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Introduction

The four articles (Brown 2003a, 2003b; Davis and others 2003; Orr and others 2003) in this series summarize much of what is known and not known about tidal wetland restoration in the San Francisco Bay (hereafter “Bay,” Figure 1) and Sacramento-San Joaquin Delta (hereafter “Delta,” Figure 2) with respect to essential fish habitat, organic carbon production, accumulation of mercury in food webs, and wetland evolution. The many uncertainties associated with each issue, particularly when considered in the context of other issues such as water storage, water conveyance, water use efficiency, flow manipulations to benefit fishes, and activities in upstream watersheds (CALFED 2001), demonstrate clearly that the task of restoring and managing wetlands is extremely complex and poses considerable technical challenges. In this respect, ecosystem restoration in the San Francisco Estuary (the combined Bay and Delta) and watershed is not unique. Restoration efforts in South Florida (Harwell and others 1999; Ogden and others 1999; Solecki and others 1999; Schrope 2001), Chesapeake Bay (Boesch 2000; Boesch and others 2001; Chesapeake Bay Foundation 2002), and the Columbia River (Williams and others 1999; Kareiva and others 2000), to name a few, have similar scope and levels of complexity and uncertainty.

The focus of this series on tidal wetland restoration reflects the importance of this activity within the Ecosystem Restoration Program (ERP) of the CALFED Bay-Delta Program (hereafter “CALFED,” see CALFED 2001 for more information). The Ecosystem Restoration Program Plan (ERPP) calls for the restoration of 30% to 50% of the freshwater tidal wetlands lost from the Delta since 1900. This translates to about 12,000 to 20,000 hectares of tidal wetland restoration in the Delta, in addition to restoration of 2,800 hectares of shallow subtidal habitat (CALFED 1999). In Suisun Marsh and Suisun Bay, the ERPP calls for restoration of 2,000 to 2,800 hectares of brackish water tidal wetlands and 600 hectares of shallow subtidal habitat. Part of the rationale for this restoration is to provide high quality rearing habitat for juvenile fishes and in particular to help support the proper aquatic habitat for rearing and outmigrating juvenile chinook salmon *Oncorhynchus tshawytscha*, steelhead rainbow trout *O. mykiss* and sturgeon *Acipenser* spp. and for rearing delta smelt *Hypomesus transpacificus*, striped bass *Morone saxatilis*, and splittail *Pogonichthys macrolepidotus* (CALFED 1999). The purchase, restoration, and management of areas of this size represent tremendous investments of money and effort. Therefore, addressing the uncertainties surrounding tidal wetland restoration is extremely important in ensuring that such investments have the expected dividends.

Here, I briefly summarize some of the major findings, uncertainties, and possible approaches to (and progress being made in) reducing the uncertainties that are described in the other four articles in this series.

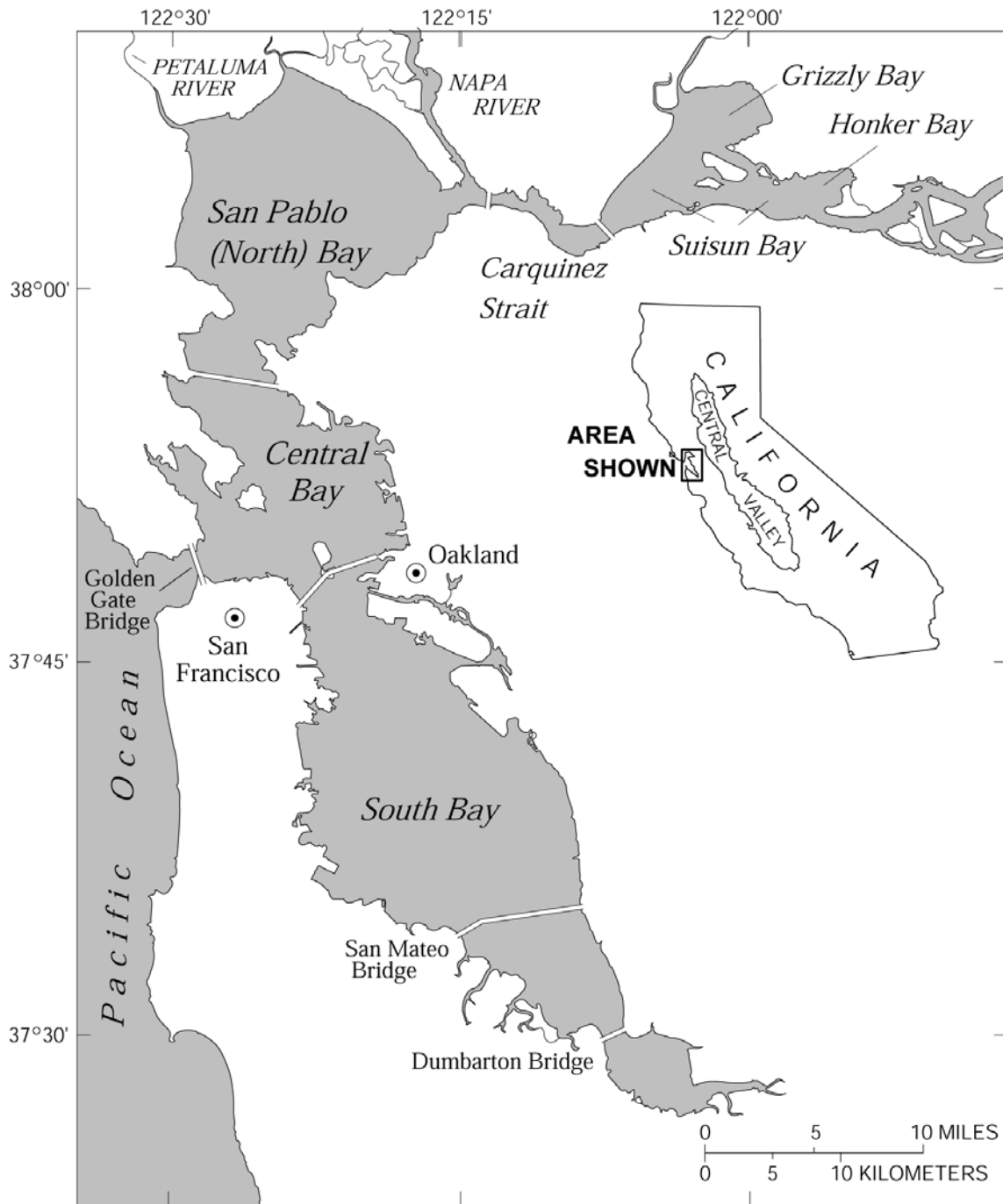


Figure 1 Areas and features within San Francisco Bay

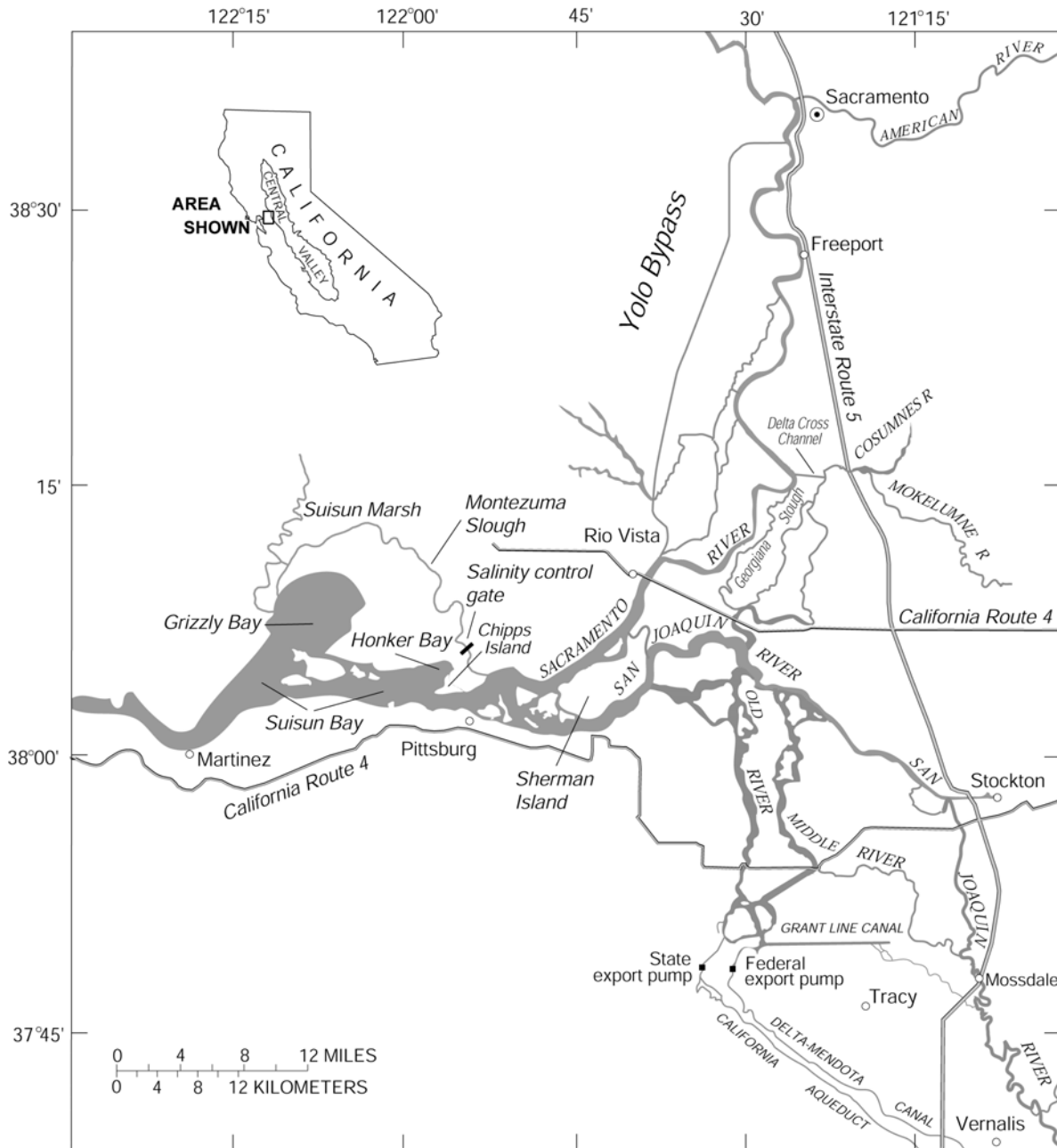


Figure 2 Areas and features within northern San Francisco Bay (west of Chipps Island) and the Sacramento-San Joaquin Delta (Delta). The Delta is approximately defined by Chipps Island to the west, Sacramento to the north, and the river confluence near Vernalis to the south.

Major Findings

Each article in the series summarizes numerous studies and sources of information and each offers findings that are worth noting.

Introductions of alien plants and animals will likely reduce any benefits of tidal wetland restoration to most native fishes (Brown 2003a). The prominent role of alien species in the Estuary is well recognized (e.g., Bennett and Moyle 1996). Until recently, the extent of the changes related to alien species that have taken place in the near-shore subtidal habitat of much of the freshwater portion of the Delta had not been documented. Simenstad and others (2000) made an important contribution in this respect by observing that the invasion of *Egeria densa*—and the distinctive fish fauna that exploits the habitat it creates—essentially makes it impossible to restore pre-development habitat conditions in areas where the plant is abundant. *Egeria* habitat does support some native fishes but such habitat does not appear to be utilized extensively by the species of greatest concern, including anadromous salmonids, splittail, and delta smelt. Although *Egeria* does not grow in the intertidal zone of tidal wetlands, it does grow in the nearshore subtidal and can hinder movements of fish moving between subtidal open water and tidal wetlands. Such observations raise serious questions about the benefits of freshwater wetland restoration in areas of the Delta that can support *Egeria densa*, emphasize the need to understand the factors determining the distribution of *Egeria densa*, and place additional importance on determining the possible benefits of wetland restoration in other regions of the estuary, such as Suisun Marsh, the North Delta, or upstream floodplains, where *Egeria* is absent or scarce.

Considerable progress has been made in the last decade in understanding sources and fate of organic carbon in the Estuary (Brown 2003b). A multidisciplinary team approach including simple modeling and scenario testing has been especially useful in revealing critical ecosystem processes and the possible effects of various restoration actions (Jassby and Cloern 2000; Lucas and others 2002). Improved understanding of the sources and chemistry of organic carbon in the Delta combined with increasing knowledge about the propensity of organic carbon from different sources in the Delta to form disinfection byproducts in water treatment facilities hold considerable promise for informing decisions about the costs and benefits of altering land uses in different regions of the Delta. For example, if restored tidal wetlands produce organic carbon that forms disinfection byproducts more easily than organic carbon from agricultural drainage, then agricultural lands near drinking water diversions might best remain as agricultural land. This would leave more resources for tidal wetland restoration or other activities in other areas of the Delta. A major challenge will be to simultaneously consider organic carbon in the contexts of the ecosystem, drinking water quality, and regional flow patterns.

Mercury in the Estuary is already known to be at levels that pose risks to the health of wildlife and humans (Davis and others 2003). Tidal wetlands often provide environmental conditions conducive to mercury methylation and thus might increase accumulation of

mercury in the food web. Consequently, restoration of tidal wetlands represents a potential increased risk to wildlife and human health. Davis and others (2003) also document considerable variation in mercury methylation and bioaccumulation at all spatial scales ranging from different locations within a single wetland to different regions within the Estuary. The present understanding of mercury in the Estuary is insufficient to reliably predict effects of specific projects or the cumulative effects of many projects. Davis and others (2003) therefore suggest a comprehensive program of research and monitoring to assess effects as restoration proceeds. This approach is compatible with the CALFED emphasis on adaptive management. If certain restoration practices are found to increase accumulation of mercury in food webs, they can be discontinued or changed before additional problems occur.

A long-term, Estuary-wide view of tidal wetland processes in the Estuary, led Orr and others (2003) to conclude that once marsh plain vegetation is established, restored tidal wetlands will likely persist for 100 years or more, even with projected rates of sea-level rise and sediment supply. This conclusion is based on several assumptions primarily related to rates of sediment accretion and erosion. However, finding practical approaches for restoring large subsided areas to vegetated marsh within a reasonable time frame will be difficult, especially in the Delta where the need for fill overwhelms the estuarine sediment supply.

Major Uncertainties

Of the numerous scientific and management uncertainties described in the other four articles of this series, many can be characterized as technical rather than conceptual. That is, the uncertainty relates more to determining what to measure or how to measure some quantity or rate, and at what scales in order to answer a larger-scale conceptual question. The major conceptual issues within each topic are, in comparison, more straightforward and mainly represent refinements of the questions posed at the beginning of each individual article. In this section I discuss the major uncertainty that seems most important for each topic and any associated technical issues.

A major uncertainty for fishes is the net benefit of restored tidal wetlands relative to existing habitats for native fishes in different regions of the Estuary given the presence of numerous invasive alien species (Brown 2003a). Of particular interest are the importance of the alien aquatic macrophyte *Egeria densa* and the distinctive group of alien and native fishes that occupy the habitat provided by dense beds of the plant. The technical challenges facing fish ecologists attempting to address this issue appear formidable. The species of greatest interest to managers tend to be anadromous, such as chinook salmon and steelhead rainbow trout, or migratory within the watershed, such as splittail and delta smelt, and therefore, only use tidal wetlands for a variable portion of a more complex life cycle. Methods for sampling fishes in the tidal wetland habitats in the Estuary are being developed or adapted from techniques used in marshes on the eastern and Gulf coasts of the United States (Hieb and DeLeón 2000; Simenstad and others 2000). One problem

is that the methods from other regions have general been developed for tidal wetlands with well-developed marsh plains and dendritic channel networks. These conditions are the exception rather than the rule in the Delta. This is not to say that the results of innovative data analysis and study design won't clarify the role of tidal wetlands in the population biology of fishes. Sommer and others (1997, 2001a, 2001b) have documented the benefits of the Yolo Bypass floodplain to splittail and chinook salmon and Simenstad and others (2000) have raised questions about the value of *Egeria densa* habitat to native fishes of concern. The difficulty is in assigning the degree of benefit to a particular fish life stage and the overall benefit to the population.

With regard to organic carbon, an important uncertainty is the net benefit in terms of organic carbon quantity and quality of converting existing land uses to tidal wetlands (Brown 2003b). The main difficulty in addressing this uncertainty is measuring the flux of organic carbon from open systems like a restored tidal wetland. Conceptually, determining the forms and quantity of organic carbon in agricultural drainage is easy. Samples are collected at the end of the pipe and the quantity of water coming out of the pipe is measured. In a tidal wetland with multiple channels, multiple discharges might have to be measured. Organic carbon and other materials will be moving in and out of the channels with the tide. Also the forms and quantity of organic carbon will change over the seasons and years depending the growth and decomposition of plants and animals and changing soil characteristics. These study design problems can be logistically formidable.

Conversion of existing land uses to tidal wetlands will almost certainly result in increased accumulation of mercury within local food webs (Davis and others 2003). The major uncertainty is whether the local food web accumulation is of concern for health of fish, wildlife, and humans, and whether there are cumulative effects at the regional scale. Mercury also poses a formidable technical challenge. Mercury accumulation in the food web is dependent on the interplay of several complex and variable factors, including mercury supply, water chemistry, microbial population dynamics, and food web structure. The present conceptual understanding of these processes is insufficient to explain the striking spatial variation observed in the Estuary. There are well-established methods of measuring mercury in water, sediment, and biological tissues and those methods are already being applied in a number of studies. Davis and others (2003) outline a research and monitoring program for assessing the effects of tidal wetland restoration as restoration activities proceed. A major challenge will be separating the incremental contribution of tidal wetland restoration to an already important regional problem.

The major uncertainty for tidal wetland sustainability is the balance between sediment accretion, sea-level rise, and erosion in the Delta and the implications this balance has for developing cost-effective approaches for restoring large subsided areas to tidal wetlands habitat (Orr and others 2003). At a larger scale there is uncertainty about the cumulative regional effects of many tidal wetland restoration projects, especially with regard to sediment supply. As for organic carbon and mercury, methods for monitoring sediment

accretion and erosion are well known; the major challenge is in designing a logistically feasible study to meet multiple objectives at multiple scales.

The common thread in addressing the various uncertainties is a need for the study design to provide data at the appropriate temporal and spatial scale. A further challenge is the development of models at the appropriate temporal and spatial scales for estimating the effects of management actions. Lucas and others (2002) and Jassby and Cloern (2000) provide excellent examples of how studies and modeling efforts may need to be scaled differently in time and space to answer different questions about organic matter in the Delta. There appear to be no technical barriers to approaching questions about mercury accumulation, sediment, or other physical and chemical variables in the same way.

A Need for A Regional Multidisciplinary Approach

Consideration of regional variability is explicitly or implicitly requested in each of the articles. For fishes, regional variability relates to the fish assemblage expected to benefit from, or be affected by, tidal wetland restoration at any particular location in the Estuary (Brown 2003a). Clearly, organic carbon exported from a tidal wetland in San Pablo Bay is unlikely to form disinfection byproducts in a water treatment plant because water in San Pablo Bay is too salty to drink. Conversely, organic carbon exported from a tidal wetland constructed near a drinking water diversion in the Delta has a higher probability of being entrained into a drinking water supply and forming disinfection byproducts during treatment. Davis and others (2003) discuss variation in the potential for food web accumulation of mercury at a variety of scales ranging from variation within individual areas of wetland to regional variation. Sustainability of wetlands will depend on regionally variable rates of sediment deposition and erosion (Orr and others 2003). The need for a regional outlook is clear.

The multidisciplinary approach has not as yet been widely applied in the Delta. Jassby and Cloern (2000) present an excellent example of how different management scenarios may affect organic matter loads into the Delta and Bay, but some of the most intriguing aspects of the paper are the inferences the authors provide about how management might affect other factors such as contaminant loadings. For example, they note that if an isolated diversion channel is constructed to transport water from the Sacramento River to the state and federal pumping plants (see Figure 2), San Joaquin River inflow would become a proportionally greater inflow to the Delta because the pumping plants would pump only Sacramento River water. The San Joaquin River, while transporting high concentrations of phytoplankton and nutrients, also transports high concentrations of pesticides and other contaminants. Concurrent analyses by experts in other fields would likely have resulted in additional insights regarding the interplay of organic matter, drinking water quality, and environmental contaminants. In the context of tidal wetland restoration, the multidisciplinary approach would integrate the study designs and results for fishes, organic carbon, mercury, and physical processes. Modeling and scenario testing would

assess the relative benefits of different regional approaches to restoration. Monitoring and adaptive management would adjust the selected approach as restoration proceeds.

There are limits to the complexity that can be incorporated into any single study design. In any large restoration program, there will always be a need to conduct, consolidate, integrate, and interpret studies at a variety of temporal and spatial scales. In California, the ERP coordinates a proposal solicitation process that has been very successful at providing funds for land purchases, restoration projects, and research into topics of particular interest, such as organic carbon and mercury (see “Grants” for various programs at <http://calwater.ca.gov/Programs/Programs.shtml>). However, given the type of interdisciplinary and hierarchical (ranging from individual projects to the entire watershed) monitoring and assessment effort that a large restoration program needs to conduct adaptive management, it is unlikely that such a program can be properly designed as part of a proposal solicitation. The task is simply too complex. The inability to reach consensus on an affordable subset of response variables or indicators was one of the factors leading to the failure of an earlier attempt to design such a program (CMARP 1999) for CALFED. Similarly, a large group of technical experts asked to evaluate salinity standards for Suisun Marsh (see Figure 2) was unable to reach consensus on standards that supported all beneficial uses equally (Suisun Marsh Ecological Workgroup 2001). Instead, subcommittees on various topics (brackish marsh vegetation, waterfowl, aquatic habitat, and wildlife) provided separate recommendations and identified areas of agreement and disagreement with other subcommittees. If CALFED is to avoid similar difficulties and succeed in using adaptive management to achieve multiple objectives, the program must develop a scientifically credible monitoring and assessment program to properly inform the decision process.

Progress

As already described in the individual articles of this series, considerable progress has been made on many technical aspects of individual topics pertaining to tidal wetlands restoration in the Delta. Some studies have included limited multidisciplinary teams. Lucas and others (2002) have incorporated biology and hydrodynamics. Simenstad and others (2000) incorporated biology and physical processes, primarily sedimentation. Progress is beginning to be made at higher levels of integration as well, primarily within CALFED, the largest and best-funded program presently involved in tidal wetland restoration. With regard to CALFED-funded tidal wetlands restoration strategies, the most concrete progress has resulted from Simenstad and others (2000) work in Delta tidal wetlands. This team is now involved in a similar project in the brackish water tidal wetlands of Suisun Marsh and Suisun Bay. With regard to higher-level integration to address a number of the questions discussed by the articles in this series, CALFED has sponsored an adaptive management workshop, in which an interdisciplinary group of researchers designed a large-scale adaptive management experiment (Reed, written communication, see “Notes”). However, the exercise was largely an intellectual one because there has been no commitment yet to actually conduct the experiment.

Most recently the CALFED Science Program (CALFED 2001) was established in 2000 to accomplish the following goals:

- Establish a body of knowledge that is unbiased, relevant, authoritative and integrated, while communicating that knowledge to the scientific community, agency managers, stakeholders and the public.
- Establish protocols and incorporate independent peer review into all program activities.
- Develop science-based performance measures for each CALFED program.

The first goal of the Science Program incorporates the need for interdisciplinary, multi-scale monitoring and assessment. The Science Program is just beginning to address the monitoring and assessment needs for tidal wetland restoration and monitoring and assessment in general (Taylor, written communication, see "Notes"). At present the Science Program does not specify parameters to monitor although it is cooperating with project personnel to help determine the parameters to monitor given the location of the site, the need to track ecosystem changes, and other work being done in the area. It is unclear at this time whether regional and larger-scale assessments of the effects of tidal wetland restoration projects on the Estuary will be accomplished by scaling up from project-specific monitoring or by establishing an independent regional monitoring and assessment program, or a combination of the two approaches. The Science Program, or some other CALFED entity, must make these decisions soon so that data and insights from ongoing projects are not lost.

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