Chapter 3. USES OF CONCEPTUAL MODELS IN MONITORING AND RESEARCH DESIGN

INTRODUCTION

The term "conceptual model," in the context of environmental monitoring, has been generally defined as a "description of causes and effects that define how environmental changes are expected to occur" (National Research Council, 1990). The intention of conceptual modeling is to show how processes may be linked across space, time, and trophic levels (cause-effect relations) to help formulate specific testable questions to be answered through monitoring and research, and to lead to predictions about the effects of environmental perturbations or management actions. In their simplest form, conceptual models can be used to describe complex system processes to policy makers and to the public. Conceptual models do not represent finished products, however. Rather, it is the process of thinking about, developing, and revising conceptual models that provides the greatest benefit to the users. As described in the Strategic Plan for [the CALFED] Ecosystem Restoration Program (1998),

> *"Conceptual models are based on concepts that can and should change as monitoring, research, and adaptive probing provide new knowledge about the ecosystem. When key concepts change, the conceptual models should be updated to reflect these changes, thereby paving the way toward changes in management."*

Despite the importance of conceptual models in environmental management, existing explicit models of the features of the San Francisco Bay-Delta and its watershed are limited to a few species and system functions. Bay, Delta, and watershed scientists, engineers, and resource managers have developed ideas about how particular features of the system function and may be influenced by natural and human-induced stressors, but these ideas have seldom been presented in a format that can be shared with and discussed by others. With the recognition that conceptual models should be the centerpiece of the design of both monitoring and research programs directed toward CALFED needs, the development of explicit models of major features of the estuary and its watershed is an important thrust of CMARP.

DEVELOPMENT OF CONCEPTUAL MODELS IN CMARP

In June 1998, CALFED and agency staff, university researchers, stakeholders, and representatives of restoration and monitoring programs from outside California participated in a workshop to discuss the role of conceptual modeling in developing CMARP research and monitoring programs (see notes from the workshop in Appendix *V*). The participants of the workshop, drawing on experience gained in programs in Puget Sound, Chesapeake Bay, and South Florida, as well as in San Francisco Bay-Delta and its watersheds, concluded that conceptual models must play an important role in the design of CALFED programs. However, workshop participants agreed that existing models are mostly implicit, i.e., not well documented, and are not generally available. Moreover, it was agreed that CALFED and local, state and federal agencies are presently not making good use of conceptual models in developing monitoring/restoration programs, in adaptive management, or in communication with other scientists, managers, and the public.

Subsequent to the June workshop, the CMARP workteams have incorporated conceptual modeling as an integral part of the monitoring and research design process. Using existing knowledge and theories, the workteams have identified and described the key features or attributes of the system under study, the inter-relations among them, and the important environmental factors (including stressors) that influence them. Existing published versions of these models take a variety of forms, including descriptive texts, complex diagrams, and combinations thereof. Whatever the format or complexity, the intent of these models is to provide the authors' written descriptions of the specific habitat, species, or system attributes and functions and the forces acting upon them. The Fish-X2 and delta smelt conceptual models, as examples, provide two contrasting approaches to ecosystem modeling; the first model (depicted in Figures. 3-1 to 3-4) describes an ecological process, while the second (Figure 3-5) is an example of a species-specific model.

The Fish-X2 model (see Appendix *VII.A.1* for details) summarizes a broad spectrum of available information (Interagency Ecological Program Technical Report 52). Understanding the underlying mechanisms for the apparent fish-X2 relationships is of great importance because these relationships form the basis for the current X2 salinity standard (the distance in kilometers up the axis of the estuary to where the tidally-averaged near-bottom salinity is 2 practical salinity units [PSU]). The possible mechanisms affected by X2 that are important to the selected fish species are summarized here in a matrix (Figure 3-1). The potential causative pathways underlying the fish-X2 relationships are summarized graphically (Figure 3-2) in a way that serves to illustrate that both trophic and physical processes may be important and that there may be multiple causes of the observed relationships. Two additional graphical displays (Figures 3-3 and 3-4) summarize the complex physical processes that may be involved in the fish-X2 relationships.

The delta smelt conceptual model (Figure 3-5; see Appendix *VII.A.7* for details) adopts a life cycle approach, emphasizing the life stages that appear to be important in understanding the population dynamics of the species. The model presents some of the major questions regarding processes that may be affecting the delta smelt population and includes some of the graphical data relationships that form the basis of major hypotheses. This conceptual model emphasizes the need for continuing or additional monitoring and research on all life stages.

Conceptual models of various physical, chemical, and biological processes and systems are being developed within each of the CALFED program areas (see Appendix *VII*).

In many instances, there is not unanimity of opinion about the described features and linkages in the models that have been developed thus far. However, the point of preparing and presenting these conceptual models is to BEGIN the discussion of the attributes, functions, and linkages described by the models, to undertake the formulation of specific questions and hypotheses, to develop appropriate monitoring and research strategies, and to provide a scientific basis for adaptive management.

MONITORING PROGRAM DESIGN

Conceptual models of individual species (e.g., delta smelt or winter-run salmon), habitat types (e.g., shallow water), physical processes (e.g., sediment transport), or ecosystem functions (e.g., primary productivity) lead naturally to the development of working hypotheses about important linkages and how the system will respond to management interventions. These hypotheses, in turn, suggest the variables that will need to be measured in order to document the status and trends of system properties, and more generalized system indicators that can provide the basis for assessing progress in meeting CALFED's objectives.

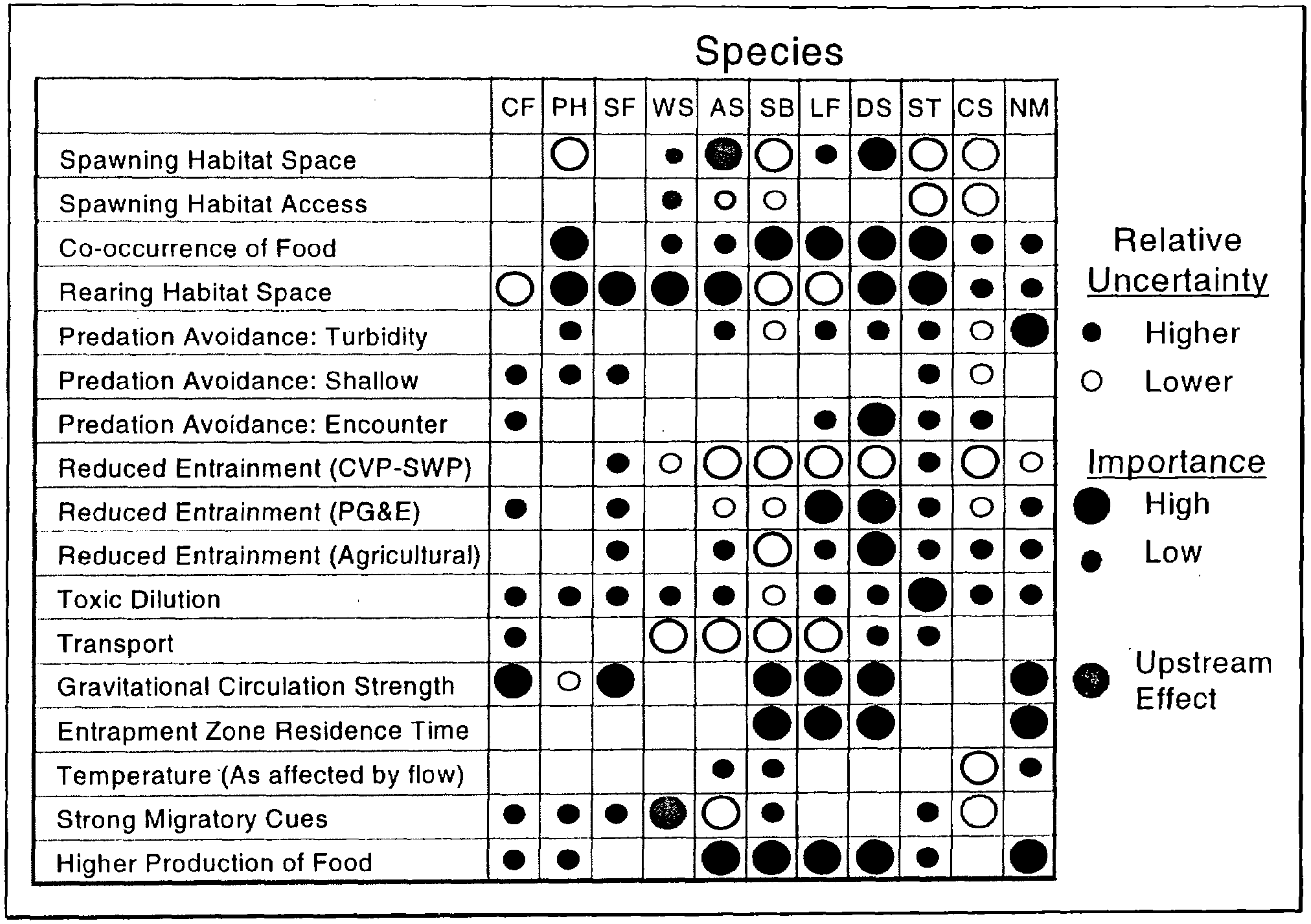

Figure 3-1. Some potential mechanisms underlying the relationships between bay-delta species and X2, the degree of uncertainty about the relationships, and the assumed relative importance of the mechanisms. Species and abbreviations are: bay shrimp CF, herring PH, starry flounder SF, white sturgeon WS, American shad AS, striped bass SB, longfin smelt LF, Delta smelt DS, splittail ST, Chinook salmon CS, Neomysis NM (see Interagency Ecological Program Technical Report 52, 1997).

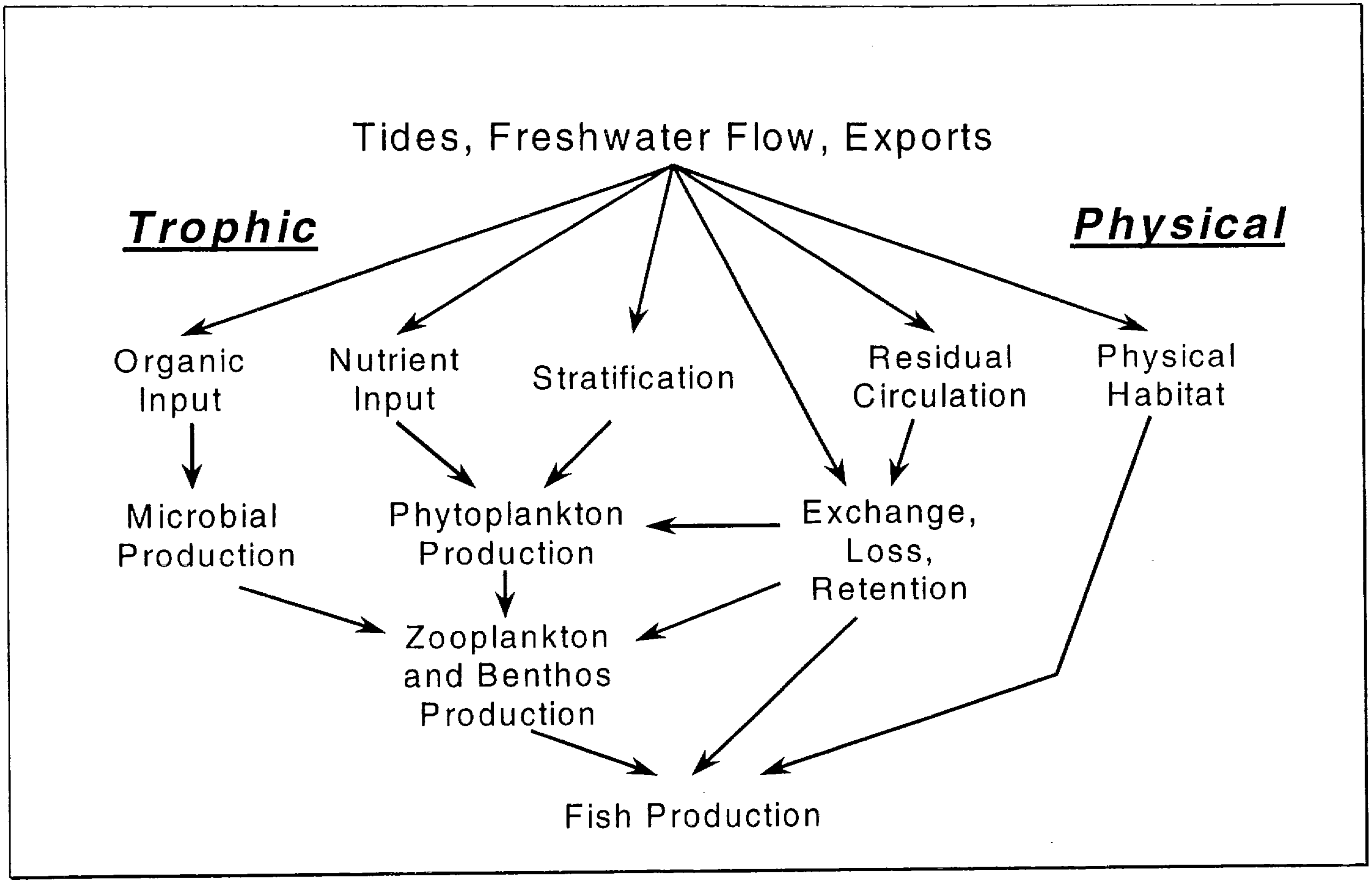

Figure 3-2. Potential causative pathways underlying the fish-X2 relationships. "Trophic" pathways based largely on feeding relationships, "physical" pathways arise through interactions between physical conditions and abundances of species of interest.

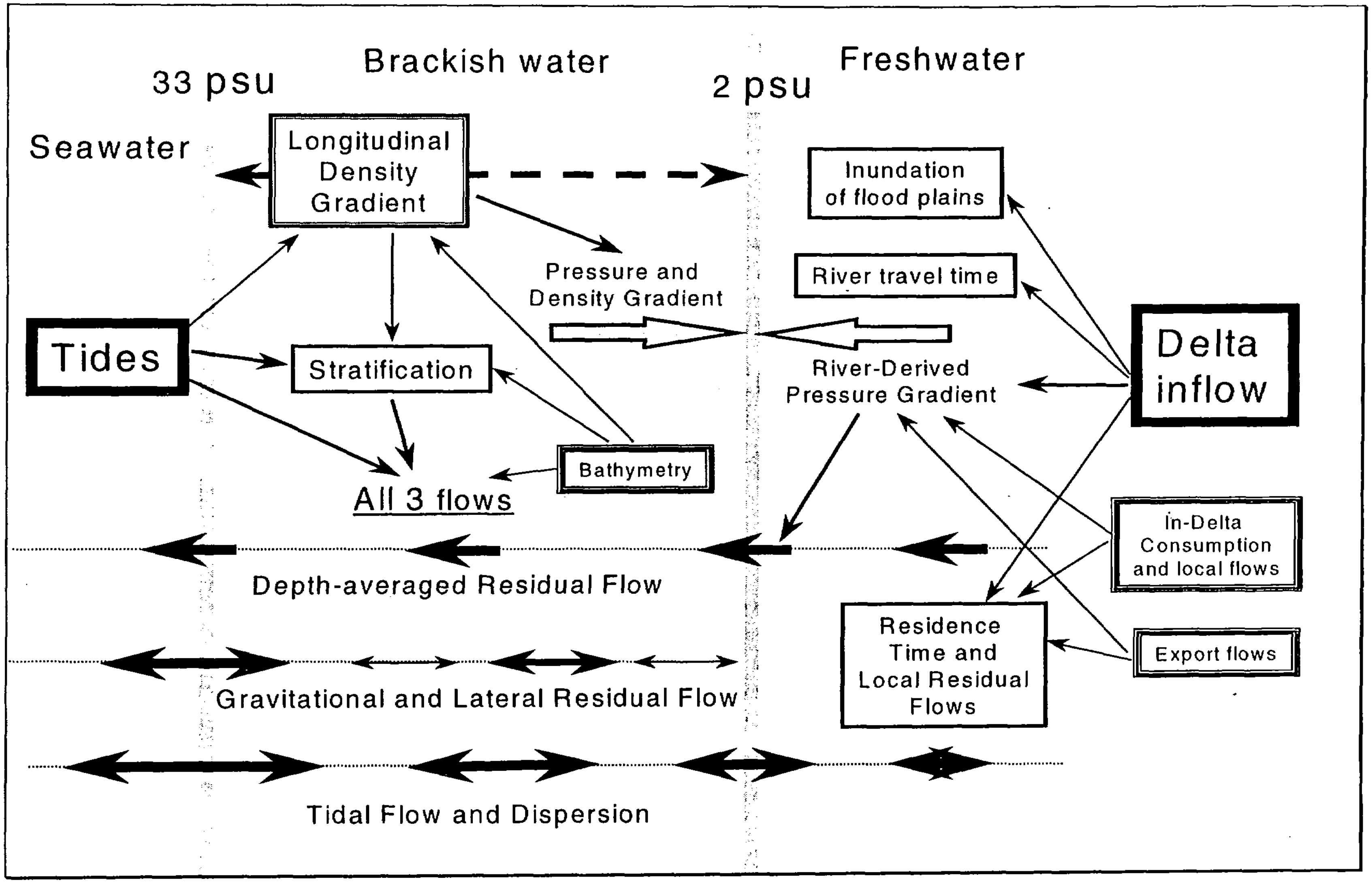

Figure 3-3. Conceptual model of the relative influences of water flow (both river and tidal flows) on the movement of water and salt in the estuary. The principle influence of freshwater flow on the brackish part of the estuary is indirect, occurring through pressure and salinity gradients.

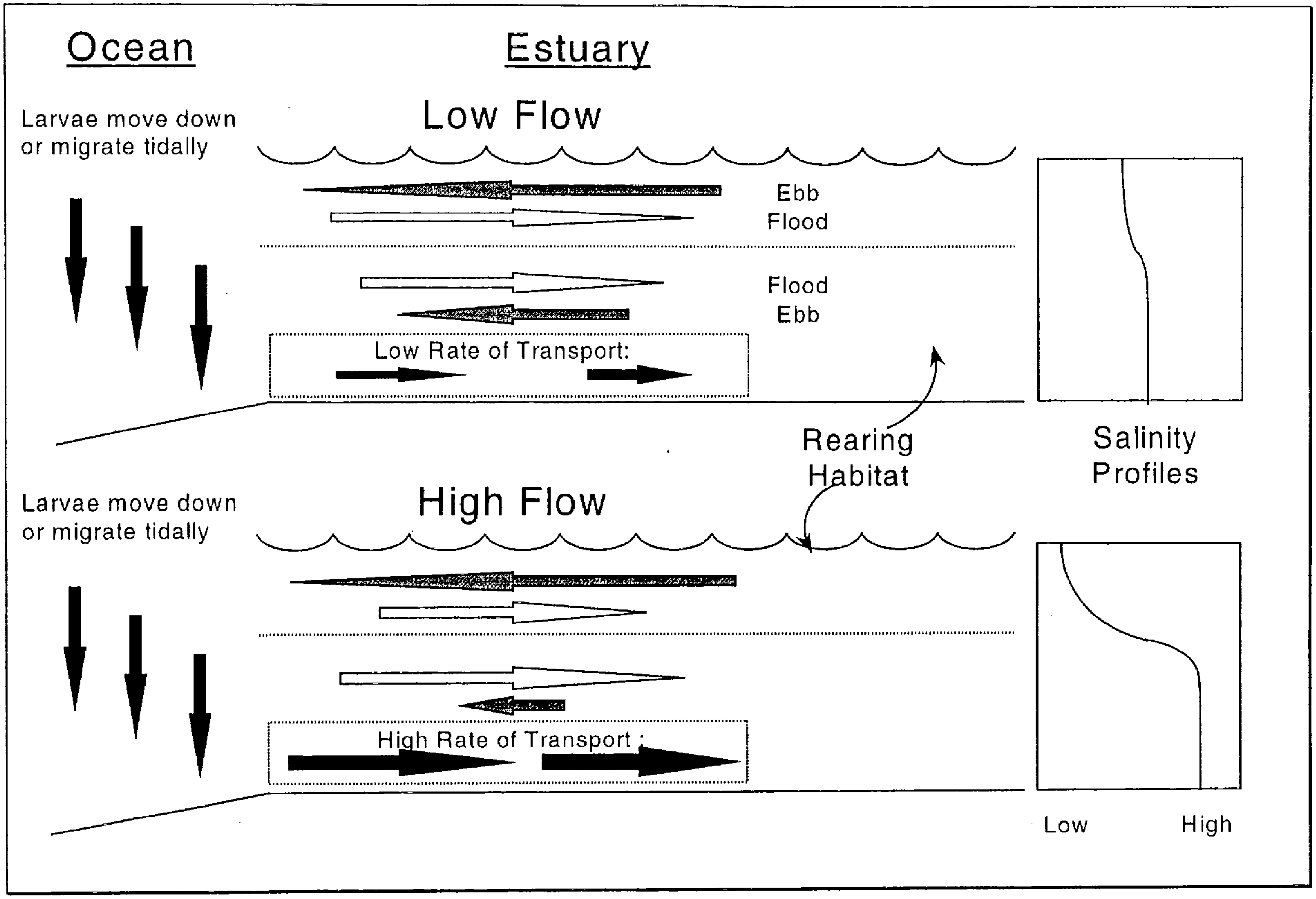

Figure 3-4. Conceptual model of the fish-X2 gravitational circulation mechanism, specifically the effect of the relative strength of gravitational circulation on the movement of fish larvae to rearing habitat in the upper estuary.

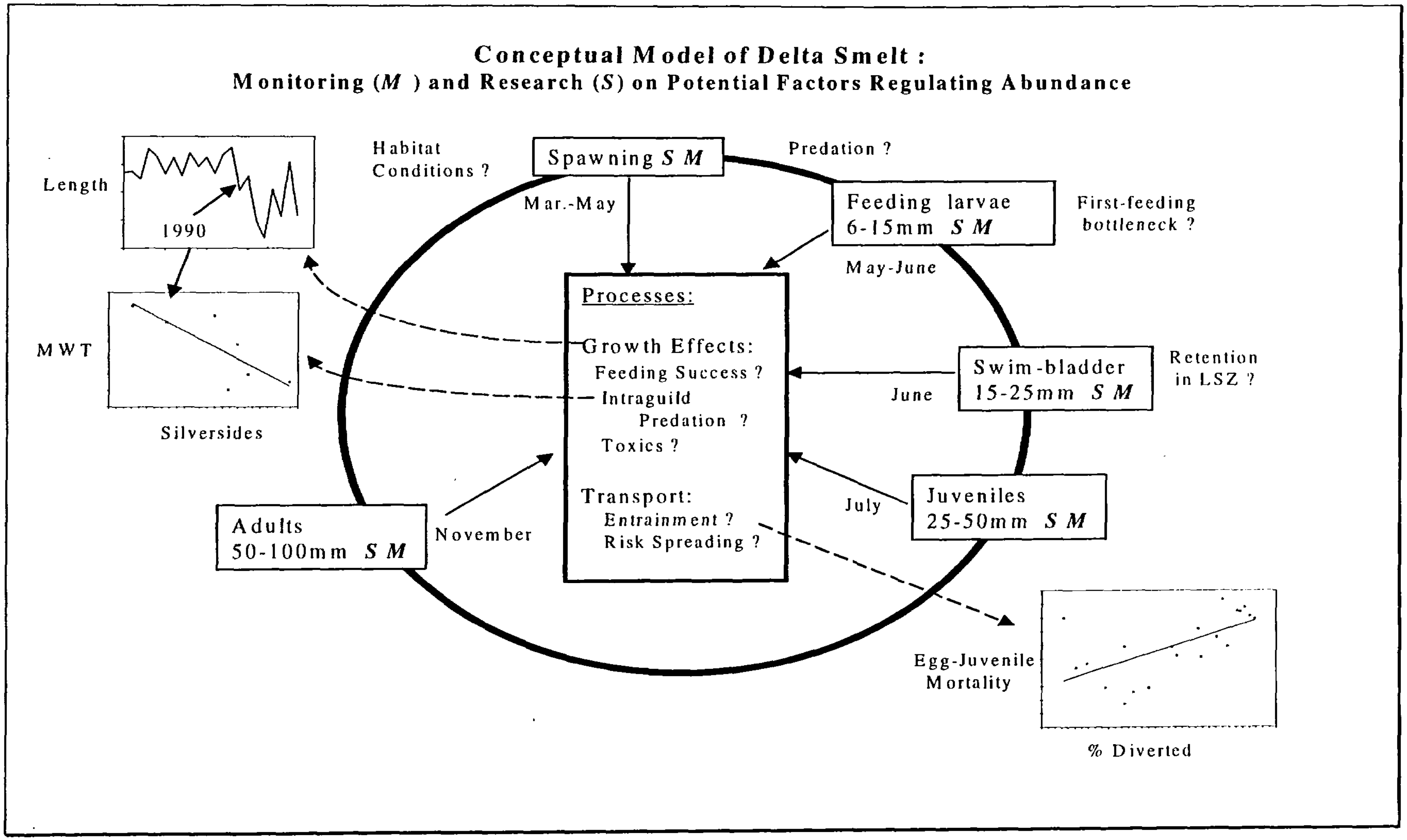

Figure 3-5. Conceptual model of the annual life cycle of Delta smelt, the potential important mechanisms regulating smelt abundance, and proposed areas for the focus of monitoring (M) and research (S).

A critical role of conceptual modeling is to narrow the list of the many possible monitoring variables to those that, within appropriate space and time scales, will produce the specific information required, i.e., that are focused on the system attributes that are of greatest concern. Some of these variables can also serve as the broader indicators or attributes that are expected to change over time in response to restoration actions. A primary purpose of the CALFED monitoring program will be to measure the status of those indicators, i.e., collecting and reporting on basic information about the critical species, habitats, and system functions and any changes that occur as a result of management actions.

For many attributes of the San Francisco Bay-Delta and watershed system, monitoring programs are already in place that can be used in the formulation and testing of hypotheses. The conceptual models assist in uncovering the gaps in these programs such as the need for more complete spatial or temporal coverage, the need for better coordination, the need for improved standardization, the need for additional variables, or the need for new or more sophisticated interpretation of existing data.

RESEARCH PROGRAM DESIGN

Conceptual models are extremely useful in identifying gaps in our understanding of critical system processes and interactions. Addressing these gaps will require targeted research investigations that can include testing of hypotheses, distinguishing among alternative hypotheses, addressing critical unanswered questions, and quantifying interactions, e.g., through combinations of field and laboratory experimentation and/or quantitative numerical modeling.

Primary goals of the CALFED Focused Research Program are to:

- build upon our existing understanding of physical, chemical, and biological processes in those areas that are relevant to CALFED program actions,
- provide information useful in evaluating the effectiveness of existing monitoring protocols and the appropriateness of monitoring attributes,
- test causal relationships among environmental variables identified in conceptual models,
- reduce areas of scientific uncertainty regarding management actions,
- incorporate relevant new information from non-CALFED-sponsored research, and
- revise conceptual and numerical models as our understanding increases.

To achieve these goals, the CALFED research program will establish clear priorities for research and incorporate peer review of proposals, ongoing work, and finished products.

The conceptual models developed to date suggest a variety of research questions that are very relevant to the fundamental questions being addressed by CALFED and that are critical to the design of "adaptive probing to distinguish among alternative hypotheses about the best management solutions" (Strategic Plan for ERP, 1998).

A major CMARP task during the next six months will be to synthesize and prioritize among the many research ideas and to develop a strategy for undertaking the most critical of these targeted research efforts. The strategy will include two mechanisms for supporting CALFED-targeted research:

1. an annual request-for-proposal process in which the scientific community at large will be asked to submit research ideas that address specific CALFED research needs, and
2. the establishment of a directed research effort, overseen by a CALFED Science Review Board, to undertake a sustained, coordinated, interdisciplinary program of study and experimentation on specific problems.

The CMARP Steering Committee, through its technical workteams, is compiling a list of relevant research questions in each of the common program areas. This list will be used to issue a series of CALFED Proposal Solicitation Packages (PSPs) for research directed toward answering the questions, and for implementing a longer-term, directed research program. Details about the CALFED Research Program are found in the Appendices.

ADAPTIVE MANAGEMENT

Conceptual models provide a means for "link[ing] human activities or management actions to outcomes important to society" (Strategic Plan for ERP, 1998). As described by Walters (1997),

"Adaptive management should begin with a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies. This modeling step is intended to serve three functions:

- *problem clarification and enhanced communication among scientists, managers, and other stakeholders;*
- *policy screening to eliminate options that are most likely incapable of doing much good, because of inadequate scale or type of impact; and*
- *identification of key knowledge gaps that make model predictions suspect."*

It is the task of the modeling effort to describe the relationships that potentially link management actions, through physical, chemical, or ecological processes, to consequences or outcomes for species or systems.

"[The conceptual] models provide the basis for informed management actions from which a better understanding of [a] system can be derived. The knowledge and hypotheses about [system] responses summarized in conceptual models lead directly to potential restoration actions, although each model is likely to suggest many possible courses of action. Such models, and simulation models developed from them, are essential for conveying why certain management actions are expected to produce desirable effects. Alternative, competing conceptual models can illustrate areas of uncertainty, paving the way for suitably-scaled experimental manipulations designed to both restore the system (according to more widely accepted models) and explore it (to test the models)." (Strategic Plan for ERP, 1998).

The models being developed (see Appendices) will be used to examine alternative hypotheses about how the bay/delta watershed systems work in order to identify and clarify situations in which uncertainties may influence decisions about specific management actions, and consensus understanding suggests where management actions are warranted.