CALFED BAY-DELTA PROGRAM

CALFED SCIENCE FELLOWS PROGRAM

In cooperation with the

California Sea Grant College Program

FELLOWSHIP APPLICATION COVER PAGE

APPLICANT TYPE [X] Postdoctoral Researcher [ ] Ph.D. Graduate Student

PROJECT NUMBER

PROJECT TITLE Prey selection of larval and juvenile planktivorous fish in the San Francisco Estuary

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APPROVAL SIGNATURES

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Will animal subjects be used? [x] Yes [ ] No

APPROVAL DATE: PROTOCOL #: PENDING: X

Does this application involve any recombinant DNA technology or research? [ ] Yes [x] No

Proposed Research **Lindsay J. Sullivan**

Prey selection of larval and juvenile planktivorous fish in the San Francisco Estuary

Introduction

Populations of pelagic fish in San Francisco Bay are in a state of dramatic decline (http://science.calwater.ca.gov/workshop/workshop_pod.shtml). One of the primary goals of the CALFED Ecosystem Restoration Program is to restore the population of threatened and at-risk fish species in the San Francisco Estuary through various management actions. Of particular concern are delta smelt. Formerly an abundant member of the San Francisco Estuary, delta smelt are now listed as a threatened species under the Federal and California State Endangered Species Acts (Bennett 2005). While striped bass and longfin smelt are of less concern, their abundance along with the abundance of many other fish species has also declined in San Francisco Bay (Matern *et al.* 2002). Information regarding the feeding ecology of delta smelt and other pelagic fishes during all life history stages is needed to understand the cause of their decline before actions can be taken to reverse it. The proposed research will collect information on the prey selection of larval and juvenile fish in the San Francisco Estuary, including delta smelt, striped bass and longfin smelt. Understanding prey selection and the mechanism that control it will help managers determine how changes in the prey field translate into population success of delta smelt and other fish species allowing managers to more accurately interpret temporal changes in fish abundance.

The decline of pelagic fish in the San Francisco Estuary could be linked to poor recruitment success. Recruitment is regulated by multiple factors which often act together, including (1) the influence of freshwater outflow on transport, entrainment, advection and retention, (2) interactions with invasive species, (3) the effect of toxic compounds, (4) food web dynamics and (5) the quantity and quality of suitable spawning habitat. The relative impact of these factors on recruitment success may differ among species making it difficult to develop management activities or predict activity outcomes. Declines in the abundance of planktivorous fish, including striped bass, longfin smelt, and delta smelt in the San Francisco Estuary are correlated to changes in both the abundance and distribution of their zooplankton prey (Orsi *et al*. 1983; Kimmerer and Orsi 1996; Orsi and Ohtsuka 1999). This correlation provides indirect evidence that declines in food supply, which is critical during development of larval fish, is contributing to the decrease in pelagic fish abundance as well as preventing certain species from recovering. Food limitation in the San Francisco Estuary has already been observed for striped bass and other organisms, including cladacerans (Bennett *et al.* 1995; Müller-Solger *et al.* 1998; Kimmerer *et al.* 2000).

Co-occurrence of larval and juvenile fish with abundant and accessible prey is especially important during development. Fish larvae are particularly sensitive to starvation and fish that are food limited grow slower and are more susceptible to predation (Policanski and Sieswerda 1979; Eldridge 1981; Houde 1987). The accessibility of prey to fish differs among fish species and prey type. Interactions between fish foraging mode(s) and prey escape behavior result in selection for or against specific prey items. The proposed research will measure prey selection of larval and juvenile striped bass, longfin smelt, and delta smelt in laboratory feeding experiments.

Understanding the factors that influence growth and survival of early life history stages, including prey selection, is ultimately important to understanding the recruitment success of planktivorous fish which is necessary to resolve the cause of their decline. Therefore, by quantifying prey selection of larval and juvenile fish in the San Francisco Estuary the proposed research directly addresses one of the CALFED Implementing Agency Needs: pelagic organism decline (POD).

Numerous studies are currently being performed to examine all aspects of delta smelt biology, including diet. Current studies to examine the diet of delta smelt involve gut content analysis of field-collected consumers. This is not the only way to examine diet. Calculating feeding rates and prey selection from gut content analysis requires accurate estimates of prey abundance and digestion times; however, prey abundance and digestion times are rarely quantified in conjunction with *in situ* gut content analysis. Laboratory experiments have the specific advantage of using defined prey assemblages. Laboratory experiments are also the only way to examine the impact of a single variable, such as changes in light or turbidity, on prey selection. Data collected in laboratory experiments can be combined and compared with *in situ* observations to more accurately interpret diet (Bennett *et al.* 1995). Thus these approaches are complementary.

Background

The threatened delta smelt (*Hypomesus transpacificus*) is now the principal species of concern for management of freshwater flow and diversions in the Sacramento-San Joaquin Delta and the principal target for restoration in the upper San Francisco Estuary. Potential reasons for its low abundance include direct and indirect effects of freshwater export pumping in the south Delta, toxic substances, and low food supply (Bennett 2005). These factors have also been linked to the decline of numerous other planktivorous fish in the San Francisco Estuary including striped bass and longfin smelt (Bennett and Moyle 1996; Kimmerer 2004).

Striped bass, delta smelt, and longfin smelt feed on zooplankton in their larval and early juvenile periods. The abundance and species composition of zooplankton in the San Francisco Estuary have undergone several changes in the last two decades. The native (or introduced >100 years ago) calanoid copepod *Eurytemora affinis* was once the dominant zooplankton species throughout the year and an important component of the diets of larval fish. However, its abundance has greatly declined in late spring of each year and *E. affinis* is now rarely found during the summer. The decline of *E. affinis* has been attributed to grazing by clams on the naupliar stages (Kimmerer *et al.* 1994), although food limitation may also be occurring. Shifts in species composition have also resulted due to the invasion of several Asian copepods, including *Limnoithona tetraspina* (Orsi *et al.* 1983; Orsi and Ohtsuka 1999). In recent years, *L. tetraspina* has became the most abundant copepod in the estuary. *Limnoithona tetraspina* may avoid predation by planktivorous fish, including delta smelt, because of its small size (Bouley and Kimmerer In press).

Concern over the decline of delta smelt has spurred numerous studies to examine all aspects of its life cycle, yet relatively little is known about its feeding ecology. Recent studies to examine the gut contents of field-collected delta smelt have revealed that they feed mainly on copepods throughout their entire life cycle (Nobriga 2002; Hobbs *et al.* In press). Predation on rotifers, which may be digested too rapidly to be identified in gut

content analyses, has also been observed under laboratory conditions (Baskerville-Bridges *et al.* 2004; Mager *et al.* 2004). The lack of detailed information on the diet and prey selection of larval and juvenile fish in the San Francisco Estuary presents an obstacle for developing management strategies. Without substantial information on larval feeding ecology, the impacts of actions such as improving water quality, creating habitat and restoring flow regimes on recruitment can not be predicted. Prey selection quantified in the laboratory can be combined with *in situ* measurements of gut contents to determine how changes in the abundance and composition of the prey field will influence recruitment.

Unlike prior reports of gut content analyses, the proposed research will directly examine feeding of fish larvae on defined prey assemblages to accurately estimate prey selection. The proposed laboratory experiments are highly complementary to *in situ* observations of gut content analyses, and to ongoing studies of the dynamics of planktonic organisms in the upper estuary. Information on prey selection and the mechanisms that control it can be used to help predict recruitment success and habitat selection. In addition, information on diet and prey selection will lead to a better understanding of how these species will respond to new predators, competitors, or prey.

The importance of prey selection

Prey selection is defined as the consumption of a prey item in greater proportion than its relative abundance in the *in situ* assemblage. Prey selection has been documented for both adult and larval fish (Meng and Orsi 1991; Limburg *et al.* 1997), gelatinous zooplankton (Sullivan *et al.* 1994; Graham and Kroutil 2001) and crustacean zooplankton (Broglio *et al.* 2004). Selection is highly dependent on the ability of the consumer to find, attack, capture and consume prey. Therefore, prey selection is a combination of active selection by the consumer and the behavior of individual prey organisms. Factors that control selection include prey size, swimming behavior, and escape response. The swimming speeds and patterns of prey influence predation by controlling the encounter rates of predators with prey. Escape response and velocity affect the capture success of predators, thereby influencing prey selection (Buskey *et al.* 1993; Chesney 2005). Environmental variables such as light and turbidity can also influence prey selection by changing the reaction distances of predators. Because the mechanisms that control prey selection are so diverse and the time and space scale on which they operates so small, multiple methods are needed to determine and understand variation in the diet of larval and juvenile fish. It is important for growth and survival of both larvae and juveniles to encounter appropriate prey items during development. Increased growth rates promote recruitment success by decreasing the time spent in the more vulnerable, smaller size range.

Conflicting evidence of suggests that prey selection may differ among life history stages. Larval striped bass feed on small zooplankton, including copepods. After metamorphosis juveniles continue to feed on copepods, switching to mysids and amphipods after several months, and become piscivorous late in the first year of life (Heubach *et al.* 1963; Stevens 1966). Boynton *et al.* (1981) observed variable and nonselective feeding habits in juvenile striped bass in both nearshore and offshore habitats. Conversely, active selection for native copepods has been observed in laboratory experiments with larval striped bass, however, the prey combinations tested many not

overlap temporally or spatially *in situ* making it difficult to interpret the results (Meng and Orsi 1991).

Additionally, information regarding the influence of environmental variables on larval feeding intensity suggests that the effects of light intensity and turbidity may be prey-specific, and consequently may influence prey selection. Although planktivorous fish are generally considered visual predators, several observations have been made of larval fish feeding in the dark (Chesney 1989; Hobbs *et al.* In press). Fuiman *et al.* (2004) reviewed the structure and function of the ear and lateral line system of fishes during development and suggested that feeding by larvae is mediated by the lateral line system. In laboratory experiments with larval striped bass incubated with the copepod, *E. affinis*, feeding was observed in low light levels and in darkness (Chesney 1989). Decreased feeding intensity was observed under reduced light levels, with highest ingestion rates observed at full light levels. Baskerville-Bridges *et al.* (2004) observed similar results for larval delta smelt feeding on rotifers.

In addition to light intensity, turbidity also influences larval predation. Turbidity reduces light and visibility, thereby limiting the number of successful predator-prey encounters (Chesney 1989). Because the reaction distances of larval fish are small, turbidity may have little effect on feeding with the exception of how it pertains to light. However, while Chesney (1989) observed no predictable effect of turbidity on feeding by larval striped bass on *E. affinis*, Breitburg (1988) observed a 40% decrease in the consumption by larval striped bass feeding on field-collected copepods (80% *E. affinis*) under high suspended solids concentrations (200 and 500 mg L^{-1}) compared to low concentrations (0 and 75 mg L^{-1}). Additionally, Breitburg (1988) observed no effects of turbidity on predation by striped bass larvae on the cladaceran *Daphnia pulex* or on the size of prey consumed.

Why laboratory feeding experiments?

Laboratory experiments with larval and juvenile fish have been used successfully to examine development (Policansky and Sieswerda 1979; Mager *et al.* 2004), growth (Cox and Coutant 1981; Chesney 1989), feeding (Breitburg 1988; Hartman 2000), prey selection (Meng and Orsi 1991) and survival (Chesney 1989; Griffin *et al.* 2004). Additionally, laboratory experiments with cultured delta smelt are currently being performed by Joan Lindberg at UC Davis and funded by the IEP to collect useful information on habitat selection. While laboratory experiments have several advantages, possible adverse effects include changes in feeding rates and prey selection resulting from stress, changes in light, turbulence, overcrowding of consumers, growth of the prey assemblage and interaction with container walls (e.g., Mullin 1963; Gibbons and Painting 1992; Toonen and Chia 1993). Bottle effects, the changes experienced by consumers and prey during incubation in a container, must be minimized in order to apply feeding rates measured in laboratory experiments to the *in situ* environment.

Benefits associated with laboratory experiments include the use of predefined prey fields, which allows for the most accurate measurements of prey selection. Laboratory manipulations also permit testing responses to single variables such as changes in light, temperature, turbidity, turbulence and food concentration. Additionally, high variability in zooplankton abundance and composition *in situ* can make it difficult to correlate changes in zooplankton with recruitment success. Therefore, the impact of the

specific taxonomic composition of the prey assemblage is more accurately examined in laboratory experiments where larvae are fed known mixtures of chosen prey.

Gut content analysis of field-collected consumers is the method most commonly used to measure feeding and selection of fish (e.g. Stevens 1966; Feyrer *et al.* 2003; Hobbs *et al.* In press). Gut contents are a good representation of diet *in situ* and are especially advantageous for field studies already quantifying abundance and distribution. Calculating feeding rate and prey selection from gut content analysis requires accurate estimates of prey abundance and digestion times for the different taxa of prey organisms consumed. Prey taxa are digested at different rates and differences in digestion times can bias the evaluation of prey selection toward items that take longer to digest. In addition, not all prey taxa are similarly recognizable in consumer guts. Differential recognition can bias the evaluation of prey selection toward larger, more easily identifiable prey. Historically, prey abundance and digestion times have rarely been quantified in combination with *in situ* gut content analysis.

In summary, although laboratory experiments have been used to examine numerous aspects of larval fish biology, gut content analysis of field-collected consumers remains the most common method for examining feeding. While gut content analysis provides information on *in situ* diet, without information on prey abundance and digestion times, gut content analysis can not be used to calculate feeding rate or prey selection. Even if zooplankton samples are collected in conjunction with larval fish, estimates of the digestion times of larval fish are so long, >1 h, that concurrent zooplankton samples may not accurately sample the prey field (Heubach *et al.* 1963). Additionally, numerous environmental variables (i.e., temperature, salinity, light, turbidity, and prey concentration) can influence feeding making it difficult to unravel dietary patterns. Despite the bottle effects associated with laboratory feeding experiments, environmental variables can be controlled in the laboratory to eliminate interactions of multiple variables. Prey selection measured in laboratory feeding experiments can be used to confirm prey selection inferred by the composition of gut contents. Additionally, the information collected from laboratory experiments with defined prey assemblages will reduce the need to quantify zooplankton abundance in conjunction with gut content analysis. This is especially advantageous because of the difficulties associated with accurately sampling the prey field. Laboratory feeding experiments can also be used to interpret trends observed in larval and juvenile gut contents, such as why certain species are commonly observed with particular prey items compared to others or why under certain environmental conditions fish may often have empty guts.

The objective of the proposed research is to quantify prey selection of larval and juvenile striped bass (*Morone saxatilis*), longfin smelt (*Spirinchus thaleichthys*) and delta smelt (*Hypomesus transpacificus*) in laboratory feeding experiments. Some of the mechanisms controlling selection will also be examined. This project will address the following questions:

- How does prey selection differ among species?
- How does prey selection differ among larvae and juveniles?
- Does prey selection differ among laboratory reared fish and field-collected fish?

- How do light and turbidity influence prey selection of each species?
- What are the underlying mechanisms that determine prey selection of each species?

Approach

Prey selection of larval and juvenile striped bass, longfin smelt and delta smelt will be measured in laboratory feeding experiments. To examine some of the mechanisms controlling prey selection *in situ*, the impact of light and turbidity on larval and juvenile prey selection will be measured and capture success of larval fish will be quantified.

Collection

Larval and juvenile fish for use during laboratory experiments will be collected using numerous approaches. Larval striped bass and delta smelt will be obtained from hatcheries and reared in the laboratory. Additionally, larval and juvenile striped bass have been successfully reared in the laboratory from field-collected adults by *in vitro* fertilization and natural spawning (e.g., Chesney 1989; Mager *et al.* 2004; Baskerville-Bridges *et al.* 2004). Therefore, field-collected striped bass and longfin smelt will be obtained as bycatch through sampling programs of the U.S. Fish and Wildlife Service and the California Department of Fish and Game, to reduce the environmental impact of sampling and reared in the laboratory. The U.S. Fish and Wildlife Service conducts weekly beach seining, focusing on juvenile salmonids using the delta as a rearing and nursery area, as part of their juvenile fish monitoring program. The California Department of Fish and Game also conducts numerous surveys to monitor fish populations in the San Francisco Estuary, including a Summer Townet Survey, a Fall Midwater Trawl Survey, and the San Francisco Bay Study (Kimmerer *et al.* 2000; Kimmerer *et al*. 2001). Adult fish may also be obtained from the fish collection facilities in the south Delta operated by the Department of Water Resources and the U.S. Bureau of Reclamation. Eggs obtained from either method will be hatched and reared in the laboratory on cultured prey. Other species of interest that may be examined, depending on availability, include pacific herring (*Clupea harengus*), northern anchovy (*Engraulis mordax*), and inland silverside (*Menidia beryllina*).

Laboratory experiments

Prey collection. Zooplankton will be collected by net tows using a 64-µm mesh ring net from locations throughout the estuary chosen by salinity. Samples will be diluted immediately upon capture into 20-L insulated carboys for transport to the laboratory. Zooplankton will be sorted using a dissecting microscope and will be maintained at *in situ* temperature and salinity in filtered seawater. Experimental prey composition will be determined from field collections and published information on abundance and distribution to coincide spatially and temporally with larval fish (Kimmerer and Orsi 1996; Kimmerer *et al.* 2002, Kimmerer unpublished).

Prey selection. Larval and juvenile fish will be starved 20-24 h prior to the selection experiments. Fish will then be transferred to experimental vessels containing filtered seawater and allowed to acclimate for 10 min before prey are added. Three larvae will be incubated in 2 L beakers containing 1 L of filtered seawater and juveniles will be incubated in larger volumes dependent on size (Meng and Orsi 1991). Field-collected

prey will then be added in known quantities and larvae will be incubated at *in situ* temperature and salinity for 3 h. Each experiment will be replicated 3–6 times. At the end of the incubation period, the contents of the beaker will be preserved in 4% Formalin and replicates with dead larvae will be discarded. Consumption will be determined from gut content analysis and confirmed with counts of the remaining prey.

The effects of light (2000, 1000, 500 and 0 lux) and turbidity (0, 50, 100 and 200 mg L^{-1}) on prey selection will be quantified in similar experiments. Light intensity will be reduced from 2000 to 1000 and 500 lux by wrapping the light sources in plastic screening. Additional incubations will be performed in darkness. The proposed light levels have been employed previously in laboratory experiments and are within the range naturally occurring in coastal waters (Chesney 1989; Kirk 1994). Light intensities will be measured using a light meter. Mean values of suspended particulate matter in the San Francisco Estuary range from 10 mg L^{-1} in the Central Bay to nearly 100 mg L^{-1} in Suisun Bay (Conomos and Peterson 1977). Turbidities in a similar range will be produced by the addition of kaolin. Determining the impacts of turbidity on prey selection requires short incubation to prevent significant changes in turbidity resulting from settling, therefore the incubation duration will be shorted to less than 2 h (Breitburg 1988).

Experiments with delta smelt may require additional measures, based on previous experience at the culture facilities. Delta smelt will not feed in clear water, and appear to do best when water is made turbid with an algal suspension. Experimental methods will be adjusted following discussions with scientists at the culture facility, and will probably be conducted there if feasible. Preliminary feeding experiments on delta smelt were conducted in 2006 at the culture facility at the SWP fish facility (Kimmerer unpublished).

There are several published measures of prey selection but few provide a means of statistical significance testing. Pearre's (1982) index uses $\chi 2$ analysis to examine levels of significance. Here, $\chi 2$ values are calculated from the percent of a prey item ingested and the percent of the total number of prey available. This method is similar to the $\chi 2$ tests performed by Meng and Orsi (1991). Prey selection of larval and juvenile fish feeding on known mixtures of field-collected zooplankton will be evaluated using Pearre's (1982) electivity index. Electivity index values range from -1 to 1. Positive and negative values indicate selection for and against a given prey category, respectively, while a value of zero indicates no selection. Differences in prey selection among treatments (light and turbidity) will be examined using multivariate statistical techniques.

After specific patterns of prey selection for each species have been defined in laboratory experiments, the data will be used to develop quantitative models of prey selection that can be applied in the field. Combined with models the data can then be used to predict how larval and juvenile fish feeding might change as plankton populations change. A rank proportion algorithm (RPA) model will be developed following Link (2004). Information on prey selection quantified in laboratory feeding experiments will be substituted for the predation processes used to estimate selection by Link (2004). The algorithm assigns ranks to individual prey categories based on relative abundance and predator preference to predict diet composition. Numerous models have been developed to simulate fish feeding; however, most of them attempt to predict selection based on differing theoretical approaches rather than by applying information on selection to the

field (e.g., Werner and Hall 1974; Aksnes and Giske 1993; MacKenzie and Kiorboe 1995).

Capture efficiency. Capture efficiency of larval feeding on various prey will be measured using standard videographic techniques. Larvae will be starved 20-24 h prior to the capture efficiency experiments. Larval fish will then be transferred to 2 L beakers containing 1 L of filtered seawater and allowed to acclimate for 10 min before prey are added. 3-D observations of predator-prey interactions will be recorded with two cameras equipped with macro zoom lenses for 30 min to achieve both vertical and horizontal resolution. Standard video recordings will be reviewed using slow-motion playback. Information regarding predation events will be gathered and categorized according to Holling (1959). Capture efficiency (CE) will be calculated by Holling (1959):

$$CE=(\text{total captures}/\text{total encounters}) \times 100.$$

Differences in capture efficiency among larval fish and for different prey will be related to video observations, prey size and published observations of prey escape response, swimming speed and behavior (e.g. Buskey *et al.* 1993; Buskey 1994; Waggett and Buskey In press). The larger container volume needed for incubating juvenile fish prohibits the use of videographic techniques to quantify their capture efficiency.

Table I. Timeline.

Research activity	Date
Preparation and preliminary research	January ‘07–March ‘07
Quantify prey selection-Larvae	March ‘07–June ‘07
Quantify prey selection-Juveniles	June ‘07–August ‘07
Data analysis and writing	August ‘07–March ‘08
Determine the effects of light on prey selection-Larvae	March ‘08–June ‘08
Measure capture efficiency-Larvae only	March ‘08–June ‘08
Determine the effects of light on prey selection-Juveniles	June ‘08–August ‘08
Data analysis and writing	August ‘08–December ‘08

Feasibility

The feasibility of the proposed research depends on the capabilities of the postdoctoral scientist, the research mentor, the availability of suitable facilities, and the availability of the necessary equipment.

Postdoctoral scientist. I have worked extensively with both gelatinous and crustacean zooplankton organisms. I have measured feeding, growth and reproduction in zooplankton using a variety of different methods. Through a series of Research Assistantships, I have worked on several NSF-funded projects. My duties have included collecting and processing hydrographic and biological data in the field and the laboratory, and on different temporal scales. In addition, I have experience quantifying the distribution and abundance of marine plankton (including microphytoplankton, microzooplankton and mesozooplankton). I have had success culturing marine organisms

in the laboratory, including phytoplankton, copepods, hydromedusae and ctenophores. My primary research interests are the ecology and physiology of marine organisms with emphasis on early life history stages. Information on feeding ecology contributes to our understanding of how marine food webs function and how environmental change may impact marine ecosystems. The proposed research will allow me to examine the role of prey selection in a different group of organisms. Although it is fundamentally the same process, the mechanisms controlling prey selection differ significantly between fish (visual predators) and gelatinous organisms (non-visual predators).

Research advisor. Dr. Wim Kimmerer, is a research professor at the Romberg Tiburon Center, a research and teaching laboratory of San Francisco State University located on the shores of San Francisco Bay in Tiburon, Marin County, California. His background and training are in chemistry and biological oceanography. His current research interests include zooplankton ecology, the ecology of estuaries with an emphasis on San Francisco Bay, and the use of models in aquatic ecology. Dr. Kimmerer has been involved in numerous projects funded by the CALFED Bay-Delta Program, including work to investigate the introduction of estuarine zooplankton in ballast water and the relationships between fish abundance and freshwater flow. Currently, Dr. Kimmerer is funded by CALFED to investigate food web support of the threatened delta smelt and to develop multiple complementary models of delta smelt population dynamics.

Facilities and equipment at Romberg Tiburon Center (RTC). The proposed research will be performed at RTC. RTC's main laboratory building has a total area of some 20,000 ft^2 and an open bay of 12,000 ft^2. The RTC seawater system has been upgraded with a 300 ft tethered intake line providing water delivery to the main building, and mixing facilities are being planned. In addition to a large research wet lab (1500 ft^2) with running bay water, the Center has constructed a temperature- and light-controlled animal culture room (700 ft^2). General use equipment includes constant temperature rooms, refrigerators and freezers (-80 & -20^oC).

The RTC owns and operates a 38' aluminum-hulled shallow draft research vessel capable of a maximum speed of 20 knots and equipped with an A-frame, adequate a/c power, a hydraulic system, a hydrographic winch with conducting cable, instrumented rosette sampling system, depth sounder/bioacoustic sampler, acoustic doppler current profiler (ADCP), differential global positioning system (GPS), and a data acquisition computer system. In addition, RTC has a number of smaller vessels such as a Twin Vee Powercat and a 17-foot Boston Whaler.

Permitting. I will obtain a Scientific Collector's Permit from the State of California. Take permits will not be needed, as listed species (delta smelt) will be obtained from culture facilities.

Relation to other projects, current and pending. The proposed research will complement several projects currently funded by the CALFED Bay-Delta Program. Dr. Kimmerer and others are finishing a project on determining the mechanisms relating freshwater flow to the abundance of estuarine biota including larval fish and zooplankton. Dr. Kimmerer and others are also conducting a project investigating food web support of

the threatened delta smelt. Specifically, the project examines possible energy sources for delta smelt and how these sources make their way through the food web. Additionally, Dr. Kimmerer and others are supported to examine *in situ* feeding by delta smelt. In particular, they will quantify prey selection and feeding rate from data collected by gut content analysis to enhance monitoring of delta smelt. Dr. Kimmerer and others have been supported to develop a suite of models of delta smelt biology. Steven Slater of the California Department of Fish and Game is also performing a study to examine the diets of age-0 delta smelt, inland silversides, striped bass and threadfin shad in the upper Estuary. He has been collecting gut content information from field-collected consumers from 2005 through the present.

Anticipated Products

- Year 1. Presentation at the State of the Estuary Conference.
- Year 2. Presentation at the CALFED Science Conference.
- Year 2. Presentation at one national conference.
- At least three manuscripts submitted to peer-reviewed journals. Tentatively, these might include:
  - Year 1. One manuscript describing the prey selection of larval and juvenile striped bass, delta smelt and longfin smelt.
  - Year 1. One manuscript describing the impacts of light and turbidity on prey selection by larval and juvenile striped bass, delta smelt and longfin smelt.
  - Year 2. One manuscript describing the capture efficiency of larval striped bass, delta smelt and longfin smelt.
- Year 1. Annual reports to the CALFED Science Program summarizing the progress of the proposed research.
- Year 2. Annual report and final report to the CALFED Science Program summarizing the progress and results of the proposed research.

Benefits to fellow. Two years of funding have been requested to complete the proposed research project (Table I). This is to allow ample time to complete laboratory experiments, data analysis and writing. During the first year of the project, effort will be placed on developing techniques for culturing and rearing larval fish and selection experiments. A manuscript on selection by larval fish and the impacts of light and turbidity on prey selection should be submitted by the start of the second field season to a peer-reviewed journal. During this time, I will also be receiving postdoctoral training from Dr. Kimmerer regarding mentoring, laboratory management, budgeting, communication and writing during this time. In the second field season, emphasis will be placed on quantifying capture efficiency. A manuscript describing the capture efficiency of larval fish should be submitted to a peer-reviewed journal by the end of the postdoctoral support. I will continue to receive postdoctoral training from Dr. Kimmerer; however, emphasis in the second year will be placed on teaching, writing, job application preparation, interviewing skills, and job negotiation. Additionally, the proposed research project directly addresses my primary research interests, which are the physiology and ecology of marine organisms with emphasis on feeding, growth and reproduction.

Through the proposed research project, I will learn new techniques including the culturing of planktivorous fish. Dr. Kimmerer's laboratory and the RTC will provide a stimulating environment in which to prepare for a long-term academic and research career. Here I will meet other scientists, with whom I will form collaborations and build relationships.

Benefits to research mentor. Dr. Kimmerer has numerous ongoing research programs to examine different aspects of delta smelt ecology. The proposed research will complement and enhance several of these projects. First, the data collected regarding food web support of delta smelt by Dr. Kimmerer and others will provide information on changes in the prey field. The proposed research examining prey selection and capture efficiency will provide insight into how delta smelt will react to these changes. Second, information on prey selection and capture efficiency can be combined with *in situ* gut content observations being collected by Dr. Kimmerer's laboratory to help explain observed dietary patterns. Additionally, prey selection and capture efficiency can be incorporated into models of delta smelt biology being created by Dr. Kimmerer and others.

Benefits to community mentor. As the designated community mentor, Dr. Ted Sommer, a Senior Environmental Scientist at the Department of Water Resources, will receive information central to understanding and managing the decline of pelagic organisms in the San Francisco Estuary. Information on prey selection and capture efficiency of larval and juvenile planktivorous fish directly and indirectly relates to numerous questions associated with the decline of pelagic organisms. The proposed research will contribute information regarding the biological effects of changes in turbidity, temporal differences in fish health, growth and survival, and regional differences in fish health, growth and survival.

Benefits to CALFED. The proposed research addresses questions important to CALFED's mission to develop and implement a long-term comprehensive plan to restore ecological health to the Bay-Delta System and more specifically, to improve conditions to allow the recovery of endangered and at-risk species. Much of the protective activity in the Delta focuses on delta smelt. Yet to date there is no evidence that any of this activity is having a measurable benefit on population size. This implies that numerous factors not under human control may be acting simultaneously and/or synergistically to limit the abundance of delta smelt. Preliminary studies have indicated poor feeding condition in a large proportion of larval smelt indicating food supply among the major factors limiting recruitment success (Bennett 2005). Understanding the feeding ecology of planktivorous fish, not only threatened species, is essential to developing effective management actions. The information on prey selection obtained through the proposed research can be used to help predict recruitment success and habitat selection, and will lead to a better understanding of how certain species may respond to the introduction of new predators, competitors, or prey.

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