In Cooperation with the Bureau of Reclamation and Interagency Ecological Program

Synthesis of Studies in the Fall Low Salinity Zone of the San Francisco Estuary, September-December 2011

By Larry R. Brown, Randy Baxter, Gonzalo Castillo, Louise Conrad, Steven Culberson, Greg Erickson, Frederick Feyrer, Stephanie Fong, Karen Gehrts, Lenny Grimaldo, Bruce Herbold, Joseph Kirsch, Anke Mueller-Solger, Steve Slater, Ted Sommer, Kelly Souza, and Erwin Van Nieuwenhuyse

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Figures

Tables

Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	1.057	quart (qt)
cubic meter (m^3)	264.2	gallon (gal)
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
	Energy	
joule (J)	0.0000002	kilowatthour (kWh)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, "North American Vertical Datum of 1988 (NAVD 88)"

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here, for instance, “North American

Datum of 1983 (NAD 83)”

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

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Abstract

In Fall 2011, a large-scale investigation (FLaSH, fall low salinity habitat investigation) was implemented by the Bureau of Reclamation (Reclamation) in cooperation with the Interagency Ecological Program (IEP) to explore hypotheses about the ecological role of low salinity habitat (LSH) in the San Francisco Estuary (SFE), and specifically the importance of fall low salinity habitat to the biology of delta smelt *Hypomesus transpacificus*, a federal and state listed species endemic to the SFE. This investigation constitutes one of the actions stipulated in the Reasonable and Prudent Alternative (RPA) issued with the 2008 Biological Opinion (BiOp), which called for adaptive management of fall Delta outflow following "wet" and "above normal" water years to alleviate jeopardy to delta smelt and adverse modification of delta smelt critical habitat. The basic hypothesis at the foundation of the RPA is that greater outflows move the low salinity zone (LSZ, salinity 1-6), an important component of delta smelt habitat, westward and that moving the LSZ westward of its position in the Fall of recent years will benefit delta smelt, although the specific mechanisms providing such benefit are uncertain. An adaptive

management plan (AMP) was prepared to guide implementation of the RPA (Reclamation 2011) and reduce uncertainty.

This report has 3 major objectives:

- Provide a summary of the results from the first year of coordinated FLaSH studies and monitoring.
- Provide an integrated assessment of whether the results of the FLaSH studies and other ongoing research and monitoring support the hypotheses behind the RPA as set forth in the AMP (Reclamation 2011.
- Begin to put the results from the FLaSH studies into context within the larger body of knowledge regarding the San Francisco Estuary (SFE) and in particular the upper SFE, including the Sacramento-San Joaquin Delta (Delta) and Suisun Bay and associated embayments.

Our basic approach was to evaluate predictions derived from the conceptual model developed aa part of the AMP. We considered all available data from studies and monitoring conducted in fall 2011 and similar data from fall 2006, which was the most recent wet year preceding 2011. We also considered 2005 and 2010 to include conditions antecedent to each of those years.

Many of the predictions either could not be evaluated with the data available or the needed data are not being collected. Most of the predictions that could be addressed involved either the abiotic habitat components (i.e., the physical environment) or delta smelt responses. In general, the FLaSH investigation has been largely inconclusive as of the writing of this report. That should not be unexpected in the first year of what is intended to be a multi-year adaptive management effort. This report should be viewed as the first chapter of a “living document” that should be continually updated as part of the adaptive management cycle. The results of this report, especially predictions with insufficient data for evaluation, suggest a number of science-based recommendations for improving the FLaSH investigations:

- Develop a method of measuring "hydrodynamic complexity". This concept is central to a number of the predictions that could not be evaluated.
- Determine if wind speed warrants a stand-alone prediction. The wind speed prediction is directly related to the turbidity predictions and wind is only one of several factors important in determining turbidity.
- Determine the correct spatial and temporal scale or scales for monitoring and other studies. Many of the assessments in this report were based on monthly sampling of dynamic habitat components such as phytoplankton and zooplankton populations that can change on daily scales.
- Address the nutrient predictions as part of developing a phytoplankton production model if feasible. At a minimum develop a mechanistic conceptual model to support more processed-based interpretations of data or design of new studies rather than making simple predictions of increase or decrease.
- Determine if studies of predation rates are feasible in areas where delta smelt occur.

Introduction

In Fall 2011, a large scale investigation was implemented by the Bureau of Reclamation (Reclamation) in cooperation with the Interagency Ecological Program (IEP) to explore hypotheses about the ecological role of low salinity habitat (LSH) in the San Francisco Estuary (SFE), and specifically the importance of LSH to the biology of delta smelt *Hypomesus transpacificus*, a federal and state listed species endemic to the SFE. These studies and other activities were motivated by a Biological Opinion (BiOp) on Central Valley Project (CVP)/State Water Project (SWP) operations issued by the US Fish and Wildlife Service (Service) in 2008. The BiOp concluded that aspects of those operations jeopardize the continued existence of delta smelt and adversely modify delta smelt critical habitat. One of the actions stipulated in the Reasonable and Prudent Alternative (RPA) issued with the

BiOp called for adaptive management of fall Delta outflow (hereafter "Fall outflow") following "wet" and "above normal" water years (see Background section for explanation of water year types) to alleviate jeopardy to delta smelt and adverse modification of delta smelt critical habitat. The basic hypothesis at the foundation of the RPA is that greater outflows move the LSH westward and that moving LSH westward of its position in the Fall of recent years will benefit delta smelt, although the specific mechanisms providing such benefit are uncertain. An adaptive management plan (AMP) was prepared to guide implementation of the RPA (Reclamation 2011) and reduce uncertainty.

The AMP was designed in accordance with the Department of Interior guidelines for design and implementation of adaptive management strategies (Williams and others 2009). All adaptive management strategies share a cyclical design including: 1) problem assessment, including development of conceptual and quantitative models; 2) design, evaluation, and implementation of actions; 3) monitoring of outcomes; 4) evaluation of outcomes; and 5) modification of problem assessment and models in response to learning from the actions (Fig. 1). Because the range of hypotheses being explored by the Fall Low Salinity Habitat Program (FLaSH) is so broad, Reclamation in cooperation with IEP perceived the need for a broad synthesis of the FLaSH studies, ongoing IEP monitoring and research, ongoing research funded by other entities and previous studies in the San Francisco Estuary. This report is the first such synthesis with regular updates expected as part of the annual AMP cycle.

Figure 1. A schematic of the adaptive management cycle (modified from Williams and others 2009).

Purpose and Scope

This report has 3 major objectives. The first major objective is to provide a summary of the results from the first year of coordinated FLaSH studies and monitoring. Given that many of the Fall 2011 studies include time intensive sample analyses, data processing, and data analysis steps, the report also documents the status of ongoing study elements that were not completed in time to provide results for this report. The second major objective is to provide an integrated assessment of whether the results of the FLaSH studies and other ongoing research and monitoring programs support the hypotheses behind the RPA as set forth in the AMP (Reclamation 2011, and Background Section below). The third major objective is to begin to put the results from the FLaSH studies into context within the larger body of knowledge regarding the SFE (Fig.2) and in particular the upper SFE, including the Sacramento-San Joaquin Delta (Delta) and Suisun Bay and associated embayments (Suisun region) (Fig. 3). This includes both intra-annual and inter-annual conditions and processes. For example, it would be unrealistic to expect an increase in the fall delta smelt population to occur, even if fall conditions appeared ideal, if conditions for spawning were exceptionally poor during the preceding spring. We specifically address 2010, the calendar year before the FLaSH investigation. We also consider the period of 2005-2006, with 2006 being the most recent wet year prior to the FLaSH investigation. Finally, as part of data integration and assessment in this report, new areas of interest warranting study will be identified and problems with previously implemented studies recognized, if any. This report will note areas of improvement needed and identify additional data needs for fully understanding the efficacy of the RPA action. This report will not recommend which improvements or new studies should be undertaken by the responsible management agencies. However, the report should provide a sound basis for making such decisions.

Figure 2. Map of the San Francisco Estuary. Also shown are isohaline positions (X2) measured at nominal distances (in kilometers) from the Golden Gate Bridge along the axis of the estuary (adapted from Jassby et al. (1995)).

Figure 3. Map of the Sacramento-San Joaquin Delta, Suisun Bay and associated areas.

The overall scope of this report is broad; however, the focus is on the low salinity zone (LSZ) and delta smelt low salinity habitat (LSH). Because FLaSH is focused on delta smelt, the LSZ is defined as the area of the upper SFE with salinity ranging from 1 to 6. This is generally considered the optimal salinity range for delta smelt (Bennett 2005), although fish also occur outside this core range (Feyrer et al. 2007, Kimmerer et al. 2009, Sommer et al. 2011). Reference to the LSZ relates specifically to the area of the estuary with salinity of 1 to 6, while the concept of LSH includes many other properties in addition to salinity that relate to characteristics of the environment important to supporting delta smelt. Clearly, there are no physical barriers between the LSZ and areas with lower or higher salinity. Indeed, exchange of energy, organic and inorganic constituents, and organisms with areas of lower and higher salinity may be critical to the productivity of LSH. The concept of habitat clearly encompasses all such exchanges and their effect on other descriptors of the environment. When not considered in the context of delta smelt we refer to the LSZ rather than LSH. This is important because other organisms have different requirements for salinity and other habitat components and their optima need not correspond with those of delta smelt.

Because the FLaSH investigation was implemented in Fall 2011, that time period is the clear focus of this report. However, the IEP monitoring and studies and other studies have been ongoing in the SFE for many years providing the opportunity to put the 2011 FLaSH studies into a broader temporal context. In fact, this broad perspective is likely critical to understanding how management of Fall LSH can contribute to the protection and recovery of delta smelt. This report represents the first step in addressing this broader scope. A more complete integration will presumably occur in future reports, if the FLaSH investigation continues. As already noted, we specifically focus on fall 2006 for comparison with fall 2011. The two years were both considered as wet years but there was not a comparable increase in the delta smelt population index in 2006 compared to 2011 (Fig. 4). We also include the antecedent year in both cases, to allow assessment of how such conditions may have affected the results observed. We also note that the results of the FLaSH studies likely have importance for other fish populations besides delta smelt and for broad understanding of the entire estuary. This broader temporal, and geographic scope will be addressed as part of a separate but related effort undertaken by the IEP Management, Analysis, and Synthesis Team (MAST).

Figure 4. Delta smelt abundance index from the fall midwater trawl survey. The survey was not conducted in 1974 or 1979.

Background

Study Area

The SFE (Fig. 2) is the largest estuary on the west coast of North America. The SFE has also been characterized as one of the best studied estuaries in the world (e.g., Conomos 1979; Hollibaugh 1996; Feyrer and others 2004). Like other estuaries around the world the SFE has been highly modified by human development and extraction of resources. Most notable are the loss of wetlands, contaminant inputs, alterations of hydrodynamics for diversion of water, and species introductions both accidental and deliberate (Moyle and Bennett 1996, Brown and Moyle 2005, Baxter and others 2010, NRC 2012). These changes and others have been implicated in declines in terrestrial and aquatic resources, including fishes. Many of these anthropogenic changes occurred before the advent of modern regulations and management when the primary focus of resource development was providing human benefits.

This report focuses on the upper SFE, principally the Delta and Suisun region (Fig. 3). Historically, the northern portion of the Delta was dominated by the Sacramento River and associated floodplains, low natural berms, and seasonal and permanent wetlands. The southern portion of the Delta was dominated by the smaller San Joaquin River and associated distributary channels and dead-end sloughs. As development progressed in the Delta, levees were constructed to protect farmlands and formerly isolated channels were connected. Channels were dredged to facilitate shipping to and from the ports of Stockton and Sacramento. Large-scale water development, primarily the CVP and SWP, resulted in further changes, primarily the installation and operation of large water diversion facilities in the southern Delta (Fig. 3).

The current configuration of the Delta includes a complex network of interconnected channels between leveed islands (Fig. 3). A few such islands have flooded, leaving pockets of open water within the Delta. Most of the channels are relatively shallow, except for a dredged deepwater ship channel in the San Joaquin River to the Port of Stockton and a similar channel in the Sacramento River to the Port of Sacramento (Sacramento River deepwater ship channel, SRDWSC). The SRDWSC splits from the main Sacramento River just upstream of the town of Rio Vista and follows the lower portion of Cache Slough north to the port (Fig. 3). Cache Slough continues north and is associated with Liberty Island, which is now flooded, several tributary creeks and sloughs and also serves as the connection of Yolo Bypass to the Sacramento River (Fig. 2). Yolo Bypass is a flood bypass that diverts high flows associated with winter storms around the city of Sacramento and also provides important floodplain habitat for Chinook salmon, splittail and other native fishes (Sommer and others 2001a,b, Sommer and others 2003, Feyrer et al. 2006).

The region where the Sacramento and San Joaquin rivers join (confluence region) is generally deep and uniform in bathymetry with relatively narrow channels compared to the Suisun region (Fig. 3). The Suisun region includes Suisun, Grizzly and Little Honker Bays. This region is also connected to

Suisun Marsh to the north, through Suisun and Montezuma sloughs. The Suisun region then connects to San Pablo and San Francisco bays through Carquinez Strait.

Delta Smelt

Early information on the delta smelt population was collected as part of sampling and monitoring programs related to water development and striped bass *Morone saxatilis* management (Erkkila and others 1950, Radtke 1966, Stevens and others 1983). Striped bass is an exotic species but supported a popular and valuable sport fishery when development of the CVP and SWP began (Moyle 2002). These early monitoring efforts, subsequently consolidated with other activities under the auspices of the IEP, provided sufficient information on the decline of delta smelt (Moyle and others 1992) to support a petition for listing under the federal endangered species act. The delta smelt was listed as threatened under the Federal Endangered Species Act in 1993 (USFWS 1993). Reclassification from threatened to endangered was determined to be warranted but precluded by other higher priority listing actions in 2010 (USFWS 2010). The species status was changed from threatened to endangered under the state statute in 2009 (California Fish and Game Commission 2009). Subsequent declines in the delta smelt in concert with three other pelagic fishes (Fig. 5) caused increased concern for avoiding jeopardy and achieving recovery of delta smelt. These declines are often referred to as the Pelagic Organism Decline (Sommer and others 2007, Baxter and others 2008, 2010).

Figure 5. Trends in abundance indices for four pelagic fishes from 1967 to 2010 based on the Fall Midwater Trawl, a California Department of Fish and Game survey that samples the upper San Francisco Estuary. No sampling occurred in 1974 or 1979 and no index was calculated for 1976. Note that the y-axis for longfin smelt represents only the lower 25% of its abundance range to more clearly portray the lower abundance range..

The delta smelt is endemic to the SFE and is the most estuary-dependent of the native fish species (Moyle and others 1992, Bennett 2005). Delta smelt is a slender-bodied fish typically reaching 60–70 mm standard length (SL) with a maximum size of about 120 mm SL. Delta smelt feed primarily on planktonic copepods, mysids, amphipods, and cladocerans. Most delta smelt complete the majority of their life cycle in the LSZ of the upper estuary and use the freshwater portions of the upper estuary primarily for spawning and rearing of larval and early post-larval fish (Fig. 6) (Dege and Brown 2004, Bennett 2005). The continued global existence of the species is dependent upon its ability to successfully grow, develop, and survive in the SFE. The current range of delta smelt encompasses the Cache Slough area, SRDWSC and Sacramento River in the northern Delta, the confluence region in the western Delta, and the Suisun region (Fig. 7). Historically, delta smelt also occurred in the central and southern Delta (Erkkila and others 1950), but they are no longer found there in the summer and fall months (Bennett 2005, Nobriga and others 2008, Sommer and others 2011). Juvenile and sub-adult delta smelt occur mostly in the LSZ and are most abundant at salinity1-2 (Swanson and others 1996, Bennett 2005, Sommer and others 2011). While delta smelt can complete their entire life cycle in fresh water, the bulk of the population is associated with the LSZ indicating that salinities 1-6 are most favorable for the physiology of juvenile and sub-adult delta smelt. Delta smelt are generally not found at salinity above 14 and cannot survive at salinity above about 20 (Swanson and others 2000). The location of the LSZ in the estuary is indexed by X2, which is the distance (in km) along the axis of the estuary from the Golden Gate to the 2 isohaline measured near the bottom of the water column (Jassby and others 1995).

Figure 6. Simple conceptual diagram of the delta smelt annual life cycle (modified from Bennett 2005).

Figure 7. In the fall, delta smelt are currently found in a small geographic range (yellow shading) that includes the Suisun region, the river confluence, and the northern Delta, but most are found in or near the LSZ. A: The LSZ

overlaps the Suisun region under high outflow conditions. B: The LSZ overlaps the river confluence under low outflow conditions (from Reclamation 2011)

Upstream migration of maturing adults generally begins in the late fall or early winter with most spawning taking place from early April through mid-May (Bennett 2005, Sommer and others 2011). Most larval delta smelt move downstream with the tides until they reach favorable rearing habitat in the LSZ (Dege and Brown 2004). As noted earlier, some fish remain in upstream reaches including the Cache Slough region, SRDWSC, and the central Delta region year-round (Sommer and others 2011), although the contributions of these fish to population production is unknown. A very small percentage of delta smelt survive into a second year and may spawn in one or both years (Bennett 2005).

Summer physical habitat has been described by Nobriga and others (2008) with summer (June-July) distribution of delta smelt determined by areas of appropriate salinity but also with appropriate turbidity and temperatures. Similarly, Feyrer and others (2007, 2010) found the distribution of delta smelt to be associated with salinity and turbidity during fall months (September-December). Kimmerer and others (2009) expanded on these studies by examining the habitat associations of delta smelt for each of the major IEP fish monitoring surveys. Overall, these studies demonstrated that most delta smelt reside in the LSZ in the summer and fall, with a center of distribution near the 2 isohaline, but move upstream during winter and spring months when spawning and early development occur in freshwater.

The year-round presence of delta smelt in the Cache Slough/SRDWSC (Fig. 3), was unexpected based on previous work and it was unknown whether such fish constituted a separate, self-sustaining population of fish or a group of fish expressing natural variability within the delta smelt life history (Sommer and others 2011). Fisch (2011) determined that individuals collected from this region were not genetically unique relative to delta smelt captured from other regions of the system; rather, there is a single, panmictic delta smelt population in the estuary. Although not conclusive, this finding suggests that freshwater resident delta smelt do not form a separate, self-sustaining population. Rather, it seems likely that the life history of delta smelt includes the ability to rear in fresh water if other factors are favorable; however, the absence of delta smelt from riverine habitats upstream of the Delta suggests that there are limits on freshwater residence.

Although abundance of delta smelt has been highly variable, there is a demonstrable long-term decline in abundance (Fig. 4; Manly and Chotkowski 2006, USFWS 2008, Sommer and others 2007, Thomson and others 2010). The decline spans the entire period of survey records from the completion of the major reservoirs in the Central Valley through the POD (Baxter and others 2010). Statistical analyses confirm that a step decline in pelagic fish abundance marks the transition to the POD period (Manly and Chotkowski 2006, Moyle and Bennett 2008, Mac Nally and others 2010, Thomson and others 2010, Moyle and others 2010) and may signal a rapid ecological regime shift in the upper estuary (Moyle and others 2010, Baxter and others 2010). The decline of delta smelt has been intensively studied as part of the POD investigation (Sommer and others 2007, Baxter and others 2010). The POD investigators have concluded that the decline has likely been caused by the interactive effects of several causes, including both changes in physical habitat (e.g., salinity and turbidity fields) and the biotic habitat (i.e., food web). This conclusion was generally supported by a recent independent review panel (NRC 2012).

Conceptual Models

There have been a number of conceptual models applied to the SFE over time. In this section we review some of the more recent conceptual models and how conceptual models evolved toward the conceptual model put forth in the AMP (Reclamation 2011), which serves as the basis for the FLaSH studies and predictions evaluated in this report. Results from monitoring and studies in 2011 will inform conceptual model refinement for future years. We acknowledge that the conceptual models presented in this report are not exhaustive and other conceptual models are certainly possible. For example Glibert (2010) and Glibert and others (2011) stress the importance of nutrients and nutrient ratios to phytoplankton and the bottom up effects of phytoplankton composition and production on upper trophic levels. Miller and others (2012) suggest a hierarchical conceptual model for consideration of factors with direct and indirect effects on delta smelt.

Adaptive management calls for the use of quantitative models when available. A wide variety of statistical approaches have been applied to studies of delta smelt in the SFE. Various forms of regression and multiple regression models have been widely applied (e.g., Manly and Chotkowski 2006, Feyrer and others 2010, Miller and others 2012). General additive models have been used to identify important abiotic habitat factors (Feyrer and other 2007, Nobriga and others 2008). Additional models include Bayesian change point models (Thomson and others 2010) and a Bayesian-based multivariate autoregressive model of delta smelt fall abundance (Mac Nally 2010). Importantly, these studies differed widely in methodology and objectives and rarely evaluated the same environmental factors. As a result, they often reached alternative conclusions about the direct or indirect importance of the same environmental factor on the species.

Life cycle models that quantify and integrate many aspects of the conceptual models are currently under development and are expected to eventually provide results that will help guide fall outflow management and other management actions in the coming years. Maunder and Deriso (2011) developed a statistical state–space multistage life cycle model that can be used to evaluate the importance of various factors on different life stages of delta smelt. The Maunder and Deriso (2011) model could be very useful for exploring the importance of fall environmental conditions to delta smelt. Another life cycle model, currently under development, has a state-space structure similar to Maunder and Deriso (2011). It differs in three critical ways: (1) the model is spatially explicit, so that management actions thought to have particular local effects can be assessed, (2) the temporal resolution is finer, a monthly time step, and (3) data from more fish surveys are being used to fit the model (Ken Newman, written communication, 2012). A numerical simulation model is also being developed by a group led by Kenneth Rose (Louisiana State University) and Wim Kimmerer (California State University-San Francisco). These models could be used to evaluate hypothesized associations in conceptual models as the FLaSH AMP proceeds.

Kimmerer (2004) summarized many of the earlier conceptual models on the physical aspects of the SFE and how they were believed to affect the movement and ecology of fishes. Simply stated, the earliest conceptual models of the estuary assumed unidirectional riverine flow with a classical entrapment zone, which supported high levels of biological production. The early models of fish populations emphasized delta outflow and diversions as driving factors (Stevens 1977, Stevens and Miller 1983).

As knowledge of the upper SFE increased, the interactions of tides, bathymetry, river flow, channel configuration, and diversions were recognized as important in generating the physical conditions that affect fishes at different life stages. Ecologically, continued invasions of SFE were recognized as having important effects on the food web. The effects of the invasive clam *Potamocorbula amurensis* was particularly important because its high grazing rates and tolerance of brackish water enabled it to remove a large proportion of phytoplankton biomass and the early life stages of zooplankton from the water column in and near the LSZ (Alpine and Cloern 1992, Kimmerer and others 1994, Kimmerer and Orsi 1996).

This evolving body of knowledge provided the backdrop for the next major conceptual model based on X2. The intent of the X2 was to develop an easily-measured, policy-relevant indicator with ecological significance for multiple species and processes (Jassby and others 1992). In this context, the position of the LSZ as indexed by X2 is more easily measured than delta outflow. Relative abundance indices of many estuarine resources do show statistically significant linear relationships with spring X2 but not delta smelt (Kimmerer 2002 a,b).

The recognition of the decline in four pelagic fishes, commonly referred to as the POD, resulted in the development of a new set of conceptual models. These models eventually evolved into the AMP model that provided the basis for the FLaSH investigation (Reclamation 2011). Each of these models is briefly summarized below.

Basic POD model

The basic POD conceptual model (Fig. 8) introduced in Sommer et al. (2007) focuses on the four POD fish species (delta smelt, longfin smelt, age-0 striped bass, and threadfin shad) and contains four major components: (1) prior fish abundance (i.e., stock-recruitment effects), which assumes that abundance history affects subsequent recruitment; (2) habitat, which assumes that the volume or surface area of aquatic habitat suitable for a species depends on characteristics of the aquatic habitat, such as estuarine water quality variables, presence of pathogens, and toxic algal blooms; (3) top-down effects, which assumes that predation and water project entrainment affect mortality rates; and (4) bottom-up effects, which assumes that consumable resources and food web interactions affect growth and thereby survival and reproduction. Each model component contains one or more potential drivers affecting the POD fishes. It is important to emphasize several points about the POD conceptual model. The habitat box is shown to overlap the top-down and bottom-up boxes. This is intended to communicate that changes in habitat not only affect the species of interest but also affect their predators and prey. The conceptual model was at least partially designed to provide a *simple* vehicle for communicating information to a wide variety of stakeholders. The traditional "box and arrow" model was too complex for such general use. The text of the two recent POD reports (Baxter and others, 2008, 2010) better represents the growing knowledge base for the SFE ecosystem and recognizes that habitat features may affect each of the other categories of drivers additively, antagonistically, or synergistically, producing outcomes that are not always easily predictable.

Figure 8. The basic conceptual model for the pelagic organism decline (adapted from Baxter and others 2010)

Delta smelt species model

Because of the graphical simplicity of the basic POD model, Baxter and others (2010) also developed species specific models for each of the POD species. These models were better able to communicate differences in factors hypothesized to affect different life stages of the four POD species. The model identifies key seasonal drivers in red, with proximal causes and effects in yellow. Several concepts in the delta smelt conceptual model (Fig. 9) are important to the FLaSH studies. The reduced size and egg supply in fall was thought to be at least partially associated with warm water temperatures and reduced food in the LSZ during the summer. These conditions require that more energy go to basic metabolic demands instead of growth and production of gametes. In fall, reduced habitat area was posited to affect the population through continued reduced growth and restricted egg supply rather than direct mortality. Fall effects therefore manifest themselves in potential limits on subsequent abundance, with the outcome depending on a variety of other seasonal factors.

Figure 9. Delta smelt species-specific model (adapted from Baxter and others, 2010)

Regime Shift Model

The idea that the POD was a manifestation of a rapid and comprehensive ecological regime shift that followed a longer-term erosion of ecological resilience in the estuary was first addressed in detail by Moyle and Bennett (2008). This concept was rapidly accepted by many researchers in SFE because it integrated various observations regarding changes in habitats and species in addition to pelagic habitat and the POD species (Baxter and others 2010, Mac Nally and others 2010, Thomson and others 2010, Moyle and others 2010). In other words, the conceptual model represents an ecosystem approach that recognizes that multiple causes of change can have interactive effects on any individual species or process.

The conceptual model adopted by Baxter and others (2010) (Fig. 10) was presented as a working hypothesis for future ecosystem investigations. Outflow, salinity, and turbidity are considered among the key "slow" environmental drivers in this conceptual model. In this context, outflow and salinity are viewed with respect to long term climatic variability. Turbidity, primarily related to suspended sediment concentration in SFE (Ganju and others 2007), is also viewed in this longer term climatic context. The conceptual model suggests that changes in these fundamental physical drivers, as well as the other five drivers (Fig. 10), shifted the system to a state that no longer favored native species.

Figure 10. Regime shift model from Baxter and others (2010). The model assumes that ecological regime shift in the Delta results from changes in environmental drivers (top panel) that lead to profoundly altered biological communities (bottom panel). Introduction of invasive species is also an important process in producing the shift. The ecosystem must pass through an unstable threshold region before the new relatively stable ecosystem regime is established.

The model suggests that a more westward (in Suisun region) and variable (annually and seasonally) salinity gradient favors native species (such as delta smelt), while a more eastward (near the confluence), constricted, and stable salinity gradient favors non-native and nuisance species (such as invasive clams and submerged aquatic vegetation and associated fishes). In this context, the fall RPA action would maintain the LSZ in a more westward position, providing improved conditions for native fishes. This conceptual model also recognizes the step decline in turbidity in Suisun Bay that occurred after the sediment-flushing outflow event associated with the 1997–1998 El Niño (Schoellhamer 2011). Along with persistent high fall salinity in Suisun Bay during the POD period, this sudden clearing may have also contributed to the POD regime shift and affected delta smelt fall habitat (Baxter and others 2010). It is important to realize that the establishment of multiple invasive species, new invasions, and ongoing human needs for resources make it highly unlikely that the SFE ecosystem will ever be fully returned to the previous conditions. The goal of the RPA action is to improve conditions within the current regime (Reclamation 2011) such that conditions for delta smelt are improved, presumably with positive effects for other desirable species. Lund and others (2010) explore some more comprehensive approaches to the issue.

Habitat Study Group Model

In a precursor to the FLaSH AMP, the 2010 Habitat Study Group (HSG) Adaptive Management Plan (USFWS 2010) adapted the POD models to address key processes associated with habitat quality and quantity for delta smelt in the fall. The position and extent of LSH as indexed by Fall X2 is envisioned as a “filter” modifying the drivers and subsequent delta smelt responses. This model represents the importance of physical habitat and how it affects delta smelt abundance, distribution, and health (Fig. 11). Bottom-up, and top-down drivers are included but the exact processes involved and responses of those processes to changes in LSH are unknown, as indicated by the question marks. The model implies that most of the potential effects of fall outflow are expected to occur through the processes that affect the growth and survival of juvenile and fecundity of adult delta smelt. The HSG conceptual model was never developed further, although several research studies were initiated to resolve questions raised during development of the model. The HSG AMP was integrated into the FLaSH AMP when the decision was made to implement the RPA.

Figure 11. Habitat Study Group model of effects of fall low salinity habitat position and indexed by X2 on delta smelt through changes in habitat quantity and quality. Position and extent of fall low salinity habitat affects (either directly or indirectly) the expected outcomes for the same drivers (from Reclamation 2011).

Estuarine Habitats Model

The estuarine habitats conceptual model (Fig. 12) was an important element in developing the new conceptual model to guide the FLaSH AMP. The general model, developed by Peterson (2003), provided an established theoretical framework for many of the ideas included in earlier conceptual models related to the position of the LSZ in the estuary and the interactions of the LSZ with delta smelt and other organisms. The Peterson (2003) model proposed an ecosystem-based view of estuarine habitats. A modified version of this conceptual framework was presented by the Environmental Flows Group (Moyle and others 2010) to the State Water Resources Control Board (SWRCB) in the recent SWRCB proceedings to develop flow recommendations for the Delta. This group included regional technical experts including several members of the IEP POD team and their view of estuarine habitats was reflected in the SWRCB's final report (SWRCB 2010). In this framework, the environment of an estuary consists of two integral parts:

- a stationary topography with distinct physical features that produce different levels of support and stress for organisms in the estuary, and
- a dynamic regime of flows and salinities. Organisms passively transported by flow or actively searching for a suitable salinity will be exposed to the different levels of support and stress that are fixed in space in the stationary topography.

Together these stationary and dynamic habitat features control the survival, health, growth and fecundity of estuarine pelagic species and ultimately their reproductive success (Fig. 12).

Figure 12. Estuarine habitat conceptual model (after Peterson 2003).

For the Delta, this dynamic and interacting view of estuarine ecology captured several important elements. First, the interactions of outflow and resulting position of the LSZ (dynamic habitat) with the physical configuration of the Delta (stationary habitat) and anticipated outcomes for estuarine organisms (e.g., Jassby 1995; recruitment) is clearly a reflection of concepts from earlier conceptual models. Second, variability in the dynamic habitat on daily, seasonal, annual, and longer time scales produces habitat complexity and variability, which can be important in promoting species diversity. This second idea is consistent with the concepts regarding regime shift.

Moyle and others (2010) highlighted the extensive literature documenting the significant roles of habitat complexity and variability in promoting abundance, diversity, and persistence of species in a wide array of ecosystems. They stressed the importance of both predictable and stochastic physical disturbances, timing and extent of resource availability, as well as the degree of connectivity among habitat patches, relative to the abilities of organisms to move between them. Further, they recognized that landscapes are not stable in their configurations through time and environmental fluctuations generally increase the duration and frequency of connections among patches of different kinds of habitat. Variability implies that different processes interact at various scales in space and time, with the result that more species are present than would be in a hypothetical stable landscape. They concluded that ecological theory strongly supports the idea that an estuarine landscape that is heterogeneous in salinity and geometry (depth, the configuration of flooded islands, tidal sloughs, floodplains, etc.) is most likely to have high overall productivity, high species richness, and high abundances of desired species (Moyle and others 2010).

A New Conceptual Model for Fall Low Salinity Habitat

The new conceptual model developed to guide the FLaSH AMP (Fig. 13) (Reclamation 2011) and thus the FLaSH studies, combines and highlights aspects of the previous models pertaining to the effects of fall outflow management on delta smelt and the estuarine habitat conceptual model (Fig. 12). The new conceptual model offers a way to describe existing knowledge and to identify what is known and what remains uncertain about abiotic and biotic components of delta smelt fall habitat under different outflow scenarios. The model includes interacting dynamic and stationary (geographically fixed) abiotic habitat components that determine the characteristics of LSH. These conditions interact with dynamic biotic habitat components of food and predators. The combined abiotic and biotic habitats determine the quantity and quality of fall LSH for delta smelt, which are expressed through the delta smelt responses. In the AMP and this report, we use the conceptual model in the context of understanding delta smelt, their predators, and their food resources in the river channels of the western Delta and in the Suisun region in the fall. The conceptual model can and should be applied to other species to ensure that actions taken to improve habitat for delta smelt do not have unanticipated consequences for other species. The basic approach should also be applied to other seasons to address all life stages of delta smelt and other species of interest.

The stationary abiotic habitat components (Fig. 13) are associated with the physical orientation and connections of the component waterbodies and the bathymetry of those waterbodies. The dynamic abiotic habitat components are associated with hydrodynamic conditions and position of the salinity gradient associated with fall outflow. The interactions of stationary and dynamic abiotic habitat components determine the position and characteristics of LSH available for delta smelt to utilize (Fig. 13). With respect to the RPA, interest is focused on two generalized flow regimes within the remaining fall range of delta smelt. In the “low outflow” regime, LSH is located in the confluence region of the

Sacramento and San Joaquin Rivers (hereafter referred to as the "river confluence"). In the "high outflow" regime, LSH is located in the Suisun region, which extends seaward from the river confluence to the west and includes Suisun Bay, Grizzly Bay, Honker Bay, and Suisun Marsh (Fig. 13).

Figure 13. Spatially explicit conceptual model for the western reach of the modern delta smelt range in the fall: interacting stationary and dynamic habitat features drive delta smelt responses.

In the FLaSH conceptual model, the LSZ represents the abiotic portion of the production area (Fig. 12), which is the dynamic outcome of the interaction between stationary and dynamic habitat components. LSZ can be considered a dynamic abiotic habitat component (Fig. 13) because its extent (e.g., surface area) and location varies with net freshwater outflow from the Delta. Delta smelt and other organisms that seek the salinity levels within the LSZ range or are transported by flow into the area, likely respond differently to the dynamic and stationary habitat features available under the high and low fall outflow regimes. In other words, conditions may or may not correspond to those necessary for successful recruitment. The conceptual model focuses on the concept of the LSZ representing the optimal region for delta smelt production. After the conceptual model is described in some detail, delta smelt habitat in the northern delta is considered.

The main objectives of this report include presentation of the results of studies and monitoring during fall 2011 and an assessment of whether the data support predictions made in the FLaSH AMP (Reclamation 2011) based on the conceptual model. Detailed justifications for the various assumptions made in the conceptual model are not repeated here. Justifications for each element of the conceptual model, based on available data, are presented in the FLaSH AMP (Reclamation 2011). In this report, each element of the conceptual model is briefly reviewed so that readers are familiar with the basis for each of the predictions to be evaluated. In some cases, some key supporting information is presented.

Stationary abiotic habitat components

The POD and HSG models suggest four key stationary habitat components that differ between the river confluence and Suisun regions and may affect habitat quality and availability for delta smelt. It is important to note that these features differ between the two regions but also all vary within each region, and all change over time in response to dynamic drivers, albeit much more slowly than the dynamic habitat components. For example, bathymetry and erodible sediment supply can change as more sediment is transported into the region and deposited or eroded and flushed out to the ocean. Contaminant sources and entrainment sites are added or eliminated with changes in land and water use. The four stationary habitat components in the river confluence and Suisun region are (Fig. 13):

- *Bathymetric complexity:* Differences in bathymetry and spatial configuration between the Suisun region and the river confluence affect nearly all other habitat features and interact strongly with the prevailing dynamic tidal and river flows to produce regionally distinct hydrodynamics. Overall, the Suisun region is more bathymetrically complex than the river confluence. Extensive shallow, shoal areas in the Suisun region are considered particularly important.
- *Erodible Sediment Supply:* The amount and composition of the erodible sediment supply is an important factor in the regulation of dynamic suspended sediment concentrations and turbidity levels in the water column. Suisun Bay features extensive shallow water areas such as Grizzly and Honker Bays that are subject to wind waves that resuspend bottom sediment and increase turbidity relative to the confluence (Ruhl and Schoellhamer 2004). The contribution of organic material to the erodible sediment supply in the Suisun region and the river confluence and its role is uncertain.
- *Contaminant Sources:* The large urban areas surrounding the estuary and the intensive agricultural land use in the Central Valley watershed and the Delta have resulted in pollution of the estuary with many chemical contaminants (Brooks and others 2012, Johnson and others 2010). Many of these

pollutants (e.g. heavy metals, pesticides) can be toxic to aquatic organisms. The largest wastewater treatment plant in the Delta, the Sacramento Regional Wastewater Treatment Plant (SRWTP), discharges effluent with high amounts of ammonium, pyrethroid pesticides, and other pollutants into the Sacramento River near the northern Delta border. The large Contra Costa wastewater treatment plant also discharges substantial amounts of ammonium and other pollutants into the western Suisun Bay near Carquinez Strait. Ammonium has been found to suppress nitrate uptake and growth of phytoplankton in the Delta and Suisun Bay (Dugdale and others 2007). In addition to man-made chemical pollution, blooms of the toxic cyanobacteria *Microcystis aeruginosa* have become a common summer occurrence in the central and southern parts of the Delta, including the river confluence and the eastern edge of the Suisun region (Lehman and others 2007; 2010). Because *Microcystis* can produce potentially toxic microcystins and is considered poor food for secondary consumers, it is considered a biological contaminant.

- *Entrainment sites*: Entrainment sites include agricultural water diversions and urban water intakes throughout the Delta and Suisun regions of the estuary, the state and federal water project pumps in the southern Delta (Fig. 3), and two power plant cooling water intakes in the Suisun region (in Pittsburg and Antioch). Entrainment can cause direct mortality in fish screens, pumps, or pipes, or it can cause indirect mortality due to enhanced predation or unsuitable water quality associated with diversion structures and operations. Direct entrainment of delta smelt in the fall months is likely rare; however, fall hydrodynamic conditions may influence where delta smelt stage in anticipation of the winter migration (Sommer and others 2011). A more eastward starting location can increase entrainment risk of delta smelt at the SWP and CVP when diversions cause flows in Old and Middle River (OMR) to move toward the projects (known as negative OMR flows) rather than seaward during smelt upstream migration periods (Grimaldo and others 2009); however, this effect is only important when turbidity exceeds about 12 NTU because delta smelt tend not to move into clear water (Grimaldo and others 2009). Current management strategies are in place to reduce exports during the first large storms of the season, usually in late fall (known as “first flush”), when turbidities increase above 12 NTU and upstream movement of delta smelt is expected (USFWS 2008).

Dynamic abiotic habitat components

The POD and HSG models also suggest a number of dynamic components that change in magnitude and spatial configuration at daily, tidal, seasonal, and interannual time scales. Their interactions with each other and with stationary habitat components determine the extent and location of production areas for estuarine species. The seven major dynamic abiotic habitat components are (Reclamation 2011):

- *Total Delta outflow and San Joaquin River contribution in the fall:* The interaction of ocean tides with inflows from tributary rivers is the main dynamic driving force in estuaries and determines outflow to the ocean. The SFE experiences twice-daily ebb and flood tides and strong fortnightly spring and neap tidal cycles. The estuary is located in a Mediterranean climate zone with highly variable precipitation and river flow patterns (Dettinger 2011). Winters are generally wet and summers are dry, but there is large interannual variability and California water managers distinguish between five different water year types (wet, above normal, below normal, dry, and critically dry). A water year begins on October 1 of the preceding year and ends on 30 September. Water year types for the Sacramento and San Joaquin River watersheds are based on calculation of an index incorporating unimpaired runoff during the current and previous water year (SWRCB 1995). For the Sacramento River, index values ≥9.2 MAF (million acre feet) denote a wet year and values >7.8 MAF and <9.2 MAF, denote an above normal year. For the San Joaquin River, index values ≥3.8

MAF denote a wet year and values >3.1 MAF and <3.8 MAF, denote an above normal year (historical water year types are available at *http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST*). On an annual basis, San Joaquin River flows are smaller than Sacramento River flows and are reduced to a much greater extent by storage and diversions compared to Sacramento River flows. Only a small amount of San Joaquin River water is actually discharged to the ocean in all but the wettest years. This is especially true in the fall months, when only a very small fraction of Delta outflow is contributed by water from the San Joaquin River.

- *Location and extent of the fall LSZ:* Under the static fall outflow regime that has been typical for the POD period, outflows throughout much of the fall are always low and salinity intrudes far to the east (X2>80km), causing the LSZ to be constricted to the confluence of the deep Sacramento and San Joaquin river channels (Figure 16). When X2 is more seaward, the LSZ includes more of the Suisun region (Figs. 14 and 15).
- *Hydrodynamic complexity in the fall LSZ*: The basic idea behind the idea of hydrodynamic complexity is habitat heterogeneity within the LSZ. It is hypothesized that when the LSZ is located in Suisun Bay, there is more shoal habitat available, connections with Suisun Marsh are possible, and there is greater likelihood of gyres and eddies forming. Conceptually, this provides a greater array of habitat types for delta smelt to utilize for resting, feeding, and other activities. Hydrodynamics are primarily driven by the interaction of dynamic river flows, and ocean tides with stationary bathymetry and spatial configuration of channels. With respect to the movement of water masses through the estuary, hydrodynamics in the estuary are generally understood and have been modeled with a variety of tools (see, for example, DSM2; CDWR 2008; CDWR 2005; Close and others, 2003). There remains much uncertainty, however, about the interaction of hydrodynamics with the stationary habitat components in the Suisun and river confluence regions and their

combined effect on other dynamic habitat components including turbidity, contaminants, and biota. The diverse configurations of shoals and channels and connections to Suisun Marsh produce complex hydrodynamic features such as floodtide pulses in Grizzly Bay (Warner and others 2004), tidal asymmetry (Stacey and others 2010), lateral density fronts in Suisun cutoff (Lacy and others 2003), and multiple null zones and turbidity maxima (Schoellhamer and Burau 1998, Schoellhamer 2001). In contrast, the river confluence area has simpler bathymetry that lacks extensive adjacent shallow embayments.

- *Wind speed in the fall LSZ*: Strong winds from the north and west are characteristic of the Suisun and river confluence regions of the SFE. On average, wind speeds are high throughout most of the year including early fall, but lower in mid to late fall. The interaction of wind with river and tidal flows and the erodible sediment supply drives the resuspension of erodible bed sediments. Wind-wave resuspension is substantial in the shallow bays of the Suisun region and helps maintain generally high suspended sediment concentration and turbidity levels in these areas (Ruhl and Schoellhamer 2004). In contrast, wind likely plays a less important role in suspending sediments in the deep channels of the river confluence.
- *Turbidity in the fall LSZ*: Turbidity, often measured as Secchi depth in the Delta, has been found to be an important correlate to delta smelt occurrence during the summer (Nobriga and others 2008) and fall (Feyrer and others 2007). Turbidity during the winter also appears to be important as a cue for the upstream spawning migration (Grimaldo and others 2009, Sommer and others 2011). Turbidity is assumed to reduce predation risk for delta smelt as it does for other fishes but no direct experiments or observations exist to support the hypothesis. In the SFE, turbidity is largely determined by the amount of suspended inorganic sediments in the water (Cloern 1987, Ganju and others 2007, Schoellhamer and others in press), although organic components may also play a role

(USGS 2008). Sediment particles are constantly deposited, eroded, and resuspended, and are transported into, within, and out of the estuary. The amount of sediment that is suspended in the water column depends on the available hydrodynamic energy, which determines transport capacity, and on the supply of erodible sediment. Strong turbulent hydrodynamics in the Suisun region caused by strongly interacting tidal and riverine flows, bathymetric complexity, and high wind speeds continue to constantly resuspend large amounts of the remaining erodible sediments in the large and open shallow bays of the Suisun region. The Suisun region thus remains one of the most turbid regions of the estuary. Turbidity dynamics in the deep channels of the river confluence are driven more by riverine and tidal processes while high wind and associated sediment resuspension has little if any effect (Ruhl and Schoellhamer 2004). In Fall, fine erodible sediment has been somewhat winnowed from the bed and wind speed is less than spring and summer, so wind wave resuspension and suspended-sediment concentrations typically are low compared to other seasons. In the fall, turbidity is usually lower in the river confluence than in the Suisun region (Bennett and Burau 2011). This difference is also consistent with preliminary analyses by W. Kimmerer (SFSU, pers. com.) that suggest that turbidity in the LSZ is higher when fall X2 is further downstream and the LSZ overlaps the Suisun region.

- *Contaminant Concentrations in the fall LSZ:* Chemical contaminants from agricultural and urban sources that are present in the estuary include pyrethroid pesticides, endocrine disruptors, and many traditional contaminants of concern (Kuivila and Hladik 2008, Johnson and others 2010, Brooks and others 2012). Some regions of the upper estuary are also enriched with the nutrient ammonium (Johnson 2010, Brooks and others 2012). In the late summer and early fall, blooms of the cyanobacteria *Microcystis aeruginosa* can release toxic microcystins (Lehman and others 2010). Agricultural contaminants are delivered into the LSZ from winter to summer in storm-water run-off, rice field discharge, and irrigation return water (Kuivila and Hladik 2008). The amount and types of agricultural contaminants that reach the LSZ vary seasonally, with more inputs from winter to summer than in the fall (Kuivila and Hladik 2008). Urban and industrial pollution from wastewater treatment plants and industrial discharges occurs more steadily throughout the year, although the amount of contaminant-containing urban storm-water run-off is largest in the winter and spring. In the fall, pollutant loading from stormwater is generally negligible and lower river flows mobilize fewer sediment bound contaminants than in other seasons.

Figure 14. The upper panel shows the area of the LSZ (9,140 hectares) at X2 = 74 km (at Chipps Island). The lower panel shows the percentage of day that the LSZ occupies different areas.

Figure 15. The upper panel shows the area of the LSZ (4,914 hectares) at X2 = 81 km (at the confluence of the Sacramento and San Joaquin rivers), when the LSZ is confined within the relatively deep channels of the western Delta. The lower figure shows percentage of day that the LSZ occupies different areas.

Figure 16. The upper panel shows the area of the LSZ (4,262 hectares) at X2 = 85 km, when positioned mostly between Antioch and Pittsburg. Connections to Suisun Bay and Marsh have nearly been lost. The lower panel shows the percentage of day that the LSZ occupies different areas.

Dynamic Biotic Habitat Components:

Estuarine fishes seek areas with a combination of dynamic and stationary habitat components that are well suited to their particular life histories. In addition to abiotic habitat components, fish habitat also includes dynamic biological components such as food availability and quality and predator abundance.

- *Food availability and quality:* Food production in estuaries is a dynamic process that involves light, nutrients, algae, microbes, and aquatic plants at the base of the food web to intermediate and higher trophic levels including invertebrates, such as zooplankton and benthos, and vertebrates such as fishes and water birds. As in many other estuaries, higher trophic level production in the open waters of the Delta and Suisun regions is fueled by phytoplankton production (Sobczak and others 2002). In contrast to many other estuaries, however, the SFE has overall low phytoplankton production and biomass (Cloern and Jassby 2008). Phytoplankton production in the estuary is highly variable on a seasonal and interannual basis (Jassby and others 2002, Cloern and Jassby 2010). The SFE also has a large amount of spatial variability in food production and food web dynamics. Estuaries and rivers often have dynamic food and biogeochemical "hot spots" (Winemiller and others 2010) that persist in one location for some time or move with river and tidal flows. There also are usually areas with low food production and biomass. The temporal and spatial variability of food production, biomass, and quality in estuaries is the result of the interaction of dynamic drivers such as biomass and nutrient inputs from upstream, estuarine hydrodynamics, salinity, turbidity, and trophic interactions with stationary habitat components such as the bathymetric complexity and spatial configuration of a particular geographic area. Food resources for delta smelt in the fall LSZ vary considerably on many spatial and temporal scales. *Microcystis* became abundant in the estuary in the early 2000s coincident with the POD (Lehman et al. 2005). The neurotoxic mycrocystins found in this cyanobacteria have been found in many components of the food web. Although *Microcystis* tends to be restricted to freshwater in the Delta, blooms can extend down into Suisun Bay into the LSZ. In relation to delta smelt, concern over *Microcystis* is currently focused on possible food web effects particularly on calanoid copepods (Ger and others 2009, 2010a,b). If blooms expand in scope and duration there may be more concern regarding direct effects. Many uncertainties remain about the dynamics of food resources at the small scales important to individual feeding delta smelt, which ultimately contribute to delta smelt survival, growth, and health in the fall. Uncertainties also remain regarding the relative importance of food subsidies from upstream regions and food produced in the LSZ. Subsidies of biomass from the San Joaquin River have been hypothesized to be important to the LSZ, when flows are sufficient to transport biomass downstream. Species invasions associated with extreme salinity intrusions during droughts have greatly altered the composition of the invertebrate community in the LSZ, with uncertain effects on delta smelt. Overall, food quantity and quality may be higher for delta smelt if the fall LSZ is in Suisun Bay than if it is in the river confluence, but many uncertainties remain.

- *Predator composition and abundance*: Predators are a natural biological component of ecosystems and most organisms are exposed to predation during some part of their lives. In general, a reduction in the area of appropriate habitat for a population of prey organisms may cause the prey density to increase in the remaining habitat area resulting in an increased probability of predator-prey encounters in that habitat. In the SFE, the fall distribution of piscivorous juvenile striped bass overlaps the fall distribution of delta smelt. Striped bass occur in both the confluence and the Suisun region (Nobriga and others 2005; Sommer et al. 2011b). Higher turbidity in the Suisun region may, however, reduce predation risk for delta smelt in these areas compared to the river confluence, where turbidity is generally lower. Largemouth bass are increasingly abundant in the central and northern Delta (Brown and Michniuk 2007) and potentially exert significant predation pressure on delta smelt in the river confluence region, although this has not yet been documented. Sacramento pikeminnow *Ptychocheilus grandis*, a native predator, occurs in both regions. Mississippi silversides, another introduced species, appear to prey on larval delta smelt in the spring, but are too small to prey on juvenile and sub-adult delta smelt in the fall (B. Schreier, DWR, pers. com.). High predator abundance has been documented in the river confluence at the release sites for fishes salvaged in the CVP and SWP fish facilities (Miranda and Padilla 2010). Overall, predator abundance and associated predation risk for delta smelt may be generally high in the river confluence, but variable in the Suisun region. Much uncertainty remains, however, about the role and magnitude of predation in these regions.

Delta Smelt Responses

The POD and HSG models suggest that delta smelt respond in several ways to outflow-related habitat changes in the fall. Specifically, access to areas of greater bathymetric complexity such as those found in the Suisun region likely offers multiple advantages to delta smelt, although many uncertainties regarding the mechanisms that link delta smelt responses to outflow conditions and the position of the LSZ remain. Note also that the responses of delta smelt may be muted depending on the status of the population. For example, severely low adult abundance is likely to generate relatively low recruitment regardless of habitat quality. At the extreme end of low abundance, the delta smelt population may be subject to Allee effects, which cause a downward spiral that may be difficult to reverse (Baxter and others 2008). However, the increase in the 2011 delta smelt abundance index compared to years in the 2000s (Fig. 4) suggests that the delta smelt population is still resilient and able to respond to favorable conditions, reducing the risk of Allee effects.

- *Distribution:* Prior to their upstream spawning migration in the winter, delta smelt are commonly found in the LSZ (Feyrer and others 2007, Sommer and others 2011a). Older life stages of delta smelt may not require the same high turbidity levels that larval delta smelt need to successfully feed, but are most likely able to discriminate level and types of turbidity (and salinity) to find waters that contain appropriate prey resources and that will provide some protection against predation. A westward LSZ (Figure 14) ensures delta smelt access to a larger habitat area that overlaps with the more bathymetrically complex Suisun region with its deep channels, large shallow shoal areas, and connectivity with Suisun Marsh sloughs.

- *Growth, survival and fecundity:* Distribution across a larger area with high turbidity and more food, when the LSZ overlaps the Suisun region, may help delta smelt avoid predators and increase survival and growth. Distance from entrainment sites and locations where predators may congregate (artificial physical structures, scour holes in river channels, *Egeria* beds) may also help increase survival. Higher phytoplankton and zooplankton production in shallow areas of the Suisun may provide better food resources for delta smelt compared to the deep river confluence during high outflow years. Increased growth should result in greater size of adult delta smelt and greater fecundity of females, since number of eggs is related to length (Bennett 2005).
- *Health and condition:* The same mechanisms listed for growth, survival and fecundity, can affect health and condition. Improved health and condition at the beginning of the spawning period may increase the likelihood of repeat spawning by females. In addition, a larger habitat area may help delta smelt avoid areas with high concentrations of toxic contaminants.
- *Recruitment in the next spring:* Ultimately, the factors listed above may lead to increased distribution, abundance, and reproductive potential of the delta smelt population. However, delta smelt need to find suitable spawning and larval rearing habitat upstream of the LSZ for reproductive potential to result in production of young fish in the spring. In addition to preceding summer and fall habitat conditions, successful spring recruitment thus requires suitable winter and spring conditions for migration, gamete maturation, spawning, and larval rearing. These habitat conditions depend on the interplay of a different set of stationary and changing dynamic habitat features. Only if habitat conditions are met year-round will delta smelt be able to successfully maintain their life history and genetic diversity.

Delta Smelt In the Northern Delta

While the center of the delta smelt distribution in the fall is the LSZ, they also occur year-round in the northern Delta (Sommer and others 2011a). Because delta smelt are currently found in the northern Delta in the fall, this region also constitutes delta smelt fall habitat. It is important to note, however, that habitat quality and resulting delta smelt survival, health, growth, fecundity and recruitment contribution to the total population may differ between this region and the LSZ. The 2011 study plan included a comparison of dynamic and stationary habitat features and delta smelt responses in the LSZ and northern Delta habitats.

The northern Delta range of delta smelt in the fall includes the SRDWSC and the Cache Slough complex with its dead-end sloughs and the large, flooded Liberty Island (Fig. 3) (Sommer and others 2011a). There is a slight gradient in salinity from freshwater in the mainstem Sacramento River up to about salinity 0.5 in the SRDWSC and the smaller sloughs. Stationary habitat features in the northern Delta have a number of similarities with those of the Suisun region. It is bathymetrically complex, turbid, productive, has low entrainment risk, and variable risk of toxin exposure and predation. Dynamic habitat features include strong tidal exchanges with the Sacramento River and variable contributions of productive tributary waters.

Although the salinity and temperature ranges may not be physiologically optimal in the northern Delta, other factors such as differences in food availability or predation rates could offset any physiological stress associated with living in freshwater. Because the northern Delta serves as a delta smelt spawning area (Sommer and others 2011a), fish rearing in the area may avoid negative factors associated with downstream dispersal followed by an upstream spawning migration. Thus, the northern Delta may represent a secondary production area for delta smelt. As noted earlier, it is important to remember that delta smelt in this region are not genetically distinct from delta smelt from other regions

(Fisch and others 2011); however, groups of individuals (contingents) within the population may exhibit different migration patterns (Sommer and others 2011),.

Hypotheses/Predictions

A key to the adaptive approach described in the FLaSH AMP is that the alternative fall outflow scenarios within the RPA lead to a suite of expected responses from dynamic habitat drivers and biological responses at multiple levels of the ecosystem. Those expectations about dynamic habitat drivers and biological responses are presented in the form of quantitative and qualitative predictions in Table 1. The science plan detailed in the FLaSH AMP is designed to test these predictions. In this report, we use data from ongoing monitoring and research programs to determine if the predictions were supported. Several important dynamic response variables are suggested by the conceptual model, but not yet incorporated into Table 1 because there are insufficient data available to make qualitative or quantitative predictions. These include contaminant concentrations and effects, jellyfish dynamics, microbial dynamics, and delta smelt responses beyond the fall such as recruitment and future abundance trends. The 81 km and 74 km columns in Table 1 correspond to RPA action X2 targets for "above normal" and "wet" water years and the high outflow variant of the variable outflow scenario described in the new conceptual model (left side of Figure 13). The 85 km column in Table 1 represents the static low fall outflow scenario (right side of Figure 13).

Table 1. Predicted qualitative and quantitative outcomes of the fall RPA action based on 3 levels of the action (modified from Reclamation 2011). In wet, years the target is X2=74 km and in above normal years the target is X2=81 km.

	Predictions for X2 scenarios

Variable (Sep-Oct)	85 km	81 km	74 km
Dynamic Abiotic Habitat Components			
Average Daily Net Delta Outflow	~5000 cfs?	~8000 cfs?	11400
Surface area of the fall LSZ	~ 4000 ha	~ 5000 ha	~ 9000 ha
Delta Smelt Abiotic Habitat Index	3523	4835	7261
San Joaquin River Contribution to Fall Outflow	0	Very Low	Low
Hydrodynamic Complexity in LSZ	Lower	Moderate	Higher
Average Wind Speed in the LSZ	Lower	Moderate	Higher
Average Turbidity in the LSZ	Lower	Moderate	Higher
Average Secchi Depth in the LSZ	Higher	Moderate	Lower
Average Ammonium Concentration in the LSZ	Higher	Moderate	Lower
Average Nitrate Concentration in the LSZ	Moderate	Moderate	Higher
Dynamic Biotic Habitat Components			
Average Phytoplankton Biomass in the LSZ (excluding Microcystis)	Lower	Moderate	Higher
Contribution of Diatoms to LSZ Phytoplankton Biomass	Lower	Moderate	Higher
Contribution of Other Algae to LSZ Phytoplankton biomass at X2	Higher	Moderate	Lower
Average Floating Microcystis Density in the LSZ	Higher	Moderate	Lower
Phytoplankton biomass variability across LSZ	Lower	Moderate	Higher
Calanoid copepod biomass in the LSZ	Lower	Moderate	Higher
Cyclopoid copepod biomass in the LSZ	Lower	Moderate	Moderate
Copepod biomass variability across LSZ	Lower	Moderate	Higher
Potamocorbula biomass in the LSZ	Higher	Moderate	Lower
Predator Abundance in the LSZ	Lower	Moderate	Higher
Predation Rates in the LSZ	Lower	Moderate	Higher
Delta Smelt (DS) Responses			
DS caught at Suisun power plants	0	0	Some
DS in fall SWP & CVP salvage	Some?	0	0
DS center of distribution (km)	85 (77-93)	82 (75-90)	78 (70-85)
DS growth, survival, and fecundity in fall	Lower	Moderate	Higher
DS health and condition in fall	Lower	Moderate	Higher

DS Recruitment the Next Year	Lower	Moderate	Higher
DS Population Life History Variability	Lower	Moderate	Higher

Methodology

Our general approach in this report was to evaluate the predictions put forth in the AMP. For each prediction in Table 1, we review the available information and make a judgment about whether each prediction was supported by the available data. .For the purposes of this report, we consider fall as being defined by the months of the Fall Midwater Trawl (FMWT) survey, which generally begins in September and ends by mid-December. Within fall, we recognize two important time periods. The RPA action requires water management to maintain X2 at a designated value in September and October (Sep-Oct), constituting the first time period of interest. The remaining months of November and December (Nov-Dec) constitute the second time period of interest. Our evaluation of predictions relies largely on agency collected monitoring data (Table 2) because those were the data available at the time and does not reflect any preference for those data.

We include analyses of data from other years besides 2011 because our approach is comparative. We include 2006, because it is the most recent wet year preceding 2011. As already noted, we recognize that preceding habitat conditions may have important implications for the outcomes of an RPA action during any particular year; therefore, we also consider data from 2005 and 2010. Coincidentally, X2 during fall 2010 averaged 85 km (see Results, Table 3) providing a good comparison with 2011 and being very close to the minimum and maximum X2 referenced in Table 1. In 2005 and 2006, X2 averaged 83 and 82 km, respectively. These results do not correspond exactly to the 81 km condition in Table 1 but do provide data for several years between X2 of 75 and 85 km.

The data analysis focuses on calendar years rather than water years. A water year begins on October 1 of the preceding year and ends on 30 September. Thus, for analysis of a selected year we include data from September 1 to 30 September, which is the overlap of water year and calendar year, plus the first three months of the following water year, 1 October to 31 December. All four years of interest fall into the POD period that started when fish abundances of delta smelt and three other pelagic species in the SFE suddenly dropped in about 2002 and then remained very low for multiple years (Fig. 4; Baxter and others 2010, Thomson and others 2010).

Analyses were generally stratified by salinity. Specifically, data were divided into salinity categories of <1, 1-6, and >6. The Cache Slough complex and SRDWSC were treated as a separate category because delta smelt are known to occupy the area for the entire year even though salinities are <1. Thus, this area is of special interest and warrants separate treatment from other freshwater areas. Sources of data are summarized in Table 2. Additional details on data collection, measurement, methods of calculation, and analysis are available in Appendix A.

Table 2. Data sources with references to subsections of Appendix A, where more detailed methods can be found.

Data source Type of data	Responsible agency	Appendix A subsection
DayFlow		
Delta average daily outflow	DWR	A.1
QWEST	DWR	A.1
X2	DWR	A.1
Delta Modeling Associates		
Surface area of LSZ	Delta Modeling Associates	A.2
Maps of LSZ	Delta Modeling Associates	A.2
USBR		
Delta smelt habitat index	USBR	A.3
Fall midwater trawl		
Delta smelt abundance index	CDFG	A.4
Water temperature	CDFG	A.4
Specific conductance	CDFG	A.4
Secchi depth	CDFG	A.4
Turbidity	CDFG	A.4

Microcystis occurrence	CDFG	A.4
Diet data	CDFG	A.4
Center of distribution	CDFG	A.4
Ammonium	UCD	A.4
Nitrate + nitrate	UCD	A.4
Chlorophyll-*a*	UCD	A.4
USGS sediment monitoring		
Analyses of turbidity and suspended sediment	USGS	A.5
Environmental Monitoring Program		
Ammonium	DWR	A.6
Nitrite + nitrate		
Chlorophyll-*a*	DWR	A.6
Zooplankton abundance	CDFG	A.6
USGS water quality monitoring		
Ammonium	USGS	A.7
Nitrite + nitrate	USGS	A.7
Chlorophyll-a	USGS	A.7

Results from other ongoing research efforts were included as appropriate. When such data are not yet available from publicly available interim or final reports, the data are included in separate appendices. Much of the data collected as part of the FLaSH studies are not yet available because sample analysis, data QA/QC, data analysis, and data interpretation are ongoing. Presumably, this information will be incorporated into the next FLaSH report.

Although the fall conditions during the years selected for data analysis roughly correspond to conditions in Table 1 with regard to X2 (see Results, Table 1), this first report should not be considered a rigorous test of the predictions. In many cases, the predictions (Table 1) are qualitative rather than quantitative, with any given parameter value at X2=74 expected to be higher or lower than values at X2=85, with values expected to be intermediate at X2=81. For these reasons, we generally limit analyses to qualitative assessment of graphical and tabular summaries of data. Some predictions could not be evaluated because data were not yet available or the needed data were not collected. These situations are identified and science-based recommendations offered for resolving the situation.

Most data are presented as boxplots. For simplicity we provide a description of the standard boxplot. The center horizontal line in each box represents the median of the data. The upper and lower ends of the box represent the upper and lower quartiles of the data. These are also known as “hinges”. The “whiskers” are the lines extending above and below the box. The whiskers show the range of values falling within 1.5 times the inter-quartile distance from the nearest hinge. Values outside this range are shown as individual symbols. Other types of plots are explicitly identified in the figure caption.

Results

Operations during Sep-Oct 2011 and the preceding months resulted in X2 similar to that prescribed for a wet year RPA action (Table 3, Fig. 17). In addition, Sep-Oct 2010 had X2 of 85 km the maximum X2 scenario considered. Fall 2005 had X2 at 83 km, somewhat below the 85 km scenario. Fall 2006 had X2 very close to the 81 km X2 scenario for an above normal year (Table 3), even though it was a wet water year (http://cdec.water.ca.gov/cgi-progs/iodir/wsihist) (Table 3). The first four predictions in Table 1 are not predictions in the usual sense. We know that Delta outflow, X2, area of low salinity habitat, and the delta smelt habitat index are related and calculations of the latter 3 values are dependent on the value of the first (Appendix A.1, A.2, and A.3, respectively). These predictions are more properly considered tests of our understanding of the system and the methods available for visualizing the LSZ and the habitat it represents.

Figure 17. Daily X2 for 2005-2006 and 2010-2010. Mean daily X2 for each year during the September to October period is shown by the horizontal bar.

As described earlier, 2006 was the most recent wet year prior to 2011; however, fall outflow, fall X2, area of low salinity habitat, and the delta smelt habitat index were all very different between the two years (Table 3, Figures 17-20). Although plots of the LSZ were not available for the exact X2 values observed, Figures 14-16 likely provide a good approximation of the differences in LSZ extent and position during the years of interest.

Table 3. Mean and standard deviation (SD) for X2, delta outflow, surface area of low salinity zone and the delta smelt habitat index (Feyrer and others 2010). Values for X2, delta outflow, surface area of low salinity zone are for Sep-Oct and values for the habitat index are for Sep-Dec.

	X2 (km)		Outflow (cfs)		Surface area LSZ (hectares)		Habitat index	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2005	83	2	5654	1745	4889	252	4294	600
2006	82	3	5895	2380	4978	320	4481	823
2010	85	2	5677	2709	4635	226	3517	346
2011	75	1	12710	3639	8366	133	7095	332

Predictions for Dynamic Abiotic Habitat Components

Variation in average Sep-Oct daily net Delta outflow during the four years of interest was high (Fig. 18). Antecedent conditions during the summer also varied (Fig. 18). In 2005 and 2006, September flows were similar to flows in the preceding month. In both years there was a rapid decline in October flows. In 2010 there was actually an increase in outflow in Sep-Oct compared to earlier months. Similarly, in 2011 there was an increase in Sep-Oct compared to late summer flows as well as higher late summer flows than in comparison years. Outflows during fall 2011 were relatively constant or increasing compared to the other years; however, there was still a rapid decline in October (Fig. 18). Increased flows in Sep-Oct are often influenced by water management actions for migrating salmonids and those required to reduce reservoir volumes in anticipation of winter storm flows for flood control.

Figure 18. Daily Delta outflow (cfs) for 2005-2006 and 2010-2010. Mean daily ouflow during the September to October period are shown by the horizontal bar.

Observed mean values of outflow (Table 3) were somewhat similar to those predicted for scenarios with similar X2 (Table 1). Predicted outflow with X2=74 km was 12,710 cfs compared to the observed outflow of 12,204±3,646 (mean±standard deviation) (Table 3). There was substantial uncertainty associated with the predictions of outflows for all the X2 scenarios. The observed values for outflow show few differences for X2 varying between 82 and 85 km (Table 3). This suggests that control of outflow to produce relatively fine scale differences in X2 will be difficult. The prediction of daily Delta outflow associated with an X2 appears to be approximately correct. The observed values for X2 of 75 km in fall 2011 suggest that the predicted value is somewhat low to produce an X2 of 74 km; however variability in the observed values is large making an exact conclusion impossible. More consistent outflows during a managed RPA action, if possible, may provide for a more definitive conclusion. There is still substantial uncertainty regarding outflows to produce X2 in the range of 81 to 85 km.

Not surprisingly, daily depth-averaged area of the low salinity zone (Fig. 19) showed patterns similar to those of daily outflow (Fig. 17). As noted earlier, outflow determines X2 and the position and area of the LSZ in the estuary. Area of the LSZ shows less variability than daily outflow (Table 3). This is likely because outflow can be changed relatively quickly by changes in operations; however, the translation of changes in outflows to changes in the position of the LSZ depends on complex hydrodynamic processes that take place over a more extended time period, which results in salinity changing in a more gradual and complex manner.

Figure 19. Daily area (hectares) of the depth averaged low salinity zone (salinity 1-6) for 2005-2006 and 2010-2010. Mean daily areas during the September to October period are shown by the horizontal bar.

There are several notable features to the general pattern of changing area (Fig. 19). First, the highest values for area above about 9,000 hectares correspond to outflows and X2s that move the LSZ through Carquinez Strait and out into San Pablo Bay. These high flows occur during the springs of wet years. High spring X2 for extended periods of time are not always associated with high production of delta smelt (Jassby and others 1995, Kimmerer 2002a,b). The other notable result is that in late summer and Sep-Oct 2011 there was an extended period of high and relatively constant area for the LSZ compared to other years (Fig. 19). In the other three years, area of the LSZ declined through the preceding summer months then remained at a low level through the fall and early winter, until the first rains.

Predicted areas of the LSZ (Table 1) were approximately the areas calculated (Table 3). The prediction of about 9,000 hectares for the LSZ at X2=74 compares favorably with the 8,366 hectares estimated from the data. The estimated areas for the greater X2s (82-85) were also very similar to predicted values (Table 3), with all between 4,500 and 5,000 hectares. Area of the LSZ was expected to decrease with increasing X2 in the range 81-85 km and the mean estimated area did decrease as expected but the variability was high (Table 3). Given the variability in the values no firm conclusions are justified concerning area of the LSZ at these larger values of X2. The prediction that area of low salinity habitat will increase with decreasing X2 appears to be true within the range of X2 considered (74-85 km). However, over the shorter range of X2 from 82 to 85 km, the prediction did not hold. Additional work is needed to better understand this relationship.

The delta smelt abiotic habitat index was clearly greater in Sep-Oct 2011 compared to the other years (Table 3, Fig. 20). The abiotic habitat index was lowest in September-October 2010; however, variability was high in all years but particularly 2005 and 2006. As for the other measures, this variability makes it difficult to reach any firm conclusions regarding values of the habitat index at X2s in the 81 to 85 km range. Note that the habitat index model was developed specifically for the time period of the FMWT survey (Sep-Dec), so the abiotic habitat index was not calculated for other months.

Figure 20. Daily delta smelt habitat index for the fall (Sep-Dec) for 2005, 2006, 2010, and 2011. Mean daily delta smelt habitat index during the September to October period are shown by the horizontal bar. The end of the data record each year is indicated by E.

There generally appeared to be little contribution of San Joaquin River flow through the confluence region and into the LSZ (Fig. 21) as measured by QWEST, the calculated net outflow from the San Joaquin River. In 2005 and 2006 QWEST was never positive during Sep-Oct. Six days of positive QWEST were observed in Sep-Oct 2010. Eleven days of positive QWEST were observed in September 2011. QWEST data for October were not available for this report. Although the prediction for San Joaquin River contribution is very qualitative, the available data suggest a very low contribution to total outflow even when X2 is 74 km; however, 11 days of positive flow in September 2011 is suggestive of a greater contribution. This outcome of this prediction can be better determined when water year 2012 data are finalized. This prediction appears to be qualitatively correct over the range of X2 considered; however, the QWEST data is a poor test of the prediction..

This prediction is potentially important to delta smelt because of the hypothesized relationship between San Joaquin River flow and downstream productivity. The hypothesis is that small “seed” populations transported downstream to the LSZ provide the initial populations for phytoplankton blooms and increased populations of calanoid copepods; however, there are no published data on which to evaluate the hypothesis. Although, Sep-Oct total daily Delta outflow (Fig. 18) is 10-fold greater than the observed QWEST flows (Fig. 21), we cannot rule out the possibility that even modest contributions of San Joaquin River flow could have a biological effect. In 2005, 2006, and 2010, negative QWEST also occurred during the preceding months, generally July and August. In contrast in 2011 positive

QWEST persisted through most of July. This greater persistence of San Joaquin River contribution into the summer could have effects on productivity that might carry over into the fall.

Figure 21. Daily net flow past Jersey Point on the San Joaquin River.

The prediction regarding habitat complexity could not be evaluated. The FLaSH AMP did not link the prediction with a specific metric to quantify habitat complexity. Mapping of the LSZ (Figs. 14-16) did show the LSZ extending into Suisun Marsh at X2=74 km but it is unknown whether this connection was observed in 2011 at X2=75 km; although it seems likely. Hydrodynamic modeling of SFE allows for calculation and mapping of hydrodynamic qualities such as velocity vectors that might be useful in quantifying habitat complexity in a quantitative and easily explainable manner. Deployment of instrument packages, including current profilers, along with existing monitoring stations should provide useful data for both calibrating models and directly evaluating hydrodynamic conditions. Some combination of modeling and data collection will likely be needed to objectively evaluate this hypothesis as the FLaSH AMP continues.

The prediction regarding wind speed could not be evaluated because of lack of data. There are climate monitoring stations in the confluence and Suisun regions; however, they are land-based stations and it is unclear how the data collected relate to winds across the open waters of the LSZ. This prediction is directly related to predictions regarding turbidity and Secchi depth through the process of wind wave resuspension of fine sediments; however, this process also depends on other factors, such as sediment deposition and transport. Wind is also determined by climatic factors independent of the position of the LSZ. Direct measurements of turbidity seem a more direct connection to factors influencing delta smelt. If there is continued interest in evaluating this prediction, developing a model for wind velocity seems a more useful approach.

Because the predictions regarding Secchi depth and turbidity are both related to water clarity, we present those results together. We first present results from data collected during the FMWT (Appendix A.4) and then results from detailed analyses of data from fixed sites (Appendix A.5). We also present additional analyses from fixed sites that are important in understanding the other results.

Secchi depth has a longer data record than turbidity in the FMWT, being collected from the beginning of the program. Secchi depth in Sep-Oct was clearly lowest in the LSZ in 2011 and highest in 2010 (Fig. 22). Overall, Sep-Oct Secchi depth was roughly comparable across years and regions, except water clarity tended to be higher in freshwater. Another exception was Cache Slough/SRDWSC which had particularly shallow Secchi depth in 2005. The prediction for Secchi depth was supported for the LSZ.

Figure 22. Secchi depth data collected during the FMWT fish sampling survey.

Turbidity data were only available for the FMWT for 2010 and 2011 (Fig. 23). Not surprisingly, differences in turbidity mirrored those for Secchi depth for the available data. Turbidity was higher in the LSZ in Sep-Oct 2011 compared to 2010. The freshwater tended to be clearer than the other regions in Sep-Oct, although differences from <6 were small especially in 2011. Turbidity in Cache Slough/SRDWSC tended to be higher than freshwater and >6 but not as high as 1-6. Except for the LSZ, turbidities were similar between 2010 and 2011.

The turbidity results were similar to those for Secchi depth for the LSZ in Nov-Dec 2011. Measurements indicated the LSZ in Nov-Dec 2011 was more turbid compared to Nov-Dec 2010. The Secchi depth data had the same trend but there was greater variability in Secchi depth measurements. The prediction that water clarity of the LSZ will be lower (Secchi depth lower and turbidity higher) with decreasing X2 appears to be true within the range of X2 considered (75-85 km); however, over the shorter range of X2 from 82 to 85 km, the prediction was not supported.

Figure 23. Turbidity data collected during the FMWT fish sampling survey. These data were not collected in 2005 and 2006.

Continuous data from fixed sites support the idea that Suisun Bay was more turbid than the confluence in the fall of 2011 (Fig. 24). However, it should be understood that this regional difference in turbidity occurs independent of any direct influence of X2 or of salinity (Appendix A.5). The association of water clarity with the LSZ mainly depends on the location of the LSZ with regard to Suisun Bay and the confluence and the water clarity conditions in those areas at any particular time. The pattern observed suggests that in September and the first part of October, Suisun Bay was more turbid than the confluence. In late October and November the confluence was generally more turbid than Suisun Bay. In December, there was no clear pattern (Fig. 24).

Although the prediction did not include the Cache Slough area, continuous fixed site data also indicated that Suisun Bay was usually more turbid than the Cache Slough complex in fall 2011 and that turbidity at Mallard Island (confluence region) was greater in fall 2011 than fall 2010 but in the Cache Slough complex the opposite was observed with turbidity being greater in fall 2010 than 2011. Differences in turbidity between Mallard Island and the Cache Slough complex were not consistent between years (Appendix A.5).

Figure 24. Percent of data showing a turbid Bay and clear confluence, September-December 2011. Calculated from the product of hourly deviations of specific conductance and suspended-sediment concentration from tidally-averaged values. Values greater than 50% indicate instantaneous salinity and SSC are either both positive (relatively turbid Bay water) or negative (relatively clear confluence water). Values less than 50% indicate that deviations of conductance and SSC have opposite signs (relatively clear Bay or relatively turbid confluence). See Appendix A.5 for details.

Although the prediction that X2=74 is associated with a more turbid LSZ is supported by the data, long term trends suggest caution in assuming that this association will remain consistent over time. Fall suspended-sediment concentration (SSC) at Mallard Island, in the confluence region, decreased by about one-half from 1994 to 2011 (Fig. 25, Appendix A.5). This is consistent with a 50% decrease in total suspended-solids concentration (equivalent to SSC in this estuary) in the Delta from 1975-1995 (Jassby et al. 2002). In 1999 there was a 36% step decrease in SSC in San Francisco Bay as the threshold from transport to supply regulation was crossed as an anthropogenic erodible sediment pool was depleted (Schoellhamer 2011). Thus, the decrease shown at Mallard Island is consistent with other observations in the estuary and reflects a general increase in water clarity in the SFE as a whole.

Figure 25. Near-surface suspended-sediment concentration at Mallard Island, September-October mean values, 1994-2011. 1995 is not included due to insufficient SSC data. See Appendix A.5 for more detail.

Although there was no specific prediction regarding water temperature, it can be an important environmental variable through its effects on fish growth and physiology and other biological and physical processes. There was relatively little variability in water temperature within a salinity region for any particular month (Fig. 26). The freshwater regions tended to be warmer than the LSZ and salinity <6 in September but not in the other months. Water temperatures in 2011 were generally cooler than water temperatures in 2010, except for September.

Figure 26. Surface water temperature (C) at FMWT sampling sites during monthly sampling.

It is generally acknowledged that the major sources of ammonium in the system are point sources of treated wastewater with the large treatment plant servicing Sacramento and discharging into the Sacramento constituting a major source (Jassby 2008). The prediction in Table 1 is based on simple dilution. It is expected that the higher flows associated with maintaining X2 at 74 km will result in lower concentrations of ammonium in the LSZ. Based on EMP data, concentrations in Sep-Oct did not show consistent patterns within or between years (Figure 27). In the LSZ, ammonium concentrations were higher in 2011 compared to 2010. Concentrations of ammonium were generally less than 0.1 mg/L during Sep-Oct in all years. The EMP data indicated that there was little difference in ammonium concentration between 2006, 2010 and 2011 in ammonium concentrations in the LSZ during Nov-Dec (Fig. 27). Ammonium concentrations appeared higher in 2005 compared to other years in the LSZ and salinities >6. The prediction of lower concentrations of ammonium in the LSZ with lower X2 was not supported by the EMP data.

Figure 27. Ammonium concentrations in Sep-Oct and Nov-Dec from the IEP Environmental Monitoring Program (see Appendix A.6).

Ammonium data collected during USGS Polaris cruises (Fig. 28) were somewhat different from the EMP data (Fig. 27). In Sep-Oct, the LSZ showed no clear trend between years. Median values in the LSZ and >6 were near or less than 0.1 mg/L in both data sets. The USGS data tended to show higher concentrations in freshwater compared to the EMP data. The USGS sampling program includes more stations in the freshwaters of the Sacramento River compared to the EMP data set (Appendix A). The USGS data showed higher concentrations of ammonium in the LSZ and >6 in Nov-Dec compared to Sep-Oct, similar to the EMP data. Again, USGS data indicated higher concentrations of ammonium in freshwater compared to the EMP data. Similar to the EMP data, the USGS data did not support the prediction of reduced ammonium with lower X2.

Figure 28. Ammonium data from USGS monthly sampling cruises.

Ammonium concentrations were measured at FMWT stations concurrent with fish sampling for the first time in 2011 (Fig. 29). Unfortunately, a time series is not yet available for comparison. The concentrations measured during FMWT were generally similar to those measured by the EMP and USGS. In Sep-Oct 2011 there was a slight trend of higher ammonium concentrations in freshwater in the USGS data and also greater variability in freshwater values, which is consistent with the FMWT data (Fig. 29). In comparison the EMP data exhibited a very slight decrease in freshwater compared to the LSZ, with little variability.

Figure 29. Ammonium concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during the fall midwater trawl (see Appendix A.4).

The EMP and USGS data used to assess the prediction are from monthly sampling at fixed locations in the estuary. Studies of nitrogen cycling generally require much shorter sampling intervals than monthly. Such studies were included in the FLaSH investigation but those data were not available for inclusion in this report. It is somewhat unclear if such research actually applies to the prediction as stated since nutrient cycling involves many other processes beyond the simple dilution behind the prediction. The differences in 2011 results between the EMP, USGS, FMWT results could be due to many factors including differences in analytical techniques, spatial variability in ammonium concentrations, and changes in ammonium concentrations over time. The relations of ammonium to X2 and the LSZ requires further research, including analysis of already collected data and continued data collection.

In the EMP data set, nitrite + nitrate concentrations were generally between 0.2 and 0.4 mg/L during Sep-Oct across all regions in all years (Fig. 30). In the LSZ, concentrations in 2011 were very similar to 2010 and clearly lower than 2005 and 2006. Overall, 2011 tended to have the lowest concentrations in all years in Sep-October. The same pattern was apparent in Nov-Dec with 2011 clearly having the lowest concentrations of nitrite + nitrate in all years and in all salinity regions. The EMP data clearly did not support the prediction..

Figure 30. Nitrite + nitrate concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during the fall midwater trawl (see Appendix A.4).

Nitrite + nitrate concentrations were lower in the USGS data set (Fig, 31) were generally lower than concentrations measured by the EMP (Fig. 30). Similar to the EMP data, there was little difference in concentrations across years and regions. In the LSZ during Sep-Oct, concentrations were generally lower than in other years. There was more variability between years during Nov-Dec; however, concentrations in 2011 were always similar to or lower than other years within each region. Like the EMP data, the USGS data did not support the prediction.

Figure 31. Nitrite + nitrate concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during monthly USGS cruises (see Appendix A.7). Original concentrations of nitrite + nitrate were measured in micromoles. Date wer converted to mg/L assuming 100% nitrate since nitrite concentrations were not yet available. This could result in concentrations biased slightly high.

As for ammonium, this is the first year that nitrite + nitrate concentrations were determined during FMWT sampling. Concentrations during FMWT in Sep-Oct were lower in freshwater than in the LSZ or >6 (Fig. 32). The lowest concentrations were observed in the Cache Slough region. There was little difference among regions in Nov-Dec; however, there was a greater range of values in the Cache Slough region (Fig. 32).

Figure 32. Nitrite + Nitrate concentrations in Sep-Oct and Nov-Dec 2011 from the samples collected during the fall midwater trawl (see Appendix A.ucd).

Predictions for Dynamic Biotic Habitat Components

Concentration of chlorophyll-*a* is a common surrogate for phytoplankton biomass. Average concentration of chlorophyll-*a* in the LSZ was predicted to increase in response to lower X2 for several reasons. If the assumed inhibitory effect of ammonium on diatom growth is decreased in the LSZ due to higher flows, production of diatoms would be expected to increase. Increased nitrate concentrations in the LSZ would also help increase biomass if initial or subsequent production was limited by available nitrate. The location of the LSZ might also influence the interaction between phytoplankton and grazers, including clams and zooplankton. The interactions with clams are discussed separately below. The prediction regarding chlorophyll-*a* also does not include *Microcystis*, which is addressed in a separate section. Finally, a recurring hypothesis is that LSZ primary production will increase when the LSZ is located in the shoals of the Suisun region, because of increased volume of the photic zone primarily related to greater area. By contrast, volume of the photic zone may be more limiting when the LSZ is located in the channelized reach upstream of the confluence because of limited area.

Chlorophyll-a concentrations were not particularly high in the LSZ in Sep-Oct 2011 based on EMP monthly sampling (Fig. 33). In Sep-Oct 2011, concentrations were lowest in the LSZ and higher in both >6 and freshwater. One high observation in >6 might be indicative of a bloom. Median chlorophyll-a concentration during Sep-Oct in the LSZ was higher in 2010 compared to 2011, and concentrations in 2005 and 2006 were lowest. The EMP data do not support the hypothesis of greater average phytoplankton biomass as measured by chlorophyll-a with lower X2. The other predictions regarding diatoms and other algae in the phytoplankton could not be evaluated because relative biomasses were not available for different algal groups or the characteristics of hydrodynamic complexity have not been defined and so cannot be applied to the available data.

Figure 33. Chlorophyll-*a* concentrations in Sep-Oct and Nov-Dec from the IEP Environmental Monitoring Program (see Appendix A.6).

In contrast to the EMP data, the data from USGS monthly cruises appeared to support the prediction of higher phytoplankton biomass (Fig. 34). Chlorophyll-a concentrations were highest in the LSZ during Sep-Oct compared to all the other years compared, with concentrations lowest in 2005 and 2006. Concentrations were greatest in Sep-Oct 2011 compared to other years across all salinity regions. High concentrations continued in the LSZ in Nov-Dec. In the other salinity regions, concentrations were more comparable across years. Although the EMP and USGS data are somewhat in conflict, we provisionally suggest that the prediction of higher phytoplankton biomass at low X2 is supported, but the other part of the prediction at higher X2s is uncertain. We give greater weight to the USGS data because of its slightly greater spatial coverage and observations made by experienced researchers during the EMP and USGS cruises.

Figure 34. Chlorophyll-a concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during monthly USGS cruises (see Appendix A.7).

Water samples collected during the 2011 FMWT were analyzed for chlorophyll-*a* (Fig. 35). The FMWT samples showed a general trend of higher concentrations of chlorophyll-*a* in freshwater habitats, particularly in the Cache Slough complex in both Sep-Oct and Nov-Dec 2011 with concentrations being much higher in Sep-Oct. In the EMP data, the highest concentrations of chlorophyll-*a* were also found in freshwater (Fig. 33). The USGS data basically showed similar median concentrations of chlorophyll-a across salinity groups (Fig. 34). Thus there is some disagreement among the three surveys about the distribution of phytoplankton biomass among salinity regions in 2011. The most interesting feature of the FMWT data is the high chlorophyll-a concentrations noted in the Cache Slough region (Fig. 35).

Figure 35. Chlorophyll-*a* concentration in Sep-Oct and Nov-Dec 2011 from samples collected during the fall midwater trawl (see Appendix A.4).

Because *Microcystis* forms floating colonies that are difficult to quantify with standard sampling techniques, there is not a good long-term dataset on abundance of *Microcystis*. A semi-quantitative (ranking scale) estimate of abundance has been made during FMWT sampling since 2007, so the data does not include 2005-2006 (see Appendix A.4). In 2010 and 2011, the *Microcystis* ranking rarely exceeded the lowest ranking for affirmative collections, so we compare the frequency of presence between years. In 2010, the most occurrences were observed in freshwater as expected (Fig. 36). In 2011, the results were generally similar, except for a high percentage of occurrences in the LSZ in September. Although occurrence data does not directly address the prediction regarding density, the implication is that the prediction is neither supported nor rejected. The average occurrences of *Microcystis* in Sep-Oct of 2010 and 2011 are not particularly different and the variability in 2011 is high.

Figure 36. Occurrence of floating *Microcystis* at FMWT sampling stations for September to December 2010 and 2011.

Several predictions concern copepods, a major food source of delta smelt. Calanoid copepods, particularly *Psedudodiaptomus forbesi*, *Eurytemora affinis*, and *Acartiella sinensis*, are generally recognized as an important prey for delta smelt. Calanoid copepod biomass per unit effort (BPUE, mg of C/m^3) tended to be slightly higher in September and October 2011 compared to other years in the LSZ and salinity >6; however, variability was high (Fig. 37). This was not the case in freshwater, where September and October 2011 were very similar to September and October 2005 and 2010. In general, calanoid copepod BPUE tended to be higher in freshwater than in the other salinity groups, mostly due to higher densities of copepodids (juvenile copepods) in freshwater. The higher BPUE in freshwater during September and October was not apparent in November and December. Overall, BPUE was low and similar across all salinity groups in November and December. There was a very slight tendency for November and December BPUE to be higher in the LSZ in the wet years of 2006 and 2011, although variability was high. The prediction was that calanoid copepod biomass would be greater in the LSZ with low X2 and the data did show that trend; however, given the high uncertainty in the data, a definite conclusion is not warranted.

Figure 37. Biomass per unit effort (BPUE, micrograms of C m-3) of juvenile and adult calanoid copepods for EMP samples (mean ± 1 standard deviation).

Cyclopoid copepods, mainly represented numerically by *Limnoithona tetraspina*, can also be consumed by delta smelt; however, delta smelt diet usually includes more of the larger calanoid copepods than the smaller cyclopoid copepods, when calanoids are available.. Because of their smaller size, *Limnoithona tetraspina* are usually only consumed by small delta smelt. Because of the small size of *Limnoithona tetraspina*, cyclopoid copepods account for only about a tenth of the biomass of calanoid copepods in zooplankton samples (compare Figs. 37 and 38). There was a great deal of monthly variability in BPUE of cyclopoid copepods (Fig. 38). In September and October 2011, BPUE of cyclopoid copepods was both the highest and the lowest in 2011. BPUE of cyclopoid copepods was generally higher in November and December compared to September and October across years (Fig. 38), except in freshwater. The prediction for cyclopoid is difficult to interpret because both X2=81 km and X2=74 km are expected to be moderate. The data suggest that when X2=74 BPUE of cyclopoid copepods might be higher than predicted in comparison to the other conditions, which is not consistent with the prediction; however, as with calanoid copepods, the data show high variability. Thus the data do not support the prediction as stated in Table 1 but we defer making a definitive judgment.

Figure 38. Biomass per unit effort (BPUE) of juvenile and adult cyclopoid copepods for EMP samples (mean ± 1 standard deviation).

Although there was not an explicit prediction for the food items that delta smelt would actually consume, we compiled the available data to better understand the significance of the copepod data. In general, calanoid copepods dominated the diet as expected, except during November in the LSZ when a large cyclopoid copepod *Acanthocyclops* sp. was a major prey item (Fig. 39). This consumption corresponded to the highest BPUE of cyclopoid copepds in the LSZ (Fig. 38), presumably due to high abundance of this large species. In some months a large proportion of the diet consisted of other organisms (Fig. 40). In particular, mysids and amphipods made up a major component of the diet in some months. Mysids were mainly *Hyperacanthomysis longirostris*. Amphipods included *Americorophium spinicorne* and *Corophium alienense* in both the LSZ and Cache Slough/SRDWSC region and *Gammarus daiberi* in the Cache Slough/SRDWSC region. The amphipods are epibenthic and they are not sampled well by the methods used to sample zooplankton. Mysids, which are effectively sampled by EMP nets, contributed large proportions to the diet in some months (Fig. 41) but never contributed large proportions to total zooplankton biomass (Fig. 38) Individual mysids are larger than copepods and may be selected by delta smelt when available.

Figure 39. Stomach contents by weight (g) of calanoid and cyclopoid copepods for delta smelt captured in the FMWT in 2011. The composition of the remaining proportion of the diet is shown in Figure 40.

Figure 40. Stomach contents by weight (g) of items other than calanoid and cyclopoid copepods for delta smelt captured in the FMWT in 2011.

To better represent total zooplankton available to delta smelt as food, we compiled data on total zooplankton, including mysids and cladocerans in addition to calanoid and cyclopoid copepods. The patterns in total zooplankton (Fig. 41) were almost identical to the patterns apparent in the calanoid copepod data (Fig. 37). Zooplankton biomass tended to be higher in freshwater but variability was also higher. There was no specific prediction for total zooplankton.

Figure 41. Biomass per unit effort (BPUE, micrograms of C m-3) of juvenile and adult calanoid copepods, cyclopoid copepods, cladocerans, and mysids for EMP samples (mean ± 1 standard deviation).

The prediction for *Potamocorbula* biomass (Table 1) is related to grazing pressure on phytoplankton and zooplankton in the LSZ and thus the channeling of primary and secondary production to clams rather than fishes and other consumers, including delta smelt. It has been hypothesized that lower X2 in wet years may result in lower fall populations of *Potamocorbula* in the LSZ because of large shifts in the salinity field and subsequent effects on the recruitment and physiology of *Potamocorbula*. So, this prediction was addressed in terms of biomass and several measures of grazing rate (Thompson and Gehrts 2012). Because clams are benthic organisms and do not move with the LSZ like delta smelt, they are considered geographically. Suisun, Grizzly and Honker Bays and western Suisun Marsh are the areas within the range of *Potamocorbula* most influenced by the LSZ and salinity gradient in general. Comparable data sets were only available for October 2009, 2010, and 2011.

In October 2011, *Potamocorbula* filtration rate was lower through much of *Potamocorbula* range than in 2009 and 2010, except for two stations in the main channel of Suisun Bay (Fig. 42). In 2011, much of the range of interest of *Potamocorbula* was inland of X2 for at least some of the time,. In 2009 and 2010, *Potamocorbula* were mainly distributed seaward of X2 over the previous 6 months, where the water was more brackish. Based on biomass, *Potamocorbula* were less abundant in Grizzly/Honker Bay and western Suisun Marsh during October 2011 compared to 2009 and 2010 (Fig. 43), supporting the prediction (Table 1). These differences were even more apparent in the turnover rate which normalizes the *Potamocorbula* grazing rates to the depth of the water column (Fig. 44). The turnover rate is the proportion of the water column a population of clams filter in a day.

Figure 42. Filtration rate (a function of biomass and temperature) for both *Potamocorbula* (blue) and *Corbicula fluminea* (orange) in October 2009, 2010, and 2011. Range of X2 over previous 6 months shown on map as range where bivalves were expected to overlap.

Figure 43. Biomass during the October sampling periods in western Suisun Marsh and Grizzly/Honker Bay shallows. Biomasses were not significantly different between 2009 and 2010 but were significantly different for 2010 and 2011 (Thompson and Gehrts 2012). Figure modified from Thompson and Gehrts (2012).

Figure 44. Turnover rate (d^{-1}) during the October sampling periods in western Suisun Marsh and Grizzly/Honker Bay shallows. Biomasses were not significantly different between 2009 and 2010 but were significantly different for 2010 and 2011 (Thompson and Gehrts 2012). Figure modified from Thompson and Gehrts (2012).

The predictions about predator abundances and predation rates could not be evaluated. There is currently no sampling program targeted at understanding predator abundance and predation rates in the channel and shoal areas occupied by delta smelt in the fall. Addressing these predictions will require new sampling programs.

Predictions for Delta Smelt Responses

The prediction for delta smelt entrainment at the Suisun region power plants could not be directly assessed because no fish counts were available; however, the power plants only operated for a limited number of days in September and October at about one-third of capacity. At the plant near Pittsburgh, 1 or 2 of 3 generation units operated for 9 days. At the other plant, 1 of 2 generation units operated for 18 days and both units operated for 4 days from September to October. It seems likely that entrainment was zero or very low as predicted; however, a definitive conclusion is not possible without fish counts. No delta smelt were captured at the CVP or SWP pumping plants from September to October in any of the years considered (ftp://ftp.delta.dfg.ca.gov/salvage/). So, this prediction was supported by data; however, few, if any, delta smelt were expected to be salvaged under any conditions (Table 1).

The center of distribution of delta smelt (median) appeared to be within the predicted range of X2 (Fig. 45) in Sep-Oct 2011, although toward the lower end of the predicted range and with many individuals found farther seaward. The results for the medians of other years also tended to meet predictions, with individual fish often found more seaward in September and October. The number of fish captured was small in all years other than 2011. The available data appear to support the prediction; however, the sparse data for years other than 2011, limits the strength of comparisons.

Figure 45. Distribution of delta smelt captured in the FMWT. The river kilometer of each site from the Golden Gate where delta smelt were captured was weighted by the number of delta smelt caught. Numbers of delta smelt captured each month is shown. The dotted line shows 75 km for reference.

Preliminary data on delta smelt growth rates determined from otoliths are available for 2011 (Teh 2012; Table 4). The data suggest declining growth from August through December of 2011 in each of the salinity regions, as expected with declining temperatures and a shift from growth in length to development of gonads. Growth in November and December were similar. Similar otolith-based growth data has been gathered as part of other studies in other years. These data need to be aggregated and results compared among years before the prediction can be evaluated.

Table 4. Estimated growth rates (mm/day) of delta smelt from August to December 2011 based on otolith analysis from 4 regions of the San Francisco Estuary: salinity <1, 1-6, >6 and Cache Slough/SRDWSC (Sacramento River Deepwater Ship Channel (modified from Teh 2012).

Region	Month	Aged (n)	Growth rate (mm/day)
Cache Slough/SRDWSC	August	37	0.41±0.06
< 1	August	0	
1-6	August	24	0.46±0.05
> 6	August	4	0.44±0.04
Cache Slough/SRDWSC	September	2	0.39±0.05
< 1	September	5	0.42±0.04
1-6	September	25	0.38±0.04
> 6	September	5	0.41±0.02
Cache Slough/SRDWSC	October	3	0.29±0.01
< 1	October	32	0.36±0.04
1-6	October	8	0.39±0.03
> 6	October	2	0.37±0.01
Cache Slough/SRDWSC	November	16	0.28±0.01
< 1	November	1	0.27
1-6	November	5	0.28±0.01
> 6	November	3	0.28±0.01
Cache Slough/SRDWSC	December	7	0.28±0.03
< 1	December	69	0.29±0.02
1-6	December	15	0.28±0.02
> 6	December	31	0.28±0.02

Delta smelt survival is not calculated directly because actual population estimates are not available; however, some information can be inferred from ratios of summer tow net and FMWT abundance indices (Fig. 46). The ratio of the FMWT to the TNS can be used as an indicator of survival of delta smelt present in the summer (July-August) into the fall (Fig. 47). This ratio was well above the median in 2011; however, this may be at least partially the result of favorable summer conditions and resulting high survival rather than only favorable fall conditions and survival. The ratio of TNS to the

FMWT of the previous year (Fig. 47) can be used as an indicator of successful recruitment of juveniles from the maturing adults sampled by the FMWT. This ratio suggests that juvenile recruitment was high in 2010 and substantially higher in 2011. This suggests that the increase in FMWT population index in 2011 resulted from a combination of favorable factors in the winter, spring, and summer preceding the fall. The data suggests that survival in the fall and preceding summer months was likely higher than other years, supporting the prediction for survival (Table 1). The prediction about fecundity could not be addressed because samples are still being processed and, even if 2011 data were available, there are few data from preceding years for comparison.

Figure 46. Plots of summer townet survey (TNS) and fall midwater trawl (FMT) delta smelt abundance indices by year. Data are available at http://www.dfg.ca.gov/delta/projects.asp?ProjectID=TOWNET and *http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT*, respectively.

Figure 47. Ratios of delta smelt abundance indices used as indicators of survival.

The prediction regarding fish health and condition cannot be assessed at this time. Assessments of delta smelt health and condition are ongoing, including new measurements that have not been previously conducted on delta smelt (Teh 2012). Analyses include fall growth (otolith daily increments and RNA/DNA ratio), fish condition (condition factor, triglyceride concentration, and histopathology), and indicators of environmental stressors (Acetylcholinesterase, Na+/K+-ATPase, histopathology, and pathogens). Preliminary results are available in Teh (2012). Results from fall 2012 will be used as the basis for comparisons with values taken in future years.

The predictions regarding recruitment to the next year and delta smelt life history variability also could not be assessed at this time. The prediction regarding life history is being addressed with otolith chemistry, specifically strontium isotope ratios. The major result is a determination of migratory history. A change in strontium ratios in the daily rings of the otolith accompanies migration from the natal habitat (freshwater for delta smelt) to a saltier rearing habitat. In 2011, 231 of 280 delta smelt exhibited the migratory life history (Teh 2012). Most of the freshwater resident fish were collected in the Cache Slough/SRDWSC. A small number of fish also showed mixed signatures, suggesting movement between different salinity regions through the year. However, there was not comparable data available from other years for assessment of the prediction.

Discussion

It is undeniable that there was an increase in the FMWT abundance index in association with the wet year of 2011 (Fig.4) with an X2 of 75 km, near the RPA objective of X2=74 km (Reclamation 2011). The scientific challenge is to understand the degree to which the two events are connected. The conceptual model developed as part of the FLaSH AMP (Fig. 13) formalized the hypotheses connecting X2=74 km (or 81 km) with improved conditions for delta smelt, presumably leading to an increase in the population. This conceptual model led directly to the predictions in Table 1.

Many of the predictions either could not be evaluated with the data available or the needed data are not being collected (Table 5). In some cases, the available data were not sufficient to provide a reasonable assessment of the hypothesis. It is unclear if precise water operations can provide desired mean X2s with sufficiently low variability for assessment of hypotheses related to X2=81 and X2=85.. Additional data will continue to become available as results from other research and monitoring are forthcoming. Such data will be incorporated into this report if possible or into later reports as part of the adaptive management cycle, assuming the FLaSH investigations continue.

Table 5. Assessments of predicted qualitative and quantitative outcomes for September to October of the fall RPA action based on 3 levels of the action (modified from Reclamation 2011). The years considered representative

of the 3 levels of action are indicated. Green means that data supported the prediction and red means the prediction was not supported. Gray indicates that data were not yet available to support a conclusion. No shading indicates there were no data to assess.

	Predictions for X2 scenarios		
	85 km	81 km Year used to test prediction	74 km
Variable (Sep-Oct)	2010 (X2=85)	2005, 2006 (X=83,82)	2011 (X2=75)
Dynamic Abiotic Habitat Components			
Average Daily Net Delta Outflow	~5000 cfs?	~8000 cfs?	11400
Surface area of the fall LSZ	~ 4000 ha	~ 5000 ha	~ 9000 ha
Delta Smelt Abiotic Habitat Index	3523	4835	7261
San Joaquin River Contribution to Fall Outflow	0	Very Low	Low
Hydrodynamic Complexity in LSZ	Lower	Moderate	Higher
Average Wind Speed in the LSZ	Lower	Moderate	Higher
Average Turbidity in the LSZ	Lower	Moderate	Higher
Average Secchi Depth in the LSZ	Higher	Moderate	Lower
Average Ammonium Concentration in the LSZ	Higher	Moderate	Lower
Average Nitrate Concentration in the LSZ	Moderate	Moderate	Higher
Dynamic Biotic Habitat Components			
Average Phytoplankton Biomass in the LSZ (excluding *Microcystis*)	Lower	Moderate	Higher
Contribution of Diatoms to LSZ Phytoplankton Biomass	Lower	Moderate	Higher
Contribution of Other Algae to LSZ Phytoplankton biomass at X2	Higher	Moderate	Lower
Average Floating *Microcystis* Density in the LSZ	Higher	Moderate	Lower
Phytoplankton biomass variability across LSZ	Lower	Moderate	Higher
Calanoid copepod biomass in the LSZ	Lower	Moderate	Higher
Cyclopoid copepod biomass in the LSZ	Lower	Moderate	Moderate
Copepod biomass variability across LSZ	Lower	Moderate	Higher
Corbula biomass in the LSZ	Higher	Moderate	Lower

Predator Abundance in the LSZ	Lower	Moderate	Higher
Predation Rates in the LSZ	Lower	Moderate	Higher
Delta Smelt (DS) Responses			
DS caught at Suisun power plants	0	0	Some
DS in fall SWP & CVP salvage	Some?	0	0
DS center of distribution (km)	85 (77-93)	82 (75-90)	78 (70-85)
DS growth, survival, and fecundity in fall [a]	Lower	Moderate	Higher
DS health and condition in fall	Lower	Moderate	Higher
DS Recruitment the next year	Lower	Moderate	Higher
DS Population life history variability	Lower	Moderate	Higher

[a] Only survival from summer to fall as the ratio of FMWT population index to TNS population index was assessed.

Most of the predictions that could be addressed involved either the abiotic habitat components or delta smelt responses (Table 5). It is not surprising that the abiotic components were relatively easy to assess since many of them are already known to be related to X2, particularly daily net delta outflow, surface area of the LSZ, and the delta smelt habitat index. However, even these measures mainly separated X2= 75 km from the other X2s compared in this report. Variability in these measures leaves some question as to whether meaningful comparisons can be made between X2 of 81 and 85 km. It is notable that the two abiotic factor where the prediction was not supported concerned the nutrients ammonium and nitrite + nitrate.. These were included in the abiotic factors because they are considered contaminants but they are hardly inert chemicals in the environment. Concentrations of both chemicals in the estuary depend not only on loadings from point and nonpoint sources but also on nutrient cycling and primary production as water passes through the estuary; therefore, it is not surprising that they did not follow a simple conceptual model.

The available data on delta smelt responses were limited to available long term data that has been previously analyzed. Salvage data from the SWP and CVP was most recently addressed by Grimaldo and others (2009) and since the POD, managers have been very careful to minimize salvage.

Delta smelt center of distribution was most recently addressed by Sommer et al. (2011). Relationships between the various delta smelt population indexes have also been explored (e.g., Baxter and others 2011). Thus these predictions were based on previous empirical assessments. The new data being collected on growth, fecundity, health and condition (Teh 2012) could not be used to assess the predictions because there were no previous data for comparison; however, these data will be extremely important in future years as the benchmark for a "good" year for delta smelt.

The assessments of predictions concerning biotic habitat components either could not be addressed or the data were inconclusive for all or part of a prediction (Table 5). The prediction for *Potamocorbula* was supported to the extent data was available and the prediction for phytoplankton production was partially supported. While there appears to be consensus that food quantity and quality are important factors in the POD (Baxter and others 2008, 2010, Glibert and others 2010, 2011), there is no consensus on the relative importance of such bottom up factors in relation to other factors or the specific mechanisms driving bottom up effects. Similarly, there has been much concern over the role of predation but there is no quantitative data on predation rates available to objectively evaluate the importance of predation to the delta smelt population.

In general, the FLaSH investigation has been largely inconclusive as of the writing of this report. That should not be unexpected in the first year of what is intended to be a multi-year adaptive management effort. This report should be viewed as the first chapter of a "living document" that should be continually updated as part of the adaptive management cycle. As part of that cycle the results of this report should be used to revise the conceptual model and predictions based on the conceptual model. This activity would likely best be accomplished as an annual update of the adaptive management plan.

The results of this report, especially predictions with insufficient data for evaluation, suggest a number of science-based recommendations for improving the FLaSH investigations.

- Develop a method of measuring "hydrodynamic complexity". This concept is central to a number of the predictions that could not be evaluated. Accomplishing this will likely require a combination of modeling and empirical studies to identify areas of high and low complexity. Once such areas are identified, additional modeling and empirical studies will also be needed to determine if hydrodynamic complexity creates the dynamic biotic habitat components hypothesized, including variability in phytoplankton and zooplankton biomass.
- Determine if wind speed warrants a stand-alone prediction. The wind speed prediction is directly related to the turbidity predictions and wind is only one of several factors important in determining turbidity. If understanding the processes generating turbidity and the ability to predict turbidity are important goals, then development of a suspended sediment/turbidity model that incorporates wind and other important factors would be warranted.
- Determine the correct spatial and temporal scale or scales for monitoring and other studies. Many of the assessments in this report were based on monthly sampling of dynamic habitat components such as phytoplankton and zooplankton populations that can change on daily scales.
- Address the nutrient predictions as part of developing a phytoplankton production model if feasible. At a minimum develop a mechanistic conceptual model to support more processed-based interpretations of data or design of new studies rather than making simple predictions of increase or decrease.
- Determine if studies of predation are feasible in areas where delta smelt occur.

As noted previously, a major limitation of this report is that many of the key analyses expected from the more research-oriented FLaSH studies have not yet been completed. Even with those analyses completed, rigorous inter-year comparisons are not possible because there are no other years with comparable levels of effort dedicated to understanding the same features of the LSZ. Such comparisons will therefore depend on detailed data collection in future years with a full range of fall flow conditions as outlined in the AMP. Moreover, the scope of this report was deliberately narrow, addressing only selected months in selected years. This was done primarily because the objective of the report was to evaluate the results of the FLaSH investigation, which is focused on the fall, but also to limit the need to incorporate larger data sets given the limited time available to prepare the report. Future iterations of this report should begin incorporating additional years of existing data into analyses in addition to new data. All seasons should also be addressed. It is difficult to evaluate the importance of a single season in isolation from other seasons in the population biology of an organism. For example, a "good" fall could easily have no measurable effect on a population if stressful spring conditions affected spawning success of adults and subsequent survival of larvae. Understanding the relative importance of such events is the basis of life cycle models, which all agree will be useful tools for managing delta smelt in the future. This broader analysis, incorporating the results of the FLaSH investigation, is one of the objectives of the newly formed IEP Management, Analysis and Synthesis Team. That effort is intended to provide a broader analysis of factors affecting delta smelt and could serve as a template for future versions of this report.

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Appendix A

See separate document.

Synthesis of Studies in the Fall Low Salinity Zone of the San Francisco Estuary, September-December 2011

By Larry R. Brown, Randy Baxter, Gonzalo Castillo, Louise Conrad, Steven Culberson, Greg Erickson, Frederick Feyrer, Stephanie Fong, Karen Gehrts, Lenny Grimaldo, Bruce Herbold, Joseph Kirsch, Anke Mueller-Solger, Steve Slater, Ted Sommer, Kelly Souza, and Erwin Van Nieuwenhuyse

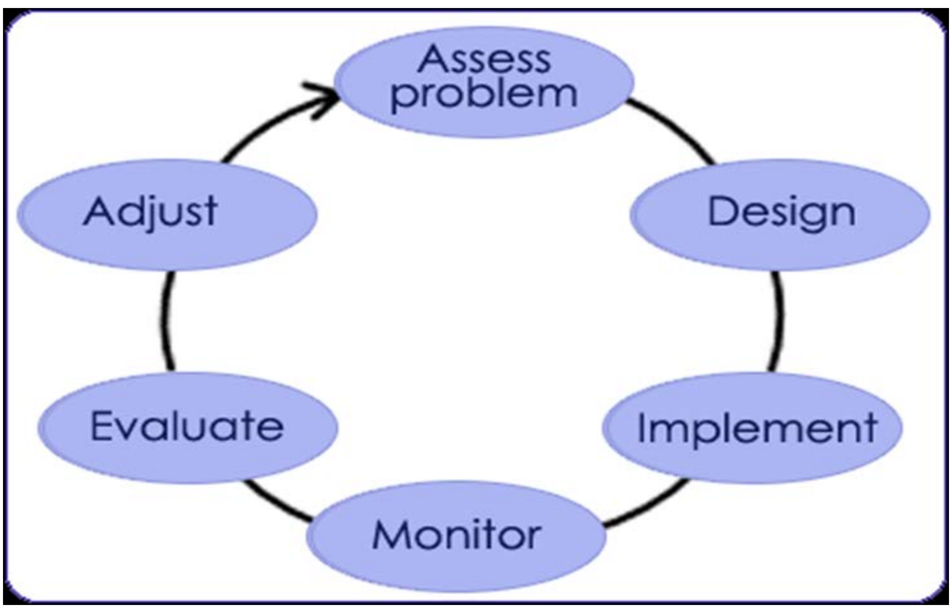


Figure 1. A schematic of the adaptive management cycle (modified from Williams and others 2009).

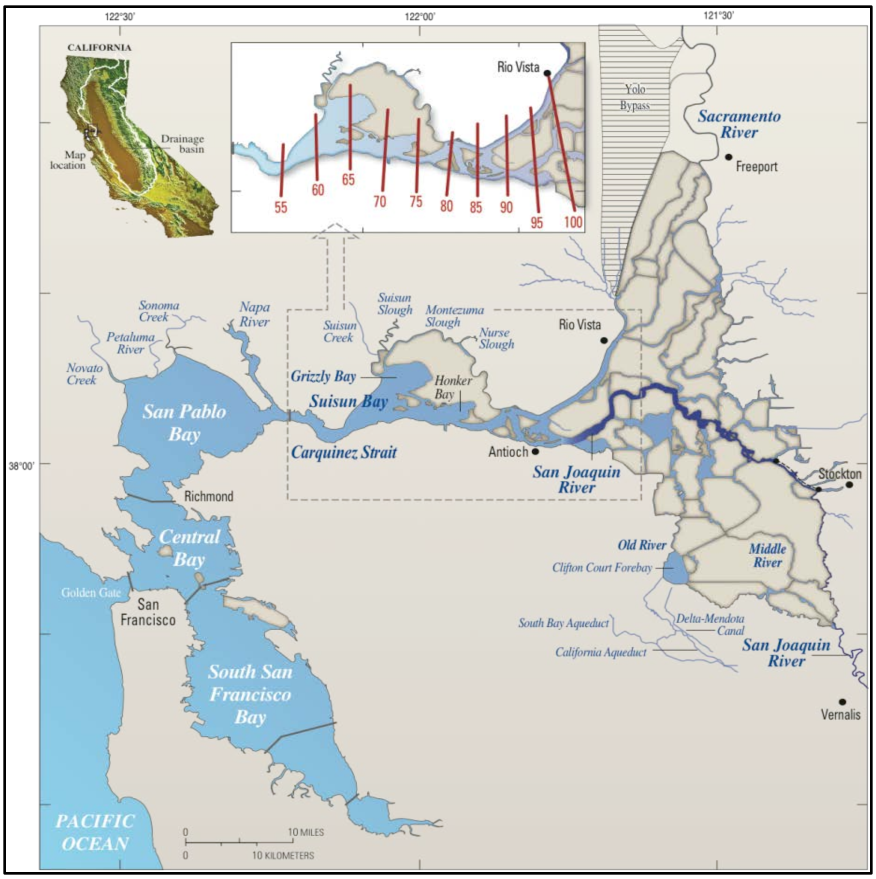
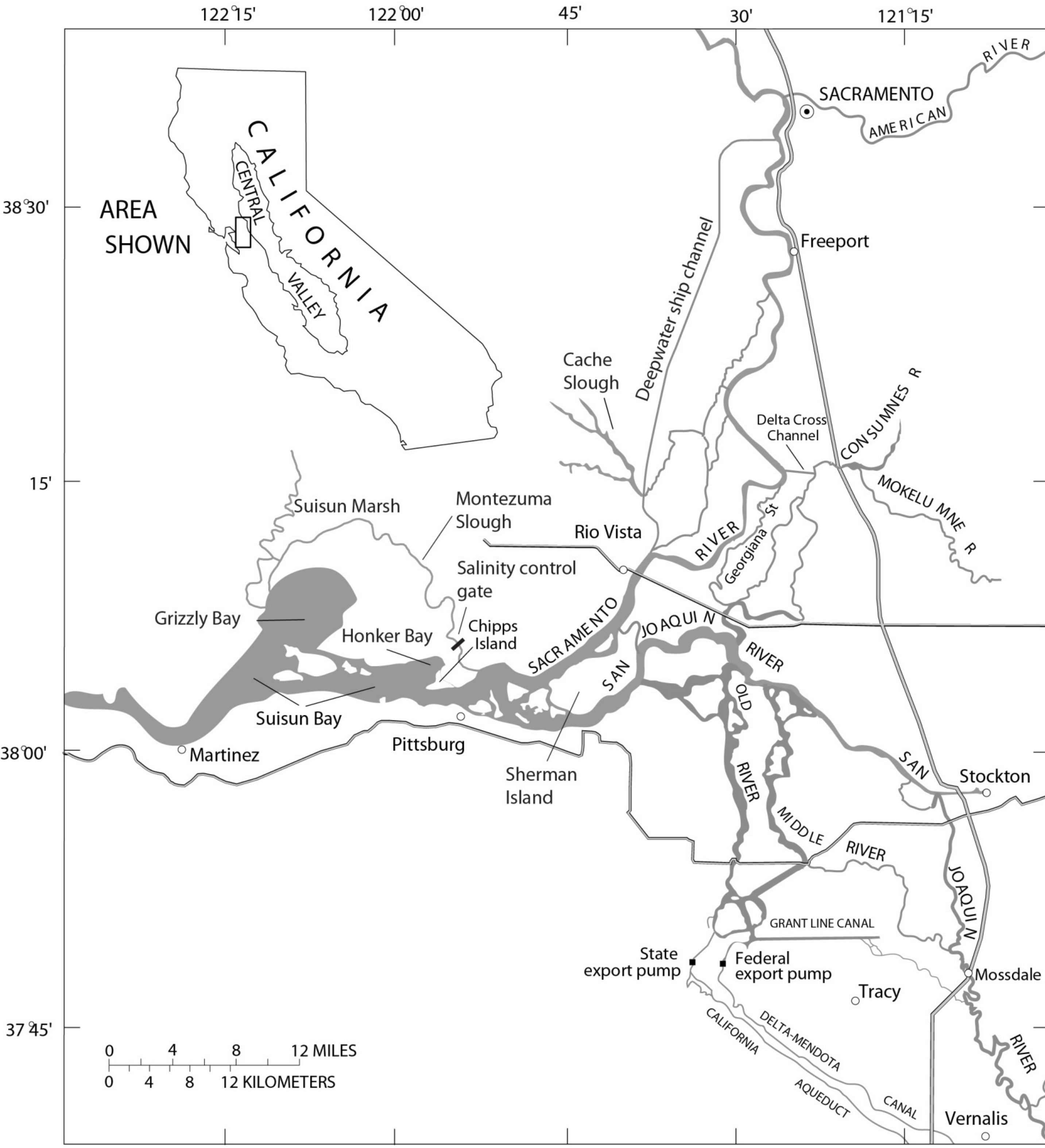


Figure 2. Map of the San Francisco Estuary. Also shown are isohaline positions (X2) measured at nominal distances (in kilometers) from the Golden Gate Bridge along the axis of the estuary (adapted from Jassby et al. (1995)).

Figure 3. Map of the Sacramento-San Joaquin Delta, Suisun Bay and associated areas.



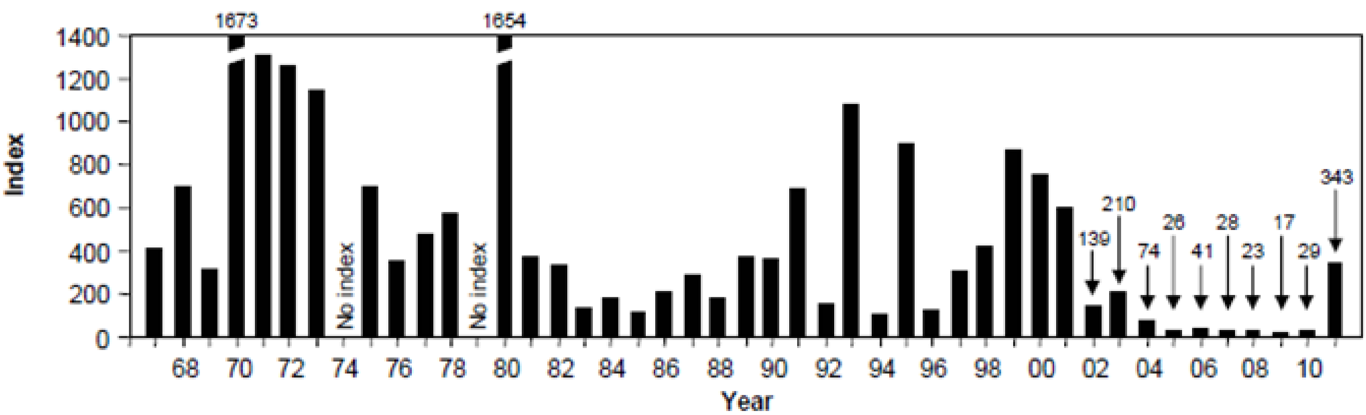


Figure 4. Delta smelt abundance index from the fall midwater trawl survey. The survey was not conducted in 1974 or 1979.

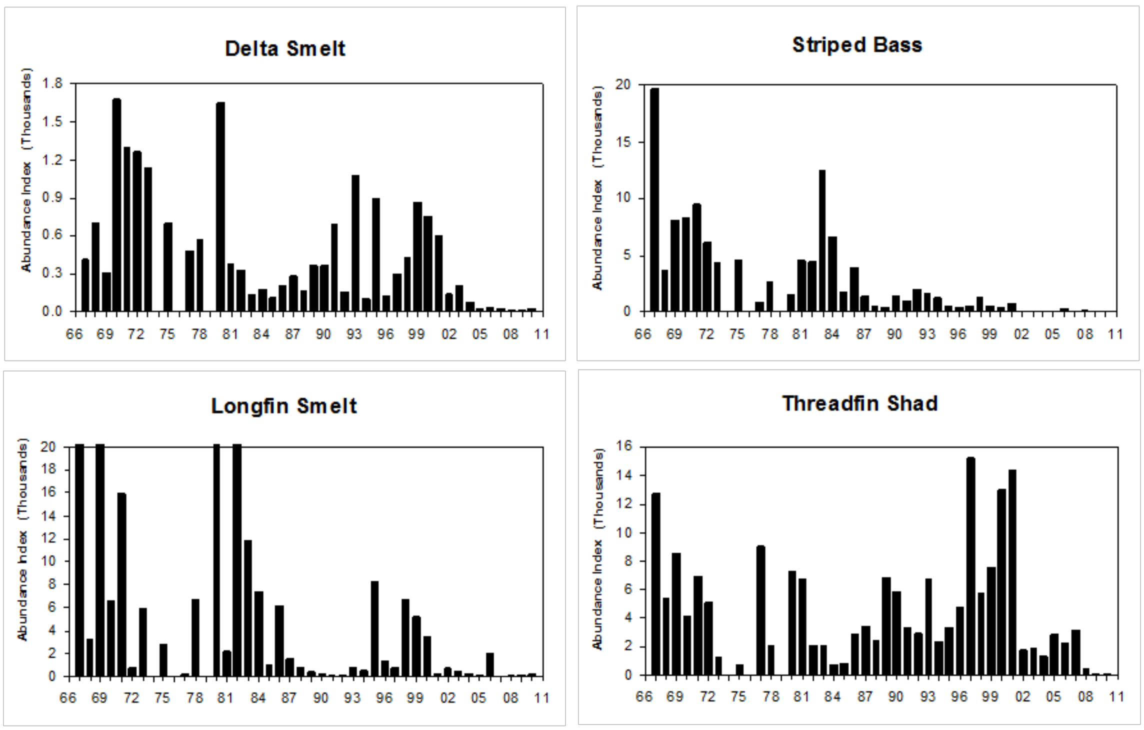


Figure 5. Trends in abundance indices for four pelagic fishes from 1967 to 2010 based on the Fall Midwater Trawl, a California Department of Fish and Game survey that samples the upper San Francisco Estuary. No sampling occurred in 1974 or 1979 and no index was calculated for 1976. Note that the y-axis for longfin smelt represents only the lower 25% of its abundance range to more clearly portray the lower abundance range.

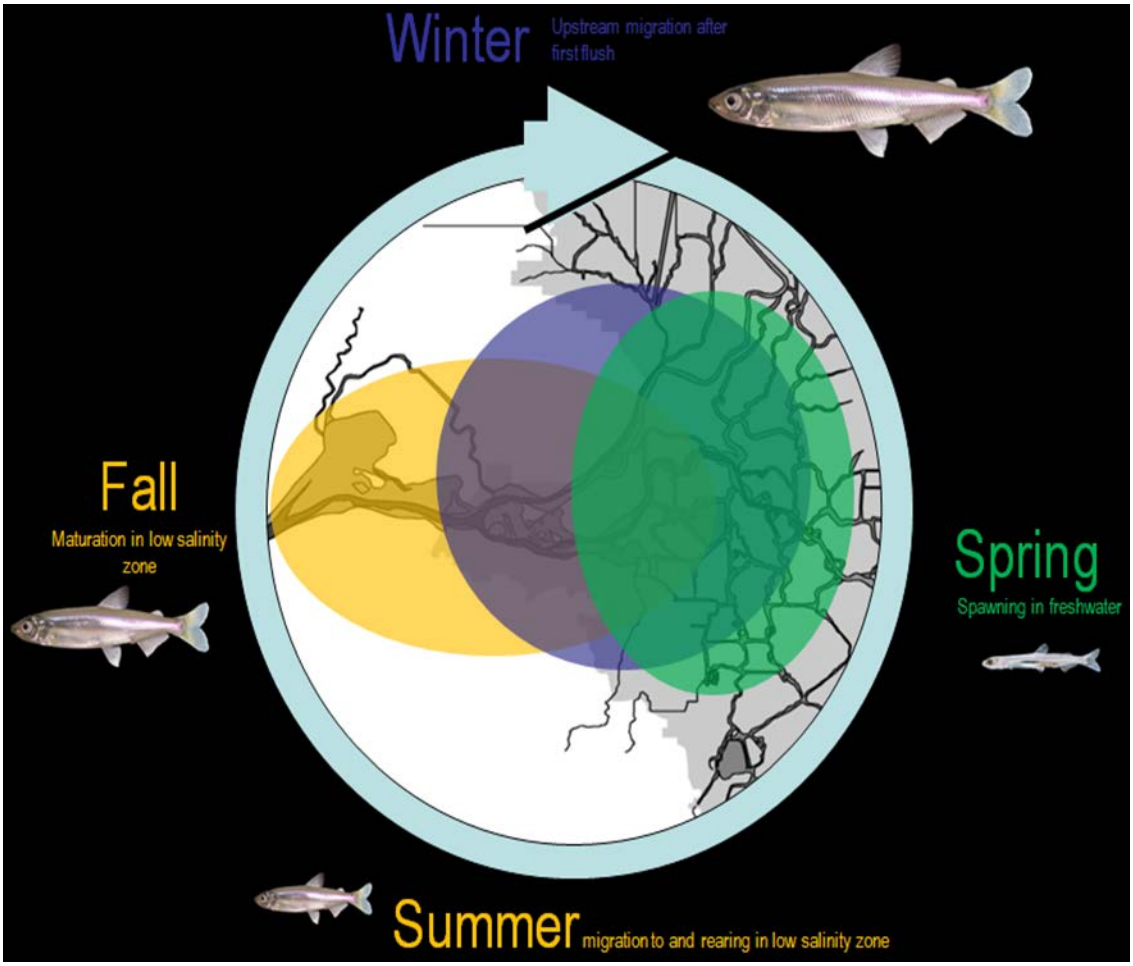


Figure 6. Simple conceptual diagram of the delta smelt annual life cycle (modified from Bennett 2005).

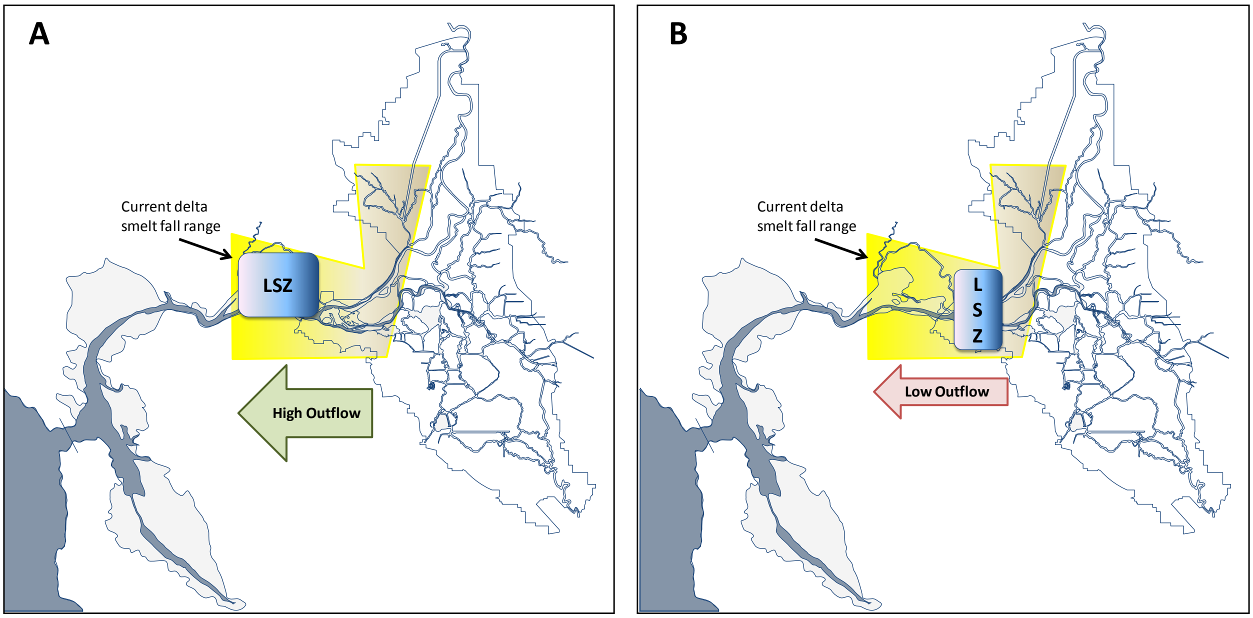


Figure 7. In the fall, delta smelt are currently found in a small geographic range (yellow shading) that includes the Suisun region, the river confluence, and the northern Delta, but most are found in or near the LSZ. **A:** The LSZ overlaps the Suisun region under high outflow conditions. **B:** The LSZ overlaps the river confluence under low outflow conditions (from Reclamation 2011).

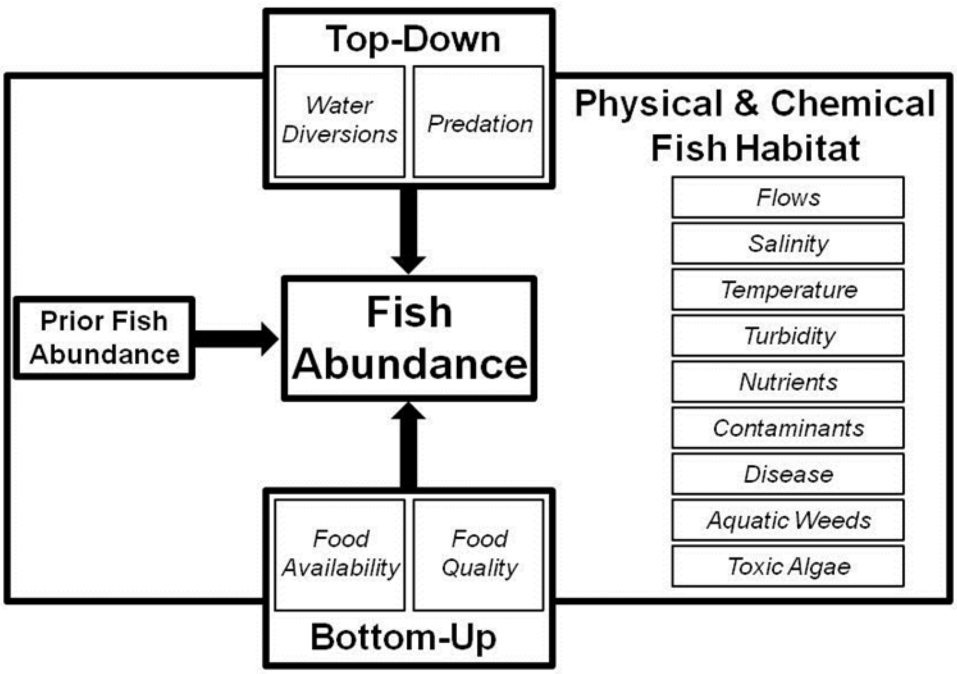


Figure 8. The basic conceptual model for the pelagic organism decline (adapted from Baxter and others 2010).

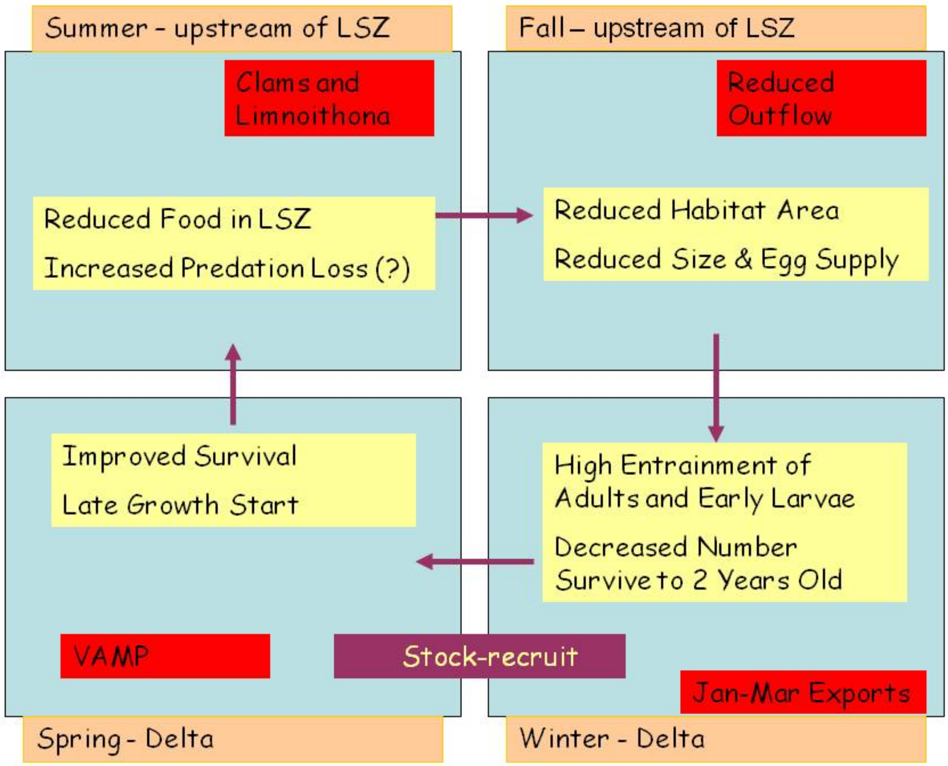


Figure 9. Delta smelt species-specific model (adapted from Baxter and others, 2010)

Old Regime	Environmental Drivers	New Regime
Variable, High	Outflow	*Variable, Lower*
To the west, Variable	Salinity gradient	*To the east, Constricted*
Complex, Variable	Landscape	*Simplified, Rigid*
Low, Variable	Temperature	*High, Uniform*
High, Variable	Turbidity	*Low, Less variable*
High P, low N	Nutrients	*Low P, High N (NH_4+)*
Few, Low	Contaminants	*Many, High*
Predation, Fishing	"Harvest"	*Predation and Entrainment*

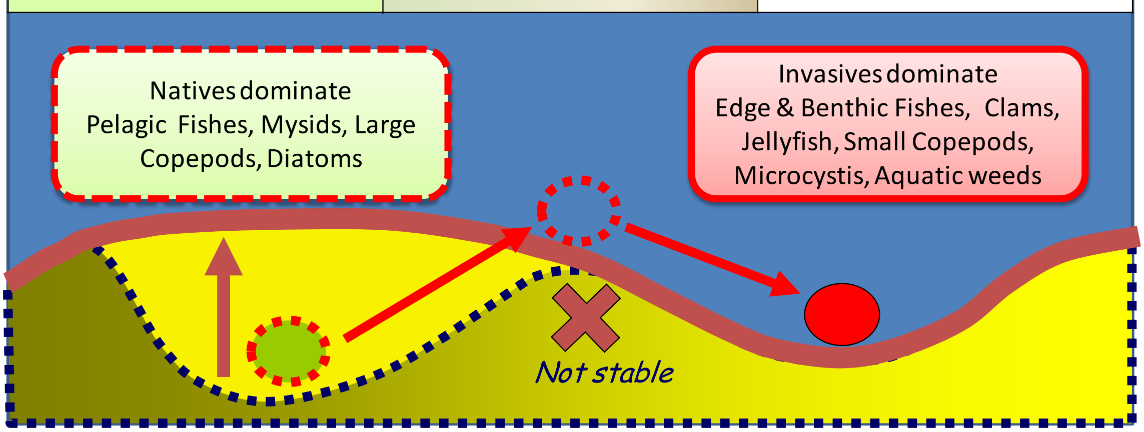


Figure 10. Regime shift model from Baxter and others (2010). The model assumes that ecological regime shift in the Delta results from changes in (slow) environmental drivers (top panel) that lead to profoundly altered biological communities (bottom panel). Introduction of invasive species is also an important process in producing the shift. The ecosystem must pass through an unstable threshold region before the new relatively stable ecosystem regime is established.

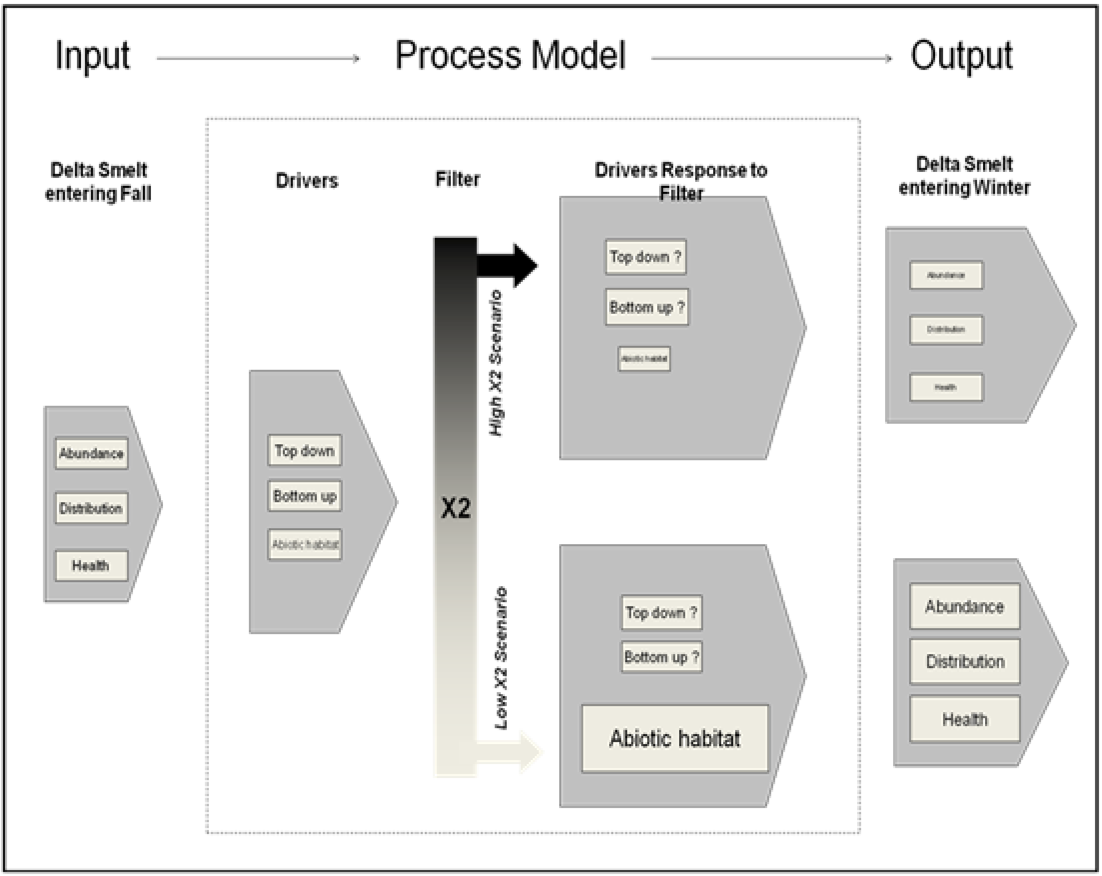


Figure 11. Habitat Study Group model of effects of fall low salinity habitat position and indexed by X2 on delta smelt through changes in habitat quantity and quality. Position and extent of fall low salinity habitat affects (either directly or indirectly) the expected outcomes for the same drivers (from Reclamation 2011).

Estuarine habitat conceptual model
(after Peterson 2003)

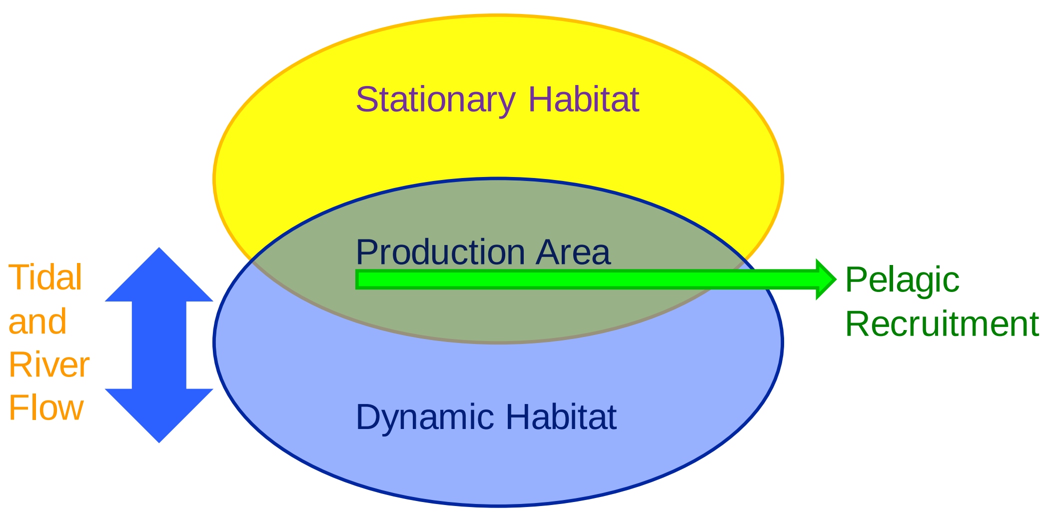


Figure 12. Estuarine habitat conceptual model (after Peterson 2003)).

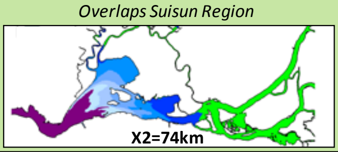
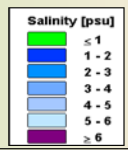
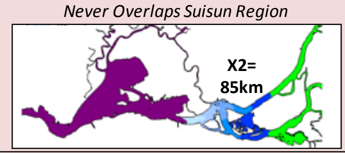
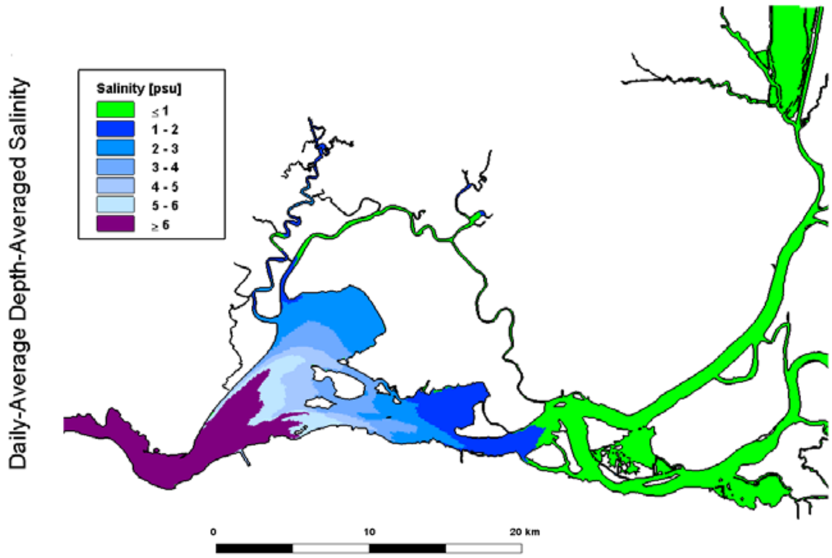
Suisun Region	**Stationary Abiotic Habitat Components**	*River Confluence*
Higher	Bathymetric Complexity	*Lower*
Higher	Erodible Sediment Supply	*Lower*
Many in South, Fewer in North	Contaminant Sources	*Many*
Fewer	Entrainment Sites	*More*
Variable Fall Outflow Regime	**Dynamic Abiotic Habitat Components**	***Static Fall Outflow Regime***
Higher After Wet Springs	Net Total Delta Fall Outflow	*Always Low*
Higher After Wet Springs	San Joaquin River Contribution to Fall Outflow	*Always Low*
After Wet Springs, Broad Fall LSZ Overlaps Suisun Region 	Location and Extent of the Fall LSZ (1-6 psu) 	*Narrow Fall LSZ In River Channels, Never Overlaps Suisun Region* 
Higher After Wet Springs	Hydrodynamic Complexity in the Fall LSZ	*Always Lower*
Higher After Wet Springs	Wind speed in the Fall LSZ	*Always Lower*
More Variable, Higher After Wet Springs	Turbidity in the Fall LSZ	*Always Less Variable, Lower*
More Variable, Maybe Lower After Wet Springs	Contaminant Concentrations in the Fall LSZ	*Less Variable, Maybe Higher*
LSZ Overlaps Suisun Region	**Dynamic Biotic Habitat Components**	***LSZ Overlaps River Confluence***
Higher	Food Availability and Quality	*Lower*
Variable	Predator Abundance	*Higher*
LSZ Overlaps Suisun Region	**Delta Smelt Responses**	***LSZ Overlaps River Confluence***
Broad, Westward	Distribution	*Constricted, Eastward*
Higher	Growth, Survival, Fecundity	*Lower*
Better	Health and Condition	*Worse*
May be Higher	Recruitment in the next Spring	*Lower*

Figure 13. Spatially explicit conceptual model for the western reach of the modern delta smelt range in the fall: interacting stationary and dynamic habitat features drive delta smelt responses.



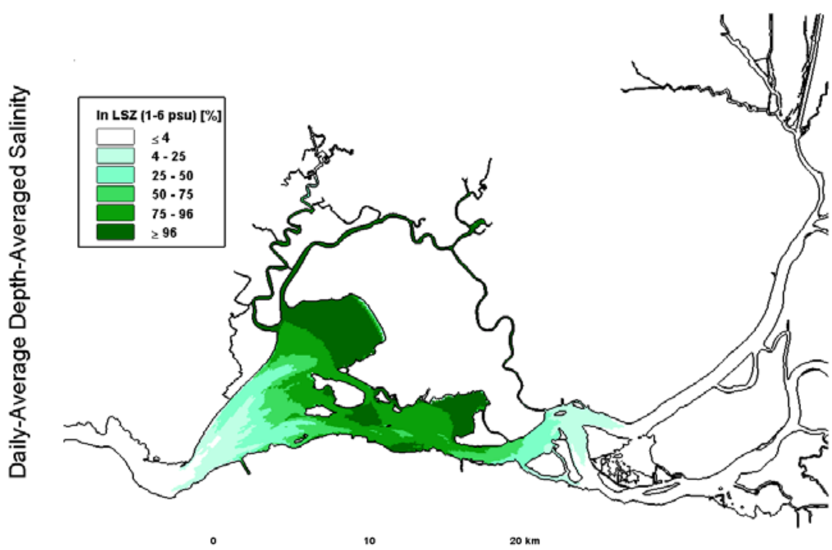
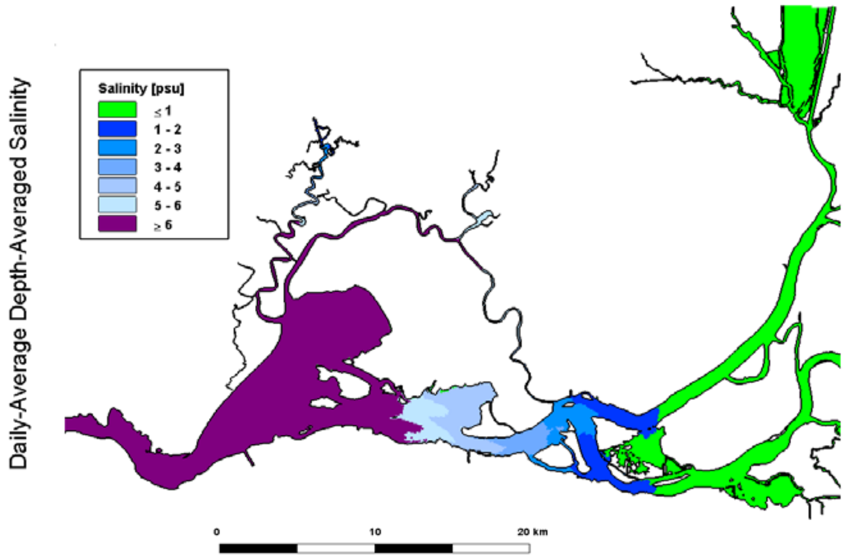


Figure 14. The upper panel shows the area of the LSZ (9,140 hectares) at X2 = 74 km (at Chipps Island). The lower panel shows the percentage of day that the LSZ occupies different areas.



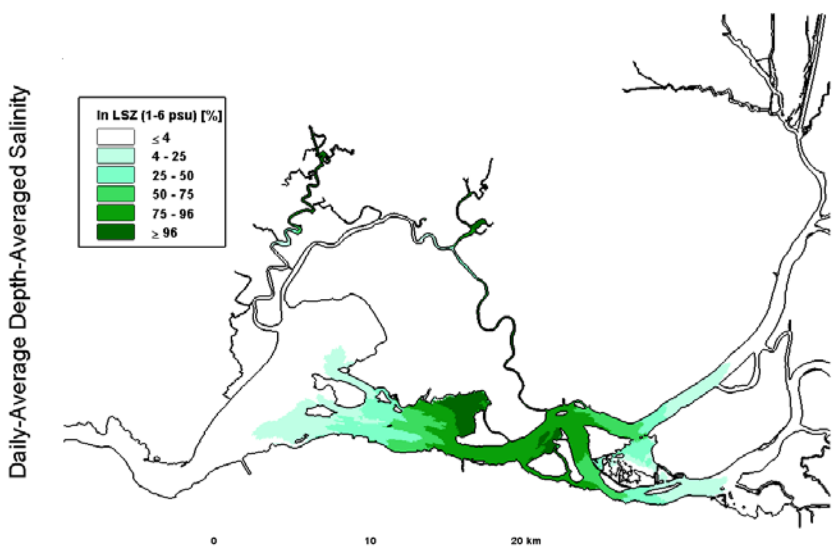
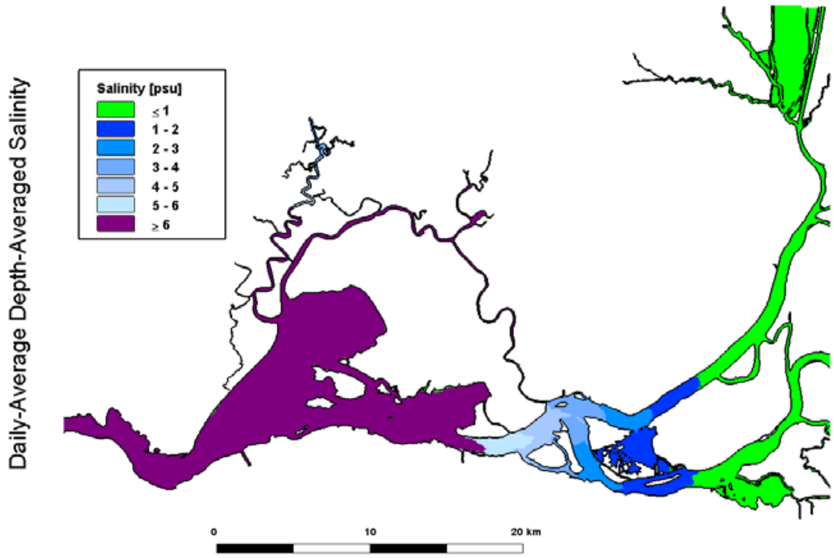


Figure 15. The upper panel shows the area of the LSZ (4,914 hectares) at X2 = 81 km (at the confluence of the Sacramento and San Joaquin rivers), when the LSZ is confined within the relatively deep channels of the western Delta. The lower figure shows percentage of day that the LSZ occupies different areas.



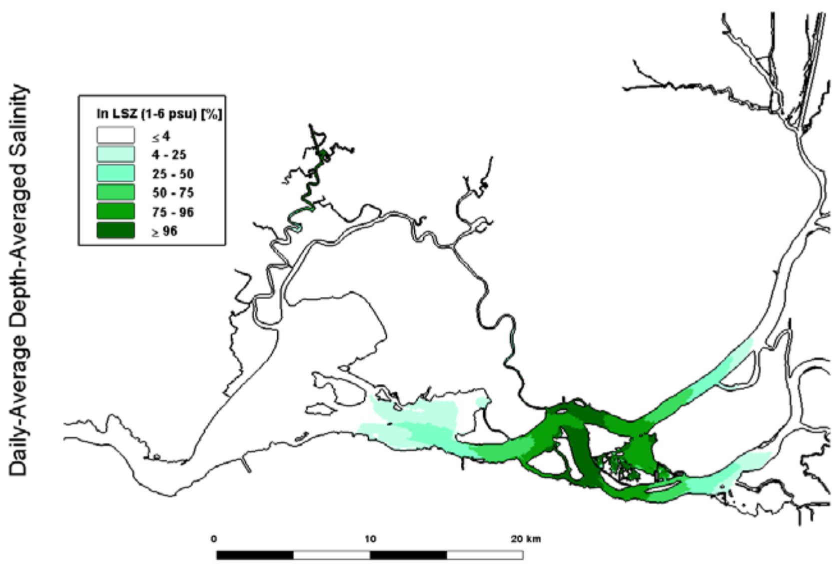


Figure 16. The upper panel shows the area of the LSZ (4,262 hectares) at X2 = 85 km, when positioned mostly between Antioch and Pittsburg. Connections to Suisun Bay and Marsh have nearly been lost. The lower panel shows the percentage of day that the LSZ occupies different areas.

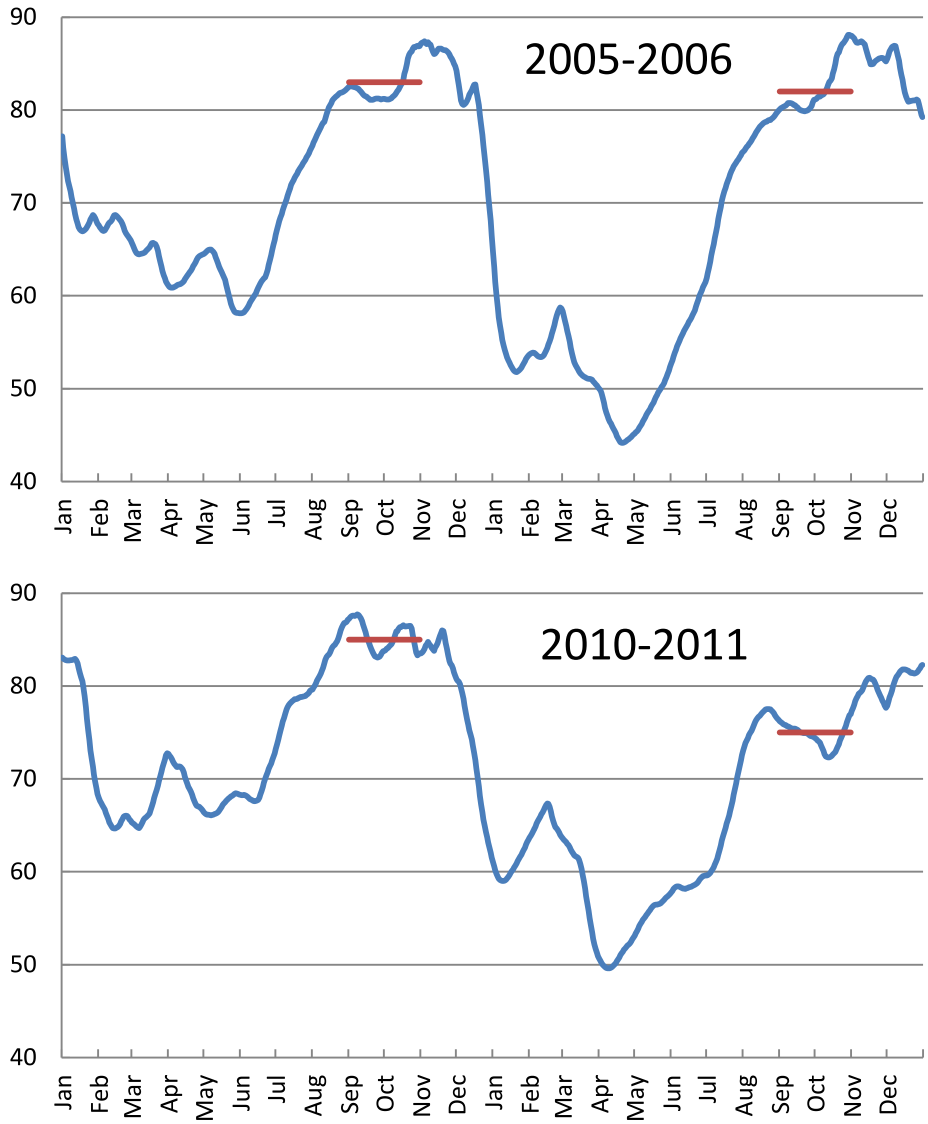
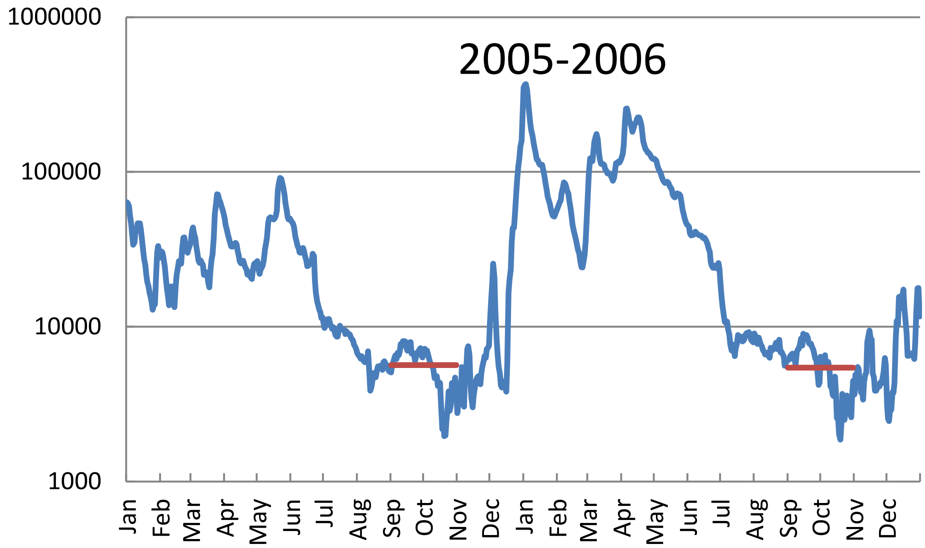


Figure 17. Daily X2 for 2005-2006 and 2010-2010. Mean daily X2 for each year during the September to October period is shown by the horizontal bar.



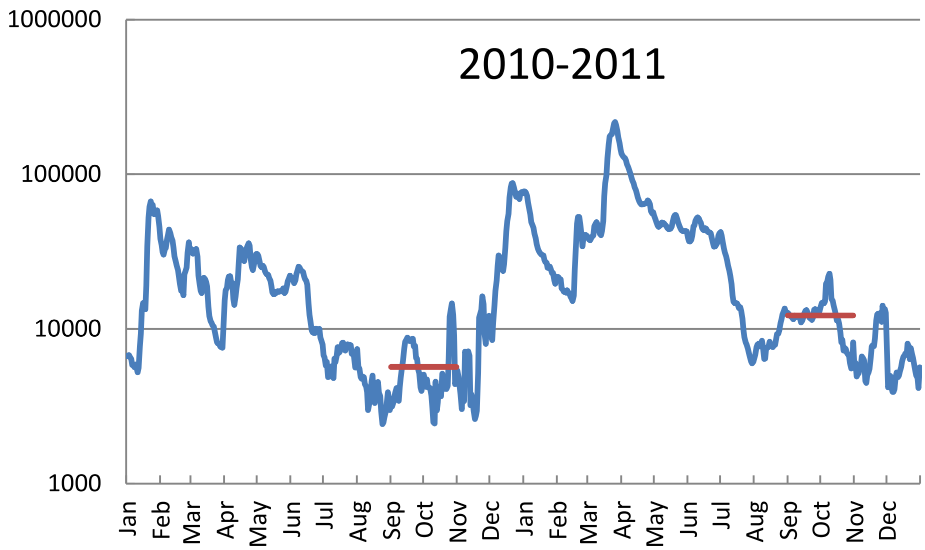


Figure 18. Daily Delta outflow (cfs) for 2005-2006 and 2010-2010. Mean daily ouflow during the September to October period are shown by the horizontal bar.

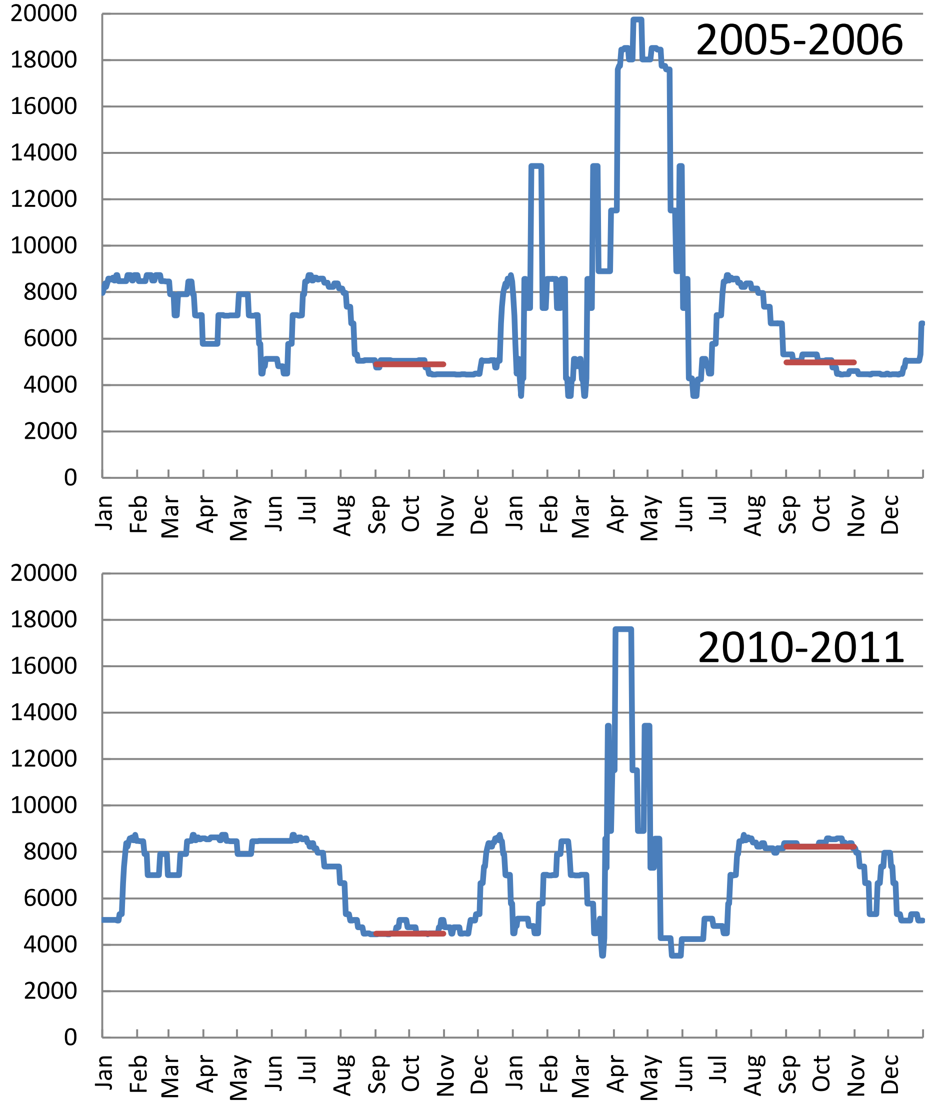


Figure 19. Daily area (hectares) of the depth averaged low salinity zone (salinity 1-6) for 2005-2006 and 2010-2010. Mean daily areas during the September to October period are shown by the horizontal bar.

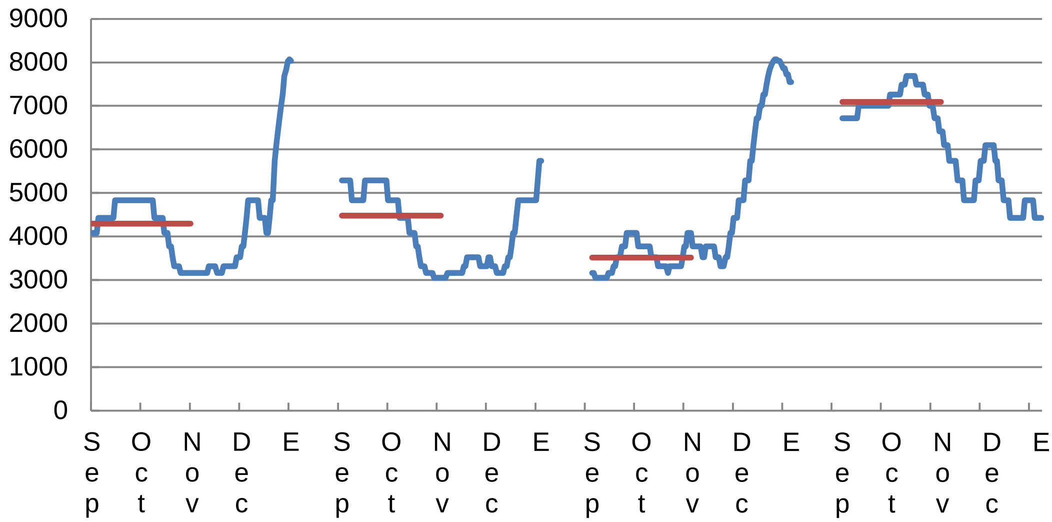


Figure 20. Daily delta smelt habitat index for the fall (Sep-Dec) for 2005, 2006, 2010, and 2011. Mean daily delta smelt habitat index during the September to October period are shown by the horizontal bar. The end of the data record each year is indicated by E.

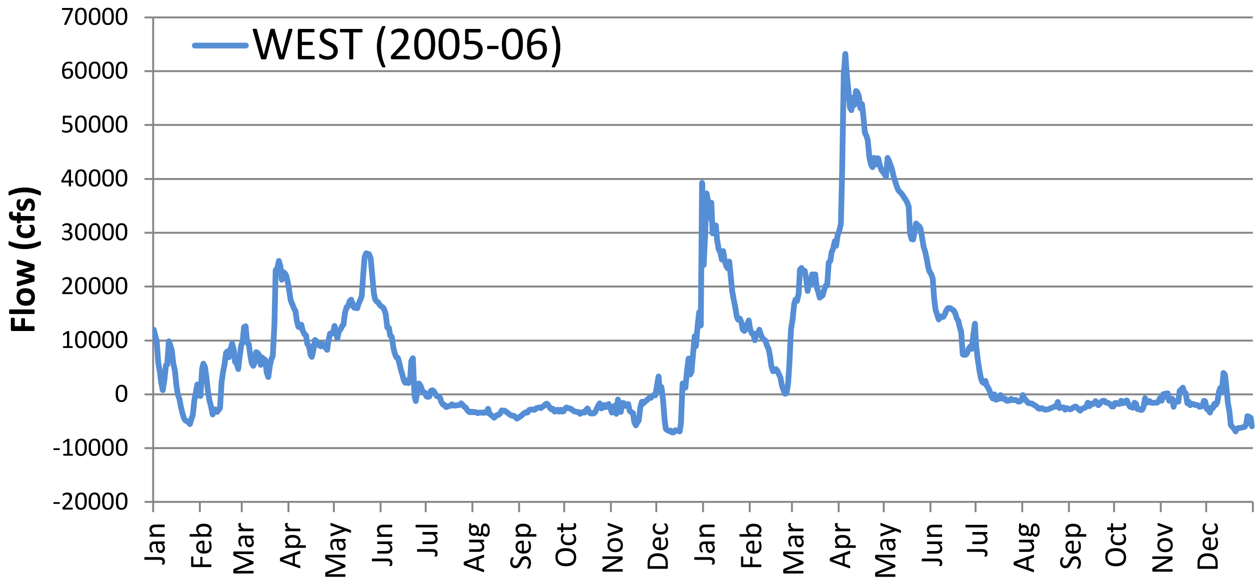


Figure 21. Daily net flow past Jersey Point on the San Joaquin River.

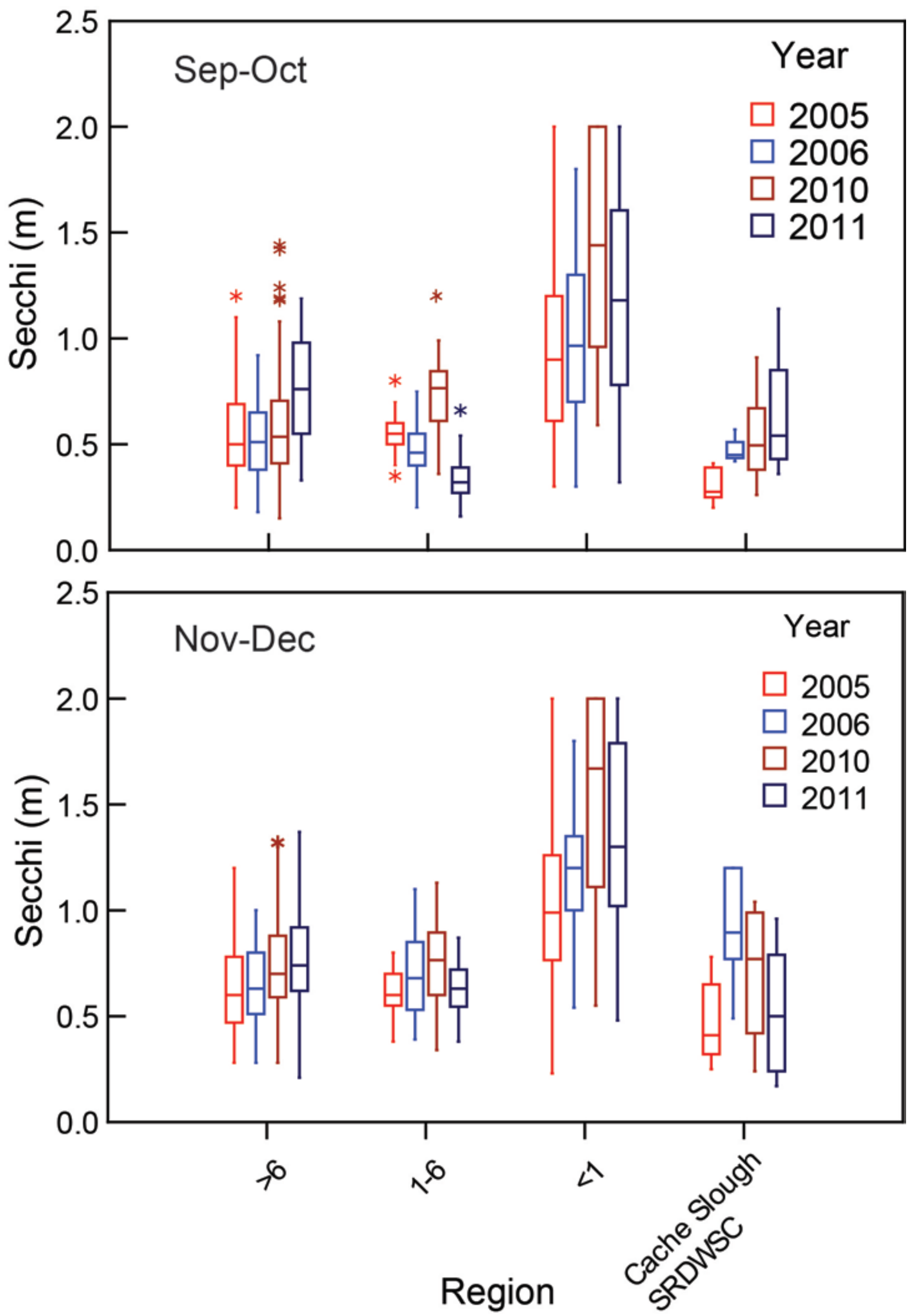


Figure 22. Secchi depth data collected during the FMWT fish sampling survey.

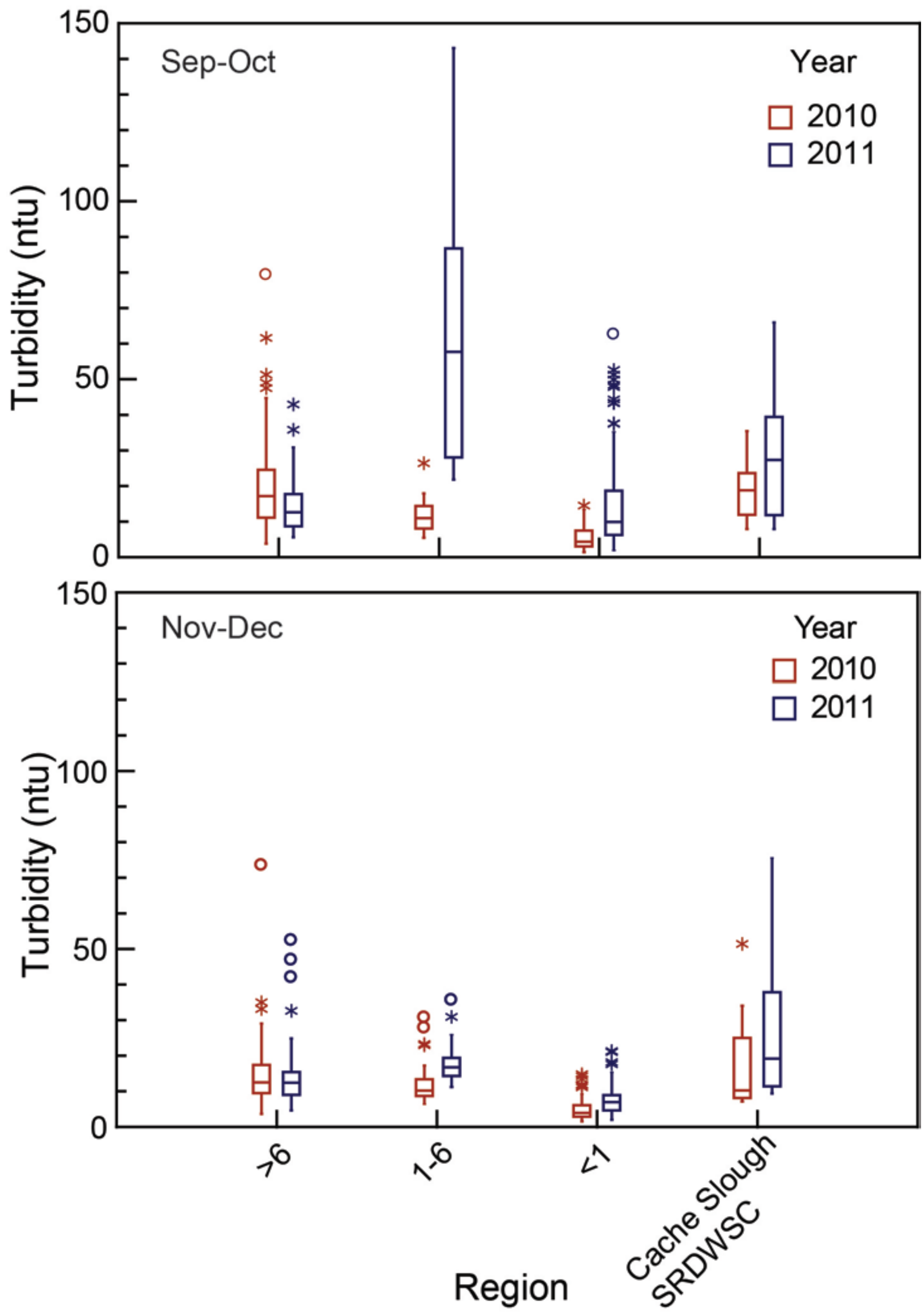


Figure 23. Turbidity data collected during the FMWT fish sampling survey. These data were not collected in 2005 and 2006.

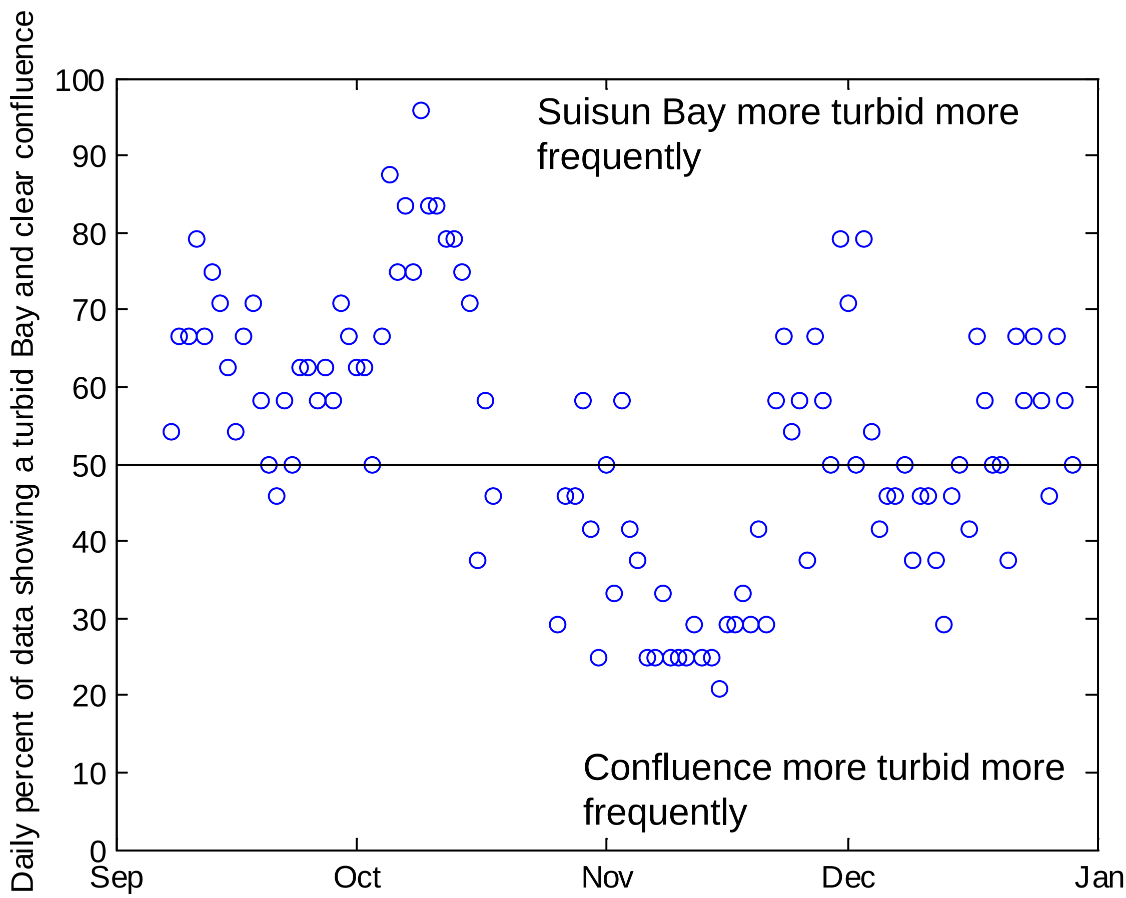


Figure 24. Percent of data showing a turbid Bay and clear confluence, September-December 2011. Calculated from the product of hourly deviations of specific conductance and suspended-sediment concentration from tidally-averaged values. Values greater than 50% indicate instantaneous salinity and SSC are either both positive (relatively turbid Bay water) or negative (relatively clear confluence water). Values less than 50% indicate that deviations of conductance and SSC have opposite signs (relatively clear Bay or relatively turbid confluence). See Appendix A.5 for details.

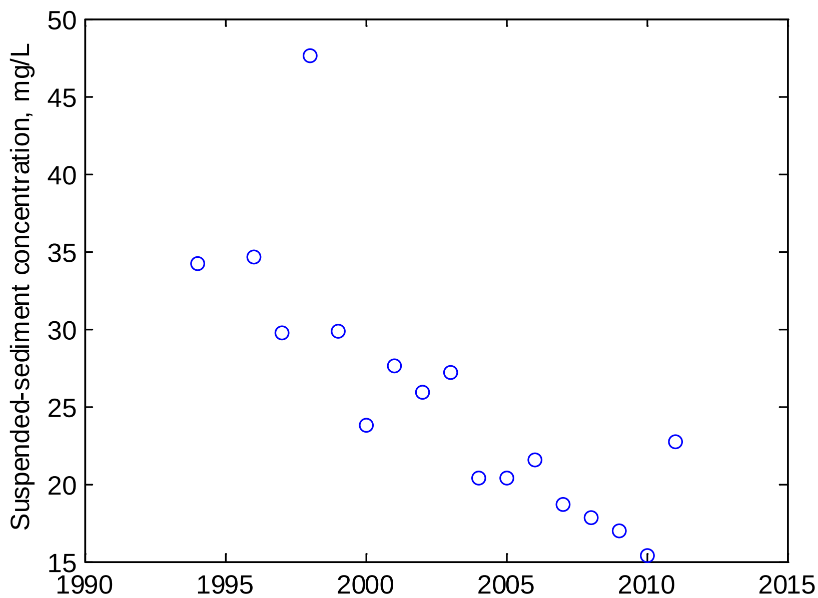


Figure 25. Near-surface suspended-sediment concentration at Mallard Island, September-October mean values, 1994-2011. 1995 is not included due to insufficient SSC data. See Appendix A.5 for more detail.

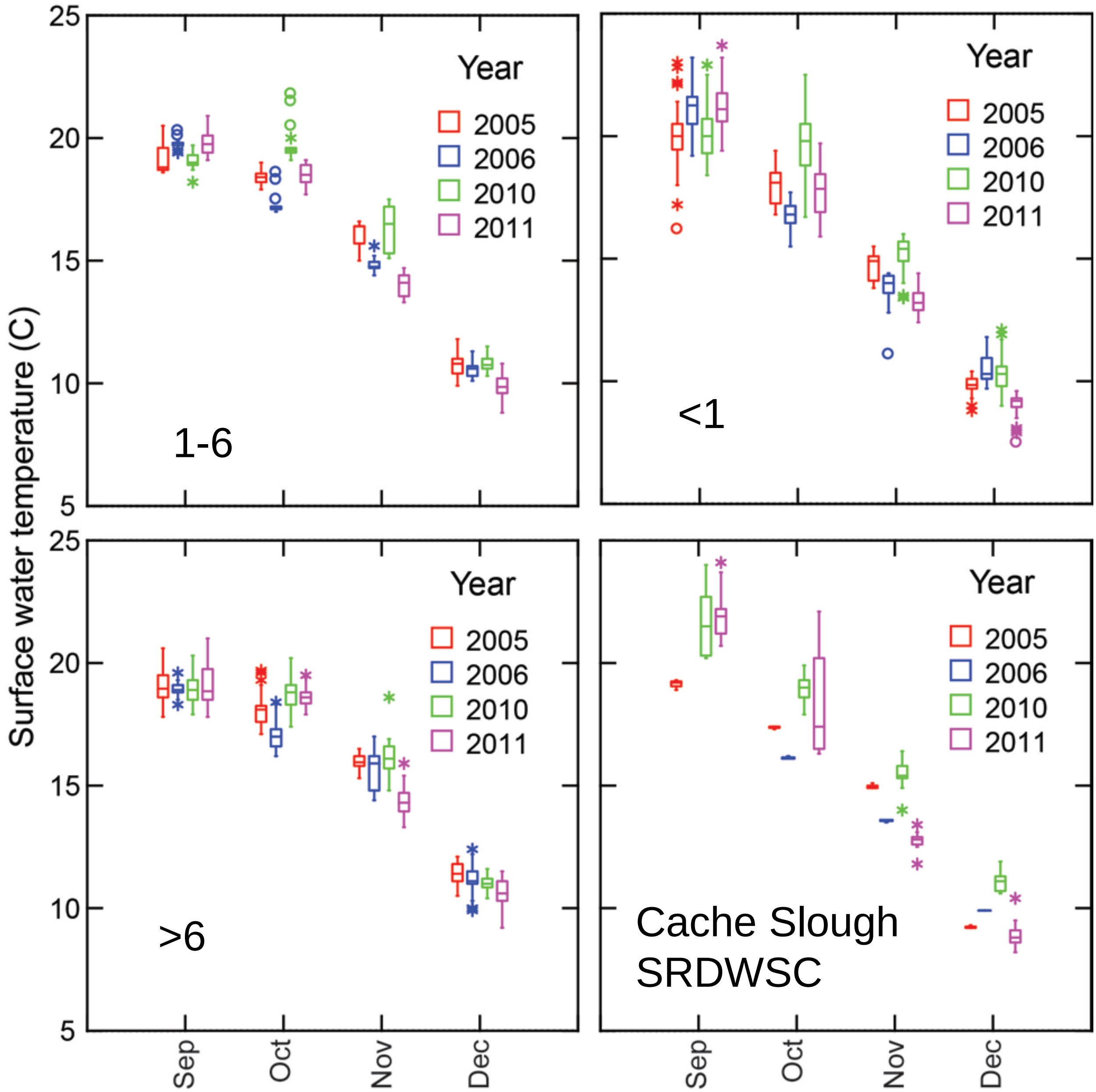


Figure 26. Surface water temperature (C) at FMWT sampling sites during monthly sampling.

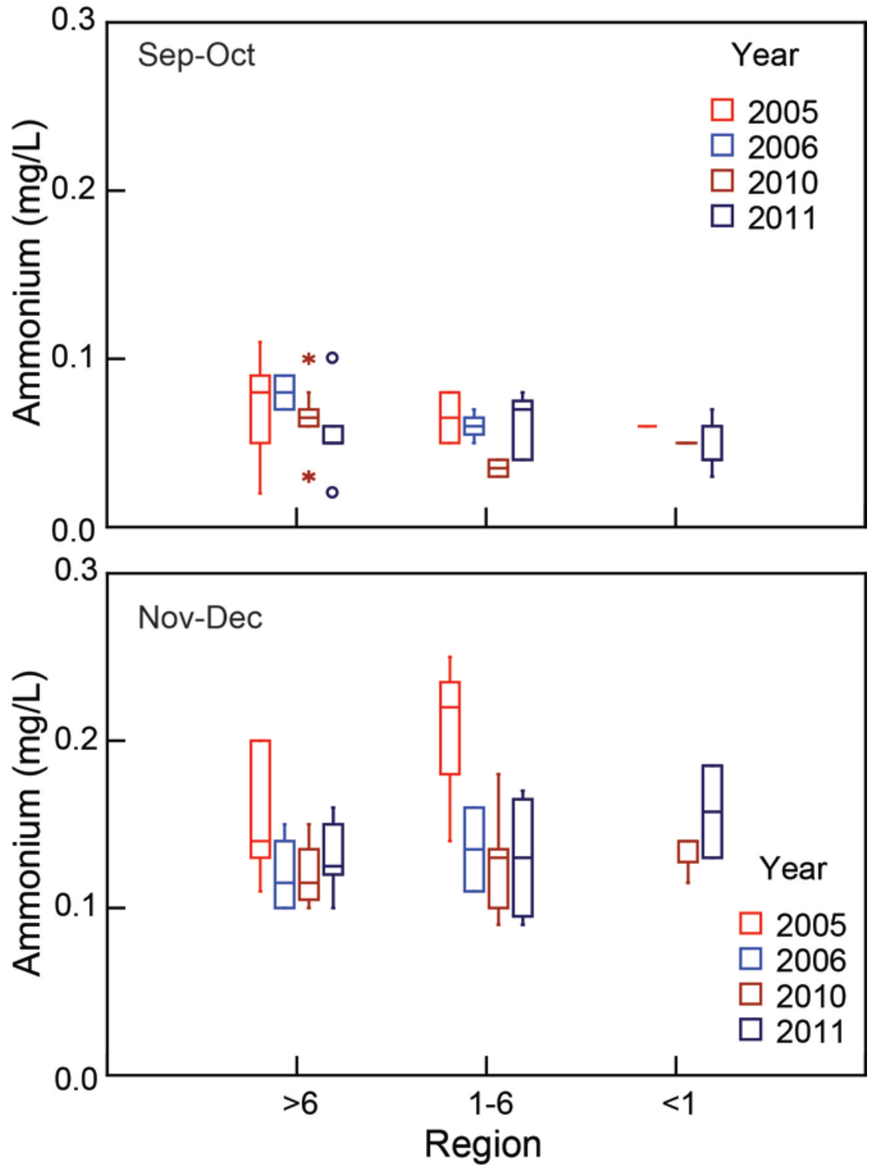


Figure 27. Ammonium concentrations in Sep-Oct and Nov-Dec from the IEP Environmental Monitoring Program (see Appendix A.6).

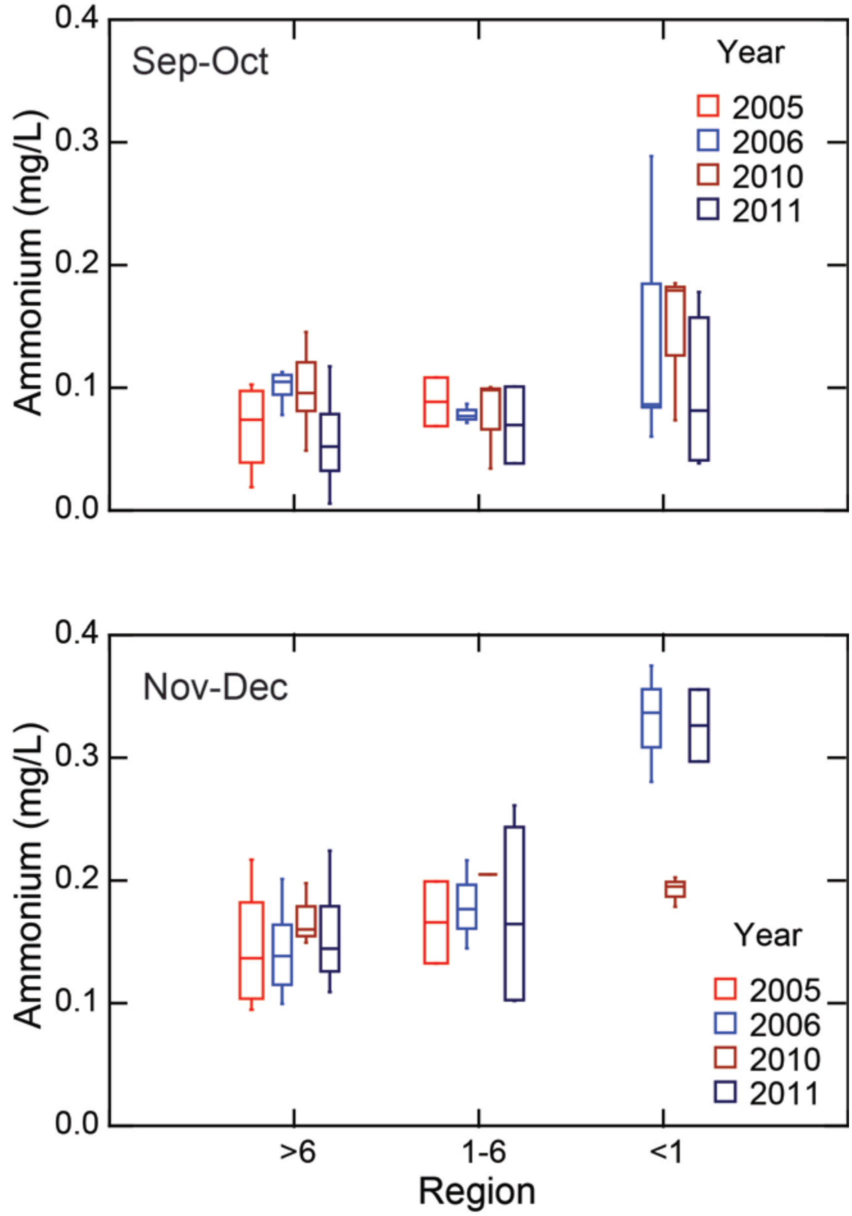


Figure 28. Ammonium data from USGS monthly sampling cruises.

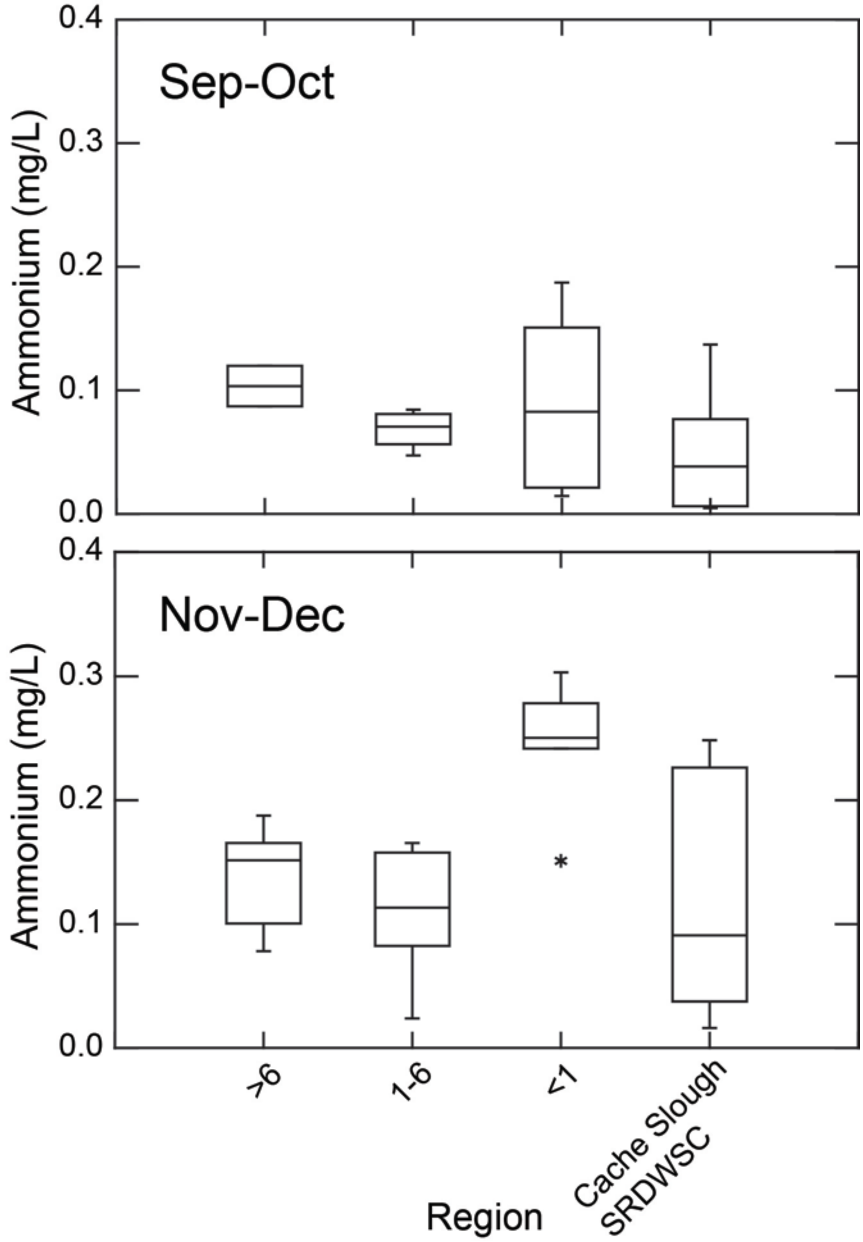


Figure 29. Ammonium concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during the fall midwater trawl (see Appendix A.4).

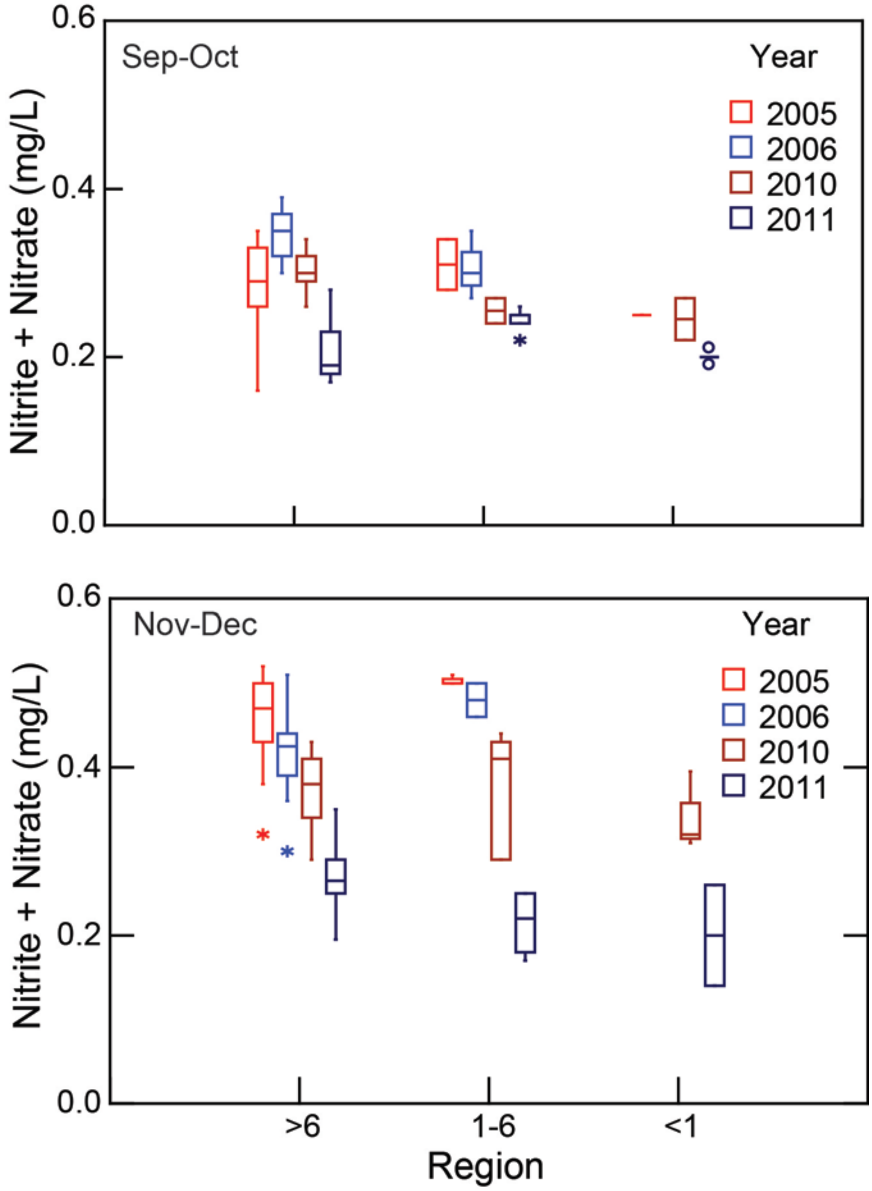


Figure 30. Nitrite + Nitrate concentrations in Sep-Oct and Nov-Dec from samples collected during EMP monitoring(see Appendix A.4).

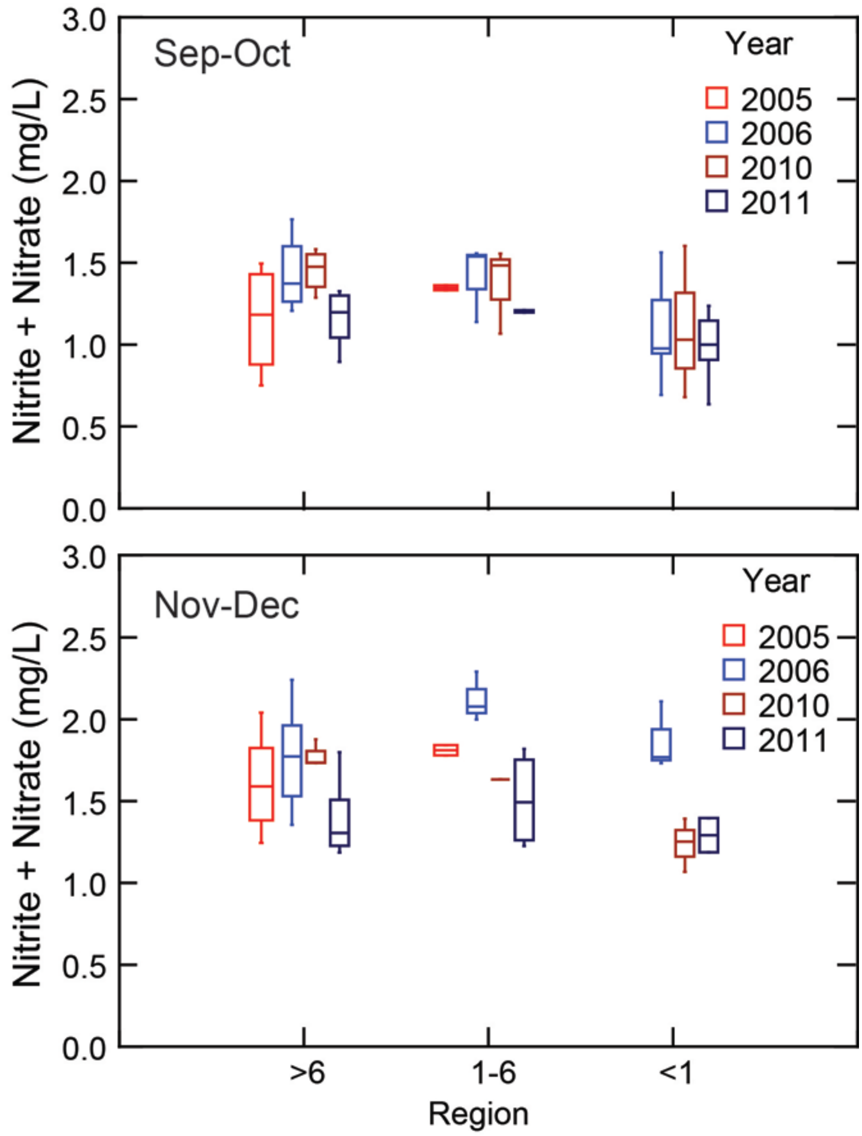


Figure 31. Nitrite + Nitrate concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during monthly USGS cruises (see Appendix A.4). Original concentrations of nitrite + nitrate were measured in micromoles. Date wer converted to mg/L assuming 100% nitrate since nitrite concentrations were not yet available. This could result in concentrations biased slightly high.

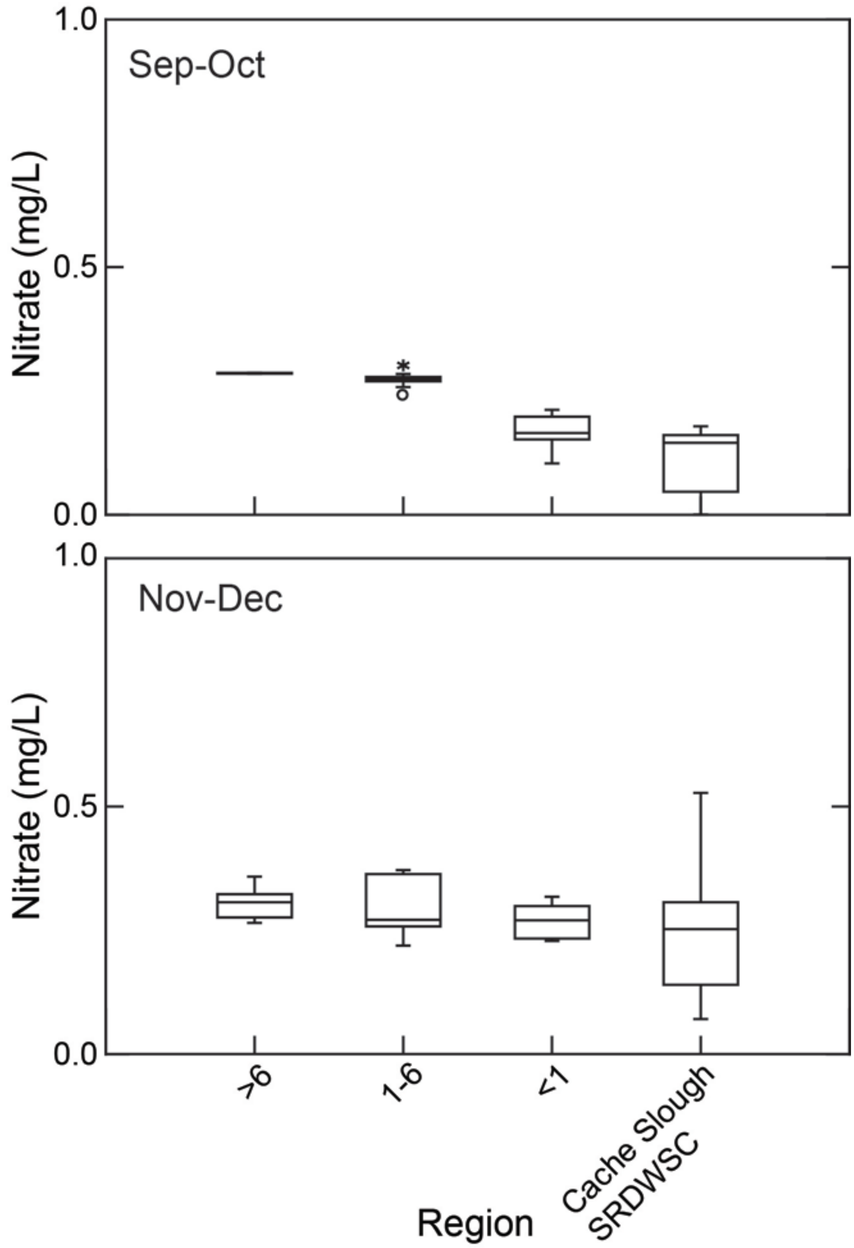


Figure 32. Nitrite + Nitrate concentrations in Sep-Oct and Nov-Dec 2011 from the samples collected during the fall midwater trawl (see Appendix A.4).

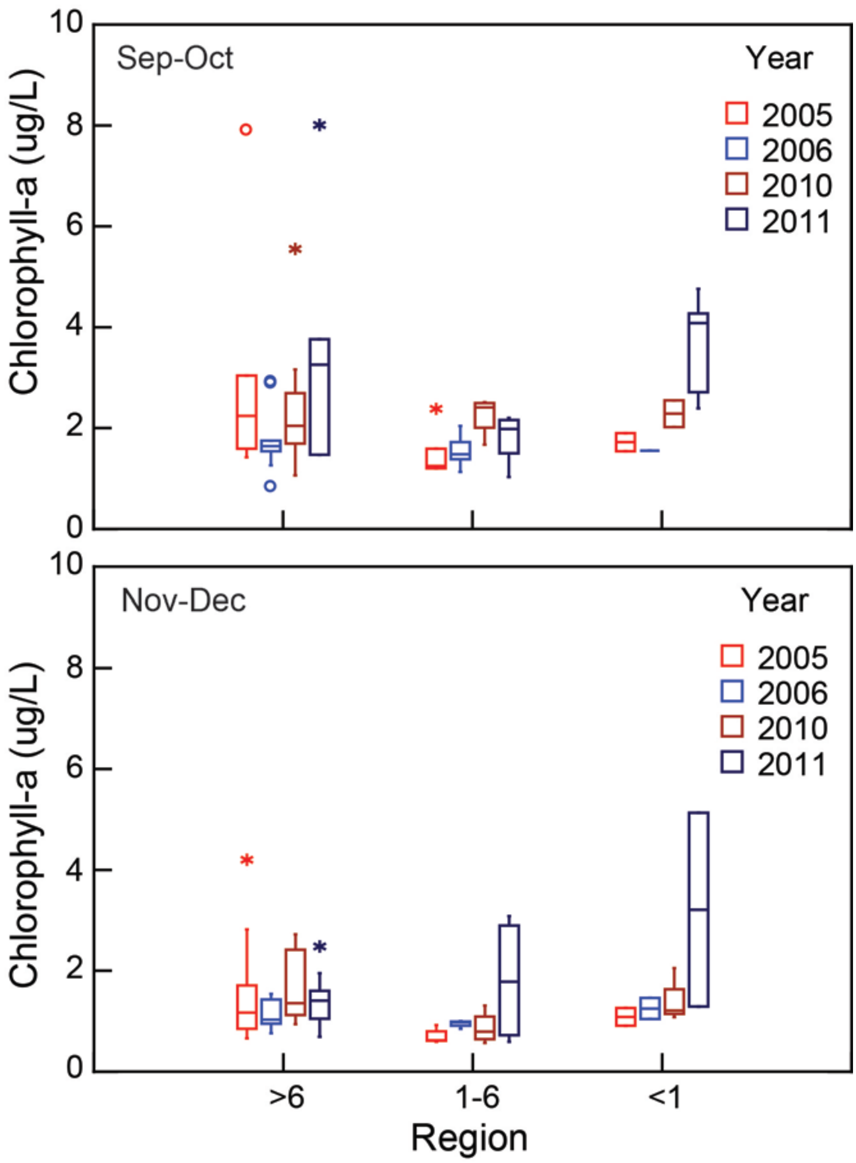


Figure 33. Chlorophyll-a concentrations in Sep-Oct and Nov-Dec from the IEP Environmental Monitoring Program (see Appendix A.6).

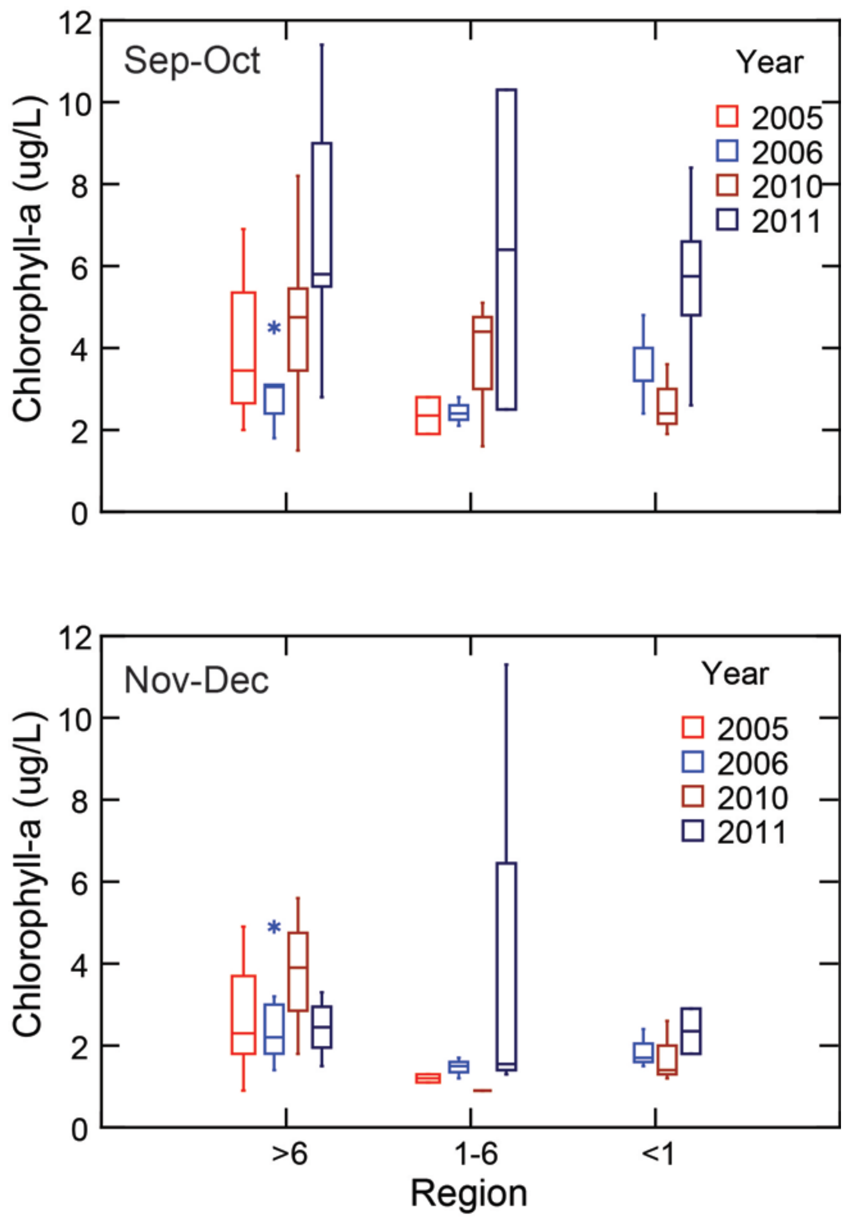


Figure 34. Chlorophyll-*a* concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during monthly USGS cruises (see Appendix A.7).

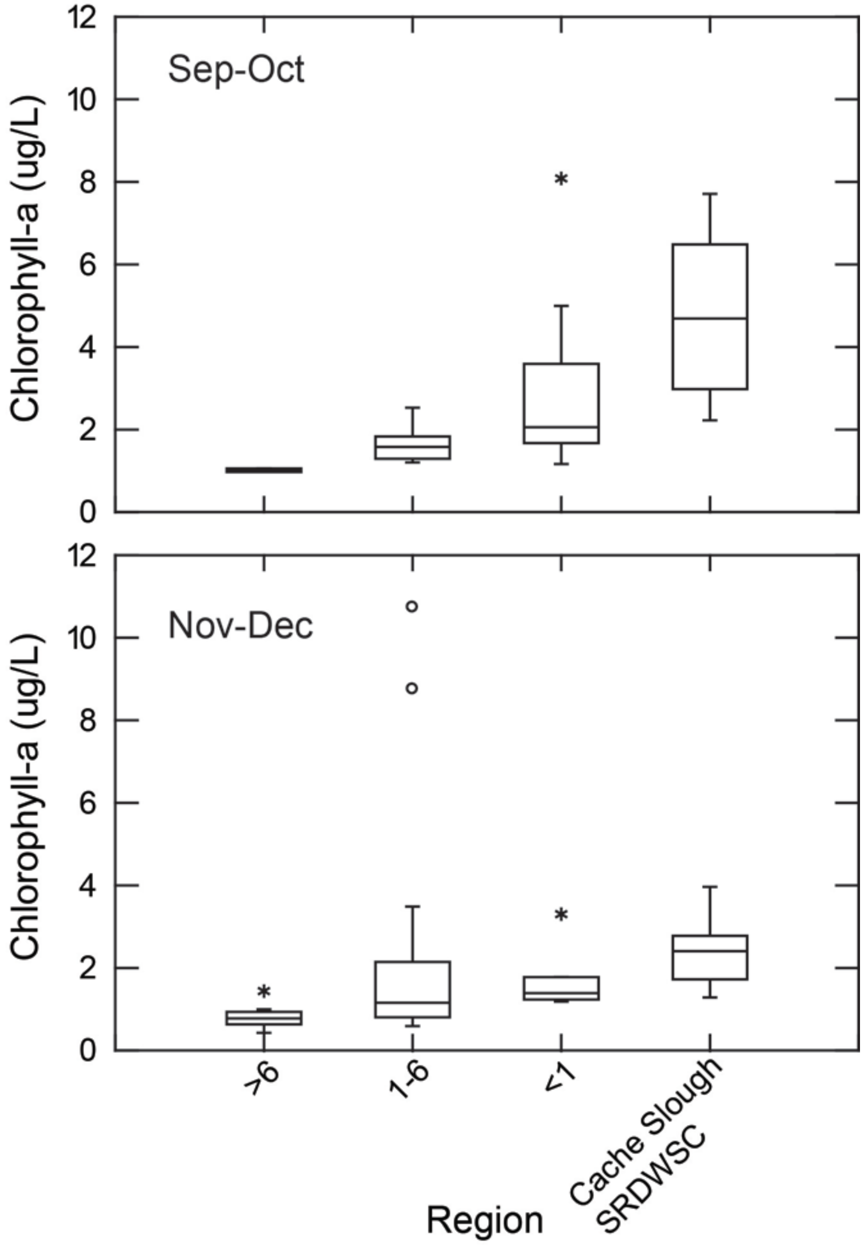


Figure 35. Chlorophyll-*a* concentrations in Sep-Oct and Nov-Dec 2011 from samples collected during the fall midwater trawl (see Appendix A.4).

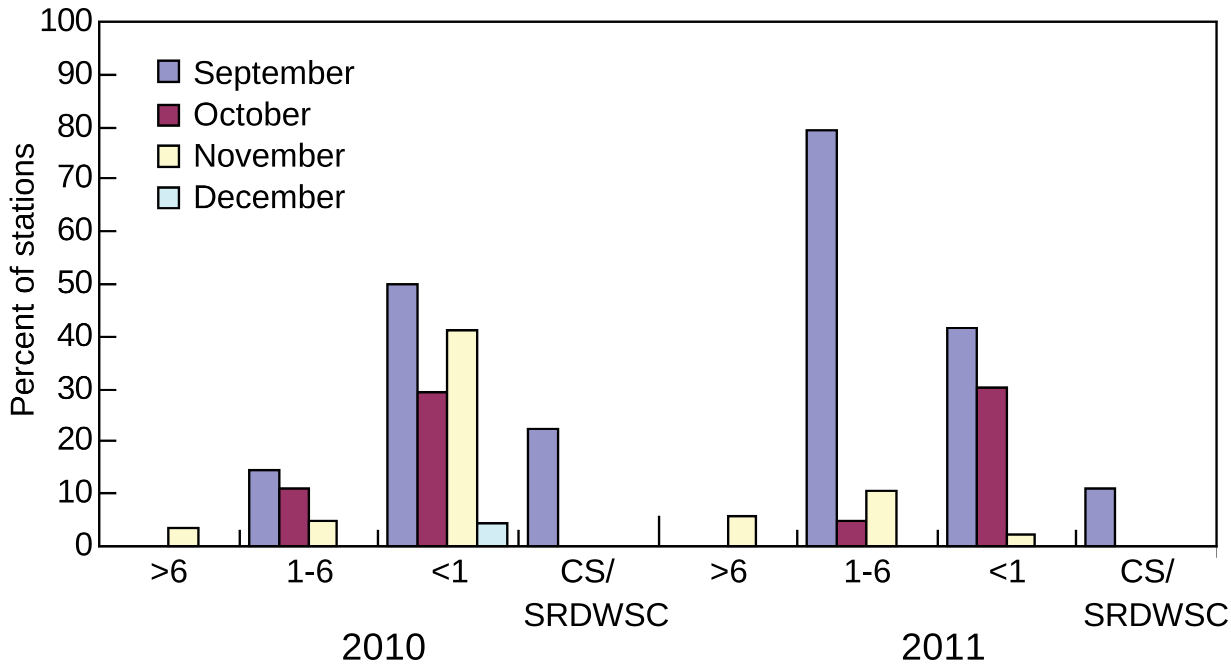


Figure 36. Occurrence of floating Microcystis at FMWT sampling stations for September to December 2010 and 2011.

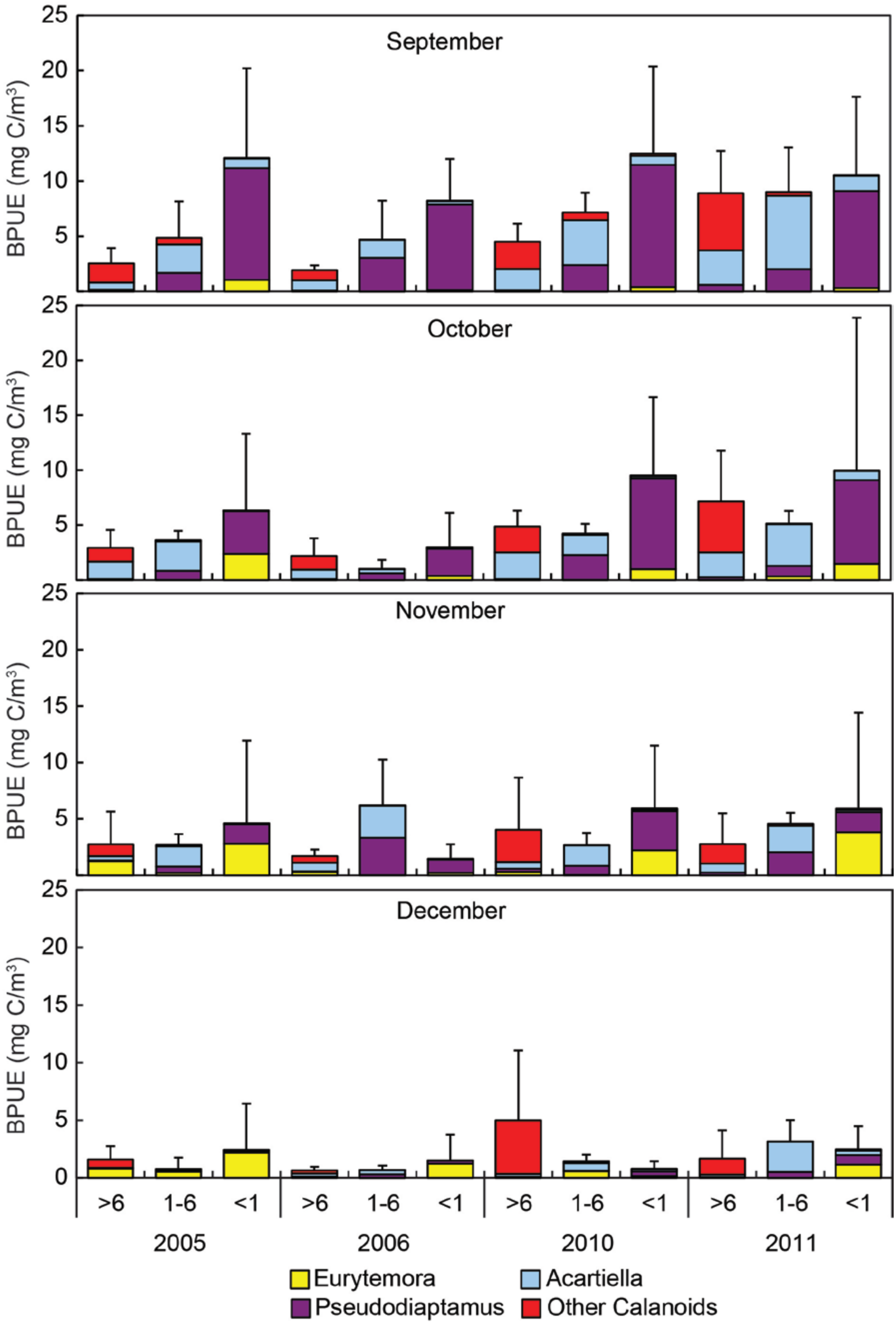


Figure 37. Biomass per unit effort (BPUE, mg C/m^3) of juvenile and adult calanoid copepods for EMP samples (mean ± 1 standard deviation).

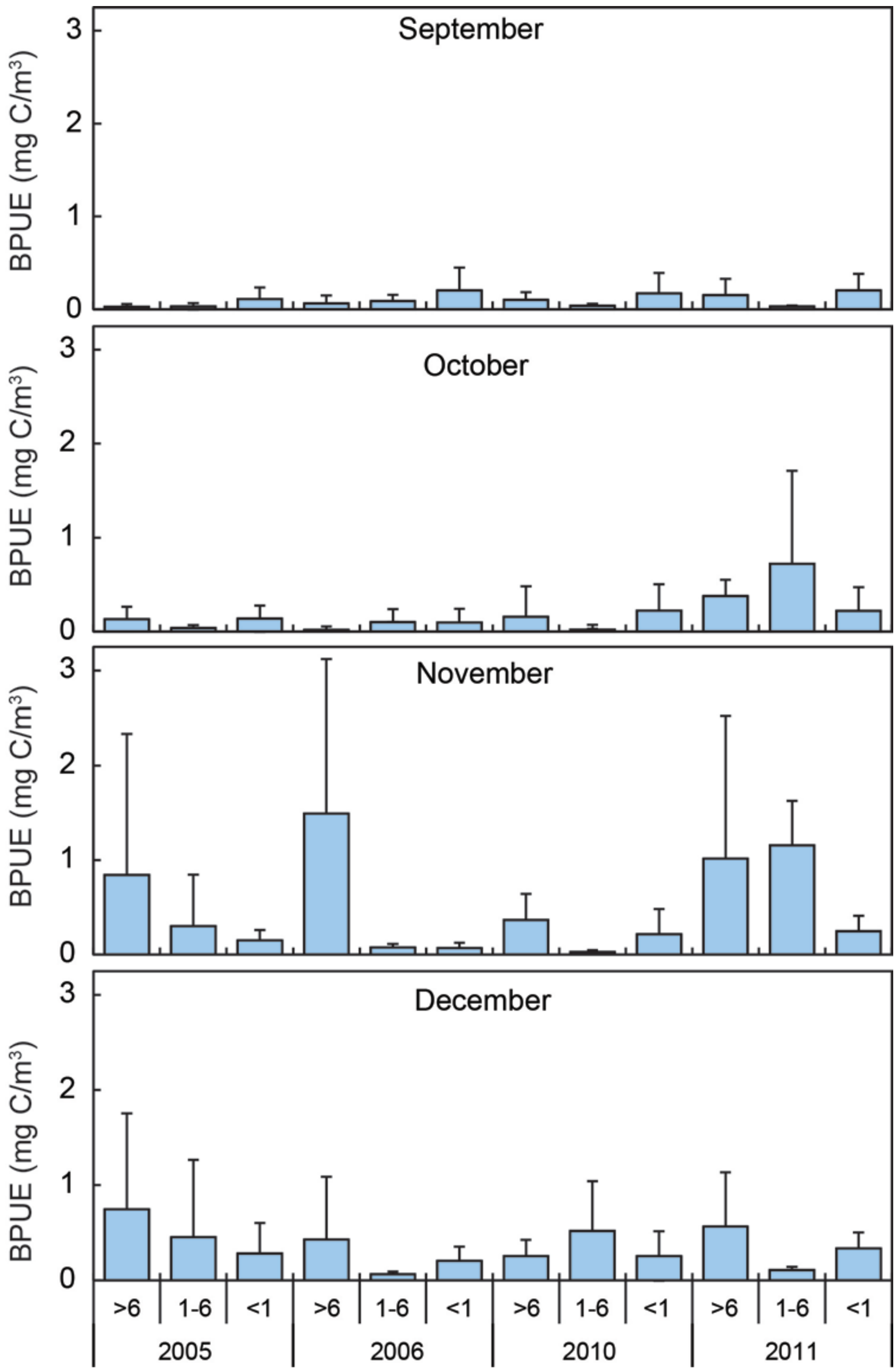


Figure 38. Biomass per unit effort (BPUE, mg C/m^3) of juvenile and adult cyclopoid copepods for EMP samples (mean ± 1 standard deviation).

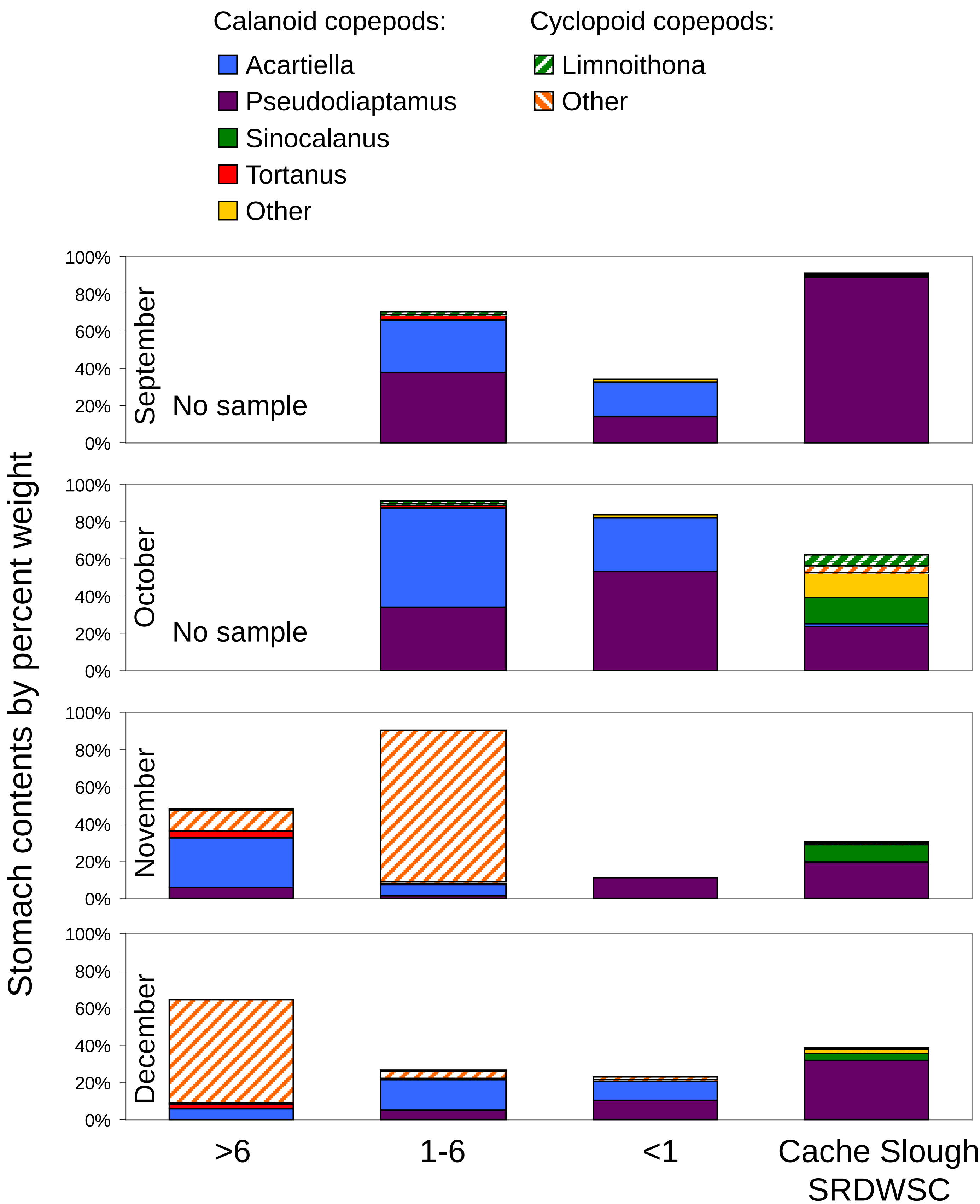


Figure 39. Stomach contents by weight (g) of calanoid and cyclopoid copepods for delta smelt captured in the FMWT in 2011. The composition of the remaining proportion of the diet is shown in Figure 40.

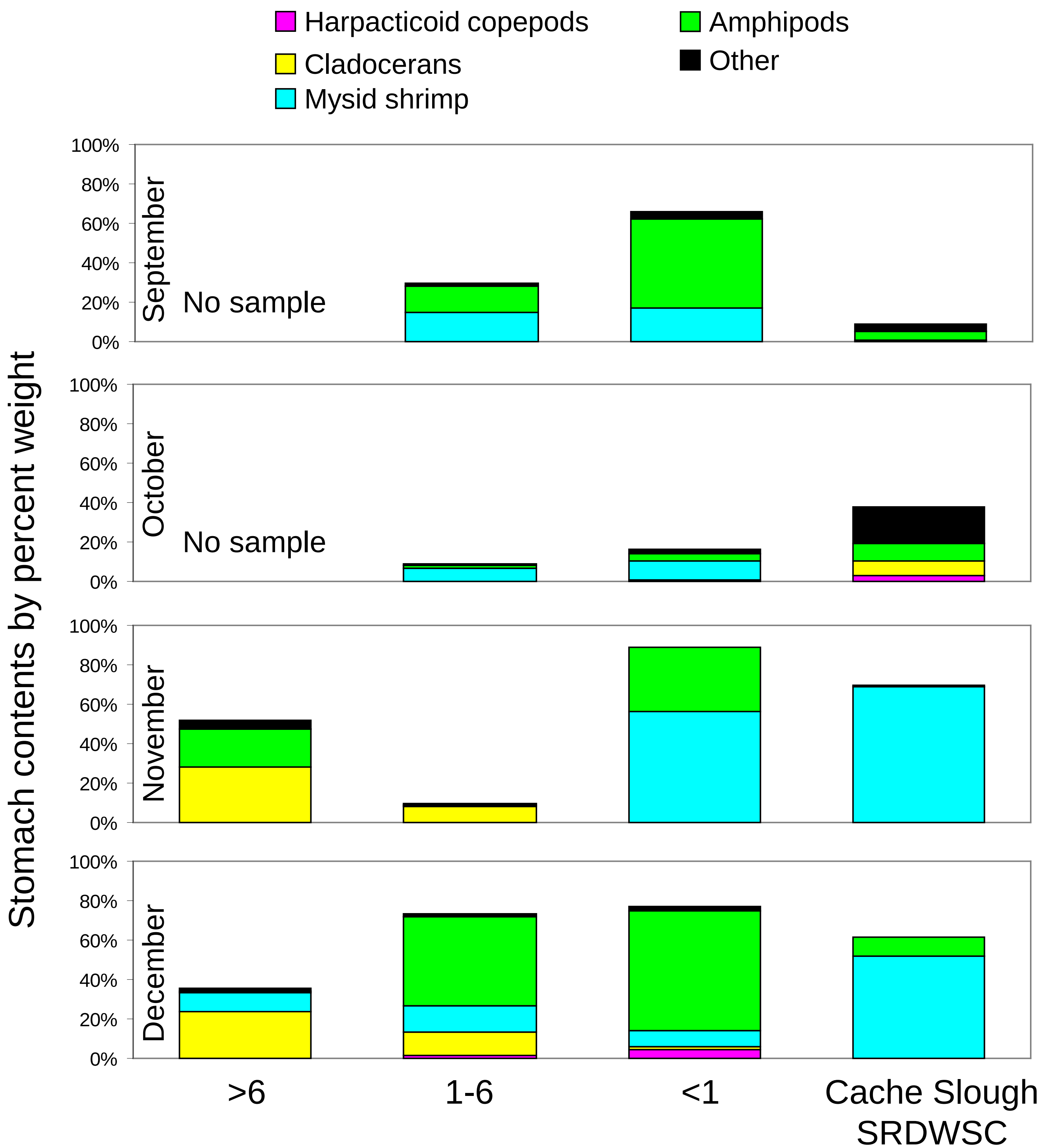


Figure 40. Stomach contents by weight (g) of items other than calanoid and cyclopoid copepods for delta smelt captured in the FMWT in 2011.

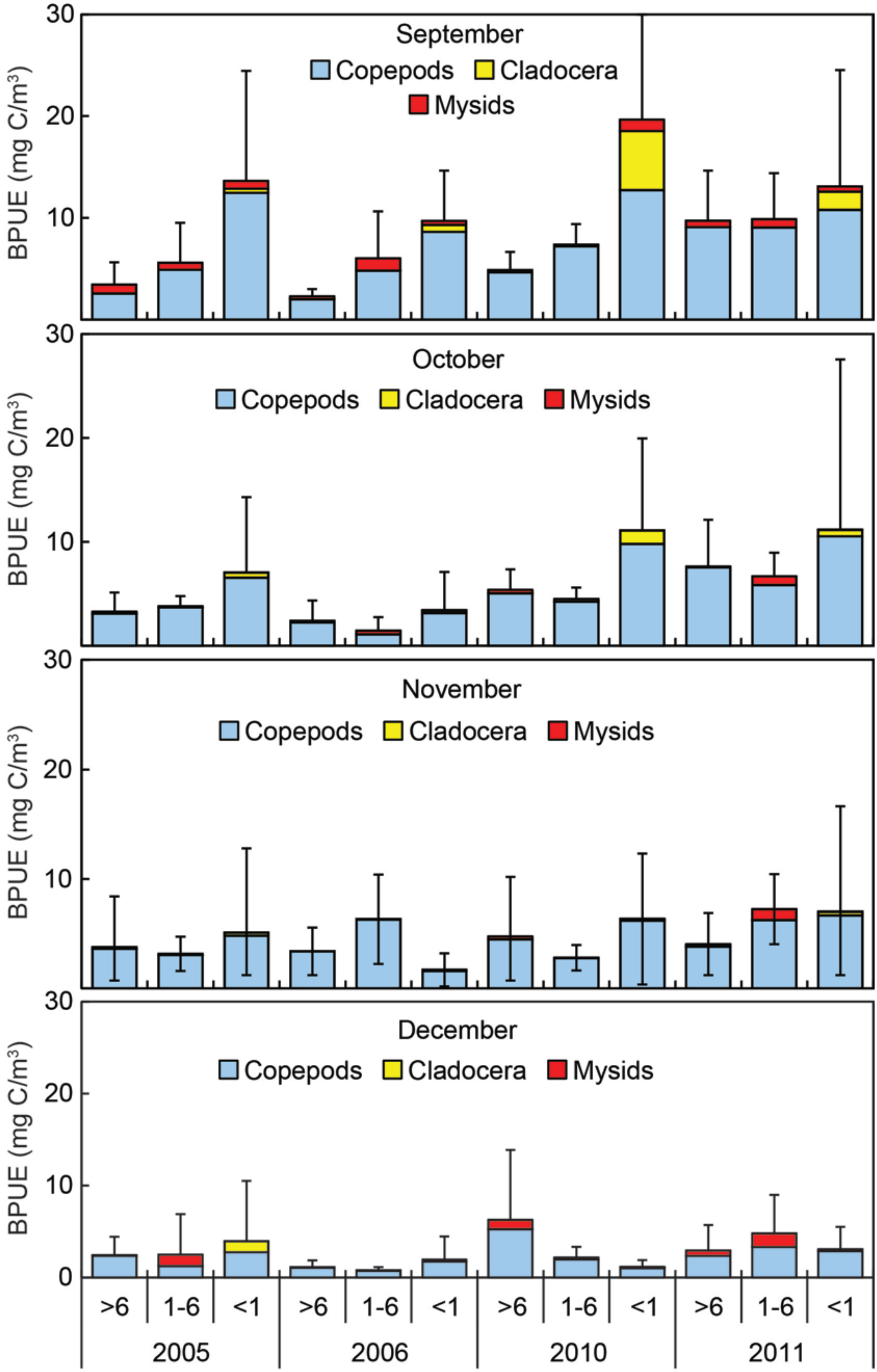


Figure 41. Biomass per unit effort (BPUE, micrograms of C m-3) of juvenile and adult calanoid copepods, cyclopoid copepods, cladocerans, and mysids for EMP samples (mean ± 1 standard deviation).

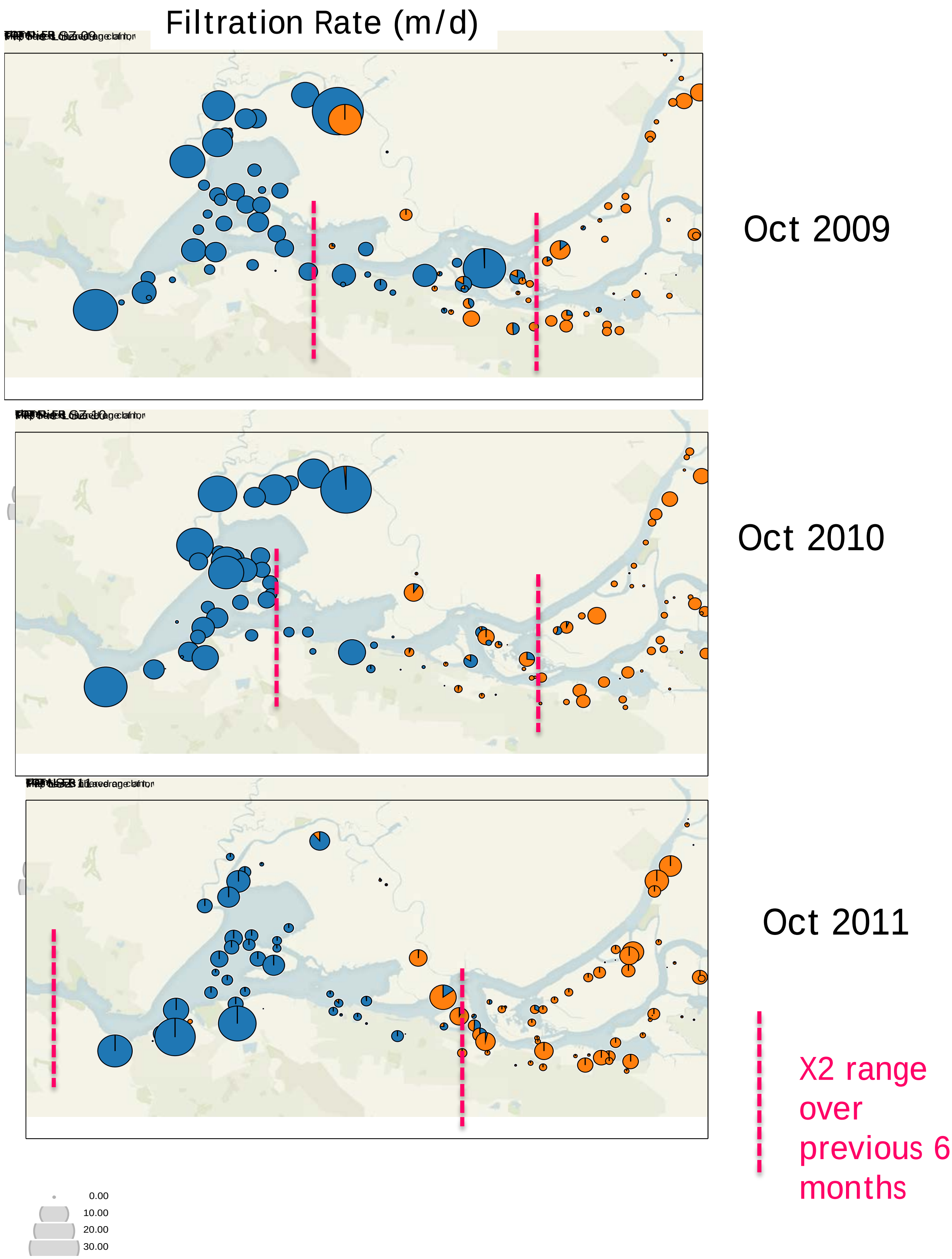


Figure 42. Filtration rate (a function of biomass and temperature) for both *Potamocorbula* (blue) and *Corbicula fluminea* (orange) in October 2009, 2010, and 2011. Range of X2 over previous 6 months shown on map as range where bivalves were expected to overlap.

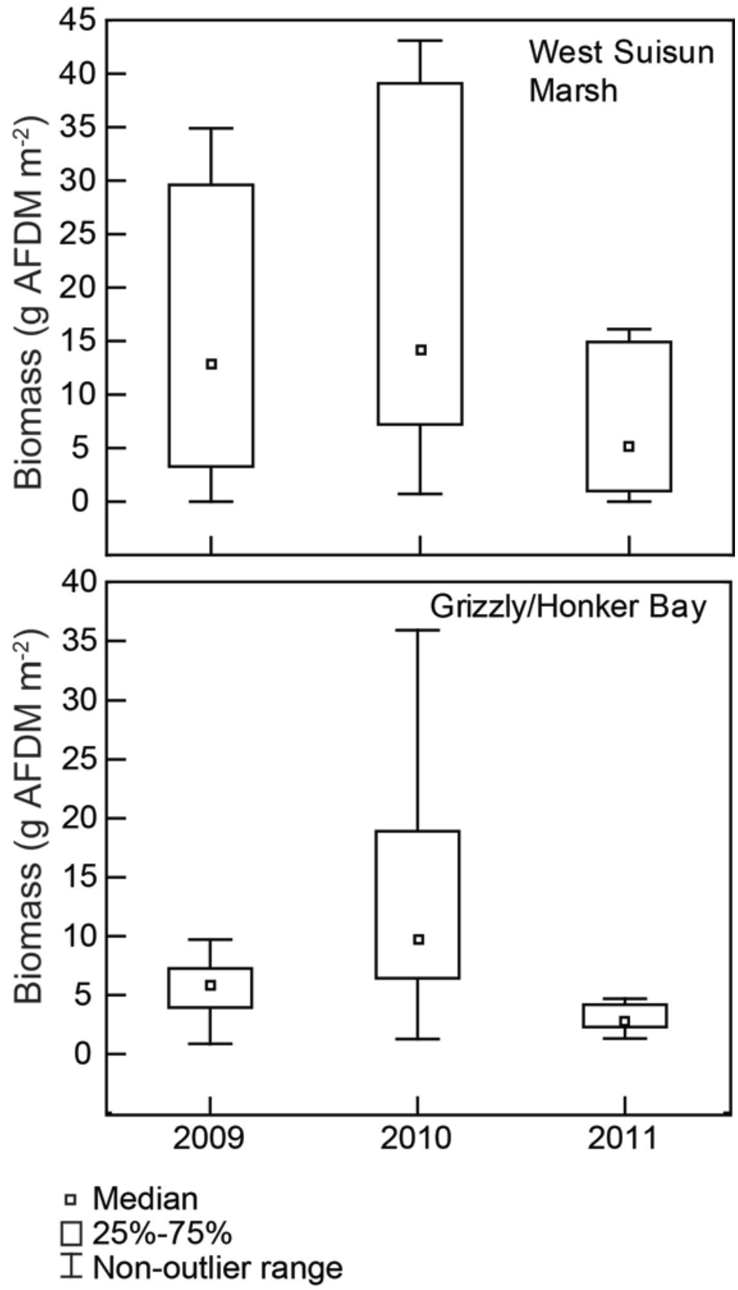


Figure 43. Biomass during the October sampling periods in western Suisun Marsh and Grizzly/Honker Bay shallows. Biomasses were not significantly different between 2009 and 2010 but were significantly different for 2010 and 2011 (Thompson and Gehrts 2012). Figure modified from Thompson and Gehrts (2012).

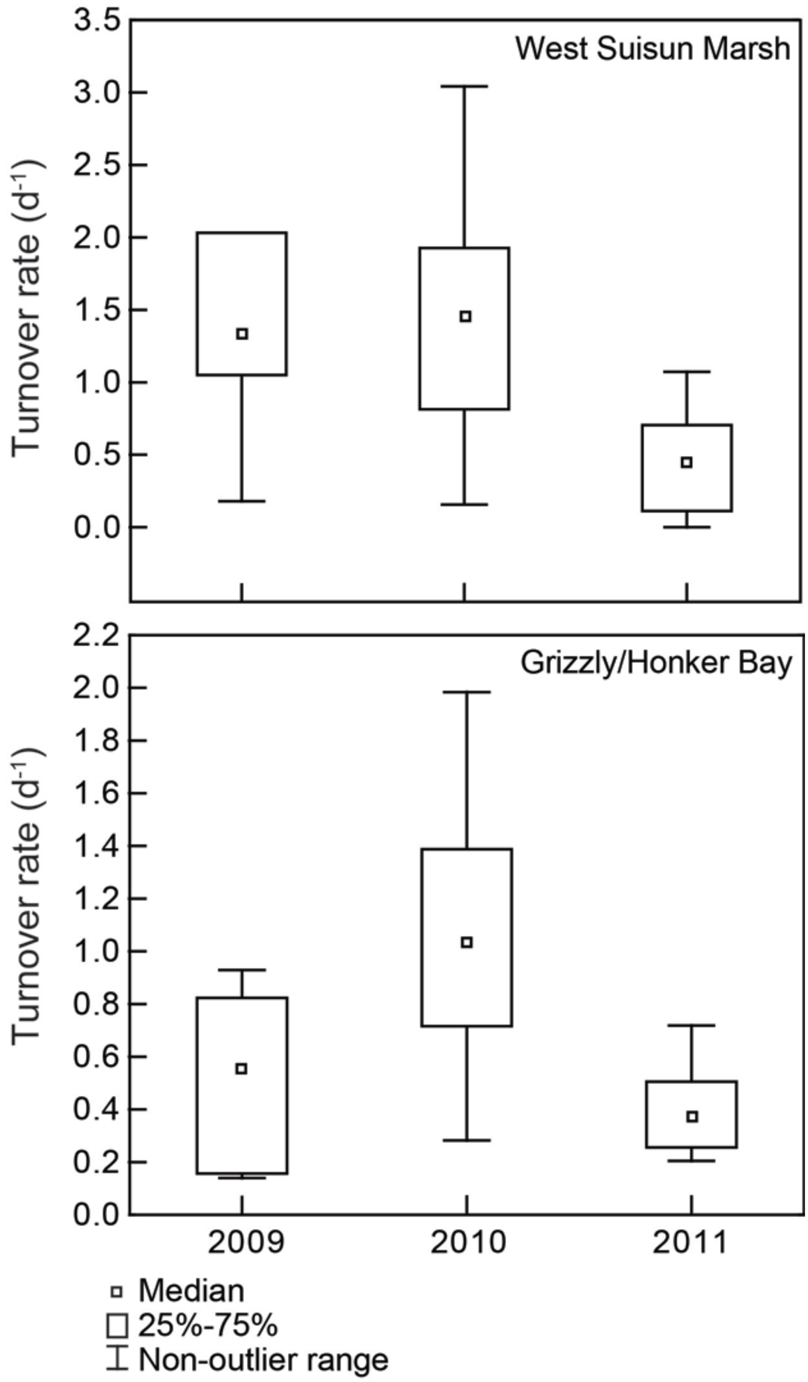


Figure 44. Turnover rate (d-1) during the October sampling periods in western Suisun Marsh and Grizzly/Honker Bay shallows. Biomasses were not significantly different between 2009 and 2010 but were significantly different for 2010 and 2011 (Thompson and Gehrts 2012). Figure modified from Thompson and Gehrts (2012).

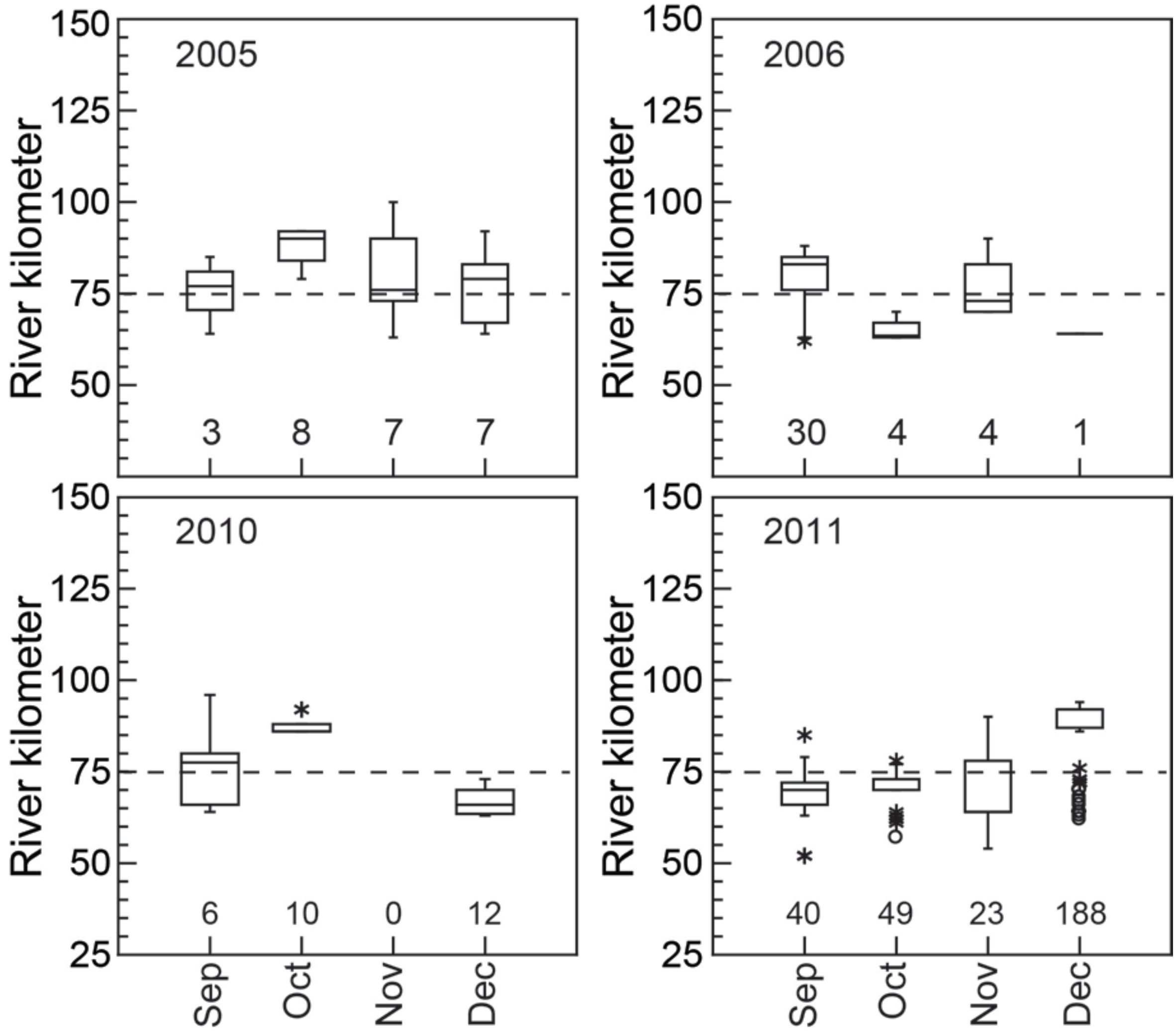


Figure 45. Distribution of delta smelt captured in the FMWT. The river kilometer of each site from the Golden Gate where delta smelt were captured was weighted by the number of delta smelt caught. Numbers of delta smelt captured each month is shown. The dotted line shows 75 km for reference.

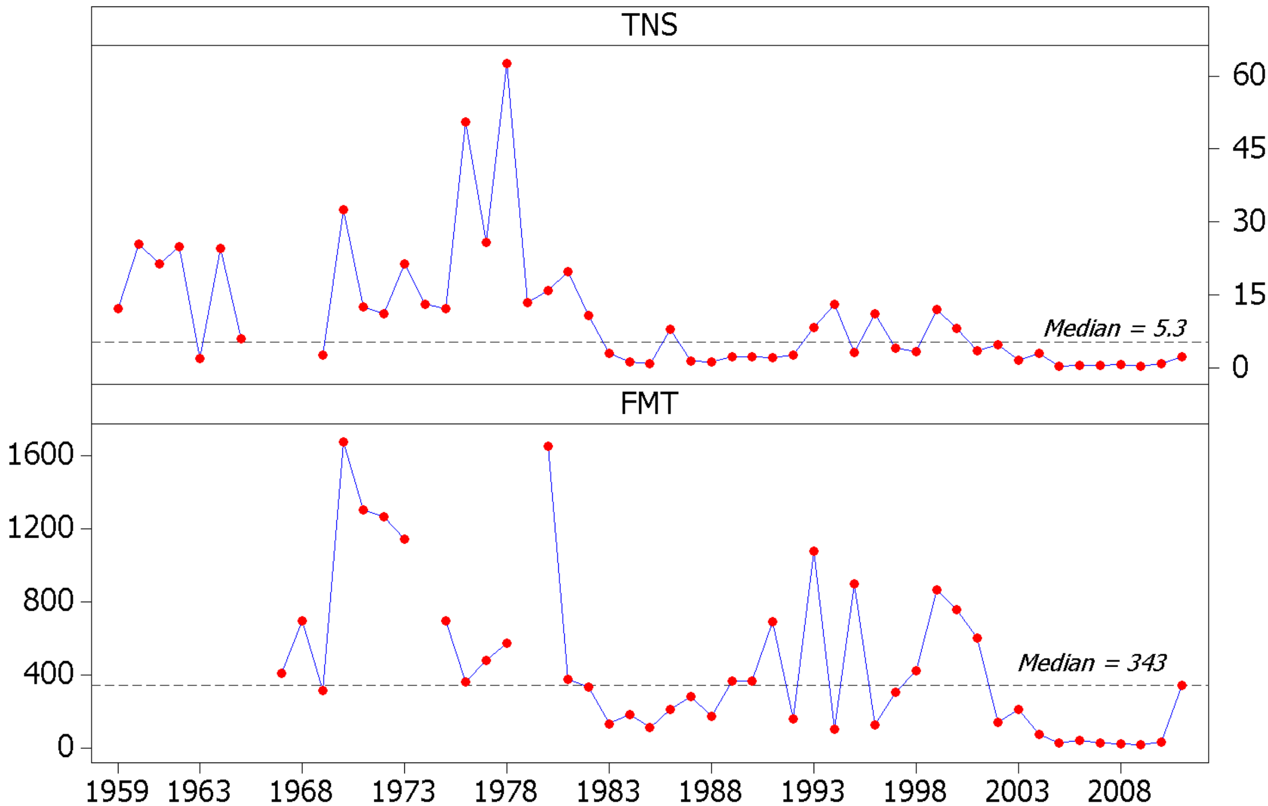


Figure 46. Plots of summer townet survey and fall midwater trawl delta smelt abundance indices by year. Data are available at http://www.dfg.ca.gov/delta/projects.asp?ProjectID=TOWNET and http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT, respectively.

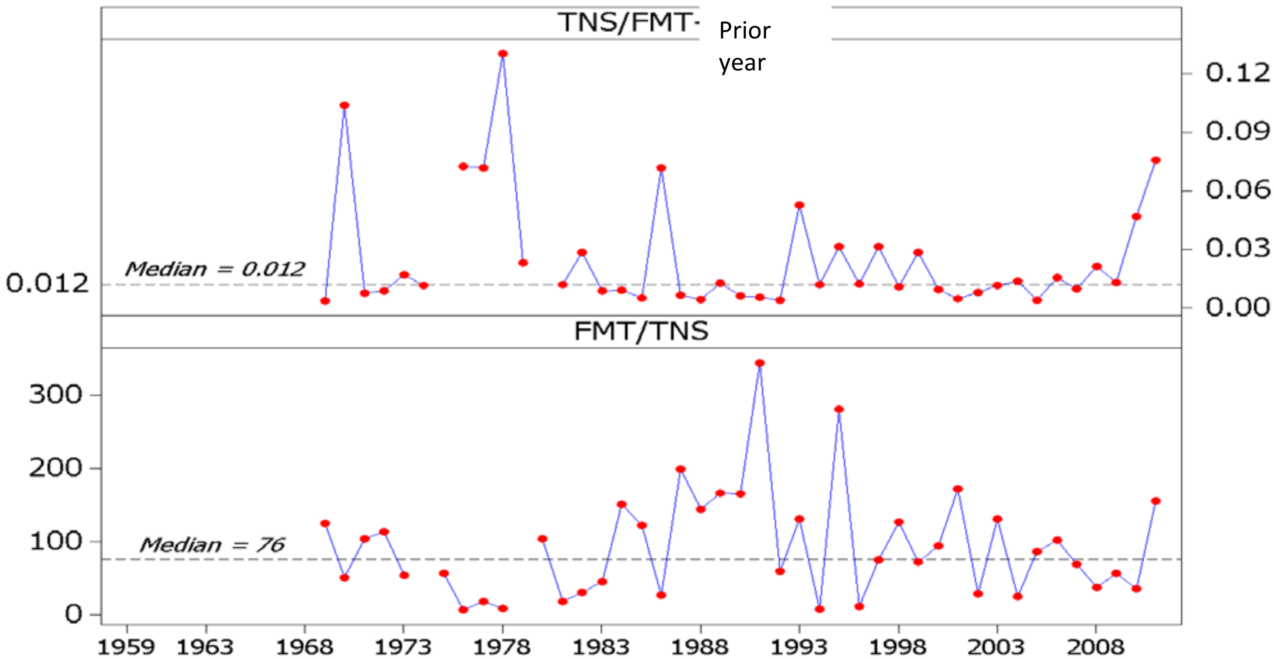


Figure 47. Ratios of delta smelt abundance indices used as indicators of survival.

In Cooperation with the Bureau of Reclamation and Interagency Ecological Program

Appendix A: Synthesis of Studies in the Fall Low Salinity Zone of the San Francisco Estuary, September-December 2011

By Larry R. Brown, Randy Baxter, Gonzalo Castillo, Louise Conrad, Steven Culberson, Greg Erickson, Frederick Feyrer, Stephanie Fong, Karen Gehrts, Lenny Grimaldo, Bruce Herbold, Joseph Kirsch, Anke Mueller-Solger, Steve Slater, Ted Sommer, Kelly Souza, and Erwin Van Nieuwenhuyse

Report Series XXXX–XXXX

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Geological Survey
Marcia K. McNutt, Director

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Contents

Appendix A

Section A.1: Dayflow

Dayflow was the source for basic flow data used in this report. Full documentation and data for Dayflow can be obtained at this website: *http://www.water.ca.gov/dayflow/*. The following description is directly from the website.

> Dayflow is a computer program designed to estimate daily average Delta outflow. The program uses daily river inflows, water exports, rainfall, and estimates of Delta agriculture depletions to estimate the "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is a key index of the physical, chemical, biological state of the northern reach of the San Francisco Estuary.
>
> The Dayflow program also estimates these flow and parameter estimates as daily averages:

1. Net flow through the Delta Cross Channel and Georgiana Slough (when measured flow is not available).
2. Net flow at Jersey Point (also called QWEST)
3. Position of X2, the 2 ppt salinity isohaline.

The Dayflow estimate of Delta outflow is referred to as the "net Delta outflow index" (NDOI) because it does not a account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is a quantity that never actually occurs in real time. Rather it is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island (~ + / - 150,000 cfs), aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much higher or lower than the Dayflow estimate. An example comparison of Dayflow output with measured daily average outflow can be seen can be seen here.

Dayflow is computed once per year following the water year (October 1). At that time, we request official QA/QC'd data from several (Table A1) sources. Once all input data is received , we compute the Dayflow estimate of Delta outflow. Our annual goal is to provide data for the previous water year by January 1.

Table A1. Responsible agencies and input data used as input to the Dayflow program.

Responsible Agency	Input data
USGS	Sacramento River at Freeport, Yolo Bypass at Woodland, Cosumnes River at Michigan Bar, San Joaquin River at Vernalis, Delta Cross Channel, Georgiana Slough
USACOE	Calaveras River
EBMUD	Mokelumne River at Woodbridge
DWR O&M	Precipitation at Stockton Fire Department, Clifton Court Forebay gate flow, Barker Slough export, Byron Bethany ID depletion, X2 (only when outflow is negative)
DWR Bay-Delta	Estimated Delta island consumptive use
DWR DPLA	Sacramento Weir spill, Lisbon Weir flow
USBR	Delta Cross-Channel gate status, Tracy export, Contra Costa export
SCWD	Lake Barryessa releases, Lake Solano inflow, Putah Creek

Over time, some inflow inputs have been lost because stream flow gages have been abandoned or discontinued due to lack of funding. The input data is further described in the Dayflow program documentation.

In 2000, the software used to perform Dayflow calculations was rewritten in Java. Input data is stored in a HEC-DSS file, and output is written to ASCII, excel, and DSS format files. Data are available in multi or single years.

The stations used in Dayflow calaulations are shown in Figure A1. We utilized three outputs from Dayflow. We utilize the net Delta outflow index; however for simplicity we refer to it as average daily net Delta outflow. Note that this is a calculated rather than a measured value. We use daily X2. Dayflow uses the following autoregressive lag model to calculate X2:

$$X2(t) = 10.16 + 0.945*X2(t-1) – 1.487\log(QOUT(t))$$

Where t = current day, and t-1 = previous day

We also use QWEST, the calculated net flow at Jersey Point in the San Joaquin River, as a measure of the influence of San Joaquin River outflow on total outflow. Note that QWEST is the quantity WEST in Dayflow data output files.

Figure A1. Sites used in Dayflow calculations from Dayflow (*http://www.water.ca.gov/dayflow/*).

Section A.2: Surface area and maps of LSZ

Our calculations of area were based on conversions of X2 to area from modeling runs for 1 April 1994 to 1 October 1995. The following methods are from a report provided through the courtesy of Michael MacWilliams, Delta Modeling Associates. The results of the described modeling were used to produce the maps of the salinity gradient shown in Figures 15-17. The results were also used to create a look-up table (Table A1) for conversion of X2 to surface area of the LSZ. Dr. MacWilliams cautions us that the distribution of salinity in the estuary for the same X2 can differ depending on whether X2 is moving seaward or landward and the exact flow conditions in the year of interest. Therefore both the maps and surface areas should be considered estimates rather than exact values.

Table A2. Estimates of the area of the low salinity zone (LSZ) for specified X2.

X2 (km)	Area of LSZ (hectares)
30	18324
31	10933
32	9544
33	12675
34	15432
35	11423
36	7413
37	14905
38	20693
39	14154
40	17138
41	19969
42	19421
43	19131
44	21651
45	19746
46	18021
47	18525
48	18450
49	17743
50	17590
51	11525
52	8908
53	13429
54	7313
55	8576
56	4284
57	3530
58	4244
59	5127
60	4813
61	4498
62	5773

63	7007
64	6981
65	6999
66	7912
67	8467
68	8474
69	8743
70	8500
71	8632
72	8539
73	8585
74	8408
75	8231
76	8380
77	8162
78	7959
79	7369
80	6653
81	5313
82	5051
83	5075
84	4753
85	4483
86	4492
87	4456
88	4463
89	4604
90	4635
91	4653
92	4655
93	4953
94	5000
95	5025
96	4996

Figure references have been updated in the following text from Dr. MacWilliams.

Low Salinity Zone Area and Depth Analysis

January 23, 2012

Michael L. MacWilliams, Ph.D.

1. Introduction

This document presents an analysis of the Low Salinity Zone (LSZ) area and depth based on a simulation of historic conditions over an eighteen month period spanning from April 1, 1994 to October 1, 1995. Model validation of predicted salinity for this period will be document in an upcoming paper in collaboration with Wim Kimmerer and Ed Gross.

In this analysis, the LSZ is defined as the area with a salinity range between 1.0 psu and 6.0 psu (similar analyses have used a slightly wider salinity range from 0.5 psu to 1.0 psu). This analysis focuses specifically on the relationship between X2 and the areal extent and average depth of the LSZ.

2. LSZ Habitat Area and Depth Calculation Approach

In this analysis, the LSZ habitat area is calculated using the predicted depth-averaged daily-averaged salinity for the simulation of a historic period spanning from April 1, 1994 to October 1, 1995. For each model time step (90 seconds), the depth-averaged salinity is calculated within each grid cell in the model domain, and then the daily-averaged depth-averaged salinity is calculated from the depth-averaged salinity calculated at each of 960 model time steps in each day. The daily-averaged LSZ habitat area for each day is then calculated by summing up the total area of the grid cells with depth-averaged daily-averaged salinity of between 1.0 psu and 6 psu within a specified geographic range. For this analysis, the geographic range extends from San Pablo Bay through the western and central Delta, and covers the domain shown in Figures 3-5. Area within the salinity range of the LSZ that is not within the domain of the maps shown on Figure 3-5 was not counted as LSZ habitat in this analysis.

Once the area of the LSZ is defined on a given day, the average depth of the LSZ for that day is calculated based on the daily-averaged water level within each cell which is within the LSZ. Water levels are only averaged during periods of when the cells are wet, such that the average depth of subtidal cells is calculated based on the average depth during the time period that cell was wet during each day.

2. X2 Calculation Approach

By definition X2 is the distance in kilometers from the Golden Gate to the tidally-averaged near-bed 2-psu isohaline. The 1995 Bay-Delta agreement established standards for salinity in the estuary. Specifically, the standards determine the degree to which salinity is allowed to penetrate up-estuary, with salinity to be controlled through Delta outflow (IEP, 2009). This regulation is based on observations that the abundance or survival of several estuarine biological populations in the San Francisco Estuary is positively related to freshwater flow (Jassby et al. 1995), although recent studies suggest that some of these relationships have changed (Sommer et al. 2007).

Jassby et al. (1995) provide a graphical depiction of X2 (Figure 2), showing X2 measured from the Golden Gate. The inset figure shows an X2 of about 75 km at Chipps Island and 81 km at Collinsville. In the UnTRIM Bay-Delta model, X2 is calculated along the axis of the estuary along the transects shown in Figure A2. For X2 greater than 75 km, the distance from the Golden Gate to the location of 2 psu bottom salinity is measured along both the Sacramento and San Joaquin transects, and the reported predicted reported "average X2" is the average of the Sacramento and San Joaquin X2 distances. Use of an average over a number of years, perhaps within water year types, could perhaps provide a consistent basis for conversion or modeling future areas.

Figure A2. Transects along the axis of northern San Francisco Bay used to measure X2 in the UnTRIM Bay-Delta model.

Section A3: Delta smelt habitat index

We used a look-up table (Table A3) to convert daily X2 to daily estimates of the delta smelt habitat index. The derivation of the habitat index is described in detail in Feyrer and others (2010). In essence, the habitat index weights the probability of occurrence of delta smelt at a FMWT station by a surface area associated with that station. The probability of occurrence of delta smelt at a station is based on a general additive model incorporating water temperature, salinity, and turbity measured at the time fish were sampled. The habitat index was calculated as the average habitat index across the four months of the FMWT, September-October. The annual habitat index was then related to mean X2 from September to December using locally weighted-regression scatterplot smoothing (LOESS regression). The LOESS regression model was then used to generate a predicted habitat index value for each value of X2 in the look-up table.

Table A3. Delta smelt habitat index values for specified X2.

X2 (km)	Predicted Habitat Index
61	7343
62	7551
63	7724
64	7863
65	7967
66	8036
67	8069
68	8067
69	8027
70	7950
71	7837
72	7685
73	7491
74	7261
75	7000
76	6716
77	6414
78	6099
79	5735
80	5292
81	4835
82	4430
83	4081
84	3777
85	3523
86	3314
87	3160
88	3054
89	2996
90	2987
91	3028
92	3116

93	3252

Section A4: Fall midwater trawl

A description of the fall midwater trawl (FMWT) sampling program and data for fish abundance indices are available at: *http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT*. The FMWT is conducted by the California Department of Fish and Game under the umbrella of IEP monitoring activities. For convenience we reprint the general description of the FWMT sampling and then provide additional detail. We also include a map of the sampling locations (Figure A3).

Figure A3. Locations of fall midwater trawl sampling stations.

> The Fall Midwater Trawl Survey (FMWT) has sampled annually since it's inception in 1967, with the exceptions of 1974 and 1979, when sampling was not conducted. The FMWT was initiated to determine the relative abundance and distribution of age-0 striped bass (*Morone saxatilis*) in the estuary, but the data has also been used for other upper estuary pelagic species, including delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*), splittail (*Pogonichthys macrolepidotus*), and threadfin shad (*Dorosoma petenense*). The FMWT samples 122 stations each month from September to December and a subset of these data is used to calculate an annual abundance index. These 122 stations range from San Pablo Bay upstream to Stockton on the San Joaquin River, Hood on the Sacramento River, and the Sacramento Deep Water Ship Channel. Sampling takes approximately 9 days per month to complete. Historically, FMWT sampling occasionally began as early as July (1972) or August (1968-1973, 1993-1994, 1996-1997) and sometimes continued past December to March (1968-1973, 1978, 1991-2001) or beyond (1992-1995). The

consistent January-March midwater trawl sampling conducted from 1991-2001 to track movements of mature adult delta smelt was replaced in 2002 with the more effective Spring Kodiak Trawl.

The midwater trawl net has mouth dimensions of 12 ft x 12 ft when stretched taught, but mouth dimensions will be smaller when under tension during a tow. Net mesh sizes graduate in nine sections from 8-inch stretch-mesh at the mouth to 0.5-inch stretch-mesh at the cod-end. All four corners of the net mouth are connected to planing doors, which together counteract the drag on net material and hold the net mouth open when being towed through the water. At each station a 12 minute tow is conducted during which the net is retrieved obliquely through the water column from bottom to surface. All fish, shrimp, and jellyfish are identified and enumerated. In addition, the crew measures water temperature, electrical conductivity (specific conductance), Secchi depth, and turbidity.

FMWT equipment and methods have remained consistent since the survey's inception, which allows annual abundance indices to be compared across time. Monthly and annual abundance indices are calculated using catch data from 100 “index” stations grouped into 17 regional “areas”. Monthly indices are calculated by averaging catch per tow for index stations in each regional area, multiplying these means by their respective weighting factors (i.e., a scalar based on water volume) for each area and summing these products for all 17 areas. Annual abundance indices are the sum of the 4 (September-December) monthly indices

The FMWT is mandated by the Delta Smelt Biological Opinion for the coordinated operation of the Central Valley Project and the State Water Project.

We primarily use water quality data collected during sampling, specifically water temperature, electrical conductivity (converted to salinity), Secchi depth, and turbidity. Turbidity has only been measured since 2010. Estimates of *Microcystis* abundance have been made since 2008, using a visual ranking system (Figure A5). Ratings of 4 or 5 were never observed. We analyzed these data as occurrence data. Diet data were collected from delta smelt collected and preserved during the fall midwater trawl. Stomachs were dissected and inspected and prey items identified to the lowest practical taxon. Data are recorded as number of each prey taxon and weight of each taxon in the diet. We present data on weight of prey items in the diet. Center of distribution of the delta smelt population was determined by weighting the distance (km) of each station from the Golden Gate by the number of fish captured at that station. The data were then plotted with the median of the data considered to be the center of distribution of the population.

In 2011, water samples were collected from a second boat during the FMWT for the first time. These water samples were analyzed at the University of California Davis, under the direction of Dr. Randy Dahlgren. Samples were returned from the field on ice in the evening and processing began the next morning.

Algal pigments were determined using SM10200-H (Clesceri et al., 1998). Samples were filtered using a Whatman GF/F glass fiber filter within 12 h of delivery and the filters were frozen prior to extraction. The method was altered by using 90% ethanol for extraction instead of 90% acetone, and the glass fiber filters were freeze dried but not ground (Sartory and Grobselaar, 1984). Samples were analyzed by fluorometric determination with the limit of detection dependent on the volume of water filtered (200 to 1000 mL); generally about 0.5 µg L-1.

A subsample was filtered through a pre-rinsed 0.45 µm polycarbonate membrane (Millipore) for quantification of ammonium (NH4-N). NH4-N was determined spectroscopically with the Berthelot reaction, using a salicylate analog of indophenol blue (LOD ~ 0.010 mg L−1; Forster 1995). Analysis of NH4-N was completed within 48 hr of sample collection. The vanadium chloride method was used to spectroscopically determine NO3+NO2-–N (LOD = 0.01 mg L-1).

Laboratory quality assurance/quality control included implementation of Surface Water Ambient Monitoring Program (SWAMP) compatible standard laboratory procedures including replicates, spikes, reference materials, setting of control limits, criteria for rejection, and data validation methods (Puckett, 2002).

All data used in this report will be posted to an accessible website/ftp site once analyses are finalized in response to review panel comments.

References:

Clesceri, L.S., A.E. Greenberg, and A.D. Eaton (eds.). 1998. Standard methods for the examination of water and wastewater, 20th ed. American Public Health Assoc., American Water Works Assoc., and Water Environment Assoc., Washington, DC.

Doane, T. A.; Howarth, R. W. Spectrophotometric determination of nitrate with a single reagent. Anal Lett 2003, 36, (2713-2722).

Forster, J.C. 1995 Soil Nitrogen, p. 79-87. In Alef, K., and P. Nannipieri (eds). Methods in Applied Soil Microbiology and Biochemistry. Academic Press.

Puckett, M. 2002. Quality Assurance Management Plan for the State of California's Surface Water Ambient Monitoring Program ("SWAMP"). California Department of Fish and Game, Monterey, CA. Prepared for the State Water Resources Control Board, Sacramento, CA. 145 pages plus Appendices.

Sartory, D.P., and J.U. Grobbelaar. 1984. Extraction of chlorophyll-a from freshwater phytoplankton for spectrophotometric analysis. Hydrobiologia. 114:177-187.

Section A5: U.S. Geological Survey sediment monitoring and analysis

The following material was provided by David Schoellhamer and others specifically for this report. The submitted analyses are appended. Only the major points related to the predictions were excerpted for the body of the report. Because the report had figures embedded in the text and the report consists largely of extensive figure captions, we maintain that structure but add appropriate figure numbers.

Preliminary analysis of suspended-sediment concentration and turbidity in the fall low salinity zone of the San Francisco Estuary

David H. Schoellhamer, Tara L. Morgan-King, Maureen A. Downing-Kunz, Scott A. Wright, and Gregory G. Shellenbarger

Highlights

- X2 does not affect Fall suspended-sediment concentration at Mallard Island
- Fall suspended-sediment concentration at Mallard Island decreased by about one-half from 1994 to 2011
- Suisun Bay was usually more turbid than the confluence in Fall 1994-2011
- Suisun Bay was usually more turbid than the Cache Slough complex in Fall 2011
- Turbidity at Mallard Island was greater in Fall 2011 than 2010 but in the Cache Slough complex the opposite was observed with turbidity being greater in Fall 2010 than 2011.

Does X2 position affect suspended-sediment concentration?

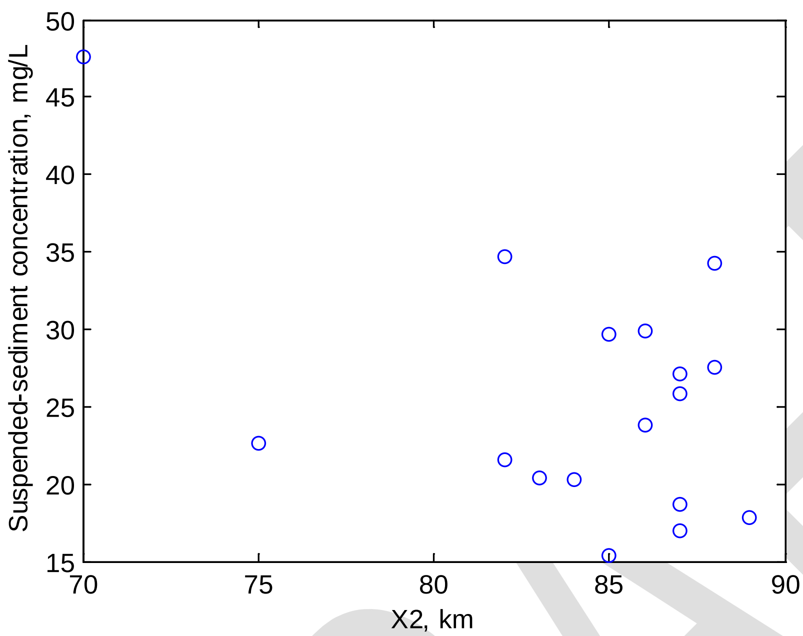

Figure A6. Near-surface suspended-sediment concentration (SSC) at Mallard Island as a function of X2, September-October mean values, 1994-2011. SSC data are collected at a 15-minute interval 1 meter below the water surface (Buchanan and Morgan 2011). 1995 is not included due to insufficient SSC data. X2 does not appear to affect SSC.

Buchanan, P.A., and Morgan, T.L., 2011, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2008: U.S. Geological Survey Data Series Report 634. http://pubs.usgs.gov/ds/634/

Did sudden clearing beginning in water year 1999 alter suspended-sediment transport processes?

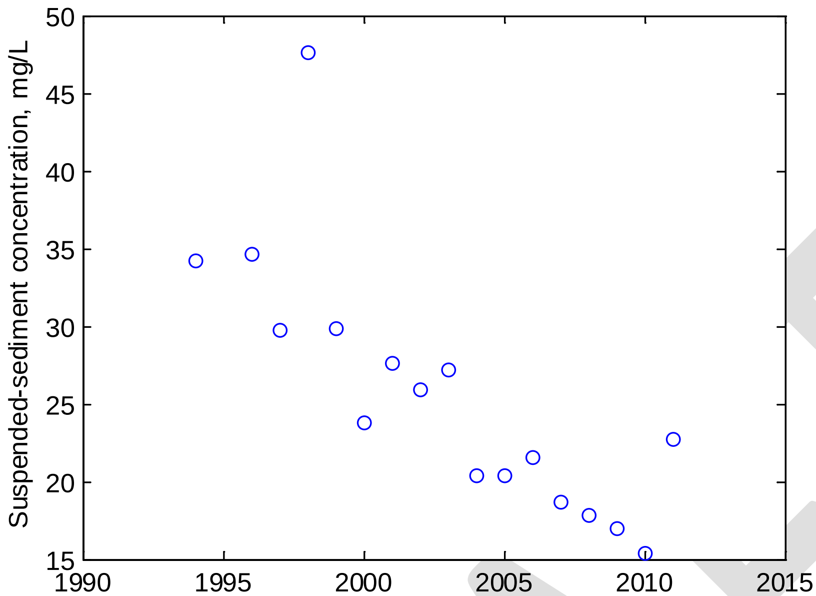

Figure A7. Near-surface suspended-sediment concentration at Mallard Island, September-October mean values, 1994-2011. 1995 is not included due to insufficient SSC data. September-October SSC decreased about 50% from 1994-2011. Total suspended-solids concentration (equivalent to SSC in this estuary) in the Delta decreased 50% from 1975-1995 (Jassby et al. 2002). In 1999 there was a 36% step decrease in SSC in San Francisco Bay as the threshold from transport to supply regulation was crossed as an anthropogenic erodible sediment pool was depleted (Schoellhamer 2011). Thus, the decrease shown at Mallard Island is consistent with other observations in the estuary. Diminished supply from hydraulic mining debris, reservoirs, flood bypasses, and armoring of river banks are all likely contributors to the decrease.

Jassby, A.D., J.E. Cloern, and B.E. Cole. 2002. Annual primary production: Patterns and mechanisms of change in a nutrient-rich tidal ecosystem. Limnology and Oceanography 47: 698–712.

Schoellhamer, D.H., 2011, Sudden clearing of estuarine waters upon crossing the threshold from transport- to supply-regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999: Estuaries and Coasts, v. 34, p. 885–899.

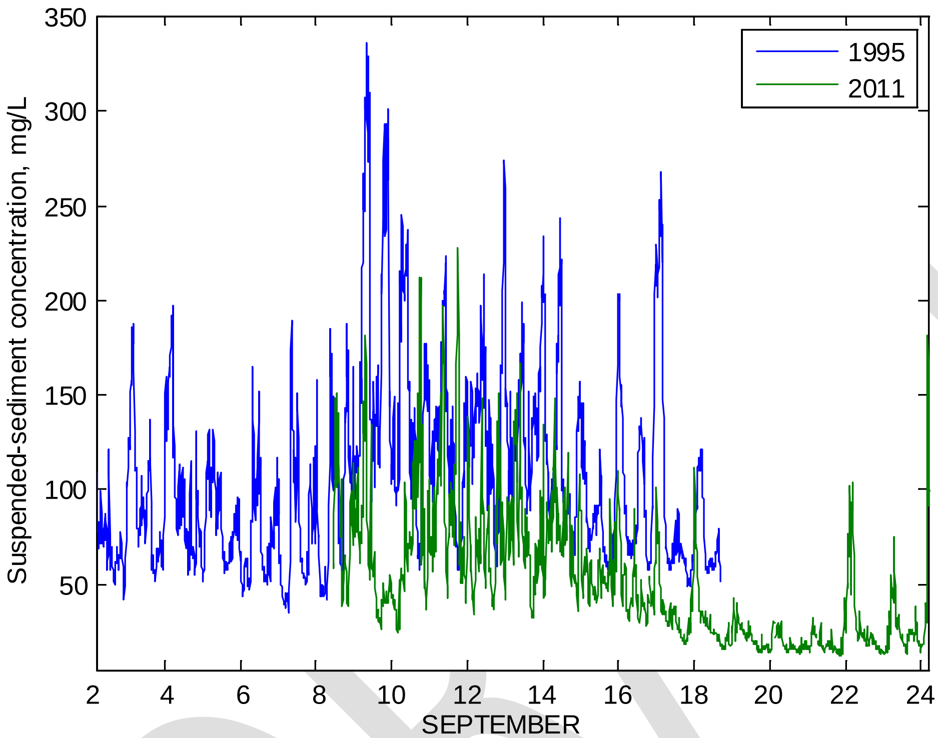

Figure A8. Suspended-sediment concentration (SSC) in Grizzly Bay at site GS, September 1995 and 2011. Data were collected 2.0 feet above the bottom in 1995 and 1.75 feet above the bottom in 2011. The period for which data have overlapping calendar dates is 10.2 days. For the dates with data in both 1995 and 2011, the following table provides a statistical summary of SSC in mg/L. For these data, mean SSC in 2011 was 45% less than in 1995. SSC decreases with distance from the bed and 2011 data were collected 0.25 feet closer to the bed than in 1995 which may lead to a small underestimation of the 1995-2011 decrease.

	1995	2011
mean	121	66
median	112	60
lower quartile	78	41
upper quartile	146	83

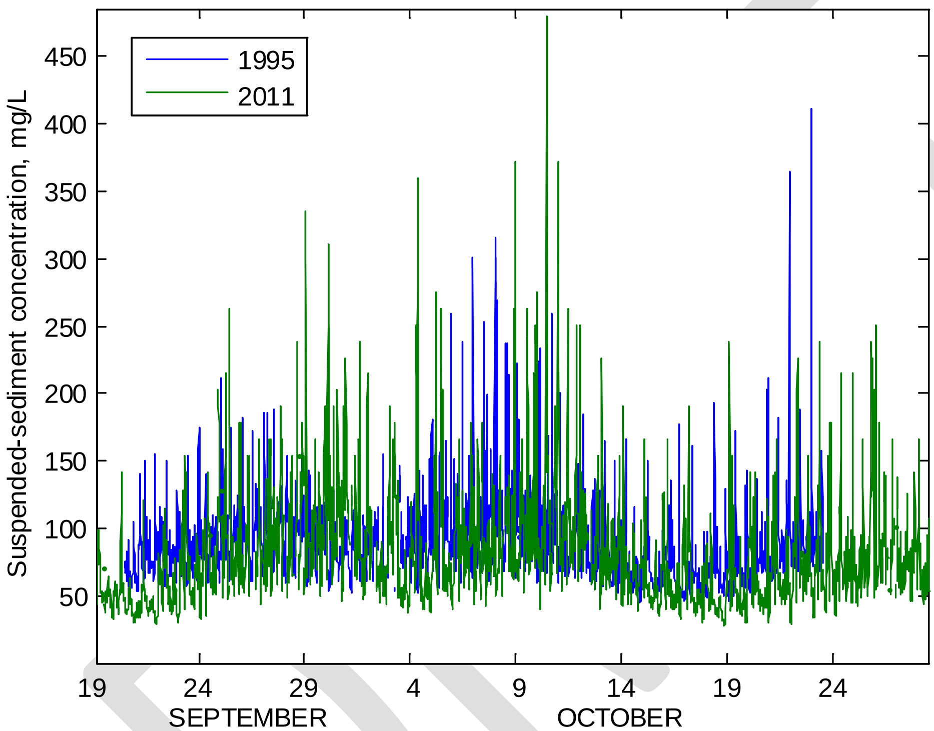

Figure A9. Suspended-sediment concentration (SSC) near the bottom in Suisun Cutoff, September-October 1995 and 2011. Data were collected 4 feet above the bottom in 1995 and 2.5 feet above the bottom in 2011. The period for which data have overlapping calendar dates is 33 days. For the dates with data in both 1995 and 2011, the following table provides a statistical summary of SSC in mg/L. For these data, mean SSC in 2011 was 9% less than in 1995. The lower quartile decreased the most (25%) and the upper quartile decreased the least (4%). Brennan et al. (2002) found that tidal asymmetry in Suisun Cutoff caused greater SSC during flood tide. The highs are still high – perhaps because the tidal asymmetry mechanism is still present, and the lows are lower – perhaps because clearer water from elsewhere (SSC in Grizzly Bay and at Mallard Island have decreased almost one-half from the mid-1990s to 2011) is transported into Suisun Cutoff. SSC decreases with distance from the bed and 2011 data were collected 1.5 feet closer to the bed than in 1995 which may account for some of the smaller observed SSC decrease from 1990s-2011 than observed elsewhere.

	1995	**2011**
mean	89	81
median	85	71
lower quartile	69	52
upper quartile	101	97

Brennan, M.L., Schoellhamer, D.H., Burau, J.R., and Monismith, S.G., 2002, Tidal asymmetry and variability of bed shear stress and sediment bed flux at a site in San Francisco Bay, USA, in Winterwerp, J.C. and Kranenburg, C., ed., Fine Sediment Dynamics in the Marine Environment: Elsevier Science B.V., p. 93-108.

Is the confluence or Suisun Bay more turbid?

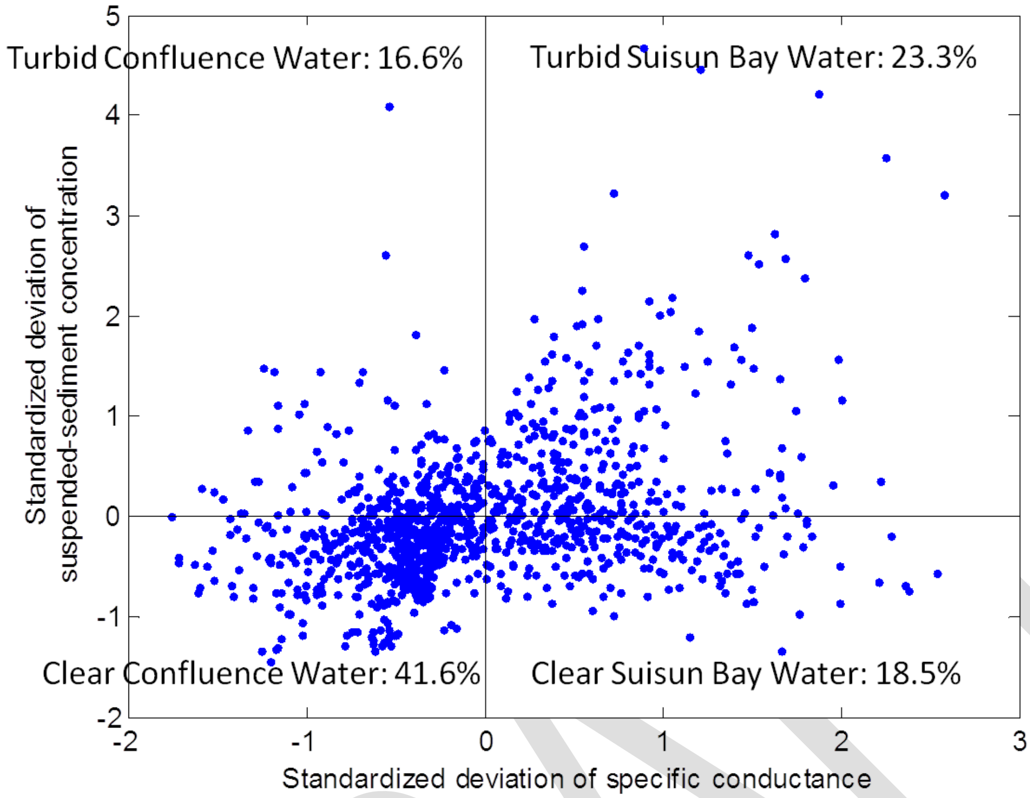

Figure A10. Standardized deviations of hourly specific conductance and suspended-sediment concentration from tidally-averaged values, Mallard Island, near-surface, September-October 2011. Positive deviation of specific conductance indicates water from seaward of Mallard Island (Suisun Bay) and negative deviation indicates water from landward of Mallard Island (confluence). Tidally-averaged time series were calculated with singular spectrum analysis for time series with missing data and a 40-hour window (Schoellhamer 2001). The modes with the greatest variability (40.1% for specific conductance and 47.6% for SSC) contained periodicity greater than 40 hours. All other significant modes contained tidal signals, so the first modes are tidally-averaged time series. The second and third modes were semidiurnal modes (37.2% of variability for specific conductance, 12.4% for SSC), indicating that advection was the most important tidal process. For SSC, quarter diurnal modes which are indicative of tidal resuspension accounted for only 7.4% of the variability. 64.9% of the data fell in the upper right or lower left quadrants, indicating relatively turbid water from Suisun Bay or relatively clear water from the confluence present at Mallard Island. Thus, Suisun Bay usually was more turbid than the confluence. This analysis assumes that advection is the dominant sediment transport mechanism.

Schoellhamer, D.H., 2001, Singular spectrum analysis for time series with missing data: Geophysical Research Letters, v. 28, no. 16, p. 3187-3190. URL http://ca.water.usgs.gov/ja/grl/ssam.pdf

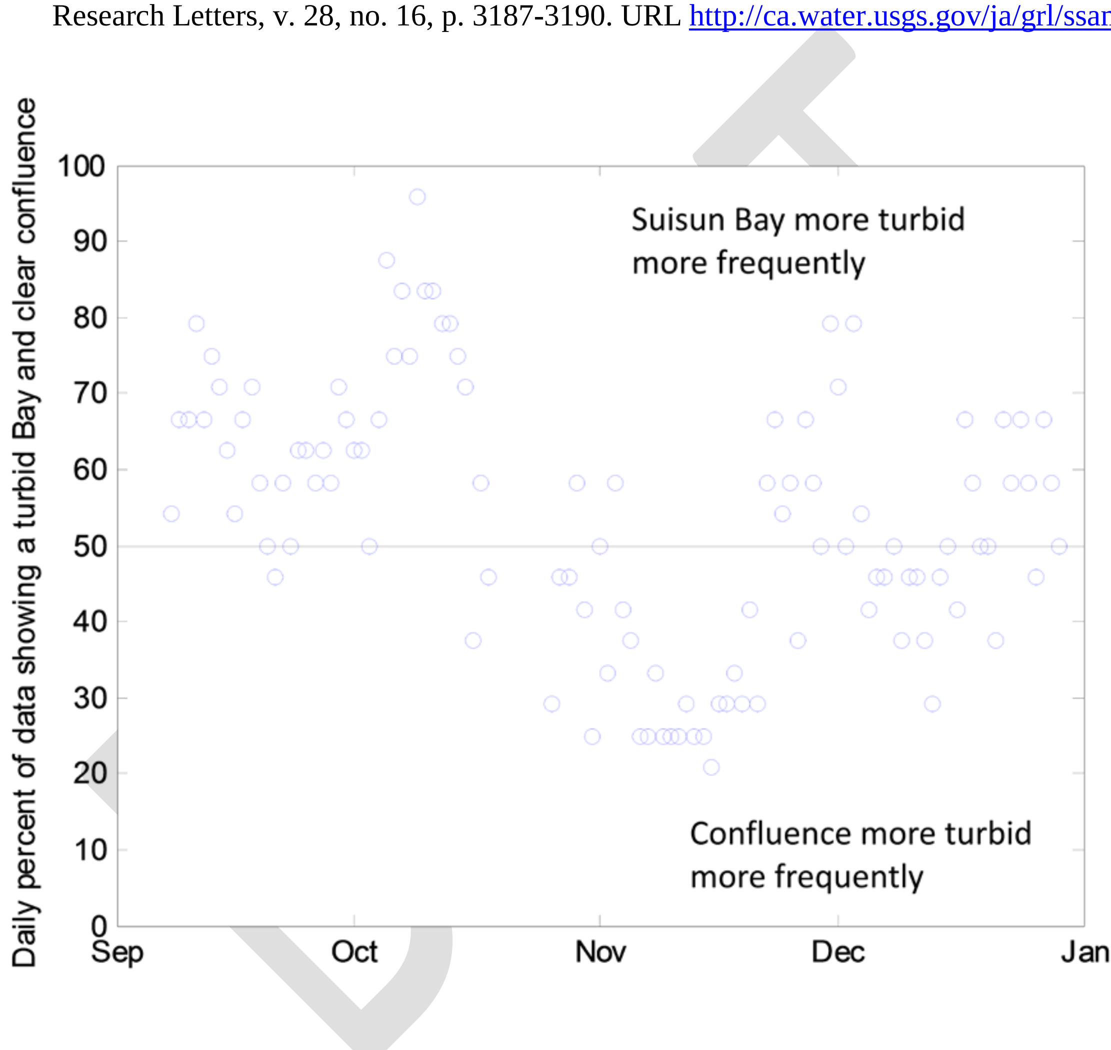

Figure A11. Percent of data showing a turbid Bay and clear confluence, September-December 2011. This was calculated from the product of hourly deviations of specific conductance and suspended-sediment concentration from tidally-averaged values. Positive values indicate instantaneous salinity and SSC are either both positive (relatively turbid Bay water) or negative (relatively clear confluence water). Negative values indicate that deviations of specific conductance and SSC have opposite signs (relatively clear Bay or relatively turbid confluence). Hourly data from Mallard Island are binned to compute daily values. This analysis assumes that advection is the dominant sediment transport mechanism. The magnitude of the deviations is not considered. The relative turbidity of Suisun Bay and the confluence varies with time. Several factors may affect this percentage, including wind-wave resuspension, the salinity field, river discharge, and the spring/neap tidal cycle.

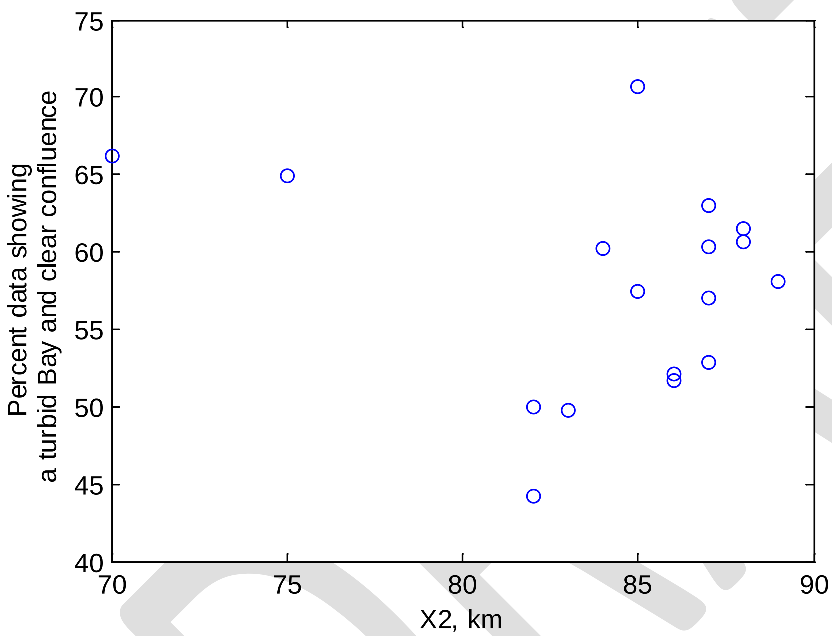

Figure A12. Percentage of specific conductance and SSC data from Mallard Island within the quadrants showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence) as a function of X2, September and October, 1994-2011. 1995 is not included due to insufficient SSC data. X2 is the mean for September and October. Using daily X2 weighted by the fraction of good specific conductance and SSC data is virtually the same. In general, 50-65% of the data indicate Suisun Bay is more turbid and this percentage is independent of X2.

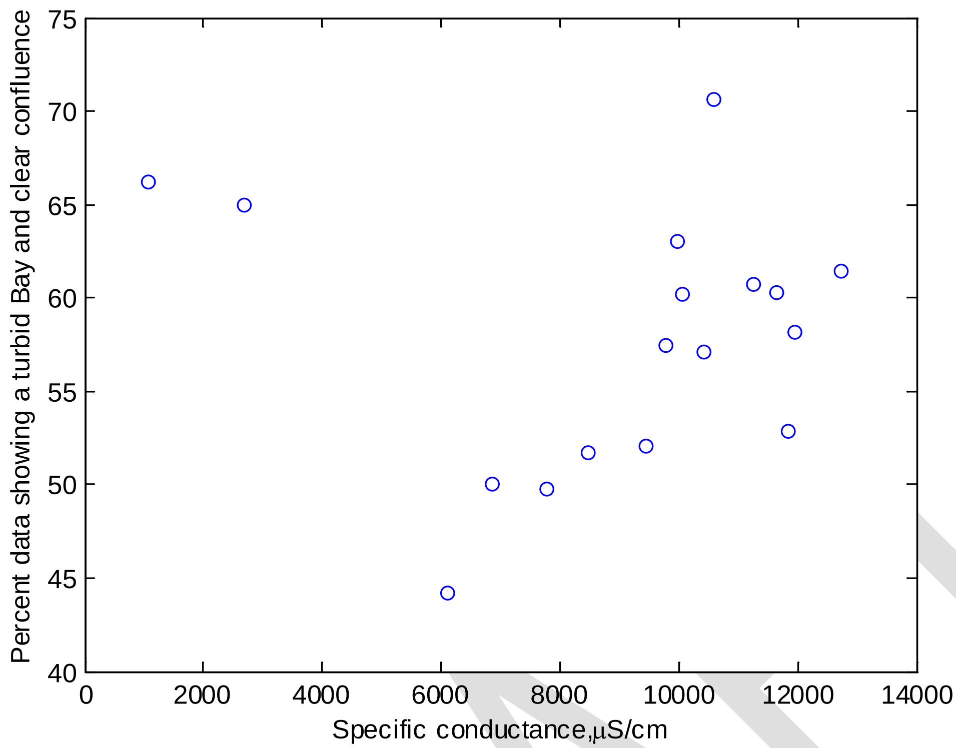

Figure A13. Percentage of specific conductance and SSC data from Mallard Island within the quadrants showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence) as a function of mean specific conductance, September -October, 1994-2011. 1995 is not included due to insufficient SSC data. Only specific conductance measurements concurrent with valid SSC measurements are considered. In general, 50-65% of the data indicate Suisun Bay is more turbid and this percentage is independent of specific conductance. A possible decrease in the percentage at 6000-9000 μS/cm may be due to formation of a small estuarine turbidity maximum (ETM) landward of Mallard Island during neap tides around salinity of 0-2 (0-4000 μS/cm) (Schoellhamer 2001). An ETM landward of Mallard Island on neap tides would decrease the percentage (which is the mean over two months). For specific conductance less than 4000 μS/cm at Mallard Island the ETM would be centered at or seaward of Mallard Island. For specific conductance greater than 9000 μS/cm the ETM would be landward of Mallard possibly far enough that it would not be transported to Mallard Island on an ebb tide and thus the percentage remains high.

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, in McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343-357. URL: http://ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf

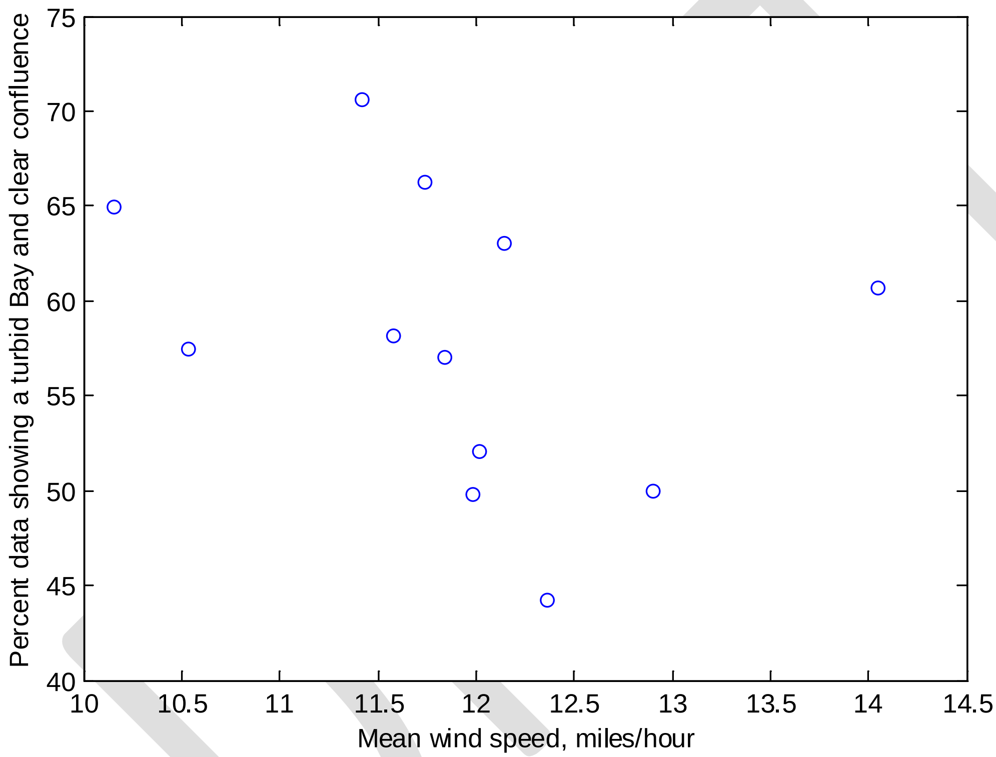

Figure A14. Percentage of specific conductance and SSC data from Mallard Island within the quadrants showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence) as a function of mean wind speed, September -October, 1994-2011. 1995 is not included due to insufficient SSC data. Wind speed was measured hourly at Travis Air Force Base. No wind speed data are available 2000-2004. Only wind speed measurements concurrent with valid SSC and specific conductance measurements are considered. In general, 50-65% of the data indicate Suisun Bay is more turbid and this percentage is independent of wind speed. Note that the range of mean wind speed is only 4 mph, which may be insufficient to observe a relation. A preliminary hypothesis is that wind in September and October is usually capable of generating waves that resuspend sediment in Suisun Bay. This makes it more turbid than the confluence, except when a neap tide ETM is landward of Mallard Island and within a tidal excursion.

Is Suisun Bay or the Cache Slough/Liberty Island complex more turbid?

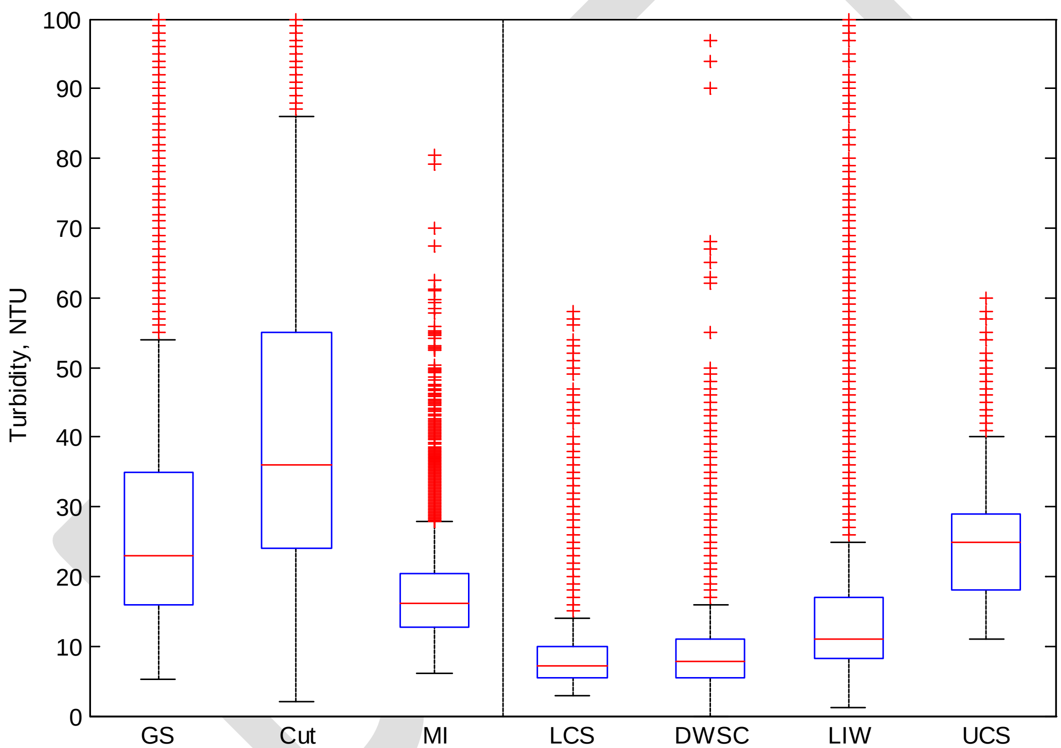

Figure A15. Boxplot of turbidity in Suisun Bay and the Cache Slough/ Liberty Island complex, September-December 2011. Data were collected every 15 minutes and only times for which all 7 sites had valid data are considered (8257 times). The red horizontal line in each box is the median, the upper and lower ends of the boxes are the upper and lower quartiles, and the whisker length is the interquartile range or distance to the extreme value, whichever is less. Values beyond the whiskers are shown with an addition sign (+). Data points with turbidity greater than 100 NTU are not shown. Suisun Bay sites are Grizzly Bay shallows (GS), Suisun Cutoff near-bottom (Cut), and Mallard Island near-surface (MI). Mallard Island turbidity data are from CDEC (http://cdec.water.ca.gov/). USGS measured turbidity at all the other sites. The vertical dashed line separates Suisun Bay and Cache Slough complex sites. Cache Slough complex sites are Lower Cache Slough mid-depth (LCS), Deep Water Ship Channel adjacent shallows (DWSC), Liberty Island shallows (LIW), and Upper Cache Slough near-bottom (UCS). Suspended-sediment concentration and therefore turbidity increase with water depth at a given site, so sensor position in the water column must be considered when analyzing these results. For shallow sites, Grizzly Bay was more turbid than Liberty Island and DWSC. For near-bottom sites, Suisun Cutoff was more turbid than Upper Cache Slough. And for near-surface and mid-depth sites, Mallard Island was more turbid than Lower Cache Slough. For all these comparisons, Suisun Bay sites were more turbid than Cache Slough complex sites.

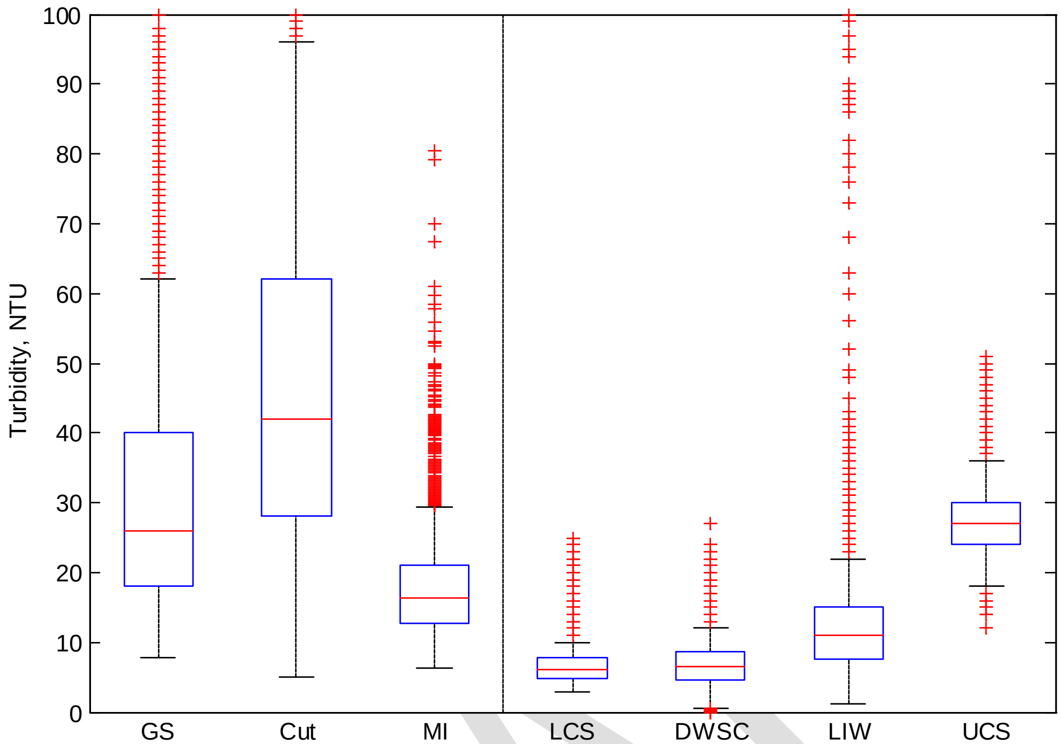

Figure A16. Boxplot of turbidity in Suisun Bay and the Cache Slough/ Liberty Island complex, September-October 2011. This figure is a subset of the previous figure. Data were collected every 15 minutes and only times for which all 7 sites had valid data are considered (4557 times). The red horizontal line in each box is the median, the upper and lower ends of the boxes are the upper and lower quartiles, and the whisker length is the interquartile range or distance to the extreme value, whichever is less. Values beyond the whiskers are shown with an addition sign (+). Data points with turbidity greater than 100 NTU are not shown. Suisun Bay sites are Grizzly Bay shallows (GS), Suisun Cutoff near-bottom (Cut), and Mallard Island near-surface (MI). Mallard Island turbidity data are from CDEC (http://cdec.water.ca.gov/). USGS measured turbidity at all the other sites. The vertical dashed line separates Suisun Bay and Cache Slough complex sites. Cache Slough complex sites are Lower Cache Slough mid-depth (LCS), Deep Water Ship Channel adjacent shallows (DWSC), Liberty Island shallows (LIW), and Upper Cache Slough near-bottom (UCS).

Suspended-sediment concentration and therefore turbidity increase with water depth at a given site, so sensor position in the water column must be considered when analyzing these results. For shallow sites, Grizzly Bay was more turbid than Liberty Island and DWSC. For near-bottom sites, Suisun Cutoff was more turbid than Upper Cache Slough. And for near-surface and mid-depth sites, Mallard Island was more turbid than Lower Cache Slough. For all these comparisons, Suisun Bay sites were more turbid than Cache Slough complex sites.

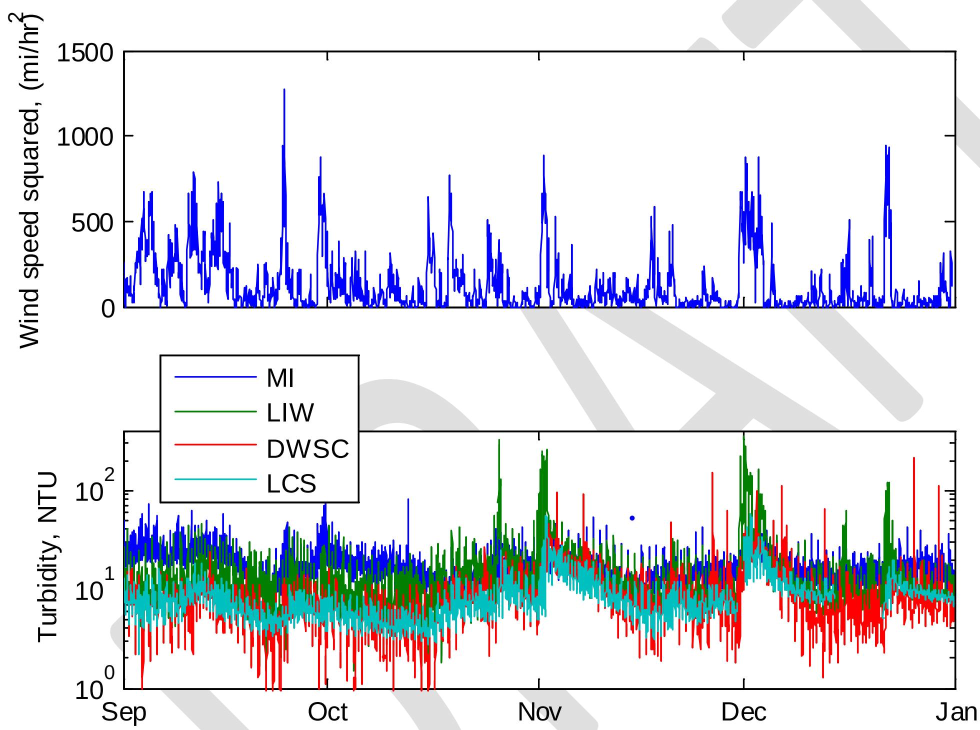

Figure A17. Wind speed squared and turbidity, September – December 2011. Wind speed was measured at Travis Air Force Base. Wind shear stress on the water surface is roughly proportional to the square of the wind speed. Turbidity is shown at four sites: Mallard Island (MI), Liberty Island shallows (LIW), Deep water ship channel (DWSC), and Lower Cache Slough (LCS). Note that a logarithmic scale is used for turbidity. Turbidity at Mallard Island (blue line) is usually greater than in the Cache Slough complex except during some windy events when wind-wave resuspension in Liberty Island (green line) increases turbidity in Deep Water Ship Channel and Lower Cache Slough. Wind direction is not considered in this initial analysis.

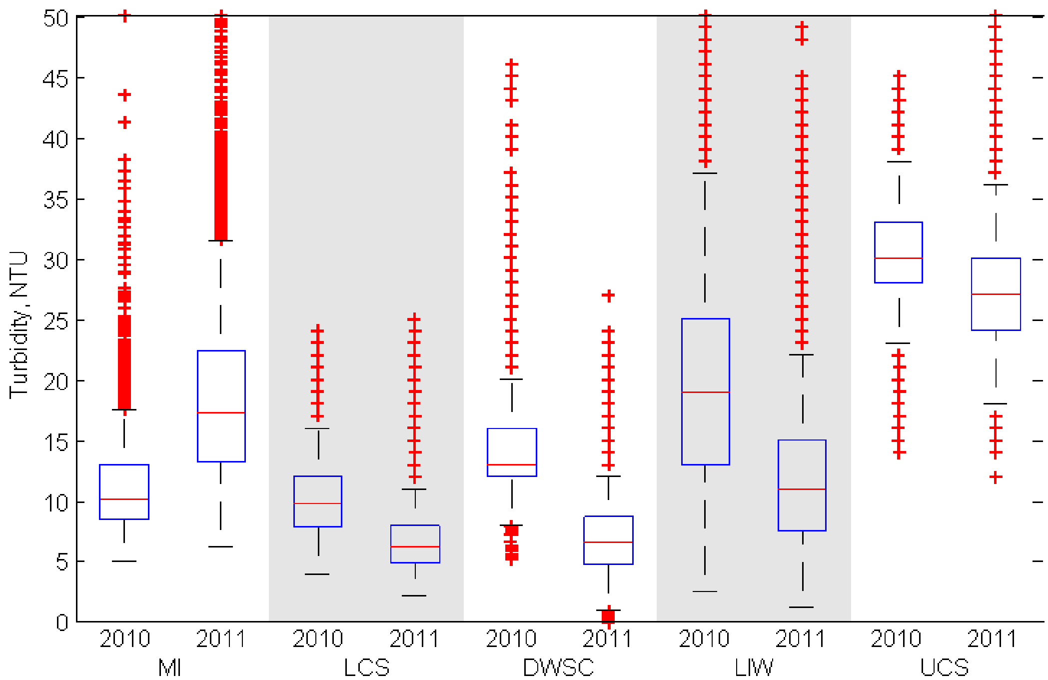

Figure A18. Boxplot of turbidity at Mallard Island and the Cache Slough/ Liberty Island complex, September-October 2010 and 2011. Data were collected every 15 minutes and only times for which all 5 sites in a given water year had valid data are considered (2418 for 2010 and 5452 for 2011). The red horizontal line in each box is the median, the upper and lower ends of the boxes are the upper and lower quartiles, and the whisker length is the interquartile range or distance to the extreme value, whichever is less. Values beyond the whiskers are shown with an addition sign (+). Data points with turbidity greater than 50 NTU are not shown. Mallard Island (MI) turbidity data are from CDEC (http://cdec.water.ca.gov/) and were edited to remove sensor drift likely caused by biofouling. USGS measured turbidity at all the other sites. Cache Slough complex sites are Lower Cache Slough mid-depth (LCS), Deep Water Ship Channel adjacent shallows (DWSC), Liberty Island shallows (LIW), and Upper Cache Slough near-bottom (UCS). Gray shading is used to delineate sites. Suspended-sediment concentration and therefore turbidity increase with water depth at a given site, so sensor position in the water column must be considered when analyzing these results. Mallard Island was more turbid in 2011 than 2010 and Cache Slough complex sites were the opposite with 2010 being more turbid than 2011. In 2010, Mallard Island was about as turbid as LCS and less turbid than the remaining Cache Slough complex sites. In 2011, Mallard Island was more turbid than all Cache Slough complex sites except UCS. A hypothesis for the difference between 2010 and 2011 is that Yolo Bypass flow in 2011 reduced deposition in the Cache Slough complex and greater watershed sediment supply in 2011increased deposition in Suisun Bay and that this more seaward deposition in 2011 accounts for the observed turbidity. Another hypothesis is that in 2010 the estuarine turbidity maximum at 0-2 psu (Schoellhamer 2001) was landward of Mallard Island at all times while it was often present at Mallard Island in 2011, leading to greater turbidity in 2011.

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, in McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343-357. URL: http://ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf

Section A6: Environmental Monitoring Program

The Environmental Monitoring Program of the IEP is carried out cooperatively by several IEP agencies. Sampling is conducted monthly. The following information is excerpted from the following web site: *http://www.water.ca.gov/iep/activities/emp.cfm.* Additional information on zooplankton sampling can be obtained at: *http://www.water.ca.gov/bdma/meta/zooplankton.cfm*

> The Environmental Monitoring Program (EMP) for the Sacramento-San Joaquin Delta, Suisun Bay, and San Pablo Bay is conducted under the auspices of the Interagency Ecological Program (IEP). The EMP was initiated in 1971 in compliance with California

State Water Resources Control Board (SWRCB) Water Right Decision D-1379 and continued from 1978 through 1999 under D-1485. Currently it is mandated by Water Right Decision D-1641. The program is carried out jointly by the two water right permittees operating the California water projects, the United States Bureau of Reclamation (USBR) and the California Department of Water Resources (DWR). Assistance is provided by the California Department of Fish and Game (CDFG) and the United States Geological Survey (USGS). The primary purpose of the IEP EMP is to provide necessary information for compliance with flow-related water quality standards specified in the water right permits. In addition, the EMP also provides information on a wide range of chemical, physical and biological baseline variables. EMP's discrete water quality stations are sampled monthly using a research vessel and a laboratory van. EMP also operates eight multi-parameter continuous "real-time" water quality stations. In addition, the EMP collects and analyzes benthos, phytoplankton, and zooplankton samples. Monitoring listed as "continuous recorder sites" in D-1641 is not part of the EMP, these sites are operated by the USBR, the USGS or DWR.

We use data from 6 fixed sites in the EMP sampling network (Fig. A19). We also include data from 2 "floating" sites, EZ2 and EZ6. These samples are taken at locations where near bottom specific conductance are 2,000 and 6,000 µS/cm, respectively. We use data for ammonium, nitrite + nitrate, chlorophyll-a, and zooplankton. Water quality data were determined from samples collected 1 m below the surface. All data used in this report will be posted to an accessible website/ftp site once analyses are finalized in response to review panel comments.

Figure A19. Sites sampled by the IEP Environmental Monitoring Program (EMP) for water quality constituents are shown by circles. Red circles show the sites considered representative of delta smelt fall range. Black circles show sites considered outside of the fall range of delta smelt and not included in analyses.

Section A6: U.S. Geological Survey Water Quality Monitoring

The USGS maintains a comprehensive database documenting the methods used and results from long term monitoring of the San Francisco estuary (*http://sfbay.wr.usgs.gov/access/wqdata/index.html*). Sampling is conducted monthly. We utilize data from samples collected 2 m below the surface. We use data for ammonium, nitrite + nitrate, and chlorophyll-*a*. Ammonium and nitrite + nitrate are presented in terms of micromoles in the USGS database. For purposes of comparison we converted these concentrations to mg/L. Because separate concentrations of nitrite and nitrate were not available the conversion was made assuming 100% nitrate in the samples. This could bias the data slightly high. We used data from 7 sites (Fig. A20), where discrete water samples were taken for analysis. Data from site 5 were used when data from site 6 were not available. These sites were considered to be representative of water quality in the fall range of delta smelt.

Figure A20. Sites sampled by the USGS water quality monitoring program (http://sfbay.wr.usgs.gov/access/wqdata/index.html) for water quality constituents. Data utilized for this report are from sites indicated by arrows where discrete water samples were collected.

Synthesis of Studies in the Fall Low Salinity Zone of the San Francisco Estuary, September-December 2011
Appendix A Figures

By Larry R. Brown, Randy Baxter, Gonzalo Castillo, Louise Conrad, Steven Culberson, Greg Erickson, Frederick Feyrer, Stephanie Fong, Karen Gehrts, Lenny Grimaldo, Bruce Herbold, Joseph Kirsch, Anke Mueller-Solger, Steve Slater, Ted Sommer, Kelly Souza, and Erwin Van Nieuwenhuyse

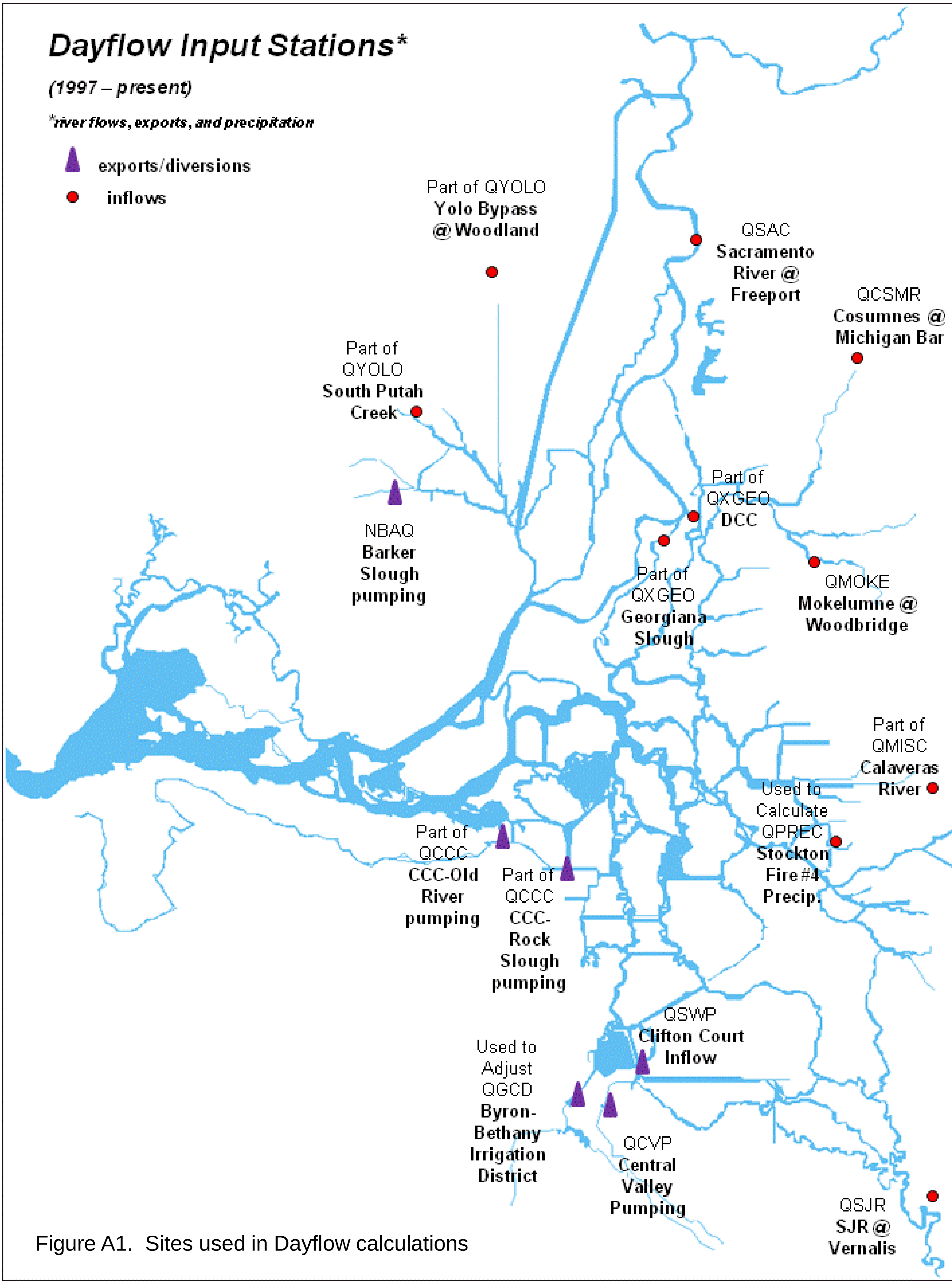

Figure A1. Sites used in Dayflow calculations

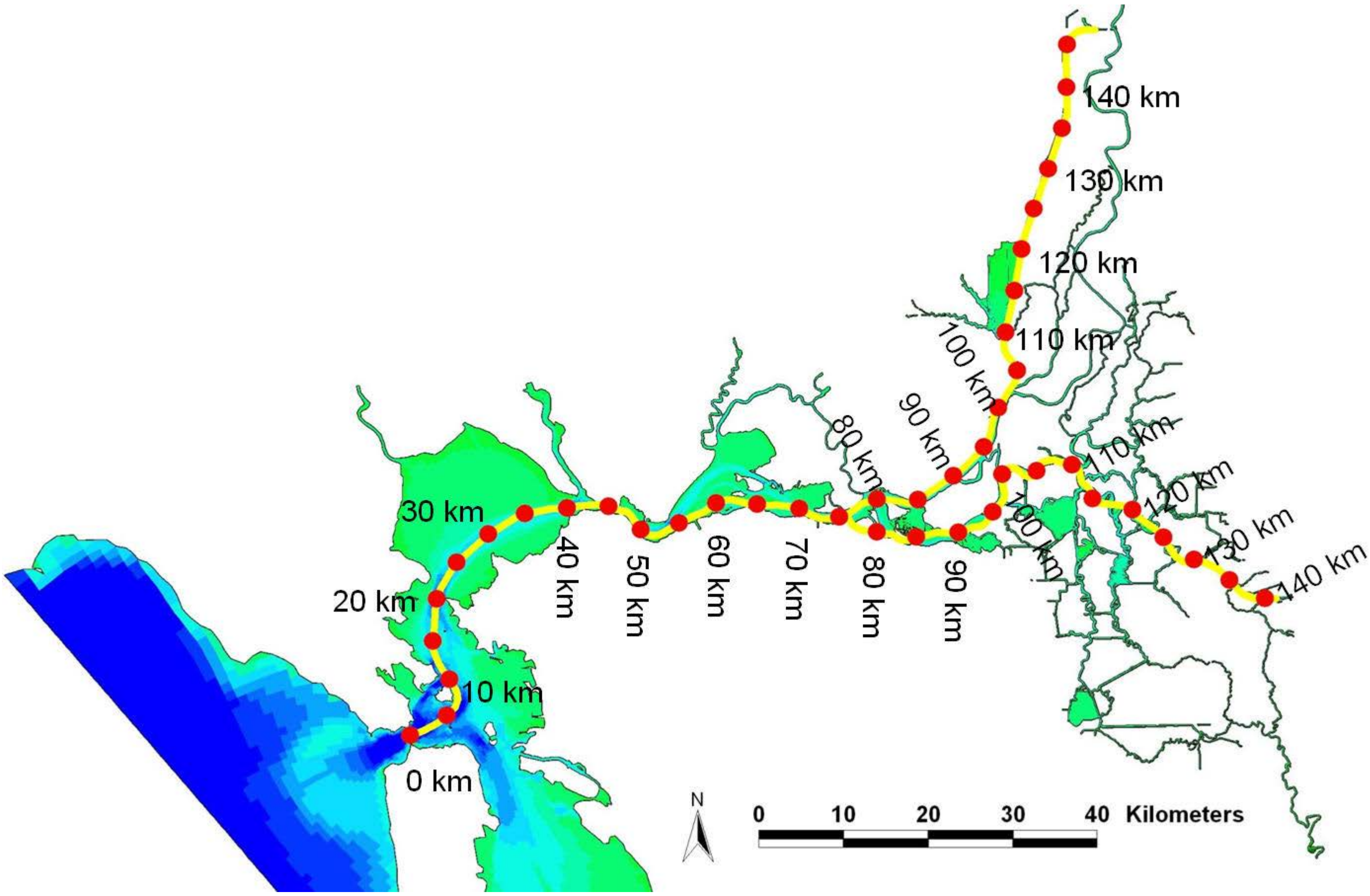

Figure A2. Transects along the axis of northern San Francisco Bay used to measure X2 in the UnTRIM Bay-Delta model.

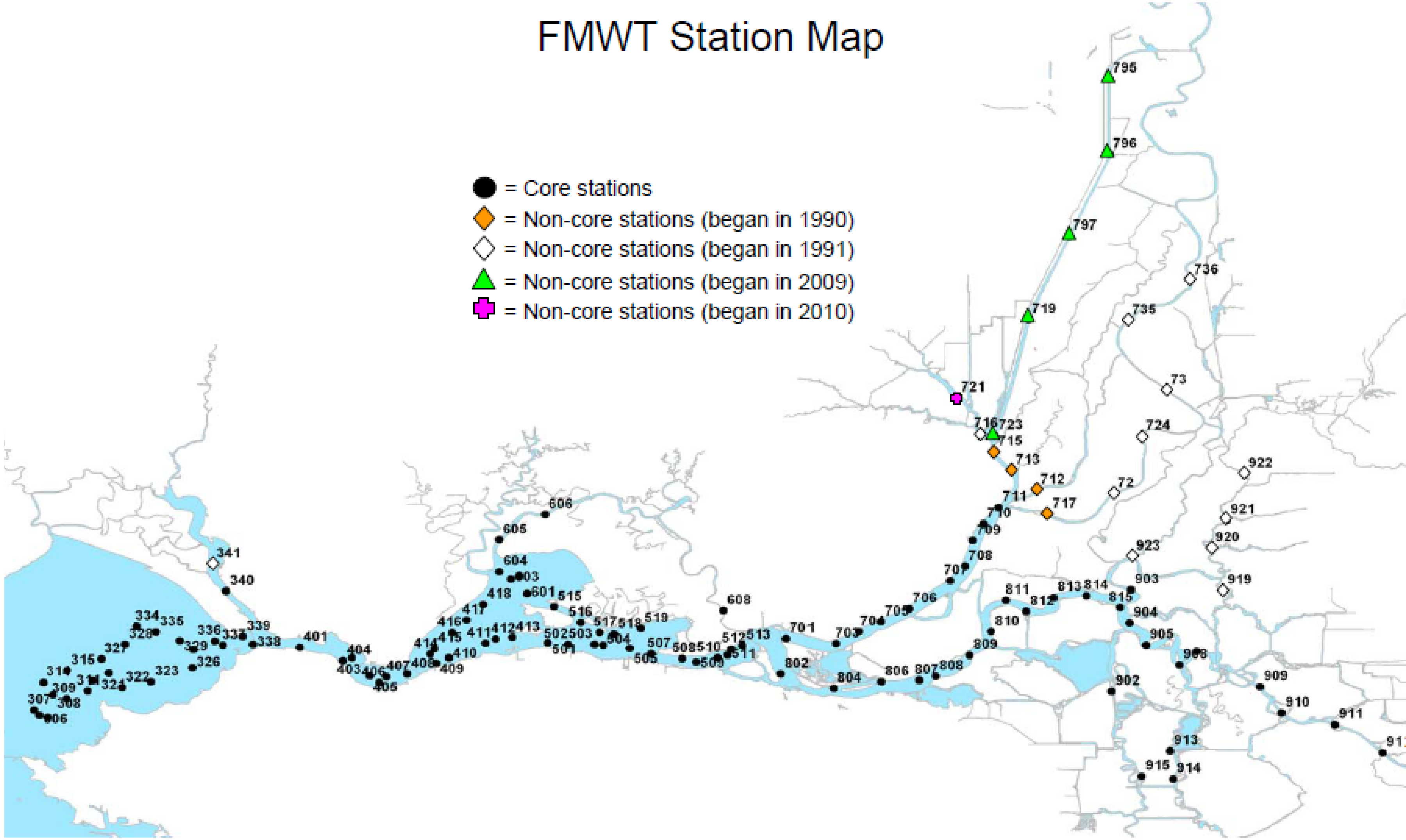

Figure A3. Locations of fall midwater trawl sampling stations.

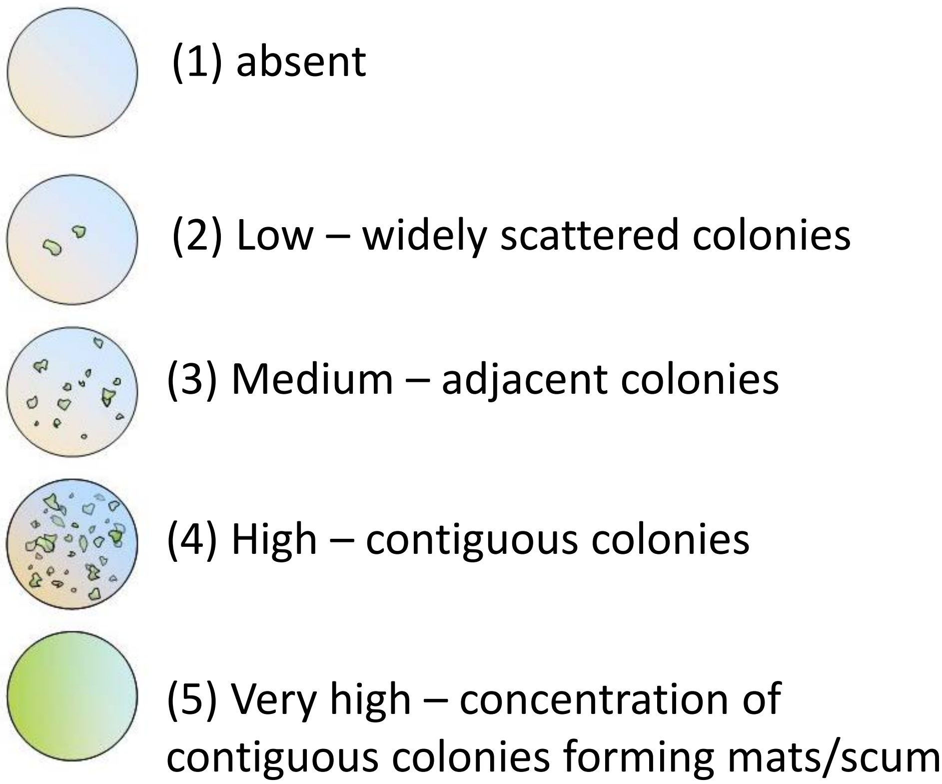

Figure A5. Visual rating system used during fall midwater trawl to document *Microcystis* abundance.

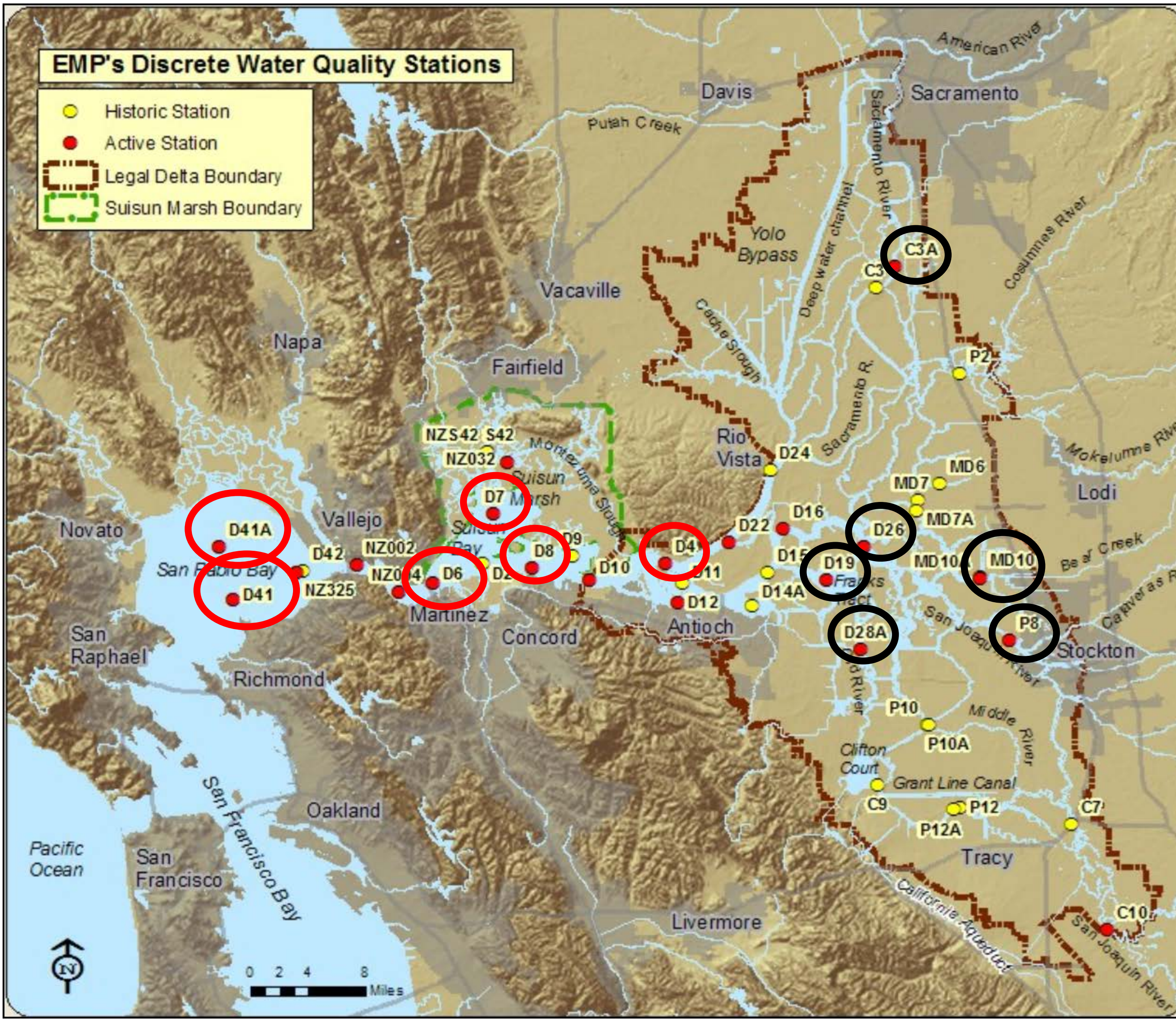

Figure A19. Sites sampled by the IEP Environmental Monitoring Program (EMP) for water quality constituents are shown by circles. Red circles show the sites considered representative of delta smelt fall range. Black circles show sites considered outside of the fall range of delta smelt and not included in analyses.

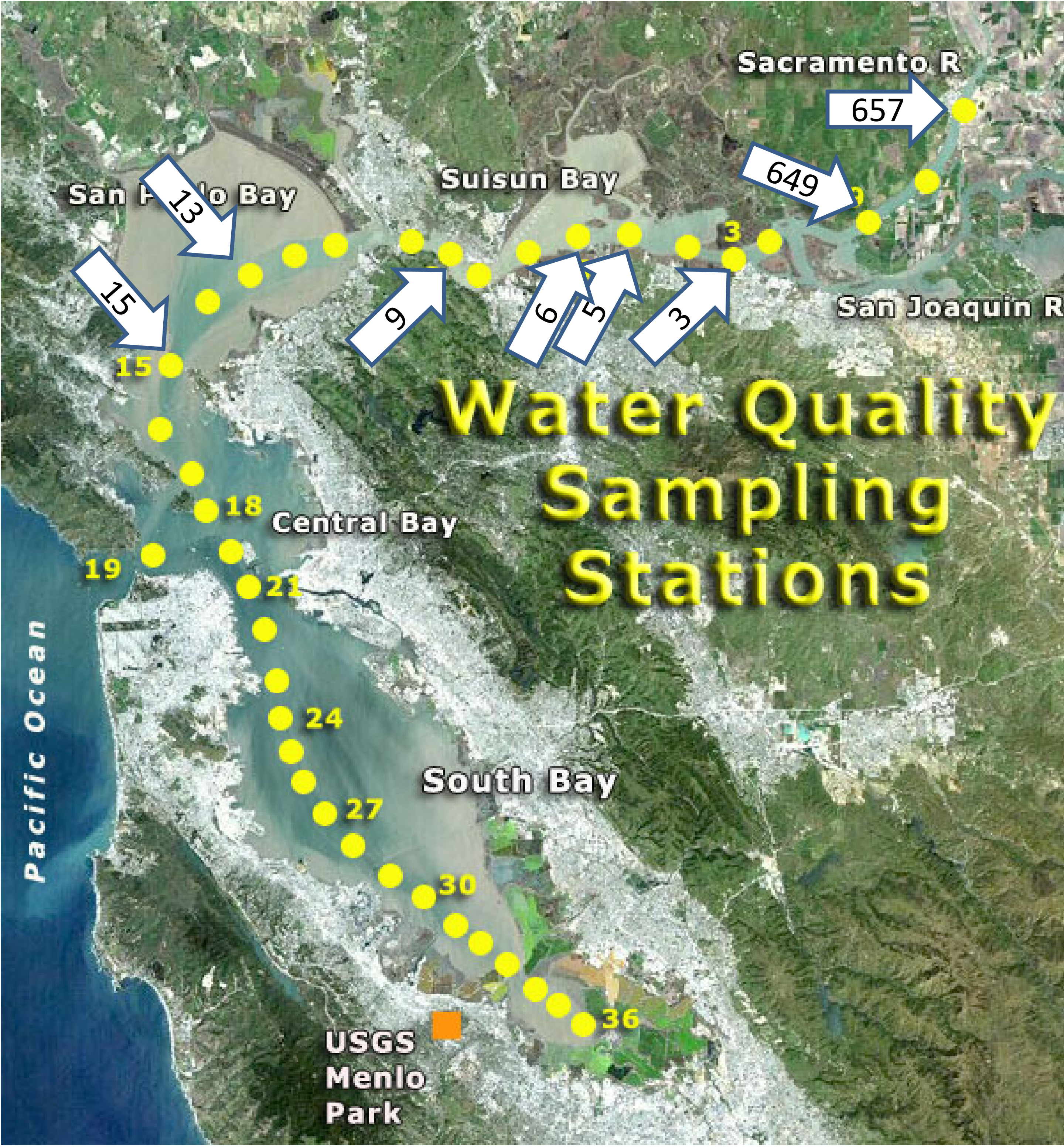

Figure A20. Sites sampled by the USGS water quality monitoring program (http://sfbay.wr.usgs.gov/access/wqdata/index.html) for water quality constituents. Data utilized for this report are from sites indicated by arrows where discrete water samples were collected..