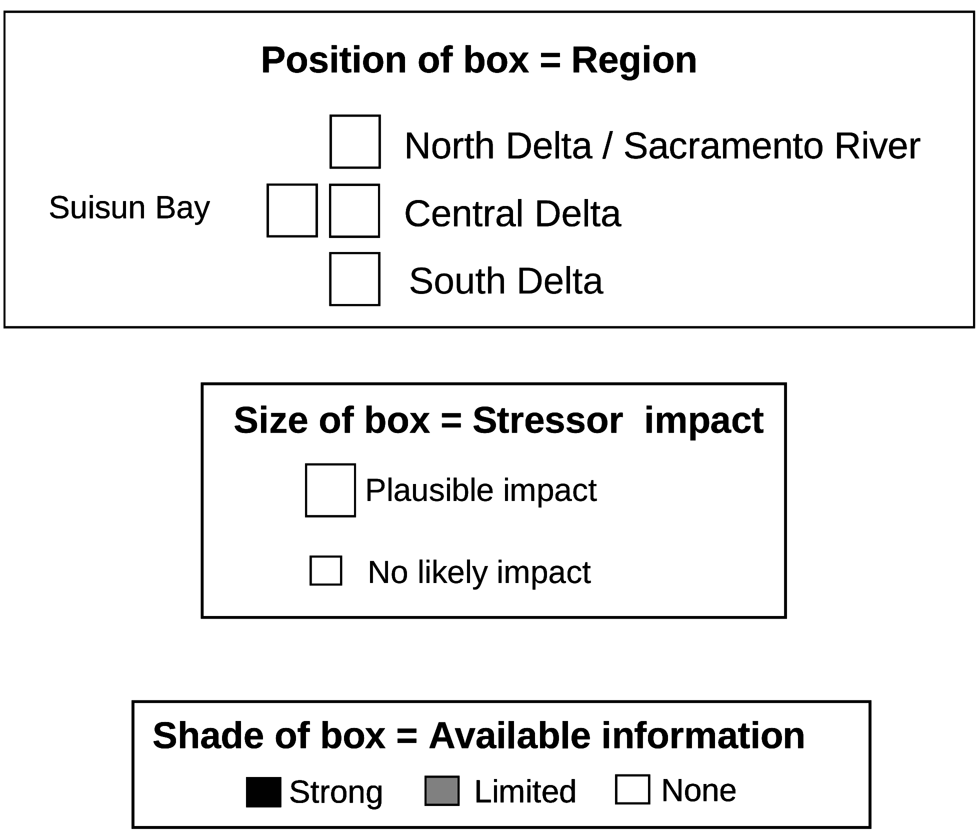


Figure 6. Longfin smelt

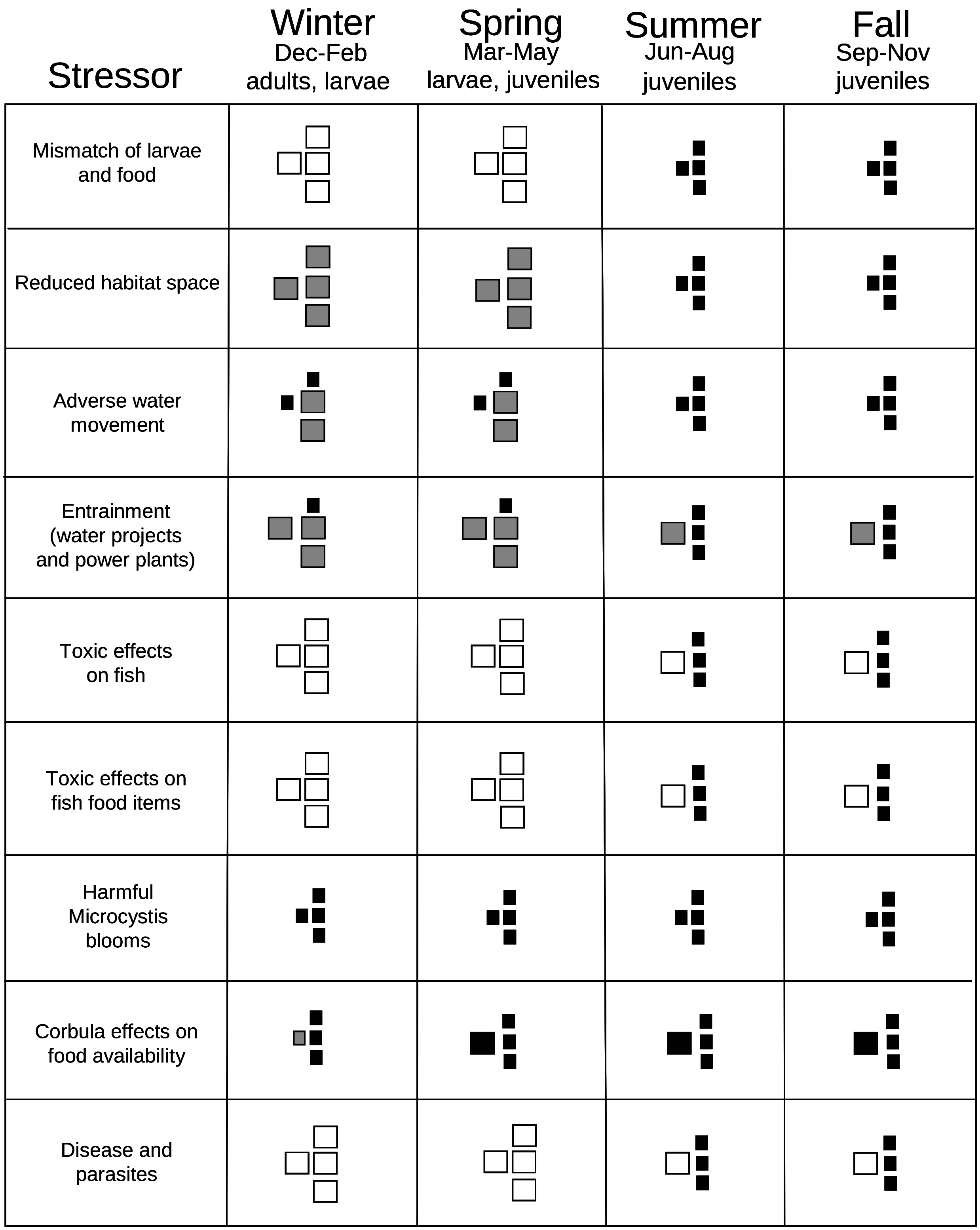


Figure 7. Threadfin shad

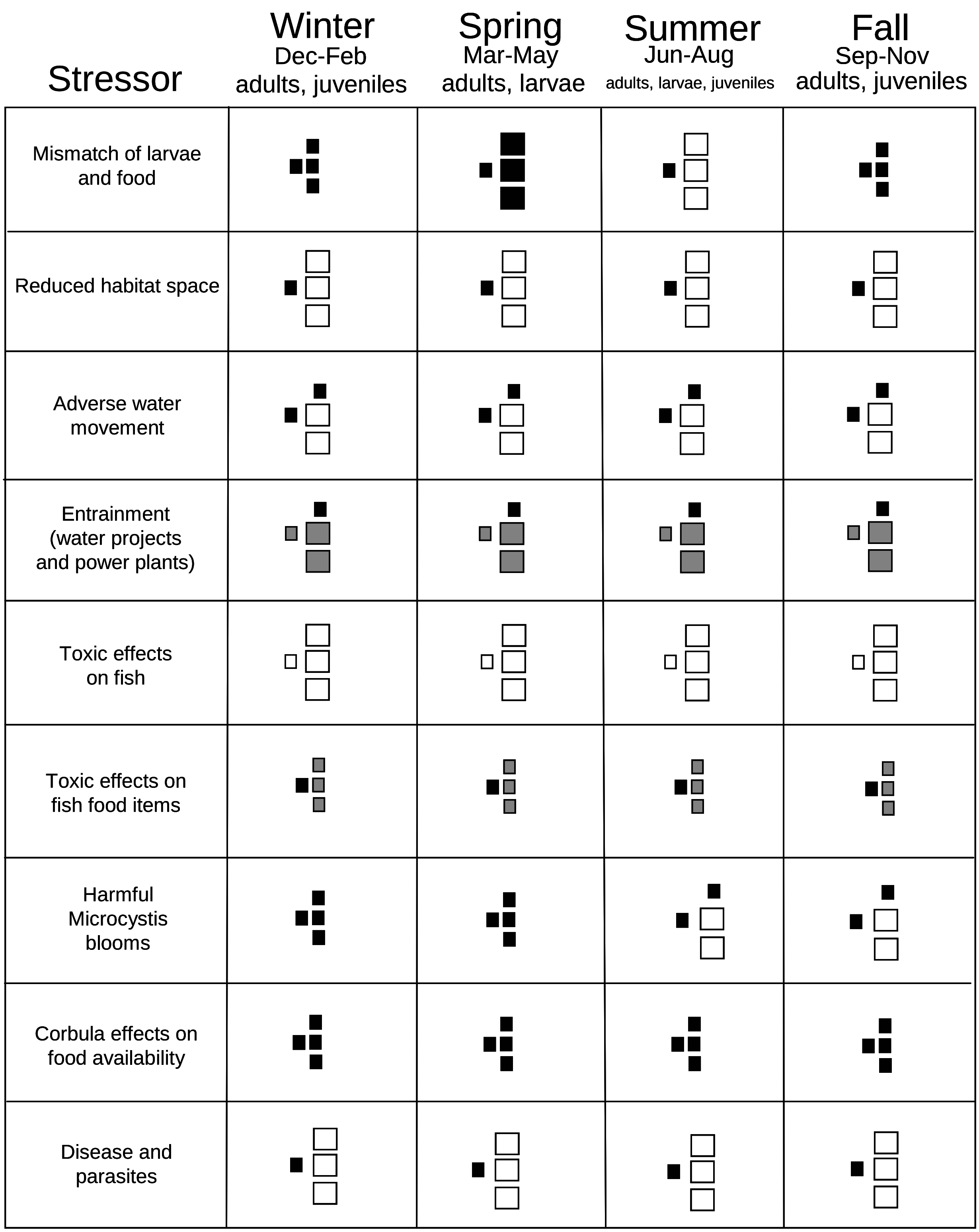


Figure 8. Striped bass

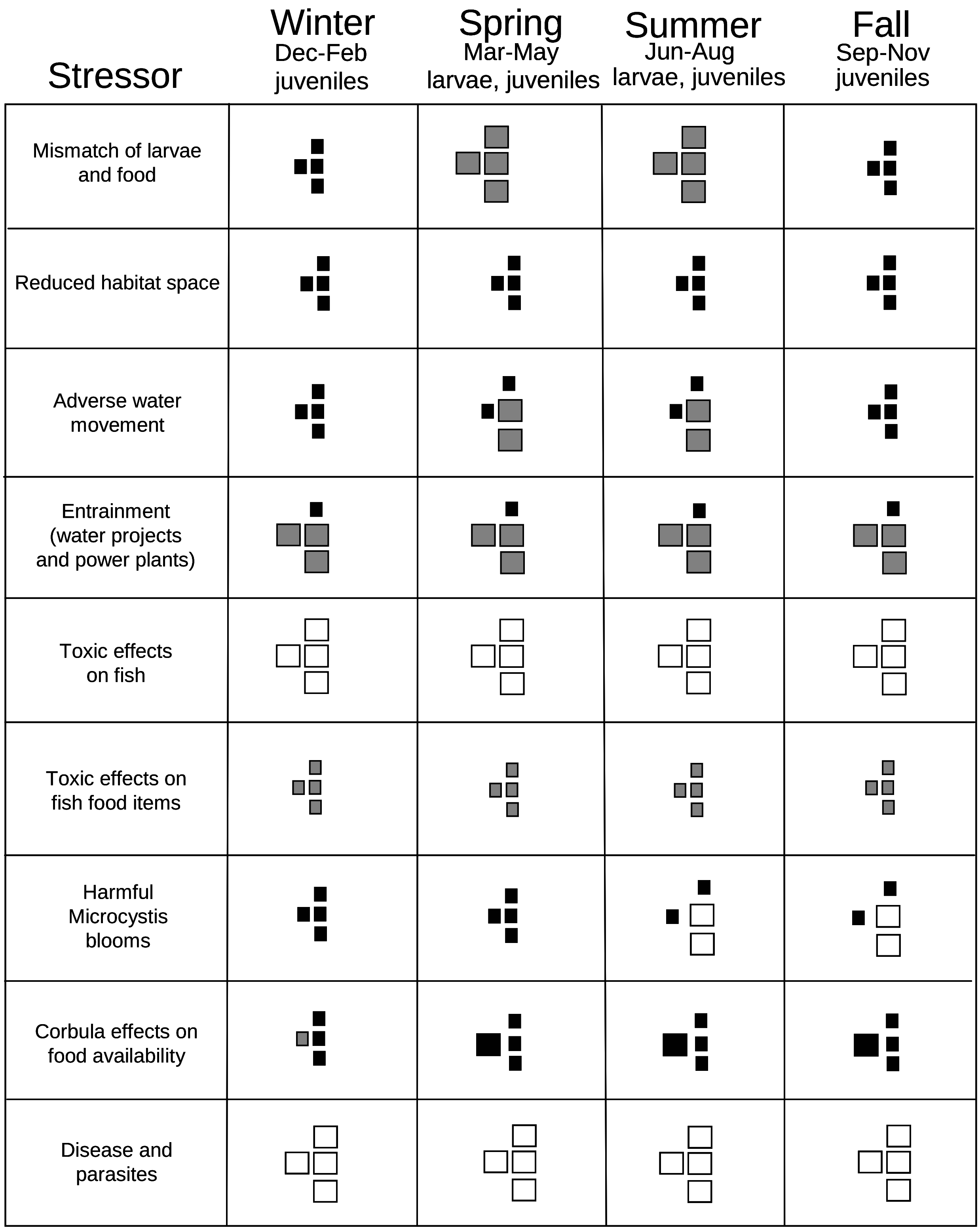
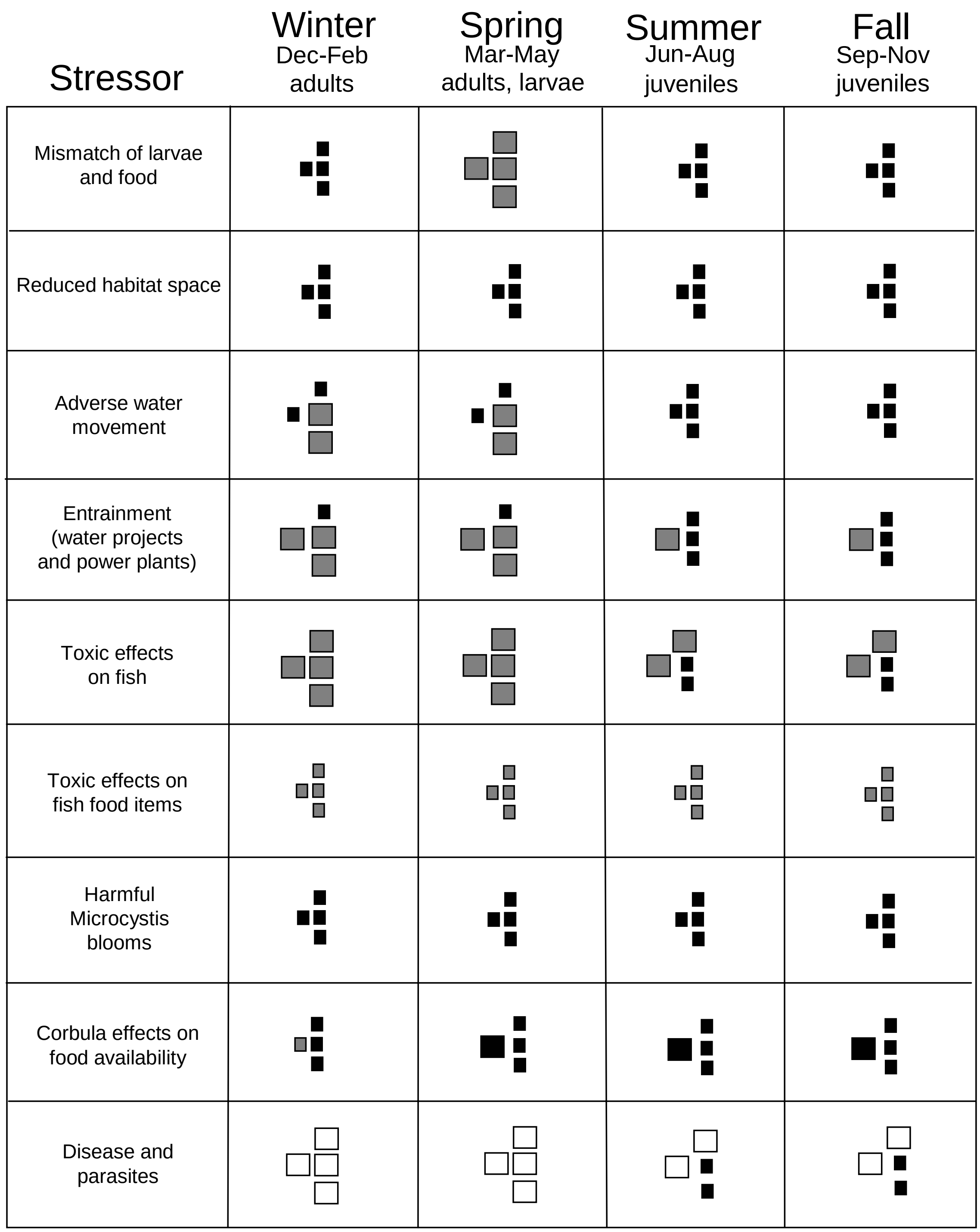


Figure 9. Delta smelt



Example Narrative Models: Guided by available results, we developed two narratives were developed to describe possible mechanisms by which recent changes in the ecosystem could produce the observed declines in catch of pelagic fish species. The first narrative describes changes in Suisun Bay that reduce its suitability as habitat for delta smelt, longfin smelt and young-of-year striped bass. Longer term trends suggest that the south Delta has previously become less suitable as habitat and therefore the loss of Suisun Bay habitat value produces a great reduction in the area of suitable habitat. The second narrative describes sharply increased loss of adult delta smelt and longfin smelt and threadfin shad from the south Delta during the winter that negatively affects the stock size. These two narratives identify key elements that will be further analyzed in 2006.

Note that these narratives are not exclusive of other explanations for the observed changes in fish abundance, nor are they intended for as priorities for resource management. Instead, they are intended as examples of how the different stressors may be regionally linked. Note that neither of these narratives by itself explains the declines of all four species though both in tandem plausibly could. Additional narrative models will be developed as data becomes available. In the meantime, we believe that the two initial narrative models provide a useful basis for the development of more detailed hypotheses and studies for 2006 and beyond. The proposed 2006 work plan will be distributed as a separate document.

Suisun Bay/Marsh has historically been a major rearing habitat for striped bass, delta smelt and longfin smelt (Stevens and Miller 1983; Steven et al. 1985; Moyle et al. 1992; Matern et al. 2002). The marshes in other adjacent shallow habitats are also used by threadfin shad (Matern et al. 2002; Nobriga et al. 2005). Pelagic productivity was reduced and trophic linkages were altered in Suisun Bay coincident with the invasion of *Corbula amurensis* (Kimmerer and Orsi 1996; Feyrer et al. 2003; Kimmerer submitted manuscript). The ***Bad Suisun Hypothesis*** posits that particularly in drier years *Corbula* depresses zooplankton production in Suisun Bay, resulting in decreased availability of food for juvenile striped bass, longfin smelt, and delta smelt. Evidence for the hypothesis includes:

1. *Corbula* abundance and distribution in 2001-2004 was higher than during the 1995-1999 wet period but similar to the 1987-1992 drought period. See Study Component 4d report by Vayssieres and Peterson for details (Appendix A).

2. 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. See Study Component 3a report by Bennett details (Appendix A).

3. In 2005, delta smelt collected from the Sacramento-San Joaquin confluence and Suisun Bay had high incidence of liver glycogen depletion. See Study Component 3b report by Teh for details (Appendix A).

4. In 2003 and 2004, striped bass condition factor decreases in a seaward direction from the delta to the bay.

5. Based on analysis of the summer townet survey and the fall midwater trawl, it does not appear that physical habitat suitability (based on available water quality data) has changed in recent years or has had a long-term trend. See reports by Nobriga et al. and Bryant and Feyrer et al. for striped bass and delta smelt in Study Component 2g (Appendix A).

6. Suisun Bay ambient water bioassays in the summer of 2005 were not toxic to *Hyalella azteca, Ceriodaphnia,* juvenile striped bass, or delta smelt. See Study Component 3e report by Werner for details (Appendix A).

7. *Microcystis* biomass was low in the Suisun Bay region in the summer of 2004 and 2005. See report by Lehman Study Component 3d for details.

8. Estuary-wide zooplankton abundance in the upper estuary has not changed substantially in recent year. However, we have not yet determined whether this conclusion applies to Suisun Bay.

These observations reveal that fishes taken in the Suisun Bay region show unusually poor growth rates and condition. Thus far, the weight of evidence suggests poor growth/condition is not attributable to the effects of toxic contaminants. Therefore, our working hypothesis is that the poor growth and condition are due to food limitation.

If fishes are food limited in Suisun Bay during juvenile development, then we would expect greater cumulative predation mortality, higher disease incidence, and consequently poorer abundance indices at later times. Slower growth rates might also distort trawl abundance indices if large numbers of fish do not grow large enough to be sampled efficiently by annual surveys.

To further develop our understanding of the role of food availability in Suisun Bay, we suggest:
(1) continuing studies cited above that are underway but not yet completed
(2) expanding fish gut content analyses to enable regional comparisons of diet, ration, and prey selectivity
(3) expanding toxicity testing of standard and native species to enable comparisons that may reveal whether we have missed exposures of Suisun Bay fishes to toxins in other seasons or places (i.e., the exposure occurs in another region before the fish move into Suisun Bay)
(4) repetition of histopathological analyses to expansion of the investigation to all POD target species.

Dramatic increases in winter CVP and SWP salvage occurred contemporaneously with recent declines in several pelagic fish species. These unexpected increases in salvage density coincide with the step decline pelagic fishes in 2002. The ***Winter Adult Entrainment Hypothesis*** posits that these events are causally linked. Evidence for the hypothesis includes:

(1) There appears to have been a step increase in salvage density of adult delta smelt, threadfin shad and longfin smelt between 2001 and 2002. This increase is consistent with recent-year changes in winter water export operations. See Herbold et al. (Appendix A).

(2) There appears to have been a step decrease in the Fall Midwater Trawl indices of adult delta smelt, threadfin shad, and longfin smelt between 2001 and 2002. See Study Component 2i report by Manly and Chotkowski for details (Appendix A).

(3) Winter exports from the CVP and SWP have increased since the late 1990s. See Study Component 2h report by Simi and Ruhl for details (Appendix A).

Increased winter entrainment of delta smelt, longfin smelt and threadfin shad represents a loss of the pre-spawning adults and all potential progeny. This means on a per capita basis loss of each adult fish may be equivalent to the loss of hundreds or even thousands of juveniles later in the year. Because an entrainment impact specifically affecting adult fishes has the potential to be strong, we regard finding an explanation for this coincidence a high priority.

The main sorts of explanations for why winter salvage densities may have increased since 2002 include: (1) the source of exported water has been changed to an area where more of these fishes occur during the winter; (2) the affected fishes have moved to areas from which exports are drawn; and/or 3) winter exports have increased past some sort of hydrodynamic threshold below which fish were better able to avoid entrainment.

The data on wintertime salvage have only begun to be examined but they reveal a consistent pattern across species that corresponds with the period of fish declines. Three main areas of explanation must all be considered. Are there operational changes that produce an apparent increase in salvage? Are there changes in the health of fish that make more of the population susceptible to entrainment? Are there changes in water movement or water quality that could produce higher densities of fish in the south Delta? Some of these factors can be rapidly assessed with data already in hand or that can be gathered in the coming months. Assessing the population impacts will be a difficult task since reliable numbers for neither the number of fish entrained or in the source population are available. If it can be shown that a large part of the field sampled population are within the range of entrainment that is probably the most compelling argument for a population level impact of entrainment.

To further develop our understanding of the role of winter adult entrainment, some initial suggestions include:
(1) a model-based investigation of Delta hydrodynamics that compares Delta- circulation patterns under conditions that existed before 2002 to conditions after 2001, to see whether any differences in circulation pattern support fish redistribution hypotheses.
(2) a model-based investigation of changes in the size and disposition of the zone of entrainment under conditions that existed before 2002 to conditions after 2001 to see whether large differences exist or whether there is any reason to believe threshold effects exist in the extent or location of the zone of entrainment.
(3) a statistical investigation of larval and juvenile abundance to see whether there is a stock-recruit effect specifically attributable to high adult salvage. There are enough concerns about the strength of the larval and juvenile monitoring programs (for this purpose) that we do not believe the absence of a measurable effect would weaken this hypothesis. However, actually affirmative or contradictory evidence from the larval and juvenile monitoring would indeed strengthen or weaken this hypothesis.

(4) Are there changes in the health of fish or water quality that make more of the population susceptible to entrainment?

Some of these factors can be rapidly assessed with data already in hand or that can be gathered in the coming months. Assessing the population impacts will be a difficult task since reliable numbers for neither the number of fish entrained or in the source population are available. If it can be shown that a large part of the field sampled population are within the range of entrainment, there would likely be a compelling argument for a population level impact.

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Appendix A
Index of material used in this report

Files may be downloaded from the CBDA website "www.calwater.ca.gov" or the DFG's Central Valley Bay-Delta Branch ftp site ftp://ftp.delta.dfg.ca.gov/

Please note that these draft reports are a work in progress and will be updated as information becomes available.

Workplan study element 1b and 1c

1. 2005 Status and trends of four pelagic fishes of the upper San Francisco Estuary
   File – Pelagic fish trends.pdf

2. Zooplankton and mysid abundance trends
   File – Zooplankton trends.pdf

Workplan study element 2a

3. Pelagic fish and zooplankton life history and sampling summary
   File – Fish and zooplankton life history summary.pdf

Workplan study element 2b

4. Apparent growth rates of pelagic fishes and relationship to abundance 2b
   File – Status report pelagic fish apparent growth rates.pdf

Workplan study element 2c

5. Changes in *Neomysis mercedis* Fecundity in the Upper Estuary Since 1979
   Files – Neomysis fecundity.pdf and Neomysis fecundity figures.pdf

Workplan study element 2d

6. Draft *Microcystis* and POD white paper
   File – Microcystis white paper

Workplan study element 2e

7. Pyrethroid Insecticides: An Analysis of Use Patterns, Distributions, Potential Toxicity and Fate in the Sacramento-San Joaquin Delta and Central Valley – Daniel R. Oros (SFEI), Inge Werner (UC Davis)
   File – Pyrethroids White Paper Final.pdf

Workplan study element 2f

8. Aquatics Herbicides: Overview of Usage, Fate and Transport, Potential Environmental Risk, and Future Recommendations for the Sacramento-San Joaquin Delta and Central Valley – Geoff Siemering and Jennifer Hayworth (SFEI)
   File – Aquatic herbicides white paper.pdf

Workplan study element 2g

9. Progress Report on Physical Habitat Trend Analyses for Fall Midwater Trawl – Fred Feyrer, Matt Nobriga, Ted Sommer
   File – Fall Midwater Trawl habitat analysis.pdf

10. A contribution to analysis of existing data/historical population trends – Matt Nobriga
    File – Fall Midwater Trawl efficiency.pdf

11. Trend Analysis of Delta Smelt and Striped Bass Physical Habitat Based on the Summer Townet Survey—Matt Nobriga, Marade Bryant, Fred Feyrer, and Ted Sommer
    File – Summer townet survey habitat analysis.pdf

Workplan study element 2h

12. Summary of Delta Hydrology Data Water Years 1985-2004 – Joseph Simi and Catherine Ruhl (USGS)
    File – Delta hydrology summary 1985-2004.pdf

13. Draft September 30, 2005, Aquatic Impacts of the Pittsburg and Contra Costa Power Plants – Zoltan Matica and Ted Sommer
    File – Power plants evaluation.pdf

14. Historical patterns in salvage data – Bruce Herbold, Chuck Armor, Randy Baxter, Mike Chotkowski, Pat Coulston, Matt Nobriga and Ted Sommer
    File – Historical patterns in salvage data.pdf

15. Evaluation of Residence Time and Entrainment using a Particle Tracking Model of the Sacramento-San Joaquin Delta – Ted Sommer, Bob Suits, Michael Mierzwa and Jime Wilde
    File – Particle tracking model results.pdf

Workplan study element 2h

16. DRAFT Progress report on analysis of historical fish and zooplankton population dynamics – Bryan Manly and Mike Chotkowski
    File – Analysis of historical pelagic fish trends.pdf

Workplan study element 3a

17. Progress Report #1-Fish Otolith and Condition Study – Bill Bennett (UC Davis)
    Files – Fish growth and otoliths.pdf and Fish growth and otoliths figures.pdf

Workplan study element 3b

18. First Progress Report: Histopathological Evaluation of Starvation and/or Toxic Effects on Pelagic Fishes – Swee J. Teh
    File – Histopathology progress report.pdf

19. Pelagic Organism Decline Element Preliminary Findings and Progress Report

Title: Pathobiological Investigation to Determine the Condition of Field Collected 2005 Striped Bass and a Pilot Study to Determine the Location and Effects of Bioavailable Lipophilic Compounds in the San Francisco Estuary – David J. Ostrach (U C Davis)
File – Striped bass prelim progress report.pdf

Workplan study element 3c

20. Fish condition and health indices – Russ Gartz
    File – Fish condition and health 2005.pdf

21. Condition and diet – Russ Gartz, Steve Slater and Matt Nobriga
    File – Diet composition study.pdf

Workplan study element 3d

22. 2005 Pelagic Organism Decline Program Progress Report: Microcystis biomass and toxicity – P.W. Lehman, G. Boyer, S. Teh, E. Bass and C. Hogel
    File – Microcystis biomass and toxicity.prf

Workplan study element 3e

23. Pelagic Organism Decline (POD) Acute and Chronic Invertebrate and Fish Toxicity Testing Progress Report, September 30, 2005 – Inge Werner (U C Davis)
    File – Fish and invert toxicity tests.pdf

Workplan study element 3f

24. Draft Report on 2005 Anadromous Striped Bass Fecundity
    File – 2005 striped bass fecundity.pdf

Workplan study element 3g

25. Analysis of long-term benthic data for the Pelagic Organism Decline investigation – Marc Vayssieres and Heather Peterson
    File – Summary of long-term benthic data.pdf

Workplan study element 4b

26. South Delta Fisheries-Hydrodynamics Studies – Lenny Grimaldo (DWR)
    Files – South Delta fish studies update.pdf and South Delta fish studies update figures.pdf

Appendix B
Annotations for the Species Matrix Models (Figures 6-9)

Longfin Smelt

Mismatch of larvae with food
In winter-spring larvae are present throughout region (See Appendix A: 2a, Baxter et al.), but no feeding data are available. In summer-fall young fish are beyond larval stage.

Reduced Habitat Space
The longfin smelt has a strong X2 relationship (Jassby et al. 1995) and the 20 mm survey shows its distribution is centered on X2 (Dege and Brown 2004). There is evidence that habitat space can vary with X2 for delta smelt; this may also apply to longfin smelt (See Appendix A: 2g, Feyrer et al; 2g, Nobriga et al.). Beyond the winter and spring larval period, habitat extends to marine waters (See Appendix A: 2a, Baxter et al.), so habitat limitation is less likely.

Adverse Water Movement
The increased amount of Sacramento River water pulled towards export facilities in winter (Appendix A: 2h, Simi and Ruhl) could potentially increase false attraction to upstream migrating adults and the retention of their larvae. In north Delta and Suisun Bay, as well as summer and fall, fish are distributed away from major water project influence (Appendix A: 2a, Baxter et al.).

Entrainment (Water Projects, Power Plants)
In winter-spring adults and larvae are present throughout region (See Appendix A: 2a, Baxter et al), and increased salvage has been observed during winter in recent years (See Appendix A: 2h, Herbold et al.) In summer-fall young fish are beyond export facility influence. In addition, salvage rates are lower in wetter years, when survival is also higher (Jassby et al. 1995; Sommer et al. 1997). In Suisun Bay, effects from power plant operations are possible year-round (See Appendix A: 2h, Matica and Sommer).

Toxics Effects on Fish
In winter-spring adults and larvae are present throughout region (See Appendix A: 2a, Baxter et al.). The juvenile and adult population is located downstream (Suisun and farther) in summer and fall. However, there is no current information on direct toxicity or histopathological evidence of toxicity.

Toxics Effects on Fish Food Items
Copepods and larger crustaceans are present throughout range of longfin (See Appendix A: 2a, Baxter et al.). Results to date, for summer only, indicate that toxicity to standard organisms (*Ceriodaphnia dubia* and *Hyalella azteca*) was sporadic in space and time (see Appendix A: 3e, Werner).

Harmful Microcystis Bloom

There is no likely impact from *Microcystis* due to mismatch of summer algal blooms in the south and central Delta and longfin smelt habitat, which extends from the north Delta through central San Francisco bay at that time (See Appendix A: 2a, Baxter et al.; 3d, Lehman et al.).

***Corbula* Impacts on Food Availability**

Corbula reduces availability of zooplankton (Kimmerer and Orsi 1996), which may have declined in Suisun Bay and the west Delta with a recent rebound in clam abundance and distribution. Kimmerer (2002b) reported a step change in longfin smelt abundance following the introduction of *Corbula*. However, *Corbula* is still only abundant in Suisun Bay (See Appendix A: 3g, Vayssieres and Peterson). Lower grazing rates are suspected to occur in winter.

Disease and Parasites

There is a plausible impact everywhere longfin smelt are present and throughout the year (Appendix A: 2a, Baxter et al.), but no current information on disease or parasites.

Delta Smelt

Mismatch of larvae with food
In spring larvae are present throughout region (See Appendix A: 2a, Baxter et al.) with some feeding data available (Nobriga 2002). In other months young fish are beyond larval stage.

Reduced Habitat Space
There is evidence that habitat space can vary with X2 for delta smelt, but it does not show a strong relationship with abundance or a time trend (See Appendix A: 2g, Feyrer et al; 2g, Nobriga et al.). There is some evidence that south Delta habitat has degraded seasonally (DFG, unpublished data); however, this is a long-term pattern (e.g. 1940s).

Adverse Water Movement
The increased amount of Sacramento River water pulled towards export facilities in winter (Appendix A: 2h, Simi and Ruhl) could potentially increase false attraction to upstream migrating adults and the retention of their larvae. In north Delta and Suisun Bay, as well as in mid summer through fall, fish are distributed away from major water project influence (Appendix A: 2a, Baxter et al).

Entrainment (Water Projects, Power Plants)
In winter-spring adults and larvae are present throughout region (See Appendix A: 2a, Baxter et al), and increased salvage has been observed during winter in recent years (See Appendix A: 2h, Herbold et al.) In Suisun and north Delta, young fish are beyond export facility influence. In addition, salvage rates are lower in wetter years (Sommer et al. 1997). In Suisun Bay, effects from power plant operations are possible year-round (See Appendix A; 2h, Matica and Sommer).

Toxics Effects on Fish
Adults and larvae are present throughout region during winter-spring but the juvenile population is distributed away from central and south Delta in summer and fall (See Appendix A: 2a, Baxter et al.). A single ambient water toxicity test in 2005 failed to show an impact to juvenile delta smelt (See Appendix A: 3e, Werner), but limited histopathology analysis showed liver lesions, potentially indicators of toxics exposure (See Appendix A: 3b, Teh).

Toxics Effects on Fish Food Items
Copepods are present throughout range of delta smelt (See Appendix A: 2a, Baxter et al.). Results to date for summer only indicate that toxicity to standard organisms (*Ceriodaphnia dubia* and *Hyalella azteca*) is sporadic in space and time (see Appendix A: 3e, Werner).

Harmful Microcystis Bloom
There is no likely impact from *Microcystis* due to mismatch of dense summer algal blooms in the south and central Delta and delta smelt habitat, which extends from the north Delta through Suisun Bay at that time (See Appendix A: 2a, Baxter et al.; 3d, Lehman et al.).

***Corbula* Impacts on Food Availability**
Sweetnam (1999), Bennett (2005) and Souza et al. (Appendix A: 2b) report a decrease in size of delta smelt following the introduction of *Corbula*. Similarly, Teh (Appendix A: 3b) reports a

chronic depletion in liver glycogen levels, possibly a result of food limitation. *Corbula* reduces availability of zooplankton (Kimmerer and Orsi 1996), which may have declined in Suisun Bay and the west Delta with a recent rebound in clam abundance and distribution. However, *Corbula* is still only abundant in Suisun Bay (See Appendix A: 3g, Vayssieres and Peterson). Lower grazing rates are suspected to occur in winter.

Diseases and Parasites
There is a plausible impact everywhere delta smelt are present and throughout the year (Appendix A: 2a, Baxter et al.), but no information on disease. A very low incidence of macroscopic internal parasites was detected in the 50 delta smelt examined in 2005 (Appendix A: 3c, Gartz).

Threadfin Shad

Mismatch of larvae with food
In summer larvae are present throughout region except Suisun Bay (See Appendix A: 2a, Baxter et al.), but no feeding data are available. In other months young fish are beyond larval stage.

Reduced Habitat Space
Threadfin shad are present everywhere, but less abundant in Suisun Bay (see Appendix A: 2a, Baxter et al.), but no information was developed on habitat trends or criteria.

Adverse Water Movement
Present everywhere (see Appendix A: 2a, Baxter et al.). Mechanism unknown, but hydrodynamic effects likely regionally limited to central and south Delta

Entrainment (Water Projects, Power Plants)
Adults and larvae are present throughout region (See Appendix A: 2a, Baxter et al.). Increased salvage has been observed during winter in recent years (See Appendix A: 2h, Herbold et al.). However, north Delta is likely outside of entrainment influences. Threadfin shad are less abundant in Suisun, where effects from power plant operations possible year round (See Appendix A; 2h, Matica and Sommer).

Toxics Effects on Fish
Adults and juveniles are throughout region, but less abundant in Suisun Bay (See Appendix A: 2a, Baxter et al.). There is no current toxicology or histopathology information.

Toxics Effects on Fish Food Items
Copepods and cladocerans are present throughout range of threadfin shad (See Appendix A: 2a, Baxter et al.). Results to date for summer only indicate that toxicity to standard organisms *Ceriodaphnia dubia* and *Hyalella azteca*) was sporadic in space and time (see Appendix A: 3e, Werner).

Harmful Microcystis Bloom
Dense blooms are present in south and central delta during summer and fall, when threadfin larvae, juveniles and adults are also present, posing a plausible impact (See Appendix A: 2a Baxter et al.; 3d, Lehman et al.).

***Corbula* Impacts on Food Availability**
There are no likely impacts at anytime. There is little distributional overlap between threadfin shad and *Corbula*. (Appendix A: 2a, Baxter et al.; 3g, Vayssieres and Peterson).

Diseases and Parasites
There is a plausible impact everywhere longfin smelt are present and throughout the year (Appendix A: 2a, Baxter et al.), but little current information on disease and parasites. A very low incidence of skin lesions was observed for threadfin shad in 2005 (Appendix A: 3c, Gartz).

Striped Bass

Mismatch of larvae with food
In spring and summer larvae are present throughout region (See Appendix A: 2a, Baxter et al.), with some feeding data available (Bennett et al. 1995; Bryant and Arnold, In press). In other months young fish are beyond larval stage.

Reduced Habitat Space
Striped bass survival has a strong X2 relationship (Jassby et al. 1995) and 20 mm survey shows its distribution is centered upstream of X2 (Dege and Brown 2004). However, X2 has no time trend (Kimmerer 2002a). There is evidence that habitat space can vary with X2 for young striped bass, but it does not show a strong relationship with abundance or a time trend during summer and fall (See Appendix A: 2g, Feyrer et al; 2g, Nobriga et al.).

Adverse Water Movement
Increased amount of Sacramento River water pulled towards export facilities in spring and summer (Appendix A: 2h, Simi and Ruhl) could potential increase the retention of eggs and larvae. Sacramento River flow can also affect transport of eggs and larvae. Flows in the Sacramento River were relatively low in winter and spring of 2001, but increased during subsequent years (Appendix A: 2h, Simi and Ruhl). In Suisun Bay, fish are away from major water project influence (Appendix A: 2a, Baxter et al.).

Entrainment (Water Projects, Power Plants)
Striped bass are present throughout region at all times (See Appendix A: 2a, Baxter et al), and increased salvage ahs been observed during winter in recent years (See Appendix A: 2h, Herbold et al.). Jassby et al. (1995) found that exports may help to explain variability in striped bass survival. In Suisun Bay, effects from power plant operations are possible year-round (See Appendix A: 2h, Matica and Sommer).

Toxics Effects on Fish
Juveniles are present throughout region at all times and larvae in late spring-summer (See Appendix A: 2a, Baxter et al.). Although earlier work showed some evidence of larval toxicity (Bennett et al. 1995), a pair of ambient water toxicity tests for striped bass in 2005 failed to show an impact to juveniles (See Appendix A: 3e, Werner).

Toxics Effects on Fish Food Items
Copepods, larger crustaceans and small fishes are present throughout range of striped bass (See Appendix A: 2a, Baxter et al.). Results to date for summer only indicate that toxicity to standard organisms *Ceriodaphnia dubia* and *Hyalella azteca*) was sporadic in space and time (see Appendix A: 3e, Werner).

Harmful Microcystis Bloom
Dense blooms are present in south and central Delta during summer and fall, when juvenile striped bass also present, posing a plausible impact (See Appendix A: 2a, Baxter et al.; 3d, Lehman et al.).
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Corbula Impacts on Food Availability

Corbula reduces availability of zooplankton (Kimmerer and Orsi 1996), which may have declined in Suisun Bay and the west Delta with a recent rebound in abundance and distribution. A diet shift and decrease in abundance of striped bass occurred following the introduction of *Corbula* (Feyrer et al. 2003; Bryant and Arnold, in press; DFG unpublished data). However, *Corbula* is still only abundant in Suisun Bay (See Appendix A: 3g, Vayssieres and Peterson). A lower grazing rate is suspected to occur in winter.

Diseases and Parasites

There is a plausible impact everywhere striped bass are present and throughout the year (Appendix A: 2a, Baxter et al.). Recent evidence of disease and parasites has been found in young bass (Appendix A: 3c, Gartz; 3h, Ostrach; Arnold and Yue 1997).