Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Project Information

1. **Proposal Title:**

   Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

2. **Proposal applicants:**

   Wim Kimmerer, San Francisco State University, Romberg Tiburon Center
   Bill Bennett, UC Davis
   Edward Gross, Independent Consultant

3. **Corresponding Contact Person:**

   Wim Kimmerer
   Romberg Tiburon Center, SFSU
   3152 Paradise Drive Tiburon CA 94920
   415 338-3515
   kimmerer@sfsu.edu

4. **Project Keywords:**

   Estuaries and Estuarine Modeling
   Estuarine/Tidal Ecology
   Saline-freshwater Interfaces

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   X2 Relationships

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude:

Longitude:

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Project being conducted at the Romberg Tiburon Center in Marin County. Subject of the project is the entire San Francisco Estuary

10. **Location - Ecozone:**

    1.1 North Delta, 1.2 East Delta, 1.3 South Delta, 1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.5 San Pablo Bay, Code 15: Landscape, Code 16: Inside ERP Geographic Scope, but outside ERP Ecozones

11. **Location - County:**

    Alameda, Contra Costa, Marin, Napa, Sacramento, San Francisco, Solano, Sonoma, Yolo

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    6

15. **Location:**

    California State Senate District Number: 3

    California Assembly District Number: 6

16. **How many years of funding are you requesting?**

    2

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       No

If no, list single overhead rate and total requested funds:

Single Overhead Rate: 50

Total Requested Funds: 509222

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

Yes

If yes, identify project number(s), title(s) and CALFED program.

99-F11	**Effects of Introduced Clams on the Food Supply of Bay-Delta Fish Species**	**ERP**
99-N09	**Effects of Introduced Species of Zooplankton and Clams on the Bay-Delta Food Web**	**ERP**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

    No

    Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

Environmental Compliance Checklist

<u>Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I</u>

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No
   b) Will this project require compliance with NEPA?

      No
   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Research proposal

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

   b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land.
Agency Name:

Permission to access state land.
Agency Name:

Permission to access federal land.
Agency Name:

Permission to access private land.
Landowner Name:

6. **Comments.**

Land Use Checklist

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   No

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   Research

4. **Comments.**

Conflict of Interest Checklist

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Wim Kimmerer, San Francisco State University, Romberg Tiburon Center
Bill Bennett, UC Davis
Edward Gross, Independent Consultant

Subcontractor(s):

Are specific subcontractors identified in this proposal? Yes

If yes, please list the name(s) and organization(s):

Wim Kimmerer	Romberg Tiburon Center
Bill Bennett	Bodega Marine Lab
Edward Gross	Independent Consultant
None	None
None	None
None	None
None	None

Helped with proposal development:

Are there persons who helped with proposal development?

Yes

If yes, please list the name(s) and organization(s):

Randy Brown **DWR Retired**

Comments:

Budget Summary

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

Federal Funds

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Planning	1501	33440	9028	1500	2350	5000		17500	68818.0	34409	103227.00
2	Model Studies	1323	25874	6152	1500	2350	121600		0	157476.0	32938	190414.00
		2824	59314.00	15180.00	3000.00	4700.00	126600.00	0.00	17500.00	226294.00	67347.00	293641.00

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Planning	1239	25471	5816	3500	100	14400		2000	51287.0	25644	76931.00
2	Model Studies	1239	25471	5816	3500	100	86020		0	120907.0	17743	138650.00
		2478	50942.00	11632.00	7000.00	200.00	100420.00	0.00	2000.00	172194.00	43387.00	215581.00

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
		0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grand Total=509222.00

Comments.

Budget Justification

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Direct Labor Hours. Provide estimated hours proposed for each individual.

(Note: estimated on the basis of 173 hours per month) Kimmerer 865 Technical Assistant 1557 Graduate Student 2880

Salary. Provide estimated rate of compensation proposed for each individual.

Kimmerer $43 Technical Assistant $19 Graduate Student $14

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

Kimmerer 38% Technical Assistant 38% Graduate Student 1.5%

Travel. Provide purpose and estimate costs for all non-local travel.

Purpose: Travel for lead PI to one national scientific conference per year, and for graduate student for one conference. Travel for two outside Steering Committee members to one meeting per year. Total estimate: $8000

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

$4500 for computer and software $400 for office supplies

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

Subcontract to Dr. Edward Gross for participation by Gross, Schaaf, and MacWilliams, all sole proprietors. Purpose as described in proposal is for preparing and running the TRIM3D model and ancillary code. Hours and hourly rates: Hours Rates Gross 184 $105 Schaaf 400 $120 MacWilliams 368 $60 Subcontract to UC Davis for participation of W. Bennett as described in proposal. Bennett 519 $30 + 28% benefits

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

None

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

This function is provided by the University administration out of overhead, and is not charged as a direct cost to the project.

Other Direct Costs. Provide any other direct costs not already covered.

Honoraria for Steering Committee members, $4000 each for 4 people for the entire project. Graduate student tuition: $2000 for 2 years, a normal cost associated with the participation of a graduate student in the work. Publication costs, $1500.

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

San Francisco State University's indirect cost rate is based on an agreement with the Federal Government. The indirect cost rate for on-campus organized research is 50%. Indirect costs (overhead rate) include costs associated with general office and laboratory requirements such as rent, utilities, phones, furniture, general office staff, etc., and are prescribed by SFSU as 50% of the modified total direct costs (i.e., total direct costs - equipment - tuition reimbursement - sub-contract costs beyond the first $25,000)

Executive Summary

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Freshwater flow to the San Francisco Estuary is regulated in part using a salinity standard based on "X2", the position of the 2 psu isohaline. The standard is based on the "fish-X2" relationships, by which abundance or survival several of estuarine species is higher when X2 is seaward and flow is high. The X2 standard is a rare example of ecosystem management, but it has several drawbacks. It is a crude tool: although the relationships are numerous and strong when compared to results from other estuaries, they are not strong enough to suggest ways to refine the seasonal pattern of protection. As statistical relationships, they provide no guidance for what will happen if the ecosystem changes through long-term effects including CALFED actions. The high cost of the water required suggests a need to make the standard as efficient as possible. Thus, a need exists to determine the mechanisms underlying the fish-X2 relationships. This will require a substantial research program, because of the multiplicity of species and potential mechanisms. Although some research has already been conducted, there is no coordinated, systematic effort to resolve these mechanisms. We propose to begin to understand these mechanisms by planning and designing a coordinated, interdisciplinary research effort, and by conducting some initial modeling studies to prepare for field research in subsequent years. The planning effort will draw on the experience and knowledge of numerous Bay Area scientists, using a workshop format to produce an optimum design for the program. Complementary modeling studies will use a 3-dimensional numerical hydrodynamic model of the estuary to investigate mechanisms involving the spatial distribution of salinity, and the effect of varying freshwater flow and X2 on retention of estuarine organisms. The resulting research program will provide CALFED with vital information needed for long-term management and restoration of the estuarine ecosystem.

Proposal

San Francisco State University, Romberg Tiburon Center

Determining the mechanisms relating freshwater flow and abundance of estuarine biota (the "Fish-X2" relationships): Phase I

Wim Kimmerer, San Francisco State University, Romberg Tiburon Center
Bill Bennett, UC Davis
Edward Gross, Independent Consultant

A. Project Description

1. Problem Statement

Abundance or survival of several estuarine biological populations in the San Francisco Estuary[1] is positively related to freshwater flow (Jassby et al. 1995). These relationships have been described in terms of "X_2", the location of the 2 psu (practical salinity units) isohaline. The "fish-X_2" relationships form an important basis for management of the estuary using a salinity standard.

The salinity standard is an ecosystem management tool, in that it appears to benefit a variety of estuarine species. However, meeting the standard comes at a high cost in water, leading to dissatisfaction with the standard in the water user community. Furthermore, some of the fish-X_2 relationships on which the standard is based have considerable statistical uncertainty, so the realized benefits of the salinity standard are not clear. Finally, some of the relationships have changed in the last several years. Thus, there is a great deal of interest in improving and refining the standard. *To do this will require a better understanding of the mechanisms underlying the fish-X_2 relationships.*

Although progress has been made toward understanding a few of the mechanisms underlying the fish-X_2 relationships, a comprehensive plan has not yet been developed for systematically evaluating the mechanisms . Implementing such a plan could markedly increase the efficiency with which knowledge is obtained and translated into policy.

We propose the first phase of a research program to elucidate these mechanisms. In this phase we will undertake the first two steps toward the development of this knowledge:

1. *Develop a plan for the research, modeling, and monitoring, identifying responsible parties, timing, dependencies, funding, and additional requirements or opportunities.*
2. *Using existing data and a 3-dimensional hydrodynamic model of the estuary, explore some of the proposed mechanisms to assess their plausibility and to aid in study design.*

2. Justification

As discussed below, the need for a program to investigate the fish-X_2 relationships has been recognized for several years, and is discussed in the CALFED Ecosystem Restoration Program Strategic Plan and the Comprehensive Monitoring, Assessment, and Research Program (CMARP).

Background: X_2, the distance in kilometers up the axis of the estuary to where the tidally-averaged near-bottom salinity is 2 psu, was developed as an indicator of the physical response of the estuarine ecosystem to changes in freshwater flow. Abundance or survival of various estuarine species of fish and invertebrates is negatively correlated with X_2, i.e., positively with outflow (Jassby et al. 1995). These relationships use values of X_2 averaged over several months, usually in the spring, when each fish

[1] We use the term "San Francisco Estuary" to mean the entire body of water from the landward reaches of the Delta to the coastal ocean.

or invertebrate species is believed to be most sensitive to flow conditions in the estuary.

Although there has been some argument about whether flow or X_2 is more suitable as the independent variable in these relationships, it hardly matters since the long averaging period means that flow and X_2 are very closely correlated. Although flow is clearly the ultimate cause of variability in salinity patterns, X_2 has several advantages as an independent variable. For one thing, it provides a geographic frame of reference that is more intuitive than a flow variable. Second, X_2 can be determined by interpolation between continuous monitoring sites, whereas delta outflow has only recently been measured, so the data record is short. Third, most estuarine species cannot be affected directly by flow unless it is extremely high, because of complete vertical mixing that usually occurs in the Low-Salinity Zone (Burau 1998); thus, X_2 more accurately reflects the conditions to which most estuarine species are exposed.

The choice of the 2 psu isohaline was not arbitrary. This salinity is high enough to be unambiguously derived from the ocean, as opposed to agricultural drainage. X_2 marks the approximate landward limit of estuarine stratification and circulation, and therefore the transition between the tidal freshwater and brackish parts of the estuary. In addition, it is the approximate center of habitat for certain estuarine-dependent species, including several zooplankton species (Kimmerer and Orsi 1996, Kimmerer et al. in press) and young striped bass (Kimmerer et al. 2001).

Table 1 summarizes the X_2 relationships of several estuarine-dependent species including all those reported by Jassby et al. (1995). These relationships have been updated through 1999-2000 by Kimmerer (1998 and submitted). Some of these relationships changed in the late 1980's, probably as a result of reduction in system productivity due to filtration and inadvertent predation by the introduced clam *Potamocorbula amurensis* (Kimmerer et al. 1994). However, all relationships that were statistically significant before the spread of *P. amurensis* are still significant, and standard errors of the slopes have not increased. In addition to the relationships in Table 1, white sturgeon year class strength is highest when flow is high, although because of the long life of this species the relationship is not strong statistically (Kohlhorst et al. 1991). In addition, mark-recapture experiments have shown that chinook salmon smolts survive better during migration through the delta when flow is high than when it is low, although flow effects are small compared with temperature effects (Rice and Newman 1997).

Dissatisfaction with the use of X_2 as a standard for ecosystem management centers on several issues. First, the water costs of using X_2 may be high, especially in dry years. Second, other ways to protect or restore estuarine populations may be more efficient (with regard to water use) or effective (with regard to species protection). Third, the relationships were developed from historical data, and some have changed. Fourth, alterations to the estuary and especially the delta may cause further change in the relationships that cannot be predicted with current information. For example, an “Isolated Transfer Facility” to divert water from the Sacramento River is among the alternatives being considered by CALFED; the net gain in water supply due to this installation may be minimal if the X_2 standards remain in their current state, yet the effect on the relationships of moving the diversion point is unknown.

For several reasons, additional analysis of the annual data used to develop the relationships is insufficient to refine the relationships or determine their causes. First, the various alternative explanatory variables (e.g., delta inflow or outflow) are all correlated and therefore cannot be distinguished statistically. X_2 is used as the independent variable to provide a common framework related to conditions existing in the estuary, not necessarily because it is statistically superior to other variables. Second, the abundance indices are annual indices, so not more than about 18-28 data points are available for analysis, which limits the number of explanatory variables that can be used in analysis. Third, regression or correlation analyses are useful for establishing relationships but uninformative for determining causes.

Thus, a program of research is needed to determine the mechanisms underlying the fish-X_2 relationships. This program would provide CALFED, management agencies, and stakeholders with vital information needed for long-term management of the estuarine ecosystem.

Conceptual models: The goal of the proposed research, in this and subsequent phases, is to understand the mechanisms underlying the fish-X_2 relationships. To do this requires comparison among alternative, potentially contrasting conceptual models. This section gives a very brief overview of some of the conceptual models.

Numerous environmental attributes may covary (positively or negatively) with freshwater flow, including flooding of river margins, proportion of freshwater diverted for agricultural and urban use, mobilization or dilution of anthropogenic inputs, turbidity, transport of materials, particles, and planktonic organisms, position of the estuarine salt field and any isohaline, salinity at any point, length and steepness of the horizontal density gradient, stratification, and possibly gravitational circulation (Postma 1967, Jassby and Powell 1994, Jassby et al. 1995). Because this list is so long, it is impossible to determine the mechanism for any particular relationship with flow/X_2 through correlative analysis. Such analyses can help to eliminate possible mechanisms, but to identify the mechanism(s) responsible for each species requires investigation into the biology of that species and its responses to its physical environment.

The Estuarine Ecology Team (EET), a Project Work Team under the Interagency Ecological Program (IEP; http://www.iep.water.ca.gov/) prepared two essays (EET 1995, 1997) on the effects of environmental variability on the estuarine ecosystem. The 1997 report focused on the potential mechanisms underlying the fish-X_2 relationships, including a ranking of the mechanisms believed by team members to be most plausibly important, and was intended as a guide for developing a research plan. The plausible mechanisms can be collapsed into a relatively few classes as discussed below, and are listed in Table 2 and described in greater detail in the documentation for CALFED's Comprehensive Monitoring, Assessment, and Research Program (CMARP): http://calfed.ca.gov/programs/cmarp/a7a1.html).

The classes of mechanisms are summarized in Figure 1. The diagram gives several alternative (not necessarily exclusive) pathways by which flow conditions can affect abundance. These include two "trophic" mechanisms on the left of the figure, by which the base of the estuarine foodweb responds to increasing inputs of organic matter or nutrients, and this response cascades to higher trophic levels. Mechanisms listed as "physical" on the right side of the diagram include direct physical effects on the quantity or quality of habitat and effects of stratification or retention on the species of interest. In the middle are mechanisms that support intermediate "foodweb" species, leading to improved food conditions for the response organisms.

Stimulation through nutrient input at the base of the foodweb and trophic transfer up the foodweb are commonly invoked to explain flow-abundance relationships for fish and large invertebrates in other estuaries (e.g., Aleem 1972, Sutcliffe 1972, Nixon et al. 1986, Drinkwater and Frank 1994). However, such "bottom-up" mechanisms are unlikely to contribute substantially to such relationships in the San Francisco Estuary. First, nutrient concentrations are usually high and phytoplankton light limited most of the time (Cloern 1996), so phytoplankton are unlikely to be stimulated by an increase in nutrient inputs with increasing freshwater flow. Second, the strongest X_2 relationships are seen in fish and bay shrimp, whereas lower trophic levels have weak relationships (Table 1). Third, the decline in chlorophyll following the spread of the clam *Potamocorbula amurensis* was accompanied by a decline in some fish species but not all. None of the existing relationships changed in slope in 1987-88, suggesting that their relationships to X_2 were governed by other mechanisms (Kimmerer 1998, submitted).

Here we briefly describe some key conceptual models, in approximate order from right to left in Figure 1. These are discussed in more detail in the references listed above. Table 2 lists several hypotheses for each conceptual model, with potential approaches to test them.

Habitat quantity or quality: By this mechanism, as X_2 moves seaward the habitat for a species increases in accessibility or spatial extent, either area or volume depending on how the habitat is used, or in quality. For the riverine part of the system this is relatively straightforward: when river flow is high enough to inundate flood plains such as the Yolo Bypass, habitat for feeding, spawning, and rearing of splittail (Sommer et al. 1997), and possibly other fish, increases in extent and accessibility.

In the brackish estuary, the prevailing conceptual model is that the quantity of suitable habitat increases or becomes more accessible as X_2 moves seaward. This idea has become particularly attached to the concept of the Low-Salinity Zone (or Entrapment Zone) as habitat. However, the example of splittail above demonstrates that an X_2 relationship does not necessarily imply that this particular salinity range is important for a given species. Unger (1994) showed that estimates of habitat for several brackish-water species were related to X_2. However, his analyses were preliminary, based on crude estimates of salinity distributions and the distributions of fish. Thus, this mechanism shows promise but has not been rigorously examined.

Transport and entrainment: Species that use the Delta are subjected to entrainment in the state and federal water projects and agricultural diversions. Recent analyses of chinook salmon smolt passage through the delta showed at most a minor effect of exports (Rice and Newman 1997). Large losses of juvenile striped bass at the export facilities appear unrelated to mortality rates of the population of young fish (Kimmerer et al. 2000, 2001). However, other populations such as the endangered delta smelt may be more vulnerable to entrainment (W.A. Bennett in prep.). Survival could increase with seaward X_2 if either movement of migrating organisms (e.g., salmon smolts) was more rapid, or if the habitat for rearing was displaced seaward (e.g., striped bass, delta smelt, longfin smelt). Either effect would reduce vulnerability to entrainment in south Delta export pumping facilities.

Residual circulation refers to the circulation remaining after oscillatory tidal currents have been subtracted out. Several mechanisms for residual circulation may occur in the estuary. Localized landward residual flows can occur because of various ebb-flood asymmetries including lateral gyres, strain-induced periodic stratification (SIPS, Monismith et al. 1996), and gravitational circulation, in which residual near-bottom currents are landward. Gravitational circulation can occur throughout the estuary wherever stratification occurs, primarily in deep regions such as the Golden Gate, the main channel through Central and San Pablo Bays, and in Carquinez Strait. It is rare in the main channel of Suisun Bay (Burau 1998). Monismith et al. (1996) showed that water depth and the steepness of the longitudinal density gradient determine the likelihood and strength of gravitational circulation, and Monismith et al. (submitted) showed that the increase in gravitational circulation with seaward X_2 resulted in a much larger increase in landward salt transport than expected by theory, probably because of the bay's bathymetry. The increase in gravitational circulation with seaward X_2 could have a profound effect on organisms that recruit from the coastal ocean or move up-estuary to rear (e.g., starry flounder, bay shrimp, Pacific herring, Baxter et al. 1999), or those that migrate vertically to maintain position in the Low-Salinity Zone (e.g., copepods and mysids, Kimmerer et al. 1998, in press; larval fish, Bennett et al. submitted). This statement can be broadened to include SIPS as well as lateral effects such as residual circulation that is up-estuary in one channel and down-estuary in another.

Low-Salinity Zone mechanisms are related to the previous class, but have received more research attention. In particular, the lack of persistent tidal asymmetry when the LSZ is in Suisun Bay (its usual location) means that organisms must migrate vertically to maintain position. Although this migration has been observed in many species, questions remain about the contribution of this migration to retention (Kimmerer et al. 1998, in press; Bennett et al. submitted).

Food supply: Several mechanisms are related to the availability of food for organisms in higher tropic levels. The food supply may be enhanced by high flow through more rapid transport or through a variety of intermediate effects. In addition, any of the above mechanisms could apply to foodweb organisms that support the species of interest. This class of mechanisms also includes the rate of supply of nutrients and organic matter resulting in stimulation of phytoplankton or bacteria; however, at present these particular mechanisms do not appear to be important.

Specific objectives Ultimately we want to know what factors control the distribution and abundance of estuarine species, how these factors vary with X_2, and how they might change in the future. This statement of research goals is too broad for even a large research program, so we constrain the objectives of the overall research program to the following two fundamental questions for each species:

I. What mechanisms cause the abundance or survival of a species to vary with freshwater flow and X_2?

II. How will these mechanisms change with various planned or expected changes in the estuary?

The first question is more central to refining protections using X_2, and more readily answered, than the second. However, the first question does not necessarily address the consequences of changes in the system not directly associated with X_2. Addressing both questions is essential for ecosystem rehabilitation.

The objectives of the work described in this proposal (Phase I) are to develop a research plan to answer the questions above, and to begin model analyses that will form the basis for the research.

The geographic scope of this plan includes the San Francisco Estuary from the Delta to the coastal ocean. Effects of flow in upstream areas are excluded from the scope of this study.

3. Approach

The proposed project has two elements with different requirements and schedules. They are linked because the outcomes of the modeling studies will provide guidance for the planning effort. Below we describe the planning activities and the model-based activities proposed here. In the following sections we describe some of the research that will likely be necessary in subsequent years of the program, i.e., the topics to be addressed in the planning phase.

Task 1. Planning: The fundamental questions will be answered through specific, focused research projects outlined briefly below. The goal of this planning effort is to develop a study design for the individual projects. Each of them needs considerable development including data analysis and modeling to pave the way for the most efficient design possible. These activities must be undertaken in a coherent program of research rather than piecemeal. Individual projects may be conducted by different organizations. Nevertheless, the design and execution of each project must support the overall program so that a comprehensive understanding emerges of how flow affects the estuarine ecosystem, and how that might change over time. Table 2 lists some hypotheses that may be tested, along with a brief description of the associated mechanism and some potential approaches, as well as dependencies among research topics.

The planning process relies heavily on expert opinion, not about the mechanisms themselves, but about the likelihood that investigating a particular mechanism will yield important insights. We also anticipate that the scientific program developed from this plan will take advantage of serendipity, following leads that develop during the progress of the research, and varying according to flow and other conditions. This means that this plan must be flexible, revisited periodically (e.g., every 3 years), and adjusted to account for the new knowledge that develops. Priorities for plan development and execution are based on the following criteria:

1. High likelihood of answering one or more of the research questions
2. Application to more than one species
3. Application to a species of concern (e.g., delta smelt, winter-run and spring-run salmon)
4. Use of existing data to test hypotheses or refine questions

Based on the above criteria, activities will be selected for each year to conduct data analysis where existing analyses have been insufficient to resolve the questions at hand, and fieldwork to answer questions for which either data analysis has gone as far as it can go, or there are no data useful in answering the question. This will allow for simultaneous activities in the laboratory and in the field at various locations and involving various groups of researchers.

The planning process will be based on the IEP's model of a Project Work Team (PWT), augmented by a Steering Committee of distinguished scientists. This format has worked well in the past, with successful, interdisciplinary results produced by the Estuarine Ecology Team (e.g., EET 1995, 1997), the Entrapment Zone Project Work Team (Kimmerer et al. 1998, in press, Bennett et al. Submitted, Burau 1998), and the Yolo Bypass Team (Sommer et al. 1997, 2001). The PWT will consist of the proponents of this project, biologists and other scientists from IEP member agencies, and other researchers.

This PWT will meet monthly to begin isolating the mechanisms and determining the most promising research avenues and approaches. Each meeting will focus on a particular issue, and the product of the meeting will be a brief working paper discussing the subject, the findings, and the next steps to be taken. Other scientists with relevant expertise will be invited to participate in each of these meetings, and any other agency, university, or other scientists will be welcome, but the emphasis will be on the products rather than on the scientific exchange itself.

The Steering Committee will be established to oversee the planning and implementation of this research program. The Committee will consist of four distinguished scientists, with at least one from outside the state; we have invited and received commitments from Dr. Randy Brown (DWR, Retired), Dr. Tom Powell (U.C. Berkeley), and Dr. Tim Hollibaugh (University of Georgia). An additional member will be selected and invited, probably somebody with a background in fish ecology. The Steering Committee members will be asked to advise on development and re-evaluation of the research program and to review written products of the PWT.

The planning process will proceed in two stages. In the first, the planning effort itself will be mapped out, and the model studies proposed here (Task 2) will be revisited for potential improvements. Initial needs for further data analysis will be determined, and a program designed to meet those needs. This process will build upon several efforts now in progress; in particular, IEP has agreed to fund two postdoctoral associates to analyze data on fish and macroinvertebrates in the estuary, and these projects may provide important insights for the fish-X_2 planning effort.

The result of the first stage will be a presentation to the IEP's Research Forum, a new entity to be established in early 2002, and to the Steering Committee. This will provide an opportunity for review and feedback, after which a written work plan will be presented and used as the basis for a proposal for the second phase of this program. Depending on the start date of Phase I, this proposal will be submitted in 2002 or 2003 to either the Ecosystem Restoration Program or the CALFED Science Program.

The second stage will focus on the longer-term research effort. Each of the potential mechanisms will be examined in turn, and a tentative research design will be developed. This design will follow the criteria above, and will take advantage of contrasts among species with similar life histories (e.g., delta smelt and longfin smelt) or habitats (e.g., mysids and copepods). Next, the required resources will be estimated. Any requirements aside from funding (e.g., ship time, equipment, technological development) will be determined, and a process started to investigate their availability. This information will be used to determine the staging of the research. Throughout the planning process, an effort will be made to find opportunities for collaboration, leverage of other funding sources and projects, and partnerships.

The outcome of this stage will be a research plan laying out the projects that will need to be completed to answer the research questions as fully as feasible. The sequence of the research projects will be determined according to the four criteria above, and the individual projects to be conducted first will be described in the greatest detail. The plan will include a provision for altering course as more is learned about the estuary's ecology.

Task 2. Model Studies The goal of the model studies is to extend existing data to test some of the hypotheses, and to help design field studies for testing other hypotheses. These hypotheses will begin to address both of our research questions for several species.

The numerical model chosen for this study is the three-dimensional TRIM model (TRIM3D). A three-dimensional model is required for this project because the interaction of vertical migration or position and three-dimensional hydrodynamics probably plays a substantial role in abundance or survival of several estuarine biological populations. In addition, one- and two-dimensional hydrodynamic models rely strongly on horizontal dispersion coefficients to represent the mixing resulting from inherently three-dimensional processes. The strength of physical dispersion mechanisms in San Francisco Bay can increase by orders of magnitude as flow and stratification increase (Monismith et al. submitted). One- or two-dimensional models would require flow-dependent dispersion coefficients to represent this observation, making these models applicable only to conditions for which dispersion coefficients have been determined, i.e., not with significant changes in bathymetry or flow. A three-dimensional model can account for flow-dependence of mixing without the use of empirically determined dispersion coefficients.

The TRIM (Tidal Residual, Intertidal, Mudflat) model is the most widely applied and best documented three-dimensional hydrodynamic model of the San Francisco Estuary. The numerical method and mathematical properties of the TRIM model have been thoroughly documented (Casulli, 1990; Casulli and Cattani, 1994; Gross et al. 1998). The numerical model has been widely applied to San Francisco Bay and the Sacramento-San Joaquin Delta by the US Geological Survey and Stanford University (Casulli and Cheng 1992, Cheng et al. 1993, Gross et al. 1999a, Gross et al. 1999b). Currently the model is applied as part of the NOAA Ports project (Cheng 1998), in several studies of the proposed expansion of the San Francisco airport, and in studies of the Sacramento-San Joaquin Delta. TRIM3D is well-suited to simulations of hydrodynamics and salinity in the San Francisco Estuary because it is highly efficient, allowing high-resolution simulations on a modest personal computer, and robust, providing confidence that the model will provide stable results for a wide range of environmental conditions. Recent applications indicate that the numerical model can simulate the salinity field in the San Francisco Estuary under a wide variety of conditions with no changes in model parameters.

Two sets of model studies are proposed. These are stated in the form of hypotheses, but the analyses will be aimed less at formal tests of these hypotheses than at estimates of the likelihood and the parameters of the various, potentially alternative, conceptual models.

Estimate the distribution of estuarine habitat: A popular class of mechanisms for several of the fish-X_2 relationships is the hypothesized increase in habitat quantity or accessibility with seaward X_2 (Table 2). Therefore we propose to test the hypothesis: **1) The area or volume of habitat for several estuarine-dependent species increases as X_2 moves seaward**.

This hypothesis will be tested by a combination of data analysis and modeling. Habitat will be defined by depth, salinity, temperature, and season, separately for different life stages of each species. Additional habitat features for which data are insufficient will be noted but not included in the analysis (e.g., substrate, fronts, water velocity). Existing data on distributions of key species (potentially all of the species listed in Table 1) will be analyzed to determine their ranges along each of the habitat axes. These ranges must be determined carefully since they change by season (and by developmental stage of the species), and will at least appear to change with population abundance. The exact form of the description of habitat cannot be predicted until some of these analyses have been completed, but we are considering a probabilistic description. In this description, the probability of an individual of species X inhabiting each salinity/temperature/depth/season combination will be calculated from the available data. This probability will be high near the center of the population's distribution, and near zero at the limits.

The salinity numerical model will then be used to develop maps or tables of habitat combinations as a function of X_2. These maps or tables will then be used to determine the quantity of habitat available based on the patterns determined through analysis of the biological data. This quantity of habitat will then be plotted against X_2, and the result compared with the relationship of species X abundance to X_2. A similar relationship of abundance and habitat quantity will be taken as evidence supporting the habitat mechanism.

Examine the influence of asymmetric residual circulation on landward movement and retention Several related classes of mechanisms for fish-X_2 relationships incorporate some effect of residual circulation patterns including gravitational circulation. These include retention of planktonic organisms in and near the Low-Salinity Zone (LSZ), and entrainment and landward movement of larvae spawned in the lower estuary or coastal ocean. We will focus our efforts within the estuary, lacking data either for calibration of the numerical model or assessment of the supply rate of larvae at the mouth of the estuary.

Although we have learned a great deal about estuarine circulation and retention, the Entrapment Zone Study was unable to show that the observed tidal migration of copepods was sufficient to offset seaward net flow, or how retention might change as X_2 moved seaward (Kimmerer et al. 1998, in press, Bennett et al. submitted). To resolve these issues requires a numerical model to extend the information gained to parts of the estuary not sampled during that study. This is because retention is a Lagrangian problem (i.e., having to do with the way water and associated particles move) but most of the measurements, especially of velocity, were necessarily Eulerian (i.e., at fixed points). A numerical model is necessary to translate between these frames of reference.

We propose to test the following hypotheses for planktonic organisms residing in or near the LSZ: **2a) Retention is due to the interaction between vertical movement or position of organisms and vertical variation in the flow field; 2b) Retention is due to the interaction between vertical movement or position and lateral circulation cells; and 2c) Retention increases as X_2 moves seaward because of increased gravitational circulation.**

All of these hypotheses will be tested in numerical experiments using the TRIM3D numerical model. The numerical model will be seeded with particles having the selected behavior, i.e., either migrating tidally or remaining near the bottom (depending on species and X_2). The numerical model will be run for a period of time with steady conditions of outflow and predicted tidal oscillations, and the spatial extent, fluxes, and daily loss rates of the planktonic population will be determined. Fluxes of particles will also be compared between alternative pathways (e.g., Suisun ship channel and Suisun Cut) to determine the importance of lateral circulation cells. For testing hypothesis 2c, the numerical model will be run for several alternative values of outflow.

Several species reproduce in the lower estuary or coastal ocean and then move into the upper estuary to rear. Under the Residual Circulation class of mechanisms, gravitational or other asymmetric residual circulation increases as X_2 moves seaward, resulting in greater entrainment of larvae into the estuary or more rapid movement up the estuary, resulting in larger populations. Existing data are insufficient to examine this question fully. Samples have not been taken recently for larvae, and the larvae of *Crangon franciscorum* have not been distinguished from those of other shrimp (K. Hieb, CDFG, pers. comm.). Thus, data may be inadequate to "seed" the numerical model with particles having appropriate behavior. Instead, we propose to explore the possibilities using what data are available, including data on vertical distribution and movements of similar species from other estuaries, as well as other alternative behaviors. The results of this series of numerical experiments can be used to constrain the likely behaviors, thereby providing input to a field study to be conducted as part of the larger program.

For example, the bay shrimp *C. franciscorum* appears to rise off the bottom during strong ebb or flood tides (Kimmerer et al. in press). The numerical model can be seeded with particles having this behavior in Central Bay and the resulting distribution of particles compared with observed distribution of shrimp. Other behaviors can be tried in the same way, and the results can be contrasted. The behavior(s) giving the most accurate result in terms of final distribution will then be set up as the target of field studies. On the other hand, if these behaviors do not result in an increase in entrainment with increasing flow, then this mechanism appears unlikely and field work may not be warranted. The hypothesis to be tested for species that move ontogenetically up the estuary is: **3) Movement up the estuary increases with seaward X_2.** Although this mechanism could conceivably be ruled out by numerical model studies, a positive finding would require field verification of migratory behavior.

An underlying assumption behind several of the mechanisms discussed above is that gravitational circulation increases in strength or frequency as X_2 moves seaward (see Conceptual Models above). Gravitational circulation is pivotal in some of the proposed mechanisms for fish-X_2 relationships. Therefore we propose to use the numerical model to test the hypothesis: **4) The intensity of gravitational circulation increases sharply with seaward X_2 because of the bathymetric profile of the estuary.** This hypothesis will be tested by running the numerical model under various flow conditions and examining model output for the occurrence and strength of tidally-asymmetric flow at various cross-sections. Model behavior will be compared with the statistical and theoretical treatments by Monismith et al. (submitted).

Activities for subsequent years The purpose of the planning effort (Task 1 in Phase I) is to lay out a program for research in subsequent years. Potential key elements of the program are presented below *as potential examples only*, to give a sense of the kinds of activities to be planned. The actual selection of activities will be made during the planning process.

Many of the alternative conceptual models can be examined using generally similar research approaches. This suggests the program be organized not around individual models, but around consistent approaches such as data analysis, hydrodynamic modeling, and synthesis, which would continue at some level throughout the program. This will leave a relatively small number of individual, 1-3-year field and experimental projects to answer individual questions.

Common themes These research themes will probably continue through the entire program.

Data analysis: A lot has been learned about this estuary through the application of state-of-the-art techniques of statistical and exploratory analysis. This approach will no doubt continue to provide new insights. We therefore incorporate this approach as a long-term, fundamental element of this research program, beginning with Phase I (see above).

Hydrodynamic modeling: Initial numerical modeling efforts are planned for the first phase of this program, as discussed above. Numerical modeling must be integrated with field research for interpreting and extending results and maximizing efficiency of field work.

Comparative analysis: the scope of this program suggests special attention to comparative studies, e.g., comparison among species, or comparison with other estuaries including collaboration with scientists from these locations. This process has already begun with 2-day sessions on effects of freshwater flow at the Estuarine Research Federation meetings in 1997 (organized by Kimmerer) and 2001 (upcoming, invited participation by Kimmerer).

Population modeling: As with data analysis, we anticipate an ongoing need for a modeling framework to this program. Modeling will be used not merely as a tool for simulating populations, but as a process by which key uncertainties and essential information gaps are identified. This implies close coordination among model-builders, field workers, and data analysts. In addition, we will explore the use of coupled hydrodynamic-population models as tools to investigate our developing conceptual models of physical influences on populations.

Examples of individual research projects*:* Here we describe briefly the research projects potentially useful to examine specific conceptual models. These are preliminary discussions of projects that are likely to be supported in the planning process, but the final mix of projects has not been determined. In many cases the studies have dependencies (Table 2) that require a sequential approach.

Physical retention The approach will be conceptually similar to that taken in the Entrapment Zone study (Kimmerer et al. 1998, in press). Gravitational circulation and other residual flow will be measured using in-situ Acoustic Doppler Current Profilers (ADCPs) and density profiles with CTD's. Movement of animals will be determined by combining vertical distribution of animals and velocity. Other variables (chlorophyll, nutrients, organic carbon) will be measured in vertical profiles to estimate fluxes of these materials. Fluxes will be determined by the use of numerical hydrodynamic models (above) seeded with particles having the observed vertical distribution and movement. These numerical model results would be compared with observed longitudinal distributions, then tested using alternative flow scenarios.

Growth, condition and survival rates: The extent to which growth rates of juvenile fish and invertebrates respond to environmental conditions (food, habitat) will be investigated. Otolith analyses will provide the age and growth history of individual fish. Evaluation of the condition of these fish will use histopathology and related techniques (Bennett et al. 1995). These will be used to compare among sites (regions believed to represent favorable and unfavorable habitat) and years of good and poor production. Survival will be estimated using cohort analysis. Growth rates of zooplankton, measured using standard incubation techniques, will be used to investigate the potential "bottom-up" effects of increased food supply.

Reproductive rates: The reproductive rates of selected species of fish and invertebrates will be investigated through field sampling for fecundity and analyzed as for growth rates.

Predation studies: Predatory interactions will be investigated for selected abundant species. Estimates of consumption rate will be based on a combination of energetics models and gut evacuation time and fullness for predators. Predation rates on specific prey will be determined from the proportion of those prey in predator guts. These rates will then be analyzed for differences among habitats and years, and dependence on environmental conditions. Laboratory studies will be conducted to determine the influence of turbidity on predation rates.

Entrainment: Entrainment losses of juvenile fish at the export facilities can be obtained from the salvage records, but additional sampling would be needed to determine losses of eggs and larvae. In addition, experiments will be needed to estimate entrainment in delta agricultural diversions. Population size can be obtained from existing monitoring programs after calibration to account for net avoidance. The proportion of major populations lost to exports would be related statistically to flow and export conditions. The effect of salvage losses on populations would be estimated using population models taking into account the existence of density-dependent factors and other factors affecting abundance.

Large-scale experimental manipulation   Most of the variability in the estuary is beyond human control, but there may be opportunities for large-scale experiments ("adaptive probing") in the Delta, particularly involving effects of entrainment. These experiments could be conducted in conjunction with the Environmental Water Account or Environmental Water Program.

4. Feasibility

The feasibility of the individual research projects will be addressed once they have been planned. The planning part of Phase I is clearly feasible in that it formalizes activities that have been going on for many years. The modeling part of Phase I is feasible in that the numerical model is already running, and the changes needed for the numerical experiments in Phase I are relatively straightforward.

5. Performance Measures

Ultimately, we hope to be able to refine the X_2 standard to make it more efficient, precise, and effective. However, this is a research project, and its success of this project will be determined by information output in the form of scientific publications, reports, research plans, and oral presentations, which are listed in Section 7.

6. Data Handling and Storage

Data developed in this project will be maintained in several locations on computer disks and occasionally transferred to CD-ROM for long-term storage. Data will be placed in the IEP database once publications have been submitted and accepted, but within a year after completion of this project.

7. Expected Products/Outcomes

The following products are expected from the proposed work:

1. Two or more oral reports to the new IEP Research Forum and the annual IEP workshop at Asilomar
2. Written report on data analysis and modeling needs
3. Written report on the outcome of the planning effort, possibly submitted to the new CALFED online publication series.
4. At least two presentations at national meetings, including the CALFED Science Conference.
5. At least two papers submitted for publication in peer-reviewed journals; one would be on modeling of the flow-X_2 relationship, another on the model results of the LSZ data, and possibly a third on flow-habitat relationships.
6. Periodic updates in the IEP Newsletter.
7. Research plan describing the long-term research effort.

8. Work Schedule

We assume a start date of 1 September 2002, although our previous experience suggests flexibility is warranted. We will not start work until a contract is in place. For Task 1 (Planning), the Project Work Team and Steering Committee will be formed immediately, and the first meeting will be for the purpose of laying out the work schedule and the timetable for deliverables. If the project begins in time, we will present the initial plan at the CALFED Science Conference in 2002. However, it is more likely this will be presented at the February 2003 IEP conference or later. A draft research plan will be prepared within one year after the start of this project. This plan will be further refined in Year 2, and will be subject to amendment as the work progresses and more is learned.

Task 2, the model study, will begin with limited hydrodynamic and salinity calibration and validation, analysis of abundance and distribution data, and a test of Hypothesis 1, in Year 1. The results of that test will be used to refine the work plan, since it may either resolve the issue of habitat space or suggest additional work. During Year 2 we will test the hypotheses related to the interaction of organism movement and vertical and lateral variation in velocity.

B. Applicability to CALFED ERP and Science Program Goals and Implementation Plan and CVPIA Priorities

1. ERP, Science Program and CVPIA Priorities

The proposed work cuts across a number of CALFED goals and PSP priorities. According to CALFED's Ecosystem Restoration Program Strategic Plan,

> "Current management of the Bay-Delta system is based largely on a salinity standard (the "X_2" standard). This standard is based on empirical relationships between various species of fish and invertebrates and X_2 (or freshwater flow in the estuary). As with all empirical relationships, these are not very useful to predict how the system will respond after it has been altered by various actions in the Delta, including altered conveyance facilities. This implies a need to determine the underlying mechanisms of the X_2 relationships so that the effectiveness of various actions in the Delta can be put in context with this ecosystem-level restorative measure."

As stated or implied by this paragraph, three problems exist with the current system of management based on the X_2 relationships. First, the relationships are empirical, and therefore predictive only to the extent that past conditions can be extrapolated to the future. Second, these relationships give no information about how the system might respond, or how the relationships might change, with some of the anticipated changes due to CALFED actions or other long-term change. Third, since the mechanisms are largely unknown, their efficiency in terms of water use is also unknown, with the corollary that they could possibly be made more efficient or effective if we knew better how they worked.

The proposed research is specifically aimed at the following PSP priority:

BR-7: Improve scientific understanding of the linkages between populations of at-risk species and inflows, especially relative to regulatory measures like "X_2."

It also addresses directly the following priorities:

DR-7: Protect at-risk species in the Delta using water management and regulatory approaches.
DR-8: Understand the implications for Delta water issues of climate and hydrologic variability.

BR-6: Protect at-risk species in the Bay using water management and regulatory approaches.
BR-8: Use monitoring, evaluations of existing monitoring data and new investigations to develop improved strategies for restoring Bay fish populations and at-risk species.

2. Relationship to Other Ecosystem Restoration Projects.

The proposed project builds on a long and distinguished record of research and monitoring in the San Francisco Estuary and watershed. In recent years some significant advances have been made in understanding the estuarine ecosystem using ERP and other restoration funds. We expect to build on those efforts, particularly recent and ongoing research on organic carbon in the Delta (J. Cloern, J.T. Hollibaugh), value of river bypasses as habitat for estuarine species (T. Sommer), hydrodynamics of the Delta and Suisun Bay (J. Burau), biology of the Low-Salinity Zone (W. Kimmerer, W. Bennett, J. Burau, J.T. Hollibaugh), and effects of introduced species in the estuarine foodweb (Kimmerer, Bennett, J. Thompson, and many others).

3. Requests for Next-Phase Funding.

Not applicable.

4. Previous Recipients of CALFED Program or CVPIA funding.

Effects of Introduced Clams on the Food Supply of Bay-Delta Fish Species (Kimmerer, CALFED). 45% complete. This is a modeling and analysis exercise using existing data. One paper was submitted in September 2001 on how the fish-X_2 relationships have changed with the introduction of the clam *Potamocorbula amurensis*. We have begun developing a model of lower trophic levels and how they may be affected by the clam.

Effects of Introduced Species of Zooplankton and Clams on the Bay-Delta Food Web (Kimmerer, Bennett, S. Bollens, CALFED). 20% complete. This project is related to the modeling/data analysis project above, and is intended to extend and amplify those results using new experimental and field data. Experimental work has been conducted on predation among zooplankton species, feeding relationships, and zooplankton reproductive and growth rates and their dependence on food supplies.

Determining the Biological, Physical and Chemical Characteristics of Ballast Water Arriving in the San Francisco Estuary (Kimmerer, A. Cohen). Contract pending. This project will be conducted by a postdoctoral associate under the supervision of Kimmerer.

Role of contaminants in the decline of delta smelt in the Sacramento-San Joaquin estuary (Bennett, CALFED). 90% complete. This project is related to the proposed work in that Bennett and colleagues have been developing the tools for quantifying the potential effects of poor food supply and contaminant exposure on the growth and survival of individual delta smelt collected in the IEP abundance surveys. Final report to be submitted to CALFED in October 2001. One paper to be submitted by December 2001, and portions of the work to be included in the Ph.D. dissertation of a UCD graduate student in Ecology by 2003.

5. System-Wide Ecosystem Benefits

No direct benefits since this is a research project. Substantial ecosystem benefits may occur if results of this research show ways to improve the efficiency or effectiveness of the X_2 standard. In addition, a possible benefit of this research is the demonstration of how future alterations of the physical system may interact with the X_2 relationships in favorable or unfavorable ways. This information can be used to avoid costly mistakes.

C. Qualifications

This project will be conducted primarily by Kimmerer and Gross, with assistance by Bennett. Various agency participants on the proposed Project Work Team will not be compensated under this proposal. Kimmerer will be lead Principal Investigator, responsible for overall conduct of the project, coordination with the Steering Committee, data analysis, and synthesis of results. Gross will be responsible for the hydrodynamic and particle-tracking modeling work. MacWilliams and Schaaf will assist Gross with development of the model. Bennett will be responsible for development of conceptual models and will help with organizing the PWT. All three will participate in publishing results of analyses.

Note regarding conflicts: Kimmerer has a potential conflict of interest in that he is co-chair of the CALFED ERP Science Board, and an advisor to the CALFED Lead Scientist on the Environmental Water Account. The Science Board position has been determined by CALFED's attorney not to constitute a conflict provided the member does not actively participate in development of the Implementation Plan, or in the evaluation of proposals. Kimmerer has not been involved in these activities.

Biographical sketches (sample publications are in Literature Cited).

Dr. William J. (Wim) Kimmerer received his B.S. degree in chemistry from Purdue University and his Ph.D. in biological oceanography from the University of Hawaii. After positions at the Hawaii Institute of Marine Biology, University of Melbourne, and BioSystems Analysis Inc., an environmental consulting firm, he became a Senior Research Scientist at the Romberg Tiburon Center, San Francisco State University. Dr. Kimmerer's expertise is in marine and aquatic ecosystems, including physical, chemical, and biological oceanography, ecology of estuaries and lagoons, fisheries management, simulation modeling, and statistical analysis of data. His current research interests include estuarine ecology, zooplankton ecology, population dynamics of fish such as salmon and striped bass, and the effect of anthropogenic influences such as freshwater flow on estuarine and marine systems. Dr. Kimmerer has written over 80 papers and technical reports on these and related topics, including the draft CALFED White Paper on Open Water Processes. He has been closely involved with the Interagency Ecological Program, acting as chair of the Estuarine Ecology Team and the Entrapment Zone study team. He was a member of the CALFED Ecosystem Restoration Program Core Team, developing a strategic plan for the program, and is now a member of the Independent Science Board.

Dr. William A. (Bill) Bennett received B.S. and Master's degrees in population biology from the

University of Massachusetts at Boston, and Ph.D. in ecology from the University of California at Davis (UCD). Dr. Bennett has been a Postdoctoral Researcher at the Bodega Marine Laboratory and is currently an Assistant Research Ecologist with the John Muir Institute of the Environment at UCD. Bennett has worked for over a decade on the ecology of fishes in the San Francisco Estuary, identifying factors affecting the survival of larval striped bass, the effects of the exotic inland silverside on delta smelt; larval fish behavior in the low salinity zone, and the effects of the ocean environment on the decline of striped bass in the estuary. Since arriving at UCD he has worked closely with the Interagency Ecological Program (IEP). He is an active member of IEP's Estuarine Ecology Team, Entrapment Zone Study Team, and Contaminant Effects Team. Recently, Dr. Bennett was the author of the CALFED white paper on delta smelt, and the co-technical program chair for the first CALFED Science Conference.

Dr. Edward S. Gross received his B.S. degree in civil engineering from University of California, Los Angeles and his M.S. and Ph.D. in civil and environmental engineering from Stanford University. Dr. Gross was a Postdoctoral Researcher at Stanford University's Environmental Fluid Mechanics Laboratory and is currently an independent consultant specializing in three-dimensional hydrodynamic modeling of San Francisco Bay. He has developed and applied state-of-the-art numerical methods for simulation of estuarine hydrodynamics for over a decade and has published several papers on numerical model development and application of numerical models to San Francisco Bay. Dr. Gross is currently involved in the environmental impact study of the proposed SFO Runway Reconfiguration Program and other three-dimensional hydrodynamic and water quality modeling projects.

Michael MacWilliams graduated Magna Cum Laude from the University of Notre Dame in 1997 with a B.S. in Engineering and Environmental Science and a B.A. in English. In 1998, he completed his M.S. in Civil and Environmental Engineering at Stanford University, where he is currently working to complete his Ph.D. dissertation on "Three-dimensional Hydrodynamic Modeling of River Systems." Prior to Stanford, Mr. MacWilliams worked for Computer Sciences Corporation doing numerical development of satellite tracking programs used by NASA. He has extensive experience in numerical and hydrodynamic modeling and has experience using GIS, MATLAB, and other visualization software.

Daniel J. Schaaf received a B.S. in Civil Engineering from San Jose State University in 1993 and a M.S. in Water Resources Civil Engineering (SJSU) in 1997. Mr. Schaaf has worked in the water resources field since 1988. He received his professional engineering license (P.E.) in 1997. His experience has concentrated on modeling (numerical and physical) and the use of Geographic Information Systems (GIS) to better analyze model data. Mr. Schaaf coauthored the paper "Humboldt Beach and Dune Monitoring" that was presented at Sand Rights '99. His primary interest is in further developing the relationship between hydrodynamic models and GIS.

D. Cost

The budget is submitted separately. No cost-sharing is contemplated for Phase I.

E. Local Involvement

Not required

F. Compliance with Standard Terms and Conditions

The applicants will comply with the standard State and Federal contract terms described in Attachments D and E of the PSP.

G. Literature Cited

Aleem, A. A. 1972. Effect of river outflow management on marine life. Marine Biology **15**:200-208.

Baxter, R., K. Hieb, S. DeLeon, K. Fleming, and J. J. Orsi. 1999. Report on the 1980-1995 fish, shrimp, and crab sampling in the San Francisco Estuary, California. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 63., Sacramento

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

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

Burau, J. R. 1998. Results from the hydrodynamic element of the 1994 entrapment zone study in Suisun Bay. pp. 13-62, Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 56. Sacramento CA

Casulli, V. 1990. Semi-implicit finite difference methods for the two-dimensional shallow water equations. Journal of Computational Physics. 86, 56-74.

Casulli, V., and E. Cattani. 1994. Stability, Accuracy and Efficiency of a Semi-Implicit Method for Three-Dimensional Shallow Water Flow. Computers Math. Applic. 27(4): 99-112.

Casulli, V., and R.T. Cheng. 1992. Semi-Implicit Finite Difference Methods for Three-Dimensional Shallow Water Flow. International Journal for Numerical Methods in Fluids. 15:629-648.

Cheng, R.T., V. Casulli, and J.W. Gartner. 1993. Tidal, Residual, Intertidal Mudflat (TRIM) Model and its Application to San Francisco Bay, California. Estuarine, Coastal, and Shelf Science 36:235-280.

Cheng, R.T., D. McKinnie, C.English, and R.E. Smith. 1998. An Overview of San Francisco Bay Ports. Ocean Community Conference ’98, Proceedings, Marine Technology Society. 1054-1060.

Cloern, J. E. 1996. Phytoplankton bloom dynamics in coastal ecosystems: a review with some general lessons from sustained investigation of San Francisco Bay, California. Reviews of Geophysics 34:127-168.

Drinkwater, K. F., and K. T. Frank. 1994. Effects of river regulation and diversion on marine fish and invertebrates. Aquatic Conservation: Freshwater and Marine Ecosystems **4**:135-151.

Estuarine Ecology Team (EET) 1995. Working conceptual model for the food web of the San Francisco Bay/Delta estuary. Interagency Ecological Program for the San Francisco Bay/Delta, Sacramento, Technical Report 42.

Estuarine Ecology Team (EET) 1997. An examination of the likely mechanisms underlying the "fish-X_2" relationships. Interagency Ecological Program for the San Francisco Bay/Delta, Sacramento, Technical Report 52.

Gross, E.S., V. Casulli, L. Bonaventura, and E.S. Koseff. 1998. A semi-implicit method for vertical transport in multidimensional models. International Journal for Numerical Methods in Fluids, 190, 802-817.

Gross, E.S., J.R. Koseff, and S.G. Monismith. 1999a. Evaluation of Advective Schemes for Estuarine Salinity Simulations. Journal of Hydraulic Engineering 125 (No.1): 32-46.

Gross, E.S., J.R. Koseff, and S.G. Monismith. 1999b. Three-Dimensional Salinity Simulations of South San Francisco Bay. Journal of Hydraulic Engineering 125 (No. 11): 1199-1209.

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

Jassby, A. D., and T. M. Powell. 1994. Hydrodynamic influences on interannual chlorophyll variability in an estuary: upper San Francisco Bay-Delta (California, U.S.A.). Estuarine, Coastal, and Shelf Science 39:595-618.

Kimmerer, W.J. 1998. A Summary of the Current State of the X_2 Relationships. IEP newsletter, Autumn 1998.

Kimmerer, W.J. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Submitted to Oecologia.

Kimmerer, W.J., W.A. Bennett, and J.R. Burau. Persistence of Tidally-oriented Vertical Migration by Zooplankton in a Temperate Estuary. In Press, Estuaries.

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

Kimmerer, W. J., J. H. Cowan, Jr., L. W. Miller, and K. A. Rose. 2000. Analysis of an estuarine striped bass population: Influence of density-dependent mortality between metamorphosis and recruitment. Canadian Journal of Fisheries and Aquatic Sciences 57:478-486.

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

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

Kimmerer, W. J., and J. J. Orsi. 1996. Causes of long-term declines in zooplankton in the San Francisco Bay estuary since 1987. Pages 403-424 in J. T. Hollibaugh, editor. San Francisco Bay: The Ecosystem. AAAS, San Francisco.

Kohlhorst, D. W., L. W. Botsford, J. S. Brennan, and G. M. Caillet. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (*Acipenser transmontanus*). Pages 277-293 in P. Williot, editor. Acipenser. CEMAGREF Publ.

Monismith, S. G., J. R. Burau, and M. Stacey. 1996. Stratification dynamics and gravitational circulation in northern San Francisco Bay. Pages 123-153 in J. T. Hollibaugh, editor. San Francisco Bay: The Ecosystem. AAAS, San Francisco.

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

Nixon, S. W., C. A. Oviatt, J. Frithsen, and B. Sullivan. 1986. Nutrients and the productivity of estuarine and coastal marine systems. Journal of the Limnological Society of South Africa

12:43-71.
Postma, H. 1967. Sediment transport and sedimentation in the estuarine environment. Pages 158-179 in G. H. Lauff, editor. Estuaries. AAAS, Washington.
Rice, J., and K. Newman. 1997. Statistical model for survival of chinook salmon smolts outmigrating through the lower Sacramento-San Joaquin system. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 59 Sacramento.
Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 126:961-976.
Sommer, T. R., M. Nobriga, B. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58:325-333.
Sutcliffe, W. H., Jr. 1972. Some relations of land drainage, particulate material, and fish catch in two eastern Canadian bays. Journal of the Fisheries Research Board of Canada **29**:357-362.
Unger 1994. Quantifying salinity habitat of estuarine species. IEP Newsletter, Autumn 1994

Figure 1. Schematic diagram illustrating alternative conceptual models of how flow or X_2 affect production of fish and other biological populations. See text for details. Signs of effects may be positive or negative.

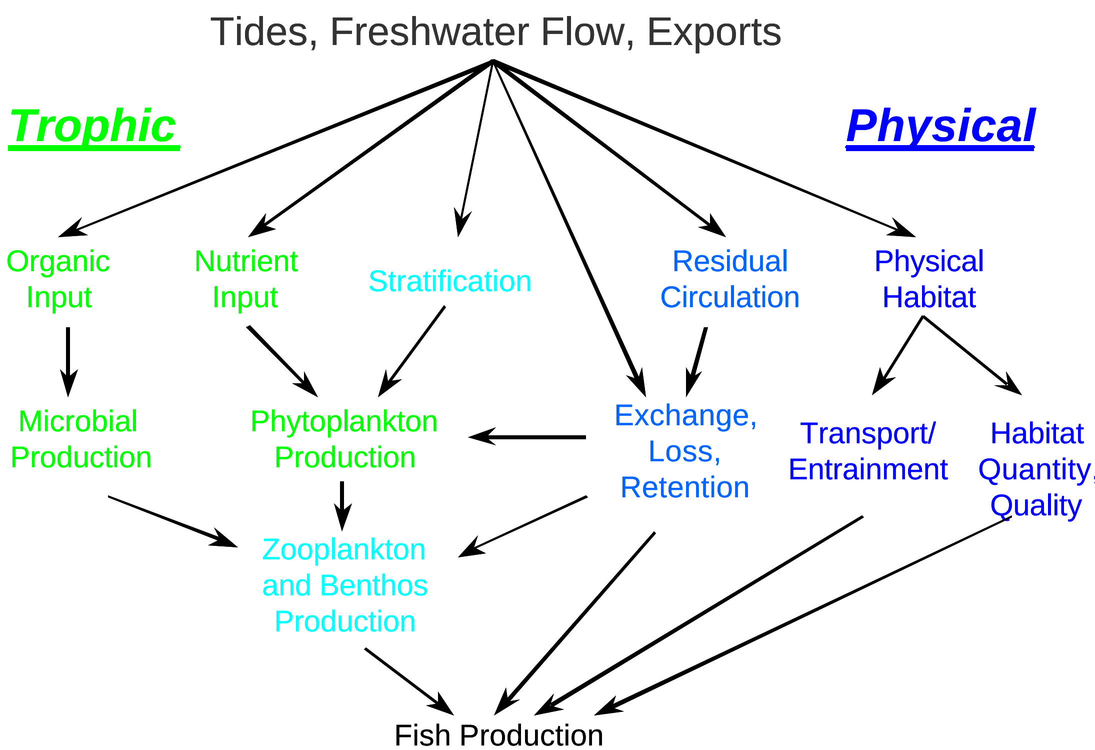

Table 1. Summary of "fish-X_2" relationships. Parameters of statistical models for biological response variables are given with estimated 95% confidence limits. Values in bold are significantly different from 0 at p< 0.05 (two-tailed). "Step" refers to a step change in 1987-88, possibly related to the influence of the clam *Potamocorbula amurensis.* Where two values are given for the X_2 effect, a significant interaction was detected between the X_2 effect and the step, so the first value is up to 1987 and the second value is after 1987. The statistical model for delta smelt split the years in 1981-82 and there was no apparent clam effect. S under Response Variable refers to salinity range.

Taxonomic group	**Response Variable**	**Averaging Period**	**N**	**X_2**	**Step**
Phytoplankton	Chlorophyll (S = 0.5-6)	Survey Mar-May	30	-0.0008 ±0.009	**-0.49 ±0.21**
Phytoplankton	Chlorophyll (S = 0.5-6)	Survey June-Oct	32	-0.003 ±0.010	**-0.62 ±0.17**
Eurytemora affinis (copepod)	Abundance + 10 (S = 0.5-6)	Survey Mar-May	16 12	-0.004 ±0.0.02 **-0.029 ±0.018**	**-0.93 ±0.29**
Eurytemora affinis	Abundance + 10 (S = 0.5-6)	Survey June-Oct	28	*-0.006 ±0.008*	**-1.42 ±0.27**
Synchaeta bicornis (rotifer)	Abundance (S = 0.5-6)	Survey June-Oct	28	0.003 ±0.015	**-0.82 ±0.25**
Neomysis mercedis (mysid)	Abundance (S = 0.5-6)	Survey May-Nov.	15 12	**-0.025 ±0.017,** **0.066 ±0.055**	**-1.7 ±0.5**
Crangon franciscorum	Abundance index	Mar-May	21	**-0.024 ±0.011**	
Starry flounder	Abundance index + 1	Mar-Jun	21	**-0.023 ±0.015**	**-0.58 ±0.36**
Pacific herring	Survival index	Jan-Apr	20	**-0.022 ±0.020**	-0.02 ±0.5
American shad	Abundance index	Feb-May	32	**-0.014 ±0.009**	**0.25 ±0.22**
Delta smelt	Abundance index	Feb-Jun	39	**0.024 ±0.017** -0.011 ±0.012	NA; Time break 1981-82
Longfin smelt	Abundance index	Jan-Jun	32	**-0.053 ±0.012**	**-0.60 ±0.27**
Sacramento splittail	Abundance index	Feb-May	31	**-0.031 ±0.013**	-0.07 ±0.3
Striped bass	Survival index	Apr-Jun	25	**-0.027 ±0.012**	-0.08 ±0.3

Table 2. Summary of classes of mechanism, hypotheses, and approaches, based on the CMARP report. All of the investigations would benefit by adequate monitoring. Items are numbered for easy reference. "Dependencies" indicates order for testing hypotheses; for example, R3 would not be tested if evidence failed to support R1 or R2. Each hypothesis could apply to one or more taxa, listed in parentheses and abbreviated as: AS American shad, CF Bay shrimp, *Crangon franciscorum,* CS Chinook salmon, DS Delta smelt, LF Longfin smelt, NM *Neomysis* and other mysids, PH Pacific herring, SB Striped bass, SF Starry flounder, ST Splittail, WS White sturgeon, ZP zooplankton.

Item	Class of Mechanism	Hypothesis	Possible Approaches	Depen-dencies
H1	Habitat quantity	The extent of habitat for spawning or rearing varies with X2 (all)	Data analysis to determine habitat characteristics for spawning and rearing, and modeling of physical circulation and salinity distribution to determine extent of habitat	None
H2	Habitat quantity	Population size depends on extent of habitat (all)	Data analysis based on monitoring of target species, and modeling of populations	H1
H3	Habitat quantity	Population reproductive rate depends on extent or quality of physical habitat (all)	Analysis of monitoring data and estimates of fecundity.	H1
H4	Habitat quantity	Juvenile growth or survival rate depends on extent or quality of physical habitat (all)	Otolith analysis for growth rates; cohort analysis for survival	H1
H5	Habitat quantity	Spatial overlap with predators varies with X2 (all)	Initially, analysis of monitoring data; detailed spatial distributions, and experimental studies of predatory interactions	None
H6	Habitat quantity	Access to spawning habitat depends on salinity and therefore X2 (PH)	Field studies of salinity distribution and spawning distribution	None
H7	Habitat quantity	Access or extent of spawning habitat depends on flow and therefore X2 (ST, AS, SB)	Analysis of monitoring data followed by field studies of spawning habitat distribution as a function of flow.	None
H8	Habitat quantity	Population reproductive rate increases with access to or quantity of spawning habitat (ST, AS, SB, PH)	Fecundity and distribution studies	H7
H9	Habitat quantity	Predation rate decreases as turbidity increases with flow (all)	Data analysis, field study of response of turbidity to flow and other conditions, and lab study of effect of turbidity on predation rates	None
E1	Entrainment	Entrainment in state and federal export facilities as a proportion of population increases as X2 moves landward (NM, CS, SB, DS, ST, AS)	Data analysis, field sampling to compare salvage and net samples	None
E2	Entrainment	Entrainment produces mortality to populations that is biologically significant (NM, CS, SB, DS, ST, AS)	Data analysis and modeling, followed by adaptive probing coupled with intensive monitoring.	E1

Item	Class of Mechanism	Hypothesis	Possible Approaches	Depen- dencies
E3	Entrainment	Entrainment in agricultural diversions increases as X_2 moves landward (NM, CS, SB, DS, ST, AS)	Field experiments using simulated diversion facilities designed for the purpose	None
E4	Entrainment	Entrainment in agricultural diversions produces mortality to populations that is biologically significant (NM, CS, SB, DS, ST, AS)	Data analysis and modeling, comparing estimates of losses to ag diversions with those to facilities	E1, E3
R1	Residual circulation	Gravitational and other residual circulation increases as X2 moves seaward	Shipboard field studies, intermediate-term monitoring, hydrodynamic modeling	None
R2	Residual circulation	Lateral processes cause increased retention as X2 moves seaward	Shipboard field studies, intermediate-term monitoring, hydrodynamic modeling	None
R3	Residual circulation	Landward movement of larval and juvenile forms increases with increasing residual circulation (CF, SF, PH)	Modeling of physical circulation and particle movement, intensive sampling at several depths and cross-channel positions and several locations.	R1 or R2
R4	Residual circulation	Increased landward movement increases population size (CF, SF, PH)	Data analysis based on monitoring of target species, together with population simulation modeling.	R3
L1	Low-salinity zone	Retention in LSZ increases with seaward X2 (DS, LF, NM, CF, SB, SF, ZP)	Modeling of physical circulation and particle movement, analysis of existing data on distributions of organisms	None
L2	Low-salinity zone	Retention in LSZ is due to lateral effects which change with X2 (DS, LF, NM, CF, SB, SF, ZP)	Modeling of physical circulation and particle movement, analysis of existing data on distributions of organisms, field studies of lateral distribution of plankton and larval fish	None
L2	Low-salinity zone	Retention in LSZ is due to vertical-longitudinal effects which change with X2 (DS, LF, NM, CF, SB, SF, ZP)	Modeling of physical circulation and particle movement, analysis of existing data on distributions of organisms	None
L3	Low-salinity zone	Population size increases with increasing retention in LSZ (DS, LF, NM, CF, SB, SF, ZP)	Coupled physical-biological simulation model; field data depending on model needs	L1
F1	Food effects	Increasing supply of nutrients increases phytoplankton production	Data analysis and modeling.	None
F2	Food effects	Supply of labile organic carbon to the estuary increases with increasing flow	Field experiments using bacterial production to estimate C supply rate, primary production to estimate in situ component; stable isotope and organic tracer analyses	None
F3	Food effects	Feeding success and growth rate of target species increases with seaward X2 (all)	Field studies combined with laboratory studies of gut clearance rate; condition, otolith analyses	None
F4	Food effects	High feeding success is associated with increasing recruitment (all)	Otolith analysis and analysis of monitoring data	F3
F5	Food effects	High feeding success is due to co-occurrence with food or increase in quantity of food (all)	Data analysis, detailed field sampling	F3, F