

Prepared 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



Scientific Investigations Report 2014–5041

Cover. California Department of Fish and Wildlife personnel deploying the net for fall midwater-trawl sampling simultaneously with data collection for the fall low-salinity habitat investigations in the following boat by personnel of the University of California, Davis and the U.S. Bureau of Reclamation.

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

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In Cooperation with the Bureau of Reclamation and Interagency Ecological Program

Scientific Investigations Report 2014–5041

U.S. Department of the Interior
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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
Area		
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi ²)
Volume		
liter (L)	1.057	quart (qt)
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)	35.31	cubic foot per second (ft ³ /s)
Mass		
gram (g)	0.03527	ounce, avoirdupois (oz)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$ at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ($\mu\text{g}/\text{L}$).

Abbreviations

20-mm	20-millimeter survey
AMP	adaptive management plan
BiOp	Biological Opinion
BPUE	biomass per unit effort
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
DWSC	deep water ship channel
EMP	Environmental Monitoring Program
ETM	estuarine turbidity maximum
FLaSH	fall low-salinity habitat
FMWT	fall midwater trawl
GF/F	glass fiber filter
HSG	Habitat Study Group
IEP	Interagency Ecological Program
LIW	Liberty Island Shallows
LOESS	locally weighted-regression scatterplot smoothing
LSH	low-salinity habitat
LSZ	low-salinity zone
MAF	million acre feet
MAST	Management, Analysis, and Synthesis Team
MI	Mallard Island
NDOI	net Delta outflow index
NH ₄ -N	ammonium as nitrogen
NRC	National Research Council
NTU	nephelometric turbidity unit
OMR	Old and Middle River
POD	pelagic organism decline
RFU	relative fluorescence unit
RPA	Reasonable and Prudent Alternative
SFE	San Francisco Estuary
SKT	spring Kodiak-trawl
SRDWSC	Sacramento River Deep Water Ship Channel
SSC	suspended-sediment concentration
Suisun region	Suisun Bay and associated embayments
SWAMP	Surface Water Ambient Monitoring Program
SWP	State Water Project
SWRCB	State Water Resources Control Board
TNS	summer townet survey
UCD	University of California at Davis
UCS	Upper Cache Slough
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
X2	the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2

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Abstract

In fall 2011, a large-scale investigation (fall low-salinity habitat investigation) was implemented by the Bureau of Reclamation in cooperation with the Interagency Ecological Program to explore hypotheses about the ecological role of low-salinity habitat in the San Francisco Estuary—specifically, hypotheses about the importance of fall low-salinity habitat to the biology of delta smelt *Hypomesus transpacificus*, a species endemic to the San Francisco Estuary and listed as threatened or endangered under federal and state endangered species legislation. The Interagency Ecological Program is a consortium of 10 agencies that work together to develop a better understanding of the ecology of the Estuary and the effects of the State Water Project and Federal Central Valley Project operations on the physical, chemical, and biological conditions of the San Francisco Estuary. The fall low-salinity habitat investigation constitutes one of the actions stipulated in the Reasonable and Prudent Alternative issued with the 2008 Biological Opinion of the U.S. Fish and Wildlife Service, which called for adaptive management of fall Sacramento-San Joaquin 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 of the adaptive management of fall low-salinity habitat is that greater outflows move the low-salinity zone (salinity 1–6), an important component of delta smelt habitat, westward and that moving the low-salinity zone 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 was prepared to guide implementation of the adaptive management of fall low-salinity habitat and to reduce uncertainty.

This report has three major objectives:

- To provide a summary of the results from the first year of coordinated fall low-salinity habitat studies and monitoring.
- To provide a synthesis of the results of the fall low-salinity habitat studies and other ongoing research and monitoring, to determine if the available information supports the hypotheses behind the adaptive management of fall low-salinity habitat as set forth in the adaptive management plan.
- To begin to put the results from the fall low-salinity habitat studies into context within the larger body of knowledge regarding the San Francisco Estuary and, in particular, the upper San Francisco Estuary, including the Sacramento-San Joaquin Delta, Suisun Bay, and associated embayments.

The basic approach of this report is to evaluate predictions derived from the hypotheses included in the conceptual model developed within the adaptive management plan. 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, were considered. Data from 2005 and 2010 were also considered, to include the conditions antecedent to those years.

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

- Develop a method of measuring “hydrodynamic complexity.” This concept is central to a number of the predictions that could not be evaluated.

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- 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 for determining turbidity.
- Determine the correct spatial and temporal scale or scales necessary for monitoring and for studies to address the predicted abiotic and biotic responses. 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 that includes nutrient cycling and other important processes, 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 there are delta smelt.

Introduction

In fall 2011, a large scale investigation was implemented by the U.S. 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) (FLaSH, fall low-salinity habitat investigations) and, specifically, hypotheses about the importance of LSH to the biology of delta smelt *Hypomesus transpacificus*, a species endemic to the SFE and listed as threatened under the Federal Endangered Species Act and as endangered under the California Endangered Species Act. The Interagency Ecological Program is a consortium of 10 agencies that work together to develop a better understanding of the ecology of the estuary and the effects of the State Water Project and Federal Central Valley Project operations on the physical, chemical, and biological conditions of the San Francisco Estuary (<http://www.water.ca.gov/iep/about/aboutiep.cfm>). The FLA SH studies and other activities were motivated by a Biological Opinion (BiOp) on Central Valley Project (CVP) and State Water Project (SWP) operations issued by the US Fish and Wildlife Service (USFWS) in 2008 (U.S. Fish and Wildlife Service, 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 Sacramento-San Joaquin Delta

(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 (hereafter, fall low-salinity habitat component of the RPA). The basic hypothesis of the fall low-salinity habitat component 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 fall low-salinity habitat component of the RPA (U.S. Bureau of Reclamation, 2012) and to reduce uncertainty. The adaptive management of fall outflow specifically refers to actions in September and October that manipulate the position of the LSZ. However, delta smelt are sampled from September to mid-December, and this longer time span is often included in the report, especially when addressing the biology of the species.

The AMP was designed in accordance with the Department of Interior guidelines for design and implementation of adaptive management strategies (Williams and others, 2009). Adaptive management strategies share a cyclical design: (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 FLA SH is broad, Reclamation, in cooperation with IEP, perceived the need for a broad synthesis of the FLA SH 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, and regular updates are expected as part of the annual AMP cycle.

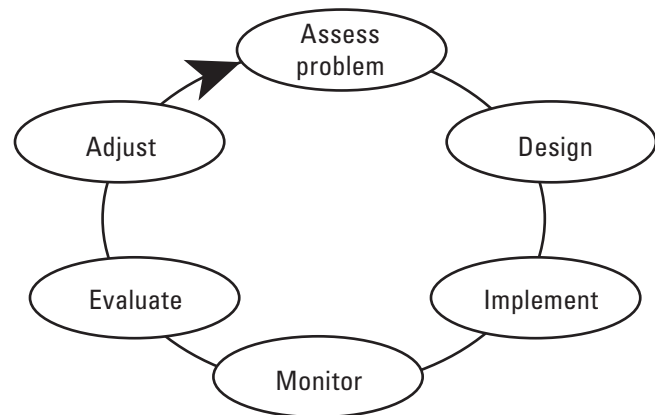


Figure 1. The adaptive management cycle (modified from Williams and others, 2009).

Purpose and Scope

This report has three major objectives. The first is to provide a summary of the results from the first year of coordinated FLaSH studies and monitoring. Because many of the fall 2011 studies included 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 a synthesis of the results, to determine whether the results of the FLaSH studies and other ongoing research and monitoring programs support the hypotheses fundamental to the fall low-salinity habitat component of the RPA as set forth in the AMP (U.S. Bureau of Reclamation, 2012, and “Background” section of this report). The final major objective is to begin to put the results from the FLaSH studies into context within the larger body of knowledge about the SFE (fig. 2), particularly the upper SFE, including the Sacramento-San Joaquin Delta (Delta) and Suisun Bay and associated embayments (Suisun region; fig. 3). Results also need to be evaluated within the context of both intra-annual and inter-annual conditions and processes. For example, even if fall conditions appeared ideal, it would be unrealistic to expect an increase in the fall delta smelt population if conditions for spawning were exceptionally poor during the preceding spring. For this reason, we specifically included 2010, the calendar year before the first year of the FLaSH investigation. We also considered 2005–2006 because 2006 was the most recent wet year prior to the FLaSH investigation. In addition, as part of data integration and assessment in this report, new areas of interest warranting study are identified, and problems with previously implemented studies recognized, if any. This report notes areas where improvement is needed and identifies additional data needs for fully understanding the efficacy of the fall low-salinity habitat component of the RPA. This report does not recommend which improvements or new studies should be undertaken by the responsible management agencies; however, the report aims to provide a sound basis for making such decisions.

The overall scope of this report is broad; however, the focus is on the low-salinity zone (LSZ) and delta smelt LSH. Because FLaSH is focused on delta smelt, the LSZ is defined as the area of the upper SFE where salinity ranges from 1 to 6. Generally, this is considered the optimal salinity range for delta smelt (Bennett, 2005), although the fish also are found outside of this core range (Feyrer and others, 2007; Kimmerer and others, 2009; Sommer and others, 2011b). Reference to the LSZ is specific to the area of the estuary with salinity of 1 to 6, although the concept of LSH includes many properties in addition to salinity that characterize the environment supporting delta smelt. Clearly, there are no physical barriers between the LSZ and areas with lesser or greater salinity.

Indeed, exchange of energy, organic and inorganic constituents, and organisms between the LSZ and areas of lesser and greater salinity could be critical to the productivity of LSH. The concept of habitat clearly includes all such exchanges and their effect on other components 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 period is the focus of this report. However, IEP monitoring and studies, as well as 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 to be 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. Although the AMP focuses on the fall because the management action of interest takes place in the fall, future reports could consider the entire annual life cycle of delta smelt so that the interactive effects of other seasons can be understood. A more complete integration of life stages and seasonal effects in future reports, if the FLaSH investigation continues, would provide an improved understanding of the key factors influencing delta smelt populations. As already noted, we specifically focus on fall 2006 for comparison with fall 2011. The 2 years were both considered wet years, but there was not a comparable increase in the delta smelt population index in 2006 as in 2011 (fig. 4). We also include the antecedent year in both cases to allow assessment of how such conditions could have affected the observed results. We also note that the results of the FLaSH studies are important for other fish populations besides delta smelt and will broaden our understanding of the entire estuary. This broader scope will be addressed as part of a separate, but related, effort undertaken by the IEP Management, Analysis, and Synthesis Team (MAST).

Background

Study Area

The SFE (fig. 2) is the largest estuary on the west coast of North America, and it has been characterized as one of the best studied estuaries in the world (for example, 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 (Lotze and others, 2006). The most notable changes are the loss of wetlands, inputs of contaminant, alterations of hydrodynamics

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

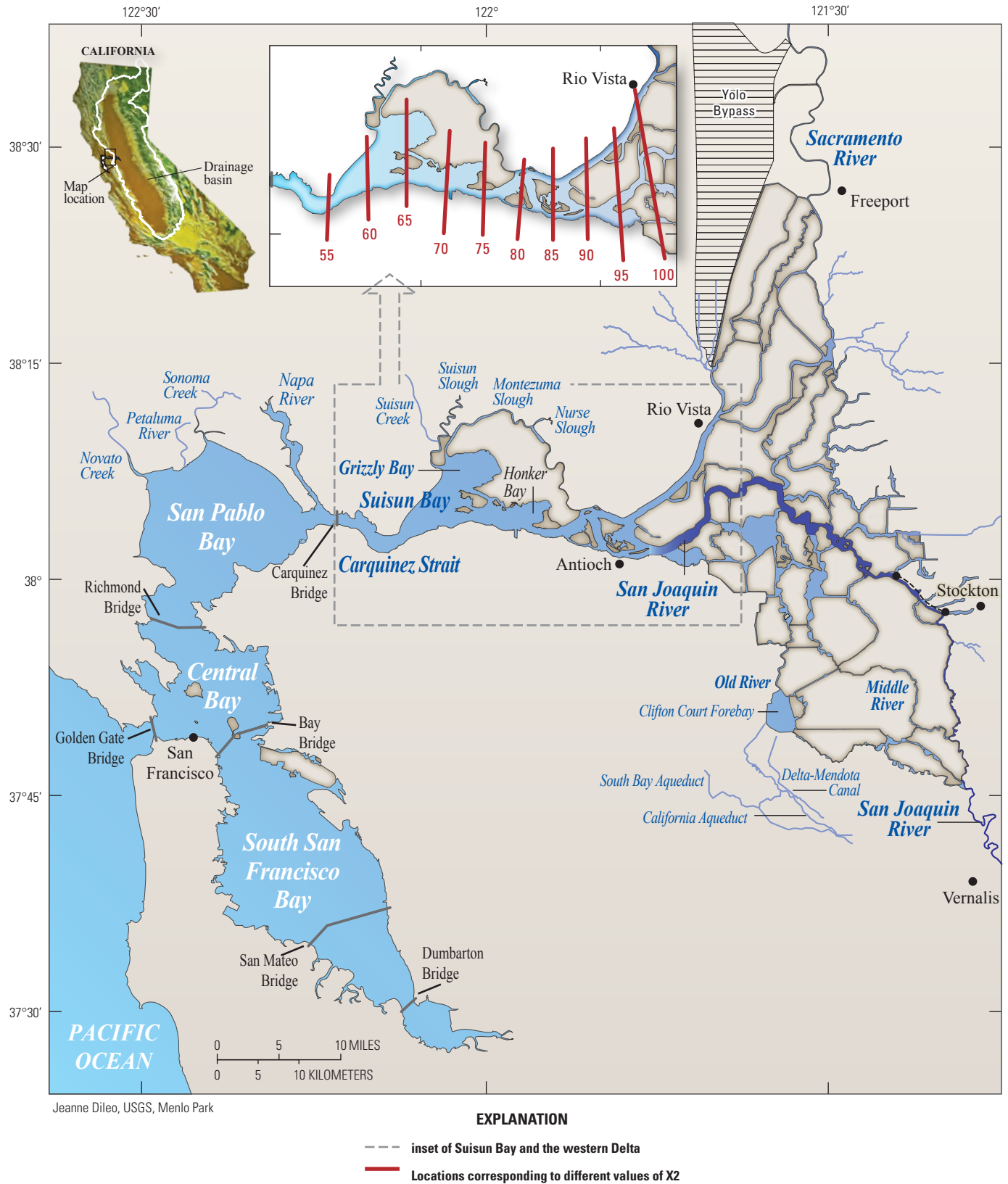
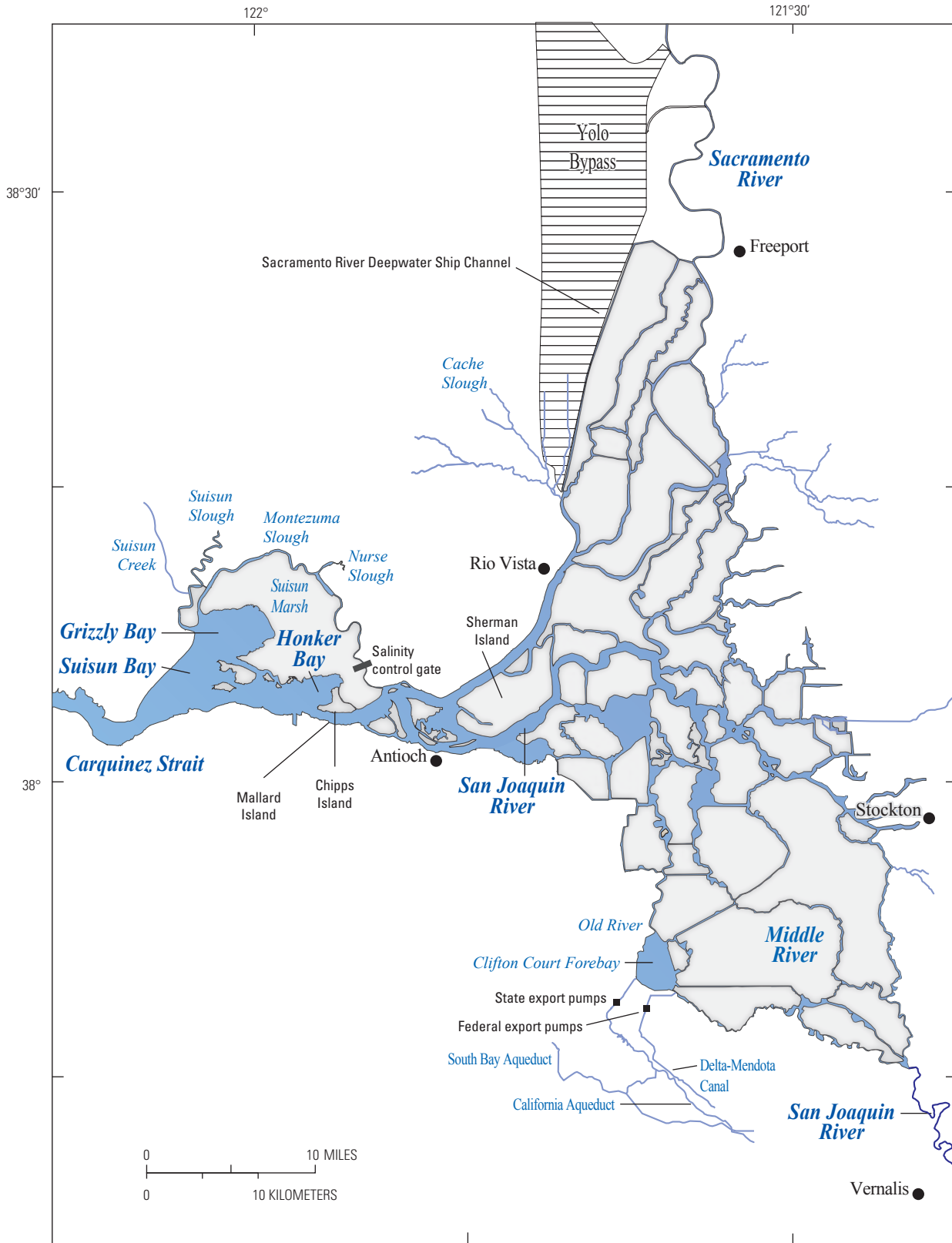


Figure 2. San Francisco Bay Estuary. Also shown are locations corresponding to different values of X2, which is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2 (adapted from Jassby and others, 1995).



Modified from fig. 2 (Jeanne Dileo, USGS, Menlo Park) by Larry Brown

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

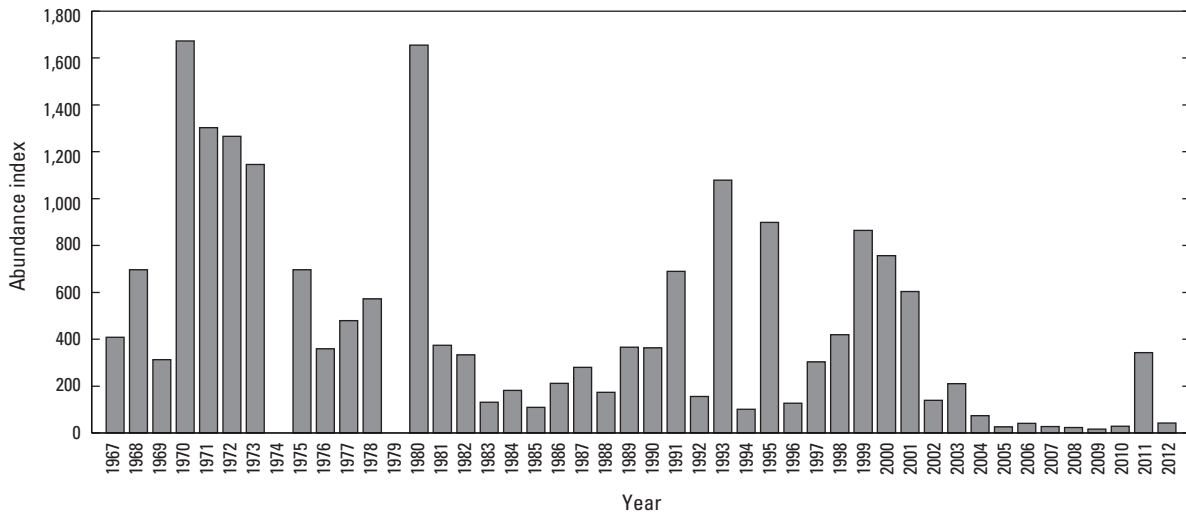


Figure 4. Delta smelt abundance index from the fall midwater-trawl survey (appendix 4). The survey was not done in 1974 or 1979.

for diversion of water, and both accidental and deliberate introductions of species (Bennett and Moyle, 1996; Brown and Moyle, 2005; Baxter and others, 2010; National Research Council, 2012). These changes and others have been implicated in declines of terrestrial and aquatic resources, including fishes. Many of these anthropogenic changes took place 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, flood basins, low natural levees, and seasonal and permanent wetlands (Whipple and others, 2012). The southern portion of the Delta was dominated by the smaller San Joaquin River, associated distributary channels, and dead-end sloughs. As development progressed in the Delta, higher levees were constructed to protect farmlands. Formerly isolated larger channels were connected, while many smaller channels were disconnected from historic channel networks. Deep new 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 the 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, through the Yolo Basin, to the port (fig. 3). Cache Slough continues northwest and is associated with Liberty Island, which is now flooded, and several tributary creeks and sloughs; it also serves as the connection between the Yolo Bypass and the Sacramento River (fig. 2). The Yolo Bypass is a flood bypass located in the historical Yolo flood basin (Whipple and others, 2012). It diverts high Sacramento River 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, 2001; Sommer and others, 2003; Feyrer and others, 2006).

The region where the Sacramento and San Joaquin rivers join (confluence region) was once dominated by sinuous sloughs and low, tidally inundated islands and wetlands (Whipple and others, 2012). Today, the waterways of this region are disconnected from most of the former wetland areas and are 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 Miller, 1983). Striped bass is an exotic species but is also a popular sport fish that supported an economically valuable sport fishing industry 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 (U.S. Fish and Wildlife Service, 1993). Reclassification from threatened to endangered was determined to be warranted, but was precluded by other higher priority listing actions in 2010 (U.S. Fish and Wildlife Service, 2010b). The species was listed as threatened under the state endangered species statute in 1993, and the status was changed from threatened to endangered in 2009 (California Fish and Game Commission, 2009). Subsequent declines in the delta smelt population, in concert with three other pelagic fishes (fig. 5), increased concern for avoiding jeopardy and achieving recovery of delta smelt. These declines are often referred to as the pelagic organism decline (POD; Sommer and others, 2007; Baxter and others, 2008, 2010).

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 are slender-bodied fish typically reaching 60–70 millimeters (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, survive, and reproduce in the SFE. The current range of juvenile and sub-adult delta smelt includes the Cache Slough area, the SRDWSC and Sacramento River in the northern Delta, the confluence region in the western Delta, and the Suisun region (fig. 7). Historically, juvenile and sub-adult delta smelt also inhabited the central and southern Delta during the summer and fall months (Erkkila and others, 1950), but they are now rare in those areas during that period (Bennett, 2005; Nobriga and others, 2008; Sommer and others, 2011b). Juvenile and sub-adult delta smelt live mostly in the LSZ and are most abundant at salinity 1–2 (Bennett, 2005; Sommer and others, 2011b). While delta smelt can complete their entire life cycle in fresh water, the bulk of the juvenile and subadult delta smelt population is associated with the LSZ, indicating

that salinities of 1–6 are most favorable for the physiology of that life stage. Delta smelt are generally not found above salinity 14 (Swanson and others, 2000); however, recent studies have shown that, under laboratory conditions, Delta Smelt can survive in seawater (Komoroske and others, 2014). For comparison, seawater is generally salinity 33 near the California coast. The location of the LSZ in the estuary is indexed by X2, which is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2 (Jassby and others, 1995).

Upstream migration of maturing adults generally begins in the late fall or early winter, and most spawning takes place from early April through mid-May (Bennett, 2005; Sommer and others, 2011b). 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 year round, including the Cache Slough region, the SRDWSC, and the central Delta region (Sommer and others 2011b), although the contribution of these fish to population production is unknown. A very small percentage of delta smelt survive into a second year and potentially spawn in one or both years (Bennett, 2005).

Summer physical habitat has been described by Nobriga and others (2008); the summer (June–July) distribution of delta smelt is determined by areas that have appropriate salinity, but also have 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 through mid-December). Kimmerer and others (2009), Sommer and others (2011b), and Merz and others (2011) expanded on these studies by examining the habitat associations and geographic distribution patterns 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 salinity 2 isohaline, but move upstream during winter and spring months for spawning and early development in freshwater.

The year-round presence of delta smelt in the Cache Slough and SRDWSC (fig. 3) was unexpected on the basis of 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 2011b). Fisch (2011) determined that individuals collected from this region were not genetically unique compared 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 indicates 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 non-tidal habitats upstream of the Delta indicates that there are limits on freshwater residence.

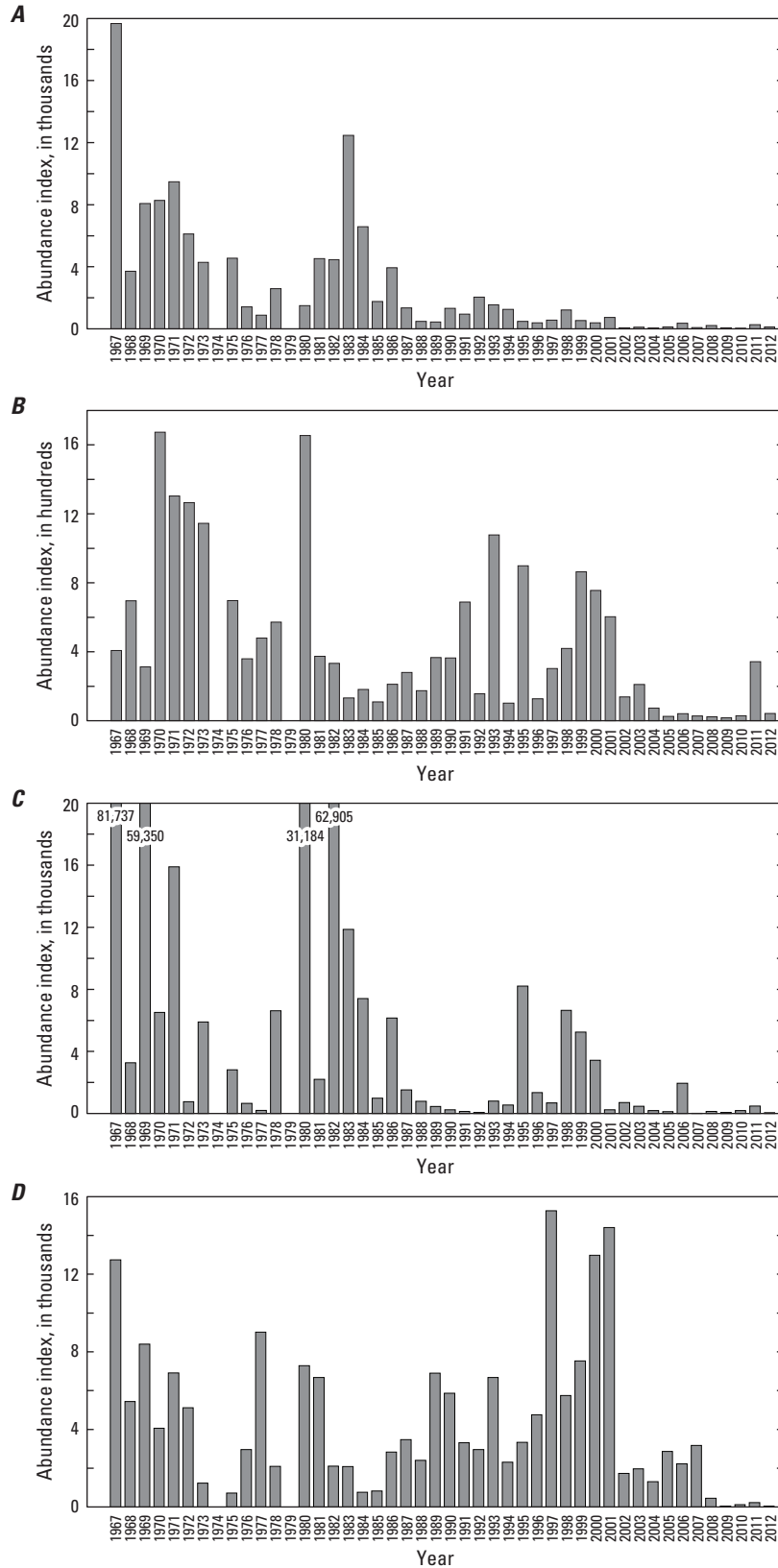


Figure 5. Trends in abundance indices for four pelagic fishes from 1967 to 2012 based on the fall midwater-trawl survey, a California Department of Fish and Wildlife survey that samples the upper San Francisco Estuary for *A*, striped bass; *B*, delta smelt; *C*, longfin smelt; and *D*, threadfin shad (appendix 4). There was no sampling in 1974 or 1979. Note that the y-axis for longfin smelt represents only the lower 25 percent of its abundance range to more clearly portray the lower abundance range.

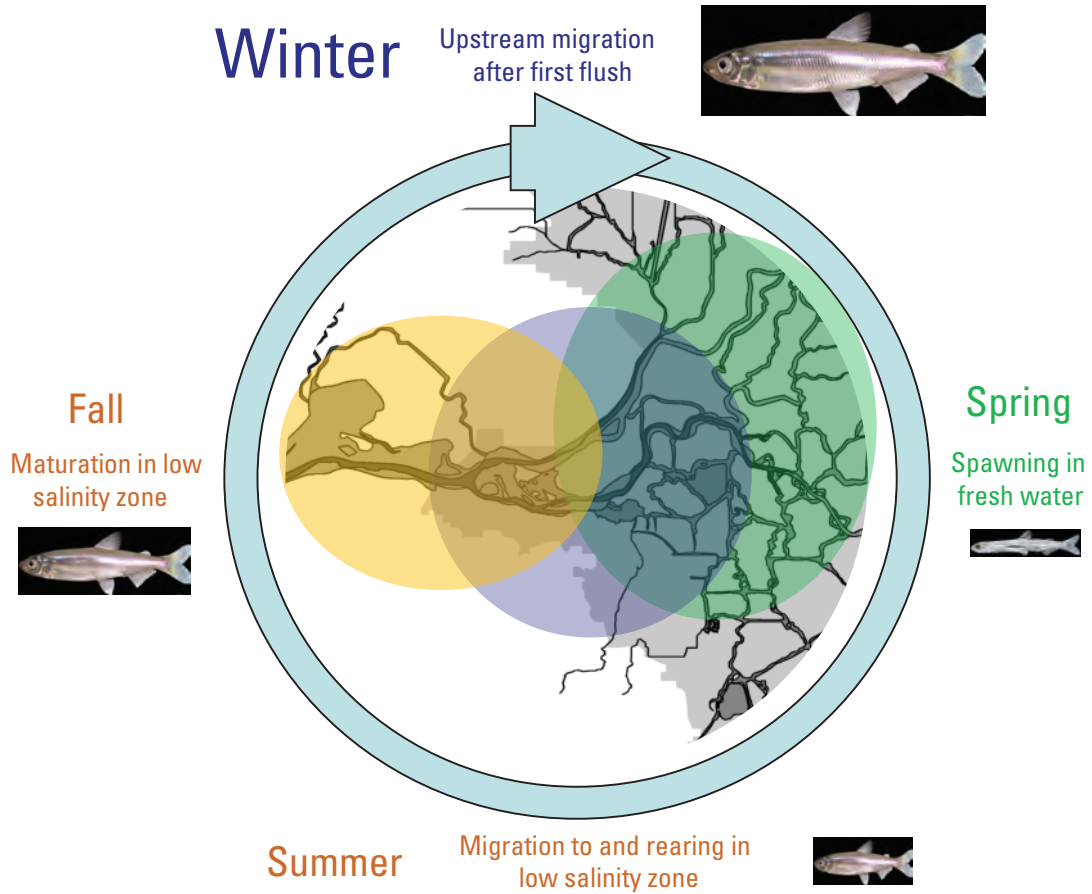


Figure 6. Simple conceptual diagram of the delta smelt annual life cycle (modified from Bennett, 2005).

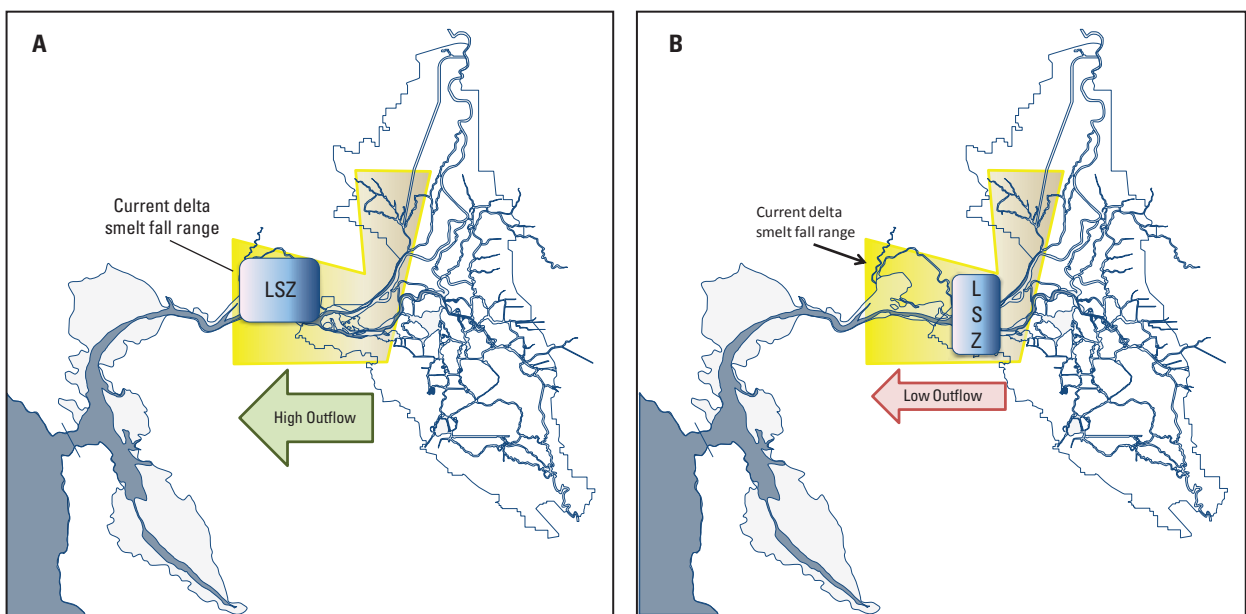


Figure 7. Location of the fall low-salinity zone (LSZ), where most delta smelt are found: *A*, under high outflow conditions, when the LSZ overlaps the Suisun region, and *B*, under low outflow conditions, when the LSZ overlaps the river confluence (from U.S. Bureau of Reclamation, 2012).

Although abundance of delta smelt has been highly variable, there is a demonstrable long-term decline in abundance (fig. 4; Manly and Chotkowski, 2006; Sommer and others, 2007; U.S. Fish and Wildlife Service, 2008; 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; Moyle and others, 2010; Thomson and others, 2010) and could signal a rapid ecological regime shift in the upper estuary (Baxter and others, 2010; Moyle and others, 2010). The decline of delta smelt has been intensively studied as part of an IEP effort to understand the POD (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 (for example, salinity and turbidity fields) and the biotic habitat (that is, food web). This conclusion was generally supported by a recent independent review panel (National Research Council, 2012).

Conceptual Models

Conceptual models are formalized versions of mental models that are communicated to others verbally and graphically. Ecologists use them to tell stories of “how ecosystems work” and to explore how human actions and other drivers change ecosystems. They usually consist of a combination of narrative text and graphical illustrations about ecosystem components and the relationships among them that summarize hypotheses about ecosystem processes and outcomes. 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 those models have evolved and contributed to the conceptual model in the AMP (U.S. Bureau of Reclamation, 2012), which serves as the basis for the FLASH studies and predictions evaluated in this report. Results from monitoring activities and FLASH 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 and others (2011) stress the importance of nutrients and nutrient ratios to phytoplankton, and of 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 (for example, 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 and others, 2010). Importantly, these studies differed widely in methodology and objectives and rarely evaluated the same environmental factors. As a result, they often reached different 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 to evaluate the importance of various factors on different life stages of 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, U.S. Fish and Wildlife Service, written commun., 2012). A numerical simulation model has also been developed by a group led by Kenneth Rose (Louisiana State University) and Wim Kimmerer (California State University, San Francisco) (Rose and others, 2013a, 2013b). These three models could be useful for evaluating 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 estuarine 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, it was recognized that the interactions of tides, bathymetry, river flow, channel configuration, and diversions were important to generating the physical conditions that affect fishes at different life stages. Ecologically, continued invasions of non-indigenous species into the SFE were shown to have important effects on the food web. The effects of the invasive clam *Potamocorbula amurensis* were particularly important because its high rate of filter feeding (grazing rate) and tolerance of brackish water enabled it to remove a large proportion of phytoplankton biomass and 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 growing body of knowledge provided the backdrop for the next major conceptual model based on X2. The intent of using X2 as an index was to develop an easily measured, policy-relevant indicator with ecological significance for multiple species and processes (Jassby and others, 1995). 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, 2002a, 2002b).

The recognition of the decline of four pelagic fish populations, commonly referred to as the POD, resulted in the development of a new set of conceptual models. These models evolved into the AMP model that provided the basis for the FLASH investigation (U.S. Bureau of Reclamation, 2012). Each of these models is briefly summarized in the following sections.

Basic POD model

The basic POD conceptual model (fig. 8), introduced in Sommer and others (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 (that is, 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 assume that predation and water-project entrainment affect mortality rates; and (4) bottom-up effects, which assume 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 (fig. 8). This is intended to show 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) represents the increasing knowledge about the SFE ecosystem and recognizes that habitat features could affect each of the other categories of drivers additively, antagonistically, or synergistically and, thereby, produce outcomes that are not always easily predictable.

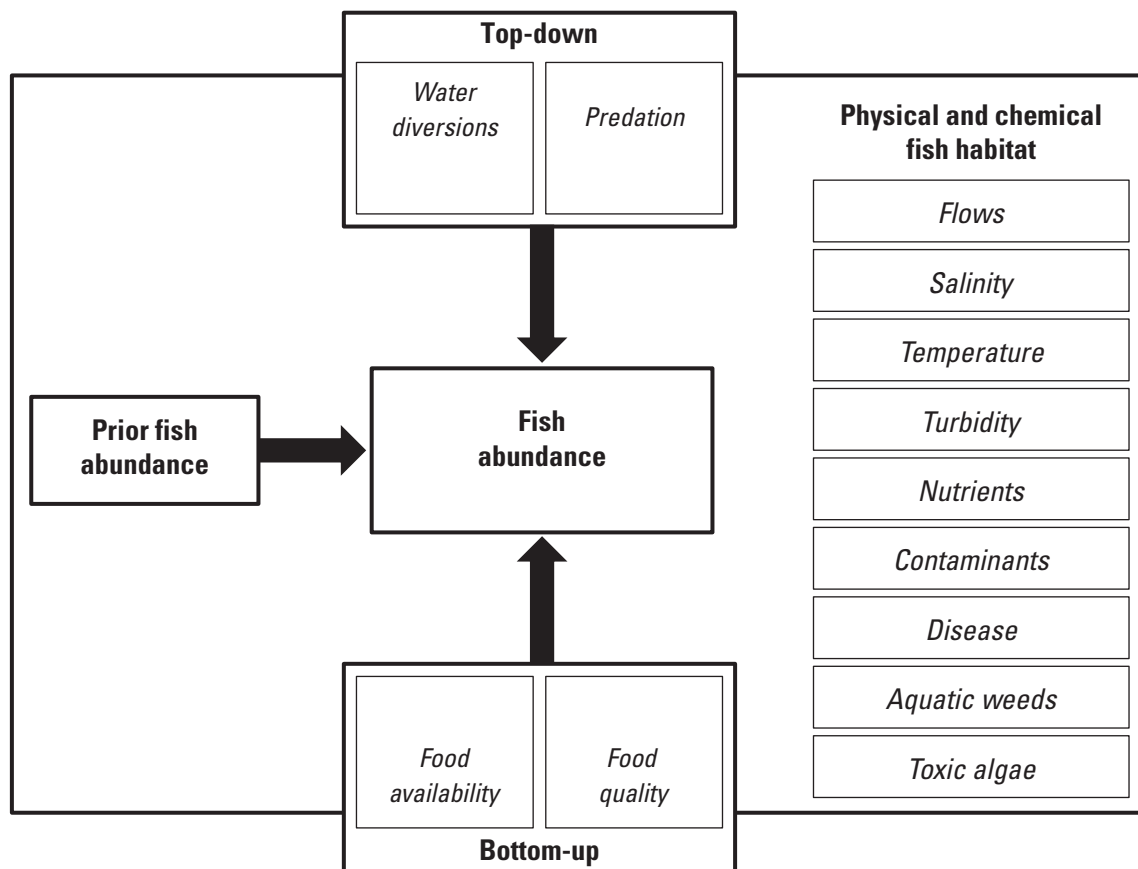


Figure 8. The basic conceptual model for the pelagic organism decline (adapted from Baxter and others, 2010).

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 able to communicate differences in factors hypothesized to affect different life stages of the four POD species. The model identifies key seasonal drivers, as well as proximal causes and effects. Several concepts in the delta smelt conceptual model (fig. 9) are important to the FLASH studies. The reduced size of spawning adults along with reduced fecundity in smaller fish affects egg supply; this 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 goes to basic metabolic demands, instead of the 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 (Baxter and others, 2010). Therefore, fall effects can manifest as potential limits on subsequent abundance, where the outcome depends on a variety of other seasonal factors (for example, outflow, exports, and water temperature).

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 accepted by many researchers of the SFE because it integrated various observations about changes in habitats and species in addition to changes in the pelagic habitat and the POD species (Baxter and others, 2010; Mac Nally and others, 2010; Moyle and others, 2010; Thomson and others, 2010). In other words, the conceptual model represents an ecosystem approach, which recognizes that multiple factors 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. Changes in 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 the SFE (Ganju and others, 2007), is also

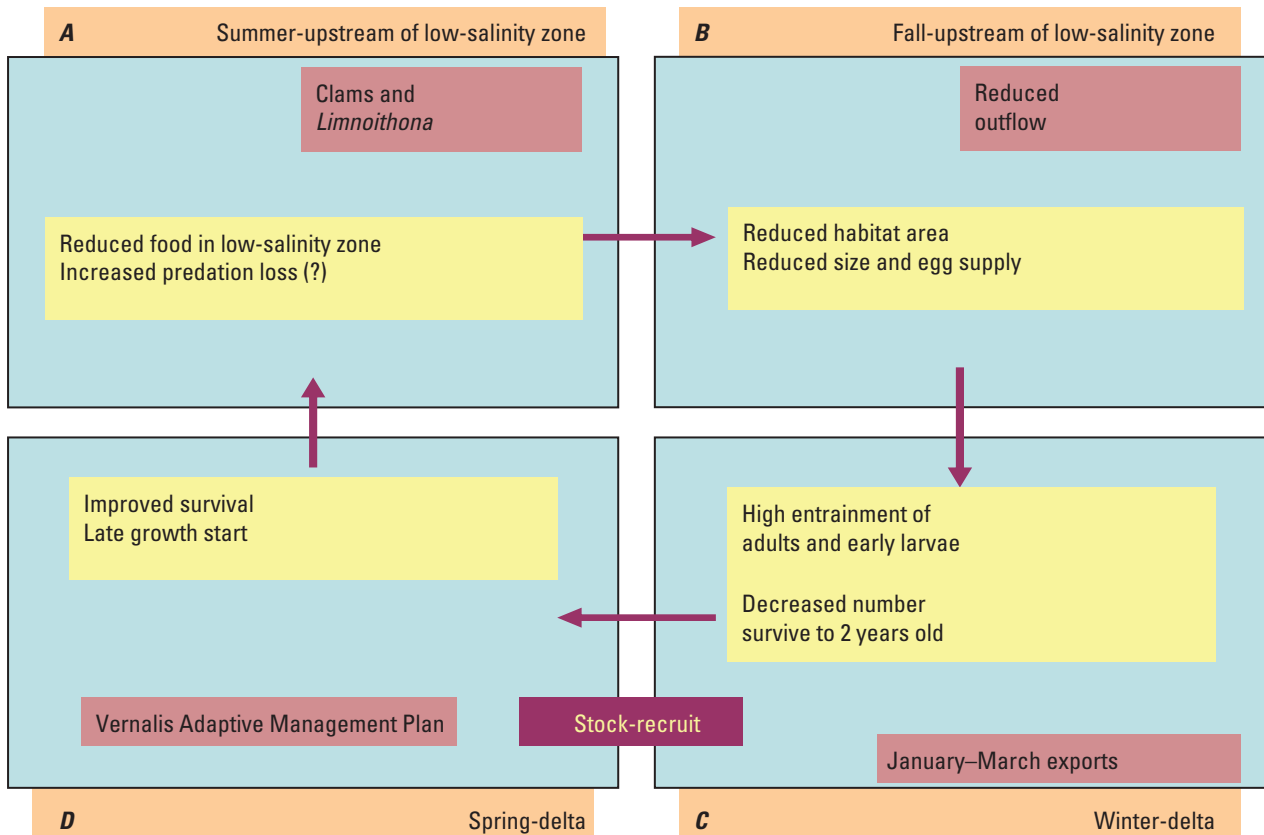


Figure 9. Delta smelt species-specific model (adapted from Baxter and others, 2010): *A*, summer conditions; *B*, fall conditions; *C*, winter conditions; and *D*, spring conditions. The model identifies key seasonal drivers in red, with proximal causes and effects in yellow.

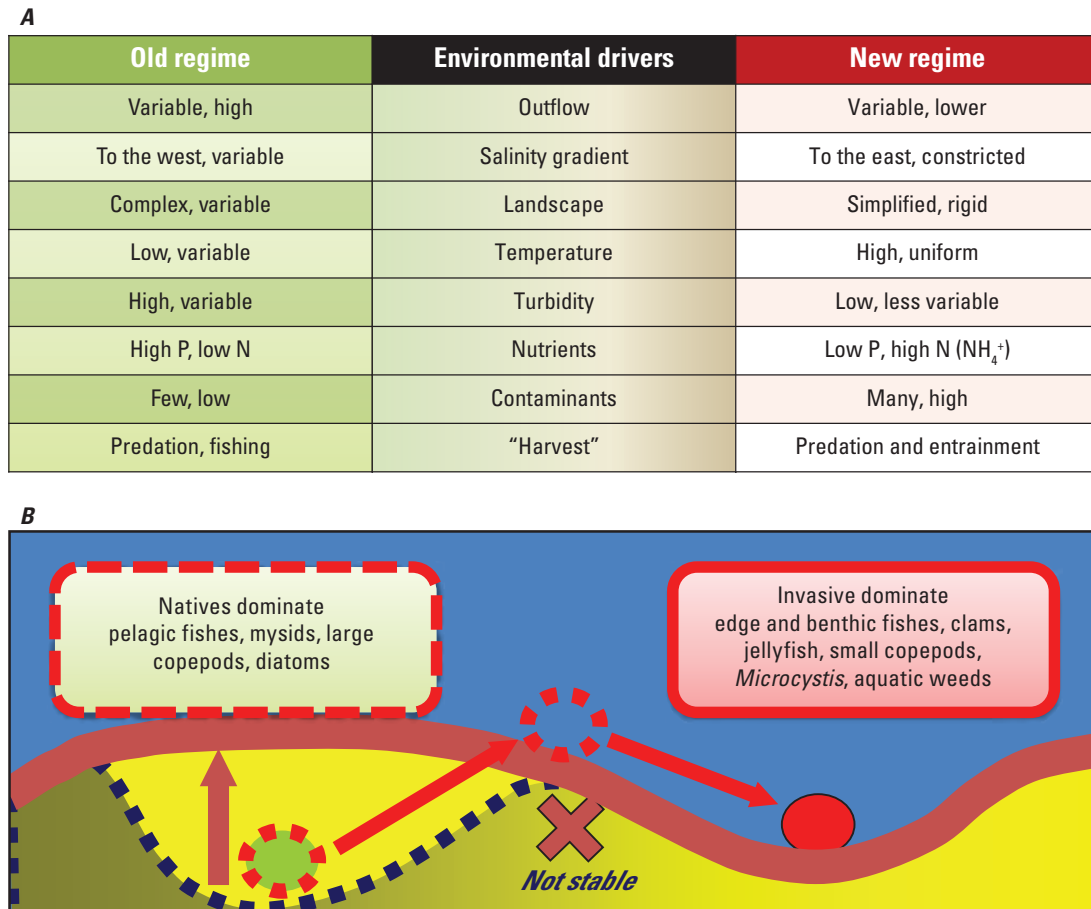


Figure 10. Regime-shift model from Baxter and others (2010). The model assumes that ecological regime shift in the Delta results from *A*, changes in environmental drivers that lead to *B*, profoundly altered biological communities. The dotted lines show the ecosystem (green ball with red dotted line) before the regime shift. The environment changes (dotted blue line moves up to solid red line) pushing the ecosystem through an unstable threshold region (red X) before the new relatively stable ecosystem (red ball) regime is established. Nutrients are P, phosphorus; N, nitrogen; and NH₄⁺, ammonium. The background colors are for contrast only and have no particular meaning.

viewed in this longer-term climatic context. The conceptual model indicates 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. Introduction of invasive species is also an important process in the shift.

The model indicates that a more westward (toward Suisun region) and variable (annually and seasonally) salinity gradient favors native species (such as delta smelt), while a more eastward (near the confluence region), constricted, and stable salinity gradient favors non-native and nuisance species (such as invasive clams and submerged aquatic vegetation and its associated fishes). In this context, the fall low-salinity habitat component of the RPA tends to move the LSZ to a more westward position in wetter years and to increase seasonal and interannual variability in salinity to provide improved conditions for native fishes. This conceptual model also recognizes that turbidity in Suisun Bay showed a step decline 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 also could have 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 difficult for the SFE ecosystem to ever fully return to its previous conditions (Moyle and Bennett, 2008; Baxter and others, 2010; Lund and others, 2010). The goal of the RPA is to improve conditions within the current regime (U.S. Bureau of Reclamation, 2012) such that conditions for delta smelt are improved, presumably with positive effects for other desirable species. Another goal is to reduce uncertainties about the fall low-salinity habitat component of the RPA through the FLaSH AMP and study. Lund and others (2010) explored some more comprehensive approaches to managing the Delta to improve the ecosystem, while maintaining human uses.

Habitat Study Group Model

In a precursor to the FLaSH AMP, the 2010 Habitat Study Group (HSG) adaptive management plan (U.S. Fish and Wildlife Service, 2010a) 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 its effects on 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 in figure 11. The model indicates that most of the potential effects of fall outflow are expected to involve the processes that affect the growth and survival of juvenile and fecundity of adult delta smelt. The HSG conceptual model was not developed further, although several areas of research identified during the development of the model were subsequently pursued. The HSG AMP was integrated into the FLaSH AMP when the decision was made to implement the RPA.

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), established a 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 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 (State Water Resources Control Board, 2010). In this framework, the environment of an estuary consists of two integral parts:

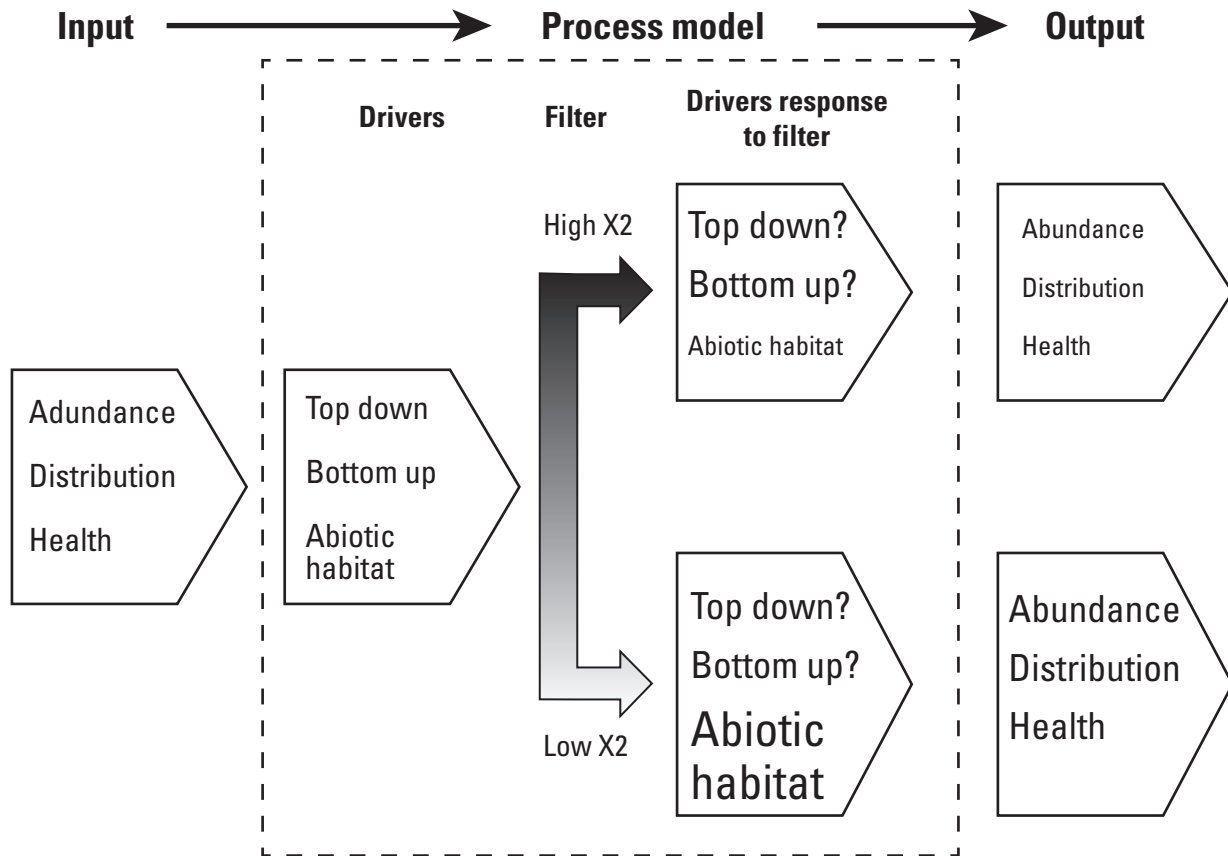


Figure 11. Habitat Study Group model of effects of fall low-salinity habitat position, as indexed by X2 (the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2), on delta smelt through changes in habitat quantity and quality. The position and extent of fall low-salinity habitat affects the expected outcomes for the same drivers either directly or indirectly (from U.S. Bureau of Reclamation, 2012). Different-sized fonts indicate expected qualitative differences between X2 and expected driver responses and measures of delta smelt population response (abundance, distribution, health).

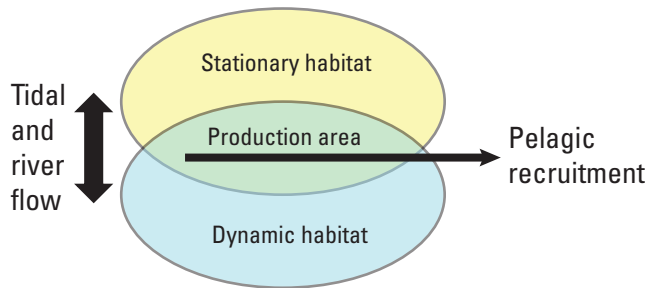


Figure 12. Illustration showing estuarine habitat conceptual model (modified from Peterson, 2003).

- A stationary topography with distinct physical features that produce different levels of support and stress for organisms in the estuary.
- A dynamic regime of flows and salinities where organisms passively transported by flow or actively searching for a suitable salinity are 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 are hypothesized to control the survival, health, growth, fecundity, and, ultimately, the reproductive success of estuarine pelagic species (fig. 12).

For the Delta, this dynamic and interactive view of estuarine ecology captured several important elements. First, the interactions of outflow, and subsequent position of the LSZ (dynamic habitat), with the physical configuration of the Delta (stationary habitat) and anticipated outcomes for estuarine organisms (for example, Jassby and others, 1995; recruitment), are clearly a reflection of concepts from earlier conceptual models. Second, variability in the dynamic habitat in daily, seasonal, annual, and longer time scales produces habitat complexity and variability, which can be important in promoting species diversity. The 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. The implication of variability is 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 uniform 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, and so on) 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 by the U.S. Bureau of Reclamation (2012) to guide the FLASH AMP (fig. 13), and thus the FLASH studies, combines and highlights aspects of previous models pertaining to the effects of fall-outflow management on delta smelt with 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 delta smelt population responses. In the AMP and this report, we use the new 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 new conceptual model could be applied to other species to evaluate whether actions to improve habitat for delta smelt could have unanticipated consequences for other species. The basic approach could 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 (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 near the confluence of the Sacramento and San Joaquin Rivers (referred to as the “river confluence” in this report). 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).

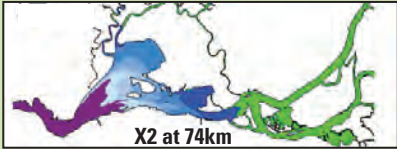
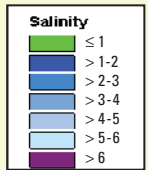

Suisun region	Stationary abiotic habitat components	River confluence
Higher	Bathymetric complexity	Lower
Higher	Erodible Sediment supply	Lower
Many in south, fewer in north	Contaminant sources	Many
Fewer	Entrainment sites	More
Variable fall outflow regime	Dynamic abiotic habitat components	Static fall 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 (salinity 1–6) 	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. The location of the low-salinity zone (LSZ) is related to the value of X2, which is the horizontal distance in kilometers (km) from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Symbols: ≤, less than or equal to; and >, greater than.

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. The LSZ can be considered a dynamic, abiotic habitat component (fig. 13) because its extent (for example, surface area) and location vary with net freshwater outflow from the Delta. Delta smelt and other organisms that seek salinity levels within the LSZ range, or are transported by flow into the area, likely respond differently to the dynamic and stationary habitat features of the fall high- and low-outflow regimes. In other words, conditions for the different outflow regimes potentially do or do not correspond to those necessary for successful recruitment. The concept that the LSZ represents the optimal region for delta smelt production is central to the FLaSH conceptual model. After describing the conceptual model in some detail, delta smelt habitat in the northern Delta is considered.

The new conceptual model provides the framework for accomplishing the main objectives of this report, including presentation of the results of studies and monitoring during fall 2011 and a synthesis of the available information assessing whether the data support predictions made in the FLaSH AMP (U.S. Bureau of Reclamation, 2012). Detailed justifications for the various assumptions made in the new conceptual model are not repeated here. Justifications for each element of the conceptual model, based on available data, are presented in the FLaSH AMP (U.S. Bureau of Reclamation, 2012). In this report, each element of the new conceptual model is briefly reviewed so that readers are familiar with the basis for each of the predictions to be evaluated. It is important to understand that it is not the purpose of this report to revise or provide support for the new conceptual model developed by the U.S. Bureau of Reclamation (2012). The conceptual model is reviewed in this report so that readers understand the basis of the predictions that are assessed in this report. Revisions to the conceptual model are more appropriate as part of a revision of the AMP.

Stationary Abiotic Habitat Components

The POD and HSG models indicate four key stationary habitat components that differ between the river confluence and Suisun regions, and that could affect habitat quality and availability for delta smelt. It is important to note that these features differ between the two regions but also 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 is 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 as follows (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 (U.S. Bureau of Reclamation 2012). 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 and role of organic material to the erodible sediment supply in the Suisun region and the river confluence are uncertain.
- *Contaminant Sources*: The large urban areas surrounding the estuary in concert with the intensive agricultural land use in the Central Valley watershed and the Delta have resulted in pollution of the estuary by many chemical contaminants (Johnson and others, 2010; Brooks and others, 2012). Many of these pollutants (for example, heavy metals and 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 large amounts of ammonium, pesticides, and other pollutants into the Sacramento River near the northern Delta border (Jassby, 2008; Weston and Leidy, 2010; Parker and others, 2012). The Contra Costa wastewater-treatment plant also discharges substantial amounts of ammonium into the western Suisun Bay near Carquinez Strait (Jassby, 2008). Ammonium has been found to suppress nitrate uptake and growth of phytoplankton in the Delta and Suisun Bay (Dugdale and others, 2007). In addition, 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, 2008, 2010). Because *Microcystis* can produce potentially toxic microcystins and is considered poor food for secondary consumers, the conceptual model considered it 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 SWP and CVP 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 (Grimaldo and others, 2009; Castillo and others, 2012), and it can cause indirect mortality due to enhanced predation or unsuitable water quality associated with diversion structures and operations (Arthur and others, 1996; Feyrer and others, 2007; Moyle and others, 2010). Direct entrainment of delta smelt in the fall months is likely to be rare; however, fall hydrodynamic conditions could influence where delta smelt stage in anticipation of the winter migration (Sommer and others, 2011b). 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 Nephelometric Turbidity Units (NTU) in the region between the staging area and the SWP and CVP 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 throughout large regions of the Delta and upstream movement of delta smelt is expected (U.S. Fish and Wildlife Service, 2008).

Dynamic Abiotic Habitat Components

The POD and HSG models also indicate a number of dynamic components that change in magnitude and spatial configuration at daily, tidal, seasonal, and annual time scales. Their interactions with each other and with stationary habitat components determine the extent and location of production areas for estuarine species. The major dynamic abiotic habitat components follow (U.S. Bureau of Reclamation, 2012):

- *Total Delta outflow and San Joaquin River contribution to outflow 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 among 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 (State Water Resources Control Board, 1995). For the Sacramento River, index values greater than or equal to 9.2 million acre feet (MAF) denote a wet year, and values greater than 7.8 MAF and less than 9.2 MAF denote an above-normal year. For the San Joaquin River, index values greater than or equal to 3.8 MAF denote a wet year, and values greater than 3.1 MAF and less than 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 less 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 during much of the fall are always low, and salinity intrudes far to the east (X2 greater than 80 km), causing the LSZ to be constricted to the confluence of the deep Sacramento and San Joaquin river channels (fig. 14). When X2 is more seaward, the LSZ includes more of the Suisun region (figs. 15 and 16).
- *Hydrodynamic complexity in the fall LSZ:* The term “hydrodynamic complexity” is meant to convey the idea of habitat heterogeneity within the LSZ. The U.S. Bureau of Reclamation (2012) 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

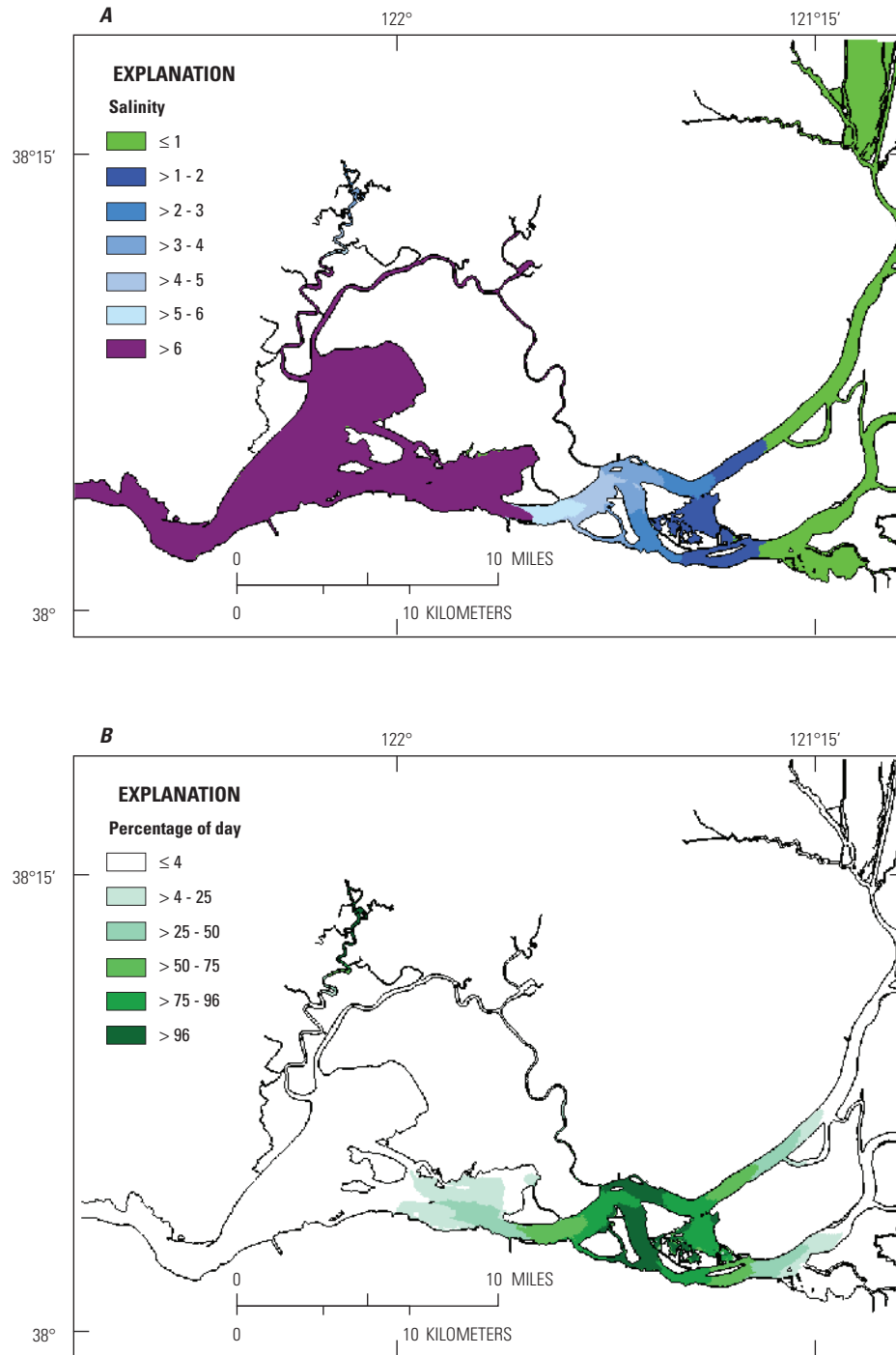


Figure 14. Maps showing *A*, Location of the low-salinity zone (salinity 1–6) when X2 is at 85 kilometers; connections to Suisun Bay and Suisun Marsh are minimal. *B*, Percentage of day that the low-salinity zone occupies different areas (appendix 2). X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Symbols: ≤, less than or equal to; and >, greater than.

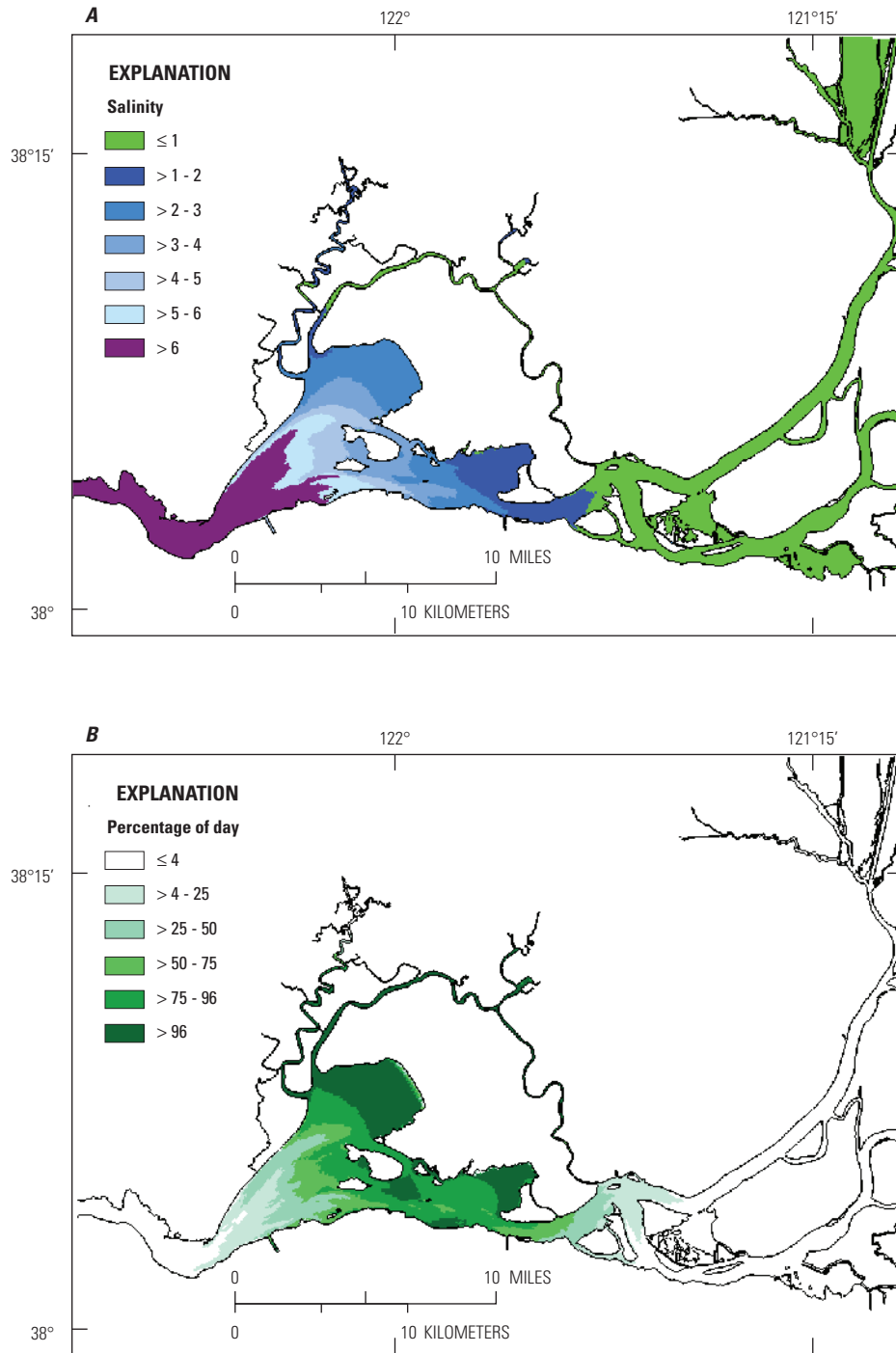


Figure 15. Maps showing *A*, Location of the low-salinity zone (salinity 1–6) when X2 is at 74 kilometers; connections to Suisun Bay and Suisun Marsh are extensive. *B*, Percentage of day that the low-salinity zone occupies different areas (appendix 2). X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Symbols: ≤, less than or equal to; and >, greater than.

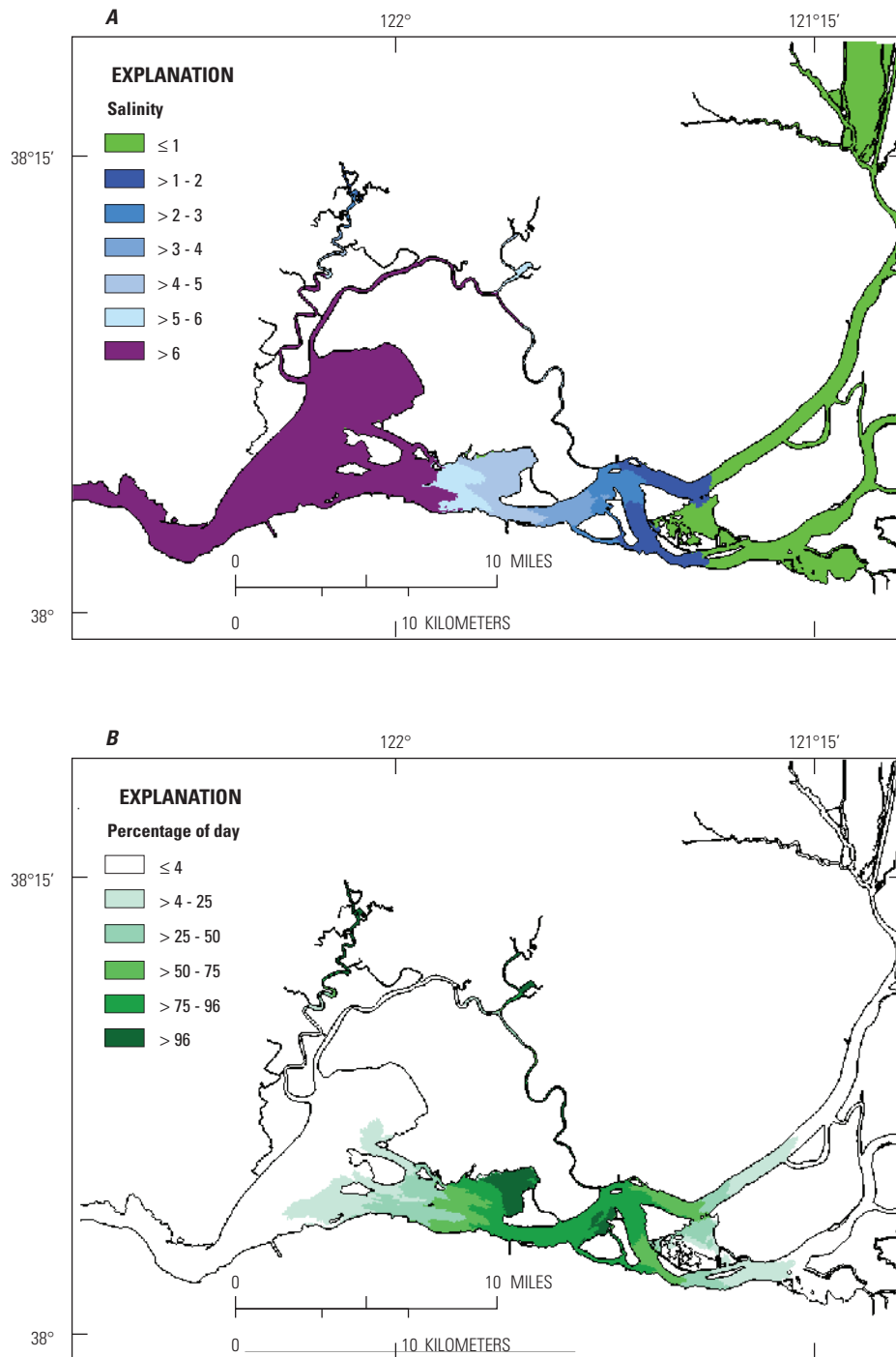


Figure 16. Maps showing *A*, Location of the low-salinity zone (salinity 1–6) when X2 is at 81 kilometers; the low-salinity zone (LSZ) is connected to Suisun Bay, but not Suisun Marsh. *B*, Percentage of day that the LSZ occupies different areas (appendix 2). X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Symbols: ≤, less than or equal to; and >, greater than.

(see, for example, Delta Simulation Model II; Close and others, 2003; California Department of Water Resources, 2005; California Department of Water Resources, 2008). 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 effects on other dynamic habitat components including turbidity, contaminants, and biota. The diverse configurations of shoals, channels, and connections to Suisun Marsh produce complex hydrodynamic features, such as flood-tide 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 shallow embayments. Large, shallow freshwater embayments (flooded islands) exist in the central and northern Delta, but are outside of the region overlain by the LSZ.

- *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 during 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 in shallow water. Wind-wave resuspension is substantial in the shallow bays of the Suisun region and helps maintain generally high suspended-sediment concentrations 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 explanatory factor in delta smelt occurrence during the summer (Nobriga and others, 2008) and fall (Feyrer and others, 2007). Secchi depth is the depth at which the pattern on a Secchi disk is no longer visible from the surface. Turbidity during the winter also appears to be important as a cue for the upstream spawning migration (Grimaldo and others, 2009; Sommer and others, 2011b). 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 this hypothesis. In the SFE, turbidity is largely determined by the amount of suspended, inorganic sediment in the water (Cloern, 1987; Ganju and others, 2007; Schoellhamer and others, 2012), although organic components could also play a role (U.S. Geological Survey, 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 constantly resuspend large amounts of the remaining erodible sediment 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 primarily by riverine and tidal processes, while high wind and associated sediment resuspension have little, if any, effect (Ruhl and Schoellhamer, 2004). In the fall, fine, erodible sediment has been somewhat winnowed from the bed, and wind speed is less than in spring and summer, so wind-wave resuspension and suspended-sediment concentrations typically are low compared to other seasons. In the fall, usually there is less turbidity in the river confluence than in the Suisun region. This difference is also consistent with preliminary analyses by W. Kimmerer (San Francisco State University, written commun.), which indicate 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 and others, 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 during the fall (Kuivila and Hladik, 2008). Urban and industrial pollution from wastewater-treatment plants and industrial discharges is more constant throughout the year, although the amount of contaminant-containing urban storm-water run-off is greatest during winter and spring. In the fall, pollutant loading from stormwater is generally negligible, and lower river flows mobilize fewer sediment-bound contaminants than during other seasons (U.S. Bureau of Reclamation, 2012).

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 and transfers to intermediate and higher trophic levels, including invertebrates, such as zooplankton, benthic invertebrates, 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 low phytoplankton production and biomass overall (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, quality, and biomass 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 and others, 2005). The neurotoxic microcystins found in this cyanobacterium have been found in many components of the food web (Lehman and others, 2010). Although *Microcystis* tends to be restricted to freshwater in the Delta, blooms can extend down into the LSZ. In relation to delta smelt, concern over *Microcystis* is currently focused on possible food-web effects, particularly negative effects on populations of calanoid copepods (Ger and others, 2009, 2010a, 2010b), which are an important food source for delta smelt. If blooms expand in scope and duration, there could be more concern regarding direct effects. Many
- uncertainties remain about the dynamics of food resources that ultimately contribute to delta smelt survival, growth, and health in the fall, particularly at the small scales important to individual delta smelt. Uncertainties also remain regarding the relative importance of food subsidies from upstream regions and food produced in the LSZ. When flows are sufficient to transport biomass downstream, subsidies of biomass from the San Joaquin River have been hypothesized to be important to the LSZ. 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 pelagic food sources and, ultimately, on delta smelt. Overall, food quantity and quality could be greater for delta smelt if the fall LSZ is in Suisun Bay, rather than the river confluence, but many uncertainties remain (U.S. Bureau of Reclamation, 2012).
- 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 extent of habitat for a population of prey organisms can cause the prey density to increase in the remaining habitat, which results in an increased probability of predator-prey encounters. In the SFE, the fall distribution of piscivorous juvenile striped bass overlaps the fall distribution of delta smelt. Striped bass are in both the confluence and the Suisun region (Nobriga and others, 2005; Sommer and others, 2011a). Greater turbidity in the Suisun region could, however, reduce predation risk for delta smelt in these areas compared to the river confluence, where turbidity is generally less. Large-mouth bass are increasingly abundant in the central and northern Delta (Brown and Michniuk, 2007) and could 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 (Baerwald and others, 2012), but are too small to prey on juvenile and sub-adult delta smelt in the fall. 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 generally could be high in the river confluence, but variable in the Suisun region (U.S. Bureau of Reclamation, 2012). Much uncertainty remains, however, about the role and magnitude of predation in these regions.

Delta Smelt Responses

The POD and HSG models indicate 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, could offer 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 could 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 could be subject to Allee effects, which cause a downward spiral that can 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) indicates that the delta smelt population is still resilient and able to respond to favorable conditions, reducing the risk of Allee effects (but see Fisch and others, 2011).

- *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, 2011b). Older life stages of delta smelt potentially do not require the same high-turbidity levels that larval delta smelt need to successfully feed, but are most likely able to discriminate degrees and types of turbidity (and salinity) to find waters that contain appropriate prey resources and that will provide some protection against predation (U.S. Bureau of Reclamation, 2012). A westward LSZ (fig. 15) 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 more turbidity and more food, when the LSZ overlaps the Suisun region, could help delta smelt avoid predators and increase survival and growth. Distance from entrainment sites and locations where predators can congregate (artificial physical structures, scour holes in river channels, and *Egeria* beds) could also help increase survival. Higher phytoplankton production in shallow areas of the Suisun could provide more zooplankton (U.S. Bureau of Reclamation, 2012) and, thus, better food resources for delta smelt compared to the deep river confluence during high outflow years when the deep water and short residence time could limit phytoplankton growth rate (Lucas and Thompson, 2012). Increased growth could result in greater size of adult delta smelt and greater fecundity of females, since the 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 could increase the likelihood of repeat spawning by females. In addition, a larger habitat area could help delta smelt avoid areas with high concentrations of contaminants.
- *Recruitment in the next spring:* Ultimately, the factors listed previously could lead to increased distribution, abundance, and reproductive potential (that is, total egg production) of the delta smelt population. However, adult delta smelt need to successfully spawn, and larvae must find suitable rearing conditions to produce increased numbers 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, delta smelt also are observed year-round in the northern Delta (Sommer and others, 2011b; Merz and others, 2011); therefore, 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 could differ between this region and the LSZ. The 2011 FLaSH studies included a comparison of dynamic and stationary habitat features to 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, 2011b). There is a slight salinity gradient from freshwater in the mainstem Sacramento River 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. The northern Delta 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 potentially are not 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, 2011b), fish rearing in the area could avoid negative factors associated with downstream dispersal followed by an upstream spawning migration. Thus, the northern Delta could represent a secondary production area for delta smelt. As noted earlier, 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 can exhibit different migration patterns (Sommer and others, 2011b).

Hypotheses and Predictions

A key to the adaptive approach described in the FLASH AMP is that the alternative fall-outflow scenarios within the fall low-salinity habitat component of the RPA lead to a suite of expected responses based on the hypotheses, which constitute the conceptual model. Such expected responses range from changes in dynamic habitat drivers to changes in 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 are supported.

Table 1. Predicted qualitative and quantitative outcomes of the fall low-salinity habitat component of the Reasonable and Prudent Alternative based on three levels of X2 (modified from U.S. Bureau of Reclamation, 2012). In wet years, the target is X2 at 74 km, and in above normal years, the target is X2 at 81 km.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. **Abbreviations:** cfs, cubic feet per second; CVP, Central Valley Project; DS, delta smelt; ha, hectare; LSZ, low salinity zone (salinity 1–6); SWP, State Water Project; ~, approximately]

Variable (September–October)	Predictions for X2 scenarios		
	85 km	81 km	74 km
Dynamic abiotic habitat components			
Average daily net delta outflow	~5,000 cfs	~8,000 cfs	11,400
Surface area of the fall LSZ	~4,000 ha	~5,000 ha	~9,000 ha
Delta smelt abiotic habitat index	3,523	4,835	7,261
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 <i>Microcystis</i>)	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 <i>Microcystis</i> 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
<i>Potamocorbula</i> 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 responses			
DS caught at Suisun power plants	0	0	Some
DS in fall SWP and 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

Several important dynamic response variables are indicated by the conceptual model, but not yet incorporated into table 1 because the available data are insufficient to support qualitative or quantitative predictions. These include contaminant concentrations and effects, jellyfish dynamics, microbial dynamics, and delta smelt population responses in seasons other than the fall. The “81-km” and “74-km” columns in table 1 correspond to 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 fig. 13). The 85-km column in table 1 represents the static low-fall outflow scenario (right side of fig. 13).

Methodology

The general approach in this report is to evaluate the predictions in the AMP. For each prediction in table 1, we reviewed the available information and made a judgment about whether the prediction was supported by the available data. For the purposes of this report, we defined fall as the months of the fall midwater-trawl (FMWT) survey, which generally begins in September and ends by mid-December. Within fall, we recognized two important periods. The RPA requires water management to maintain X2 at a designated value in September and October, which is the first period of interest. November through mid-December constitute the second period of interest. Our evaluation of predictions relied largely on agency collected monitoring data (table 2) because those were the data available at the time, but this does not reflect any preference for those data. Note that data can include actual measurements, calculations from measurements, or the output of models (table 2 and appendixes 1–8). Chlorophyll- α concentrations were measured by chemical analysis of pigments, unless noted otherwise.

We included analyses of data from other years besides 2011 because our approach is comparative. We included 2006 because it is the most recent wet year preceding 2011. As already noted, we recognize that preceding habitat conditions can have important implications for the outcomes of the fall low-salinity habitat component of the RPA during any particular year; therefore, we also considered data from 2005 and 2010. Coincidentally, during fall 2010, X2 averaged 85 km (table 3), which provided a good comparison with 2011 because X2 was very close to the minimum and maximum referenced in table 1. In 2005 and 2006, fall X2 averaged 83 and 82 km, respectively. While these values do not correspond exactly to the 81-km condition in table 1, they do provide contrasting data for years where X2 was between 75 and 85 km.

The data analyses focused 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 calendar year, we included data from January 1 to September 30, which is the overlap of water year and calendar year, plus the first 3 months of the following water year, October 1 to December 31. All 4 years of interest were during the

Table 2. Data sources with references to appendixes 1–8, where more detailed methods can be found.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. **Abbreviations:** CDFW, California Department of Fish and Wildlife; DWR, Department of Water Resources; LSZ, low salinity zone (salinity 1–6); QWEST, the calculated net outflow from the San Joaquin River; UCD, University of California at Davis; USGS, U.S. Geological Survey; +, plus; —, not available]

Type of data	Responsible agency	Data type	Appendix
DayFlow data			
Delta average daily outflow	DWR	Calculation	1
QWEST	DWR	Calculation	1
X2	DWR	Calculation	1
Delta Modeling Associates data			
Surface area of LSZ	Delta Modeling Associates	Model output	2
Maps of LSZ	Delta Modeling Associates	Model output	2
U.S. Bureau of Reclamation data			
Delta smelt habitat index	Reclamation	Model output	3
Fall midwater trawl data			
Delta smelt abundance index	CDFW	Calculation	4
Water temperature	CDFW	Measurement	4
Specific conductance	CDFW	Measurement	4
Secchi depth	CDFW	Measurement	4
Turbidity	CDFW	Measurement	4
Microcystis occurrence	CDFW	Measurement	4
Diet data	CDFW	Measurement	4
Center of distribution	CDFW	Calculation	4
Ammonium	UCD	Measurement	4
Nitrate	UCD	Measurement	4
Chlorophyll- α	UCD	Measurement	4
USGS sediment monitoring data			
Analyses of turbidity and suspended sediment	USGS	Calculation	5
Environmental Monitoring Program data			
Ammonium	DWR	Measurement	6
Nitrite + nitrate	DWR	Measurement	6
Chlorophyll- α	DWR	Measurement	6
Zooplankton abundance	DWR	Measurement	6
USGS water quality monitoring data			
Ammonium	USGS	Measurement	7
Nitrite + nitrate	USGS	Measurement	7
Chlorophyll- α	USGS	Measurement	7
CDFW fish sampling data			
Spring kodiak trawl delta smelt abundance index	CDFW	Calculation	8
20-mm survey delta smelt abundance index	CDFW	Calculation	8
Summer townet survey delta smelt abundance index	CDFW	Calculation	8

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 (appendix 1), delta outflow (appendix 1), surface area of low salinity zone (appendix 2) are for September–October and values for the habitat index (appendix 3) are for September–December.

[**Abbreviations:** LSZ, low salinity zone (salinity 1–6); SD, standard deviation; X2, the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2]

Year	X2 (kilometers)		Outflow (cubic feet per second)		Surface area LSZ (hectares)		Habitat index	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2005	83	2	5,654	1,745	4,889	252	4,294	600
2006	82	3	5,451	2,020	4,978	320	4,481	823
2010	85	2	5,677	2,709	4,635	226	3,517	346
2011	75	1	12,204	3,646	8,366	133	7,095	332

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 less than 1, 1–6, and greater than 6. The Cache Slough complex and SRD-WSC were treated as a separate category because delta smelt are known to occupy the area for the entire year even though salinities are less than 1. Thus, this area was of special interest and warranted 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 appendices.

Results from other ongoing research efforts were included as appropriate. When such data were not yet available from publicly available interim or final reports, the data were included in the appendix. Much of the data collected as part of the FLASH studies were not yet available because sample analysis, data processing, data analysis, and data interpretation are ongoing. This information will be incorporated into the next FLASH report.

Although fall conditions during the years selected for data analysis roughly correspond to values of X2 designated in the AMP (compare values in tables 1 and 3), this report cannot be considered a rigorous test of the predictions. In many cases, the predictions (table 1) were qualitative rather than quantitative, where the parameter values for X2 at 74 km were expected to be greater or less than values for X2 at 85 km, and values were expected to be intermediate for X2 at 81 km. For these reasons, we generally limited 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 approaches are offered for resolving the situation.

Most data are presented as boxplots. 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 when all values are within one and a half times the inter-quartile distance from the nearest hinge; otherwise, it denotes one and a half times the inter-quartile distance from the nearest hinge. Values outside this range are shown as individual symbols. Other types of plots are explained in the figure captions.

Evaluation of Predictions

Operations during September–October 2011 and the preceding months resulted in an average X2 similar to that prescribed for a wet-year in the fall low-salinity habitat component of the RPA (table 3, fig. 17). In addition, during September–October 2010, X2 was at 85 km—the maximum X2 scenario considered. During fall 2005, X2 was at 83 km, somewhat below the 85-km scenario. During fall 2006, X2 was very close to the 81-km X2 scenario for an above-normal year (table 3), even though it was a wet water year (see <http://cdec.water.ca.gov/cgi-progs/iudir/wsihist> for specific definitions of water-year types; table 3). The first four predictions in table 1 are not predictions in the usual sense. We know that Delta outflow, X2, the size of low-salinity habitat, and the delta smelt habitat index are related, and calculations of the latter three values are dependent on the value of the first (see appendices 1, 2, and 3). 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.

As described earlier, 2006 was the most recent wet year prior to 2011, and fall outflow, fall X2, the surface area of the LSZ, and the delta smelt habitat index differed between the 2 years (table 3, figs. 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.

Predictions for Dynamic Abiotic Habitat Components

Variation in average September–October daily net Delta outflow during the 4 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 an increase in outflow in September–October compared to earlier months. Similarly, in 2011, there was an increase in September–October compared to late-summer flows, as well as higher late-summer flows

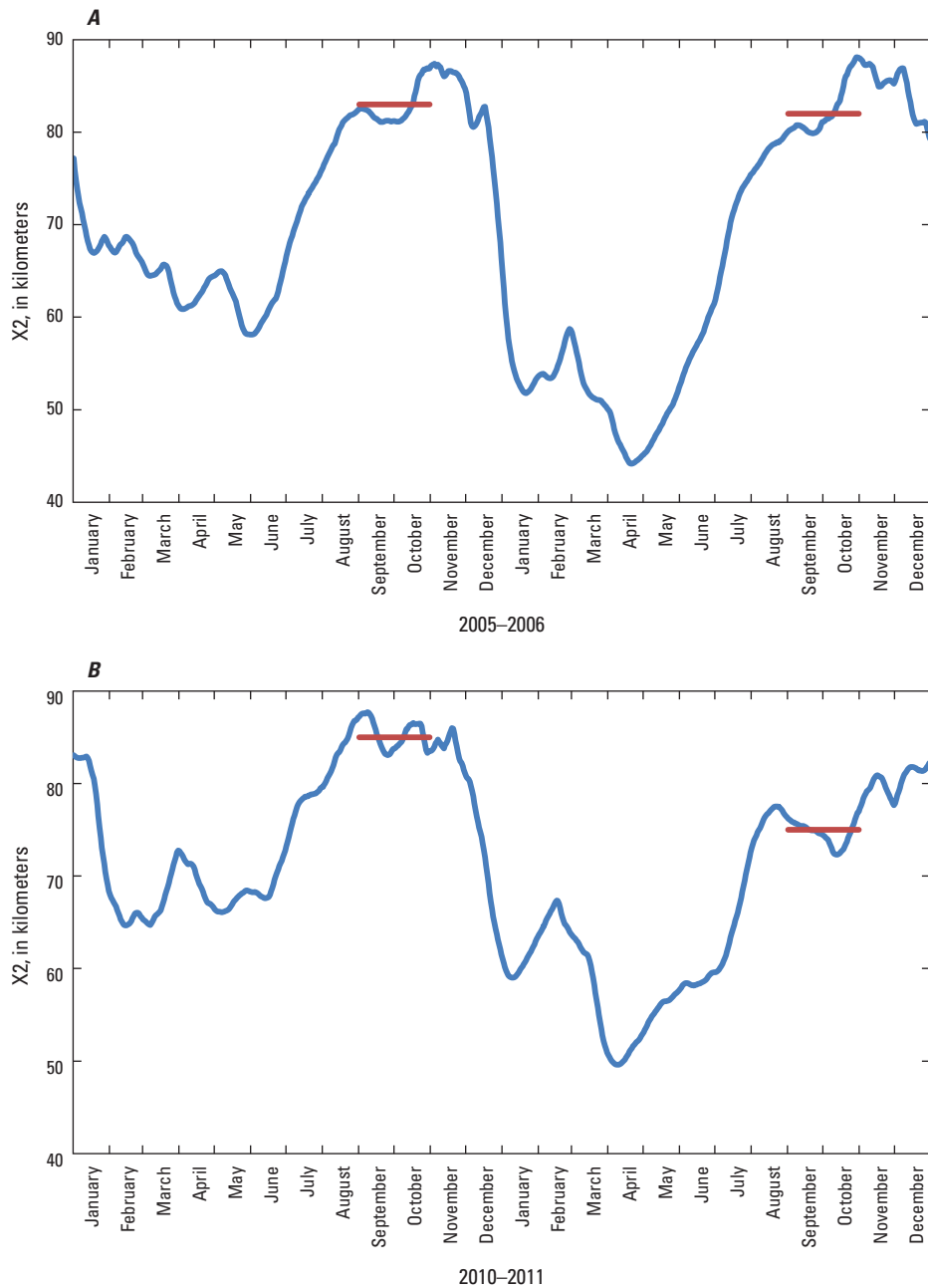


Figure 17. Daily X2 for A, 2005–2006 and B, 2010–2011. Mean daily X2 for each year during September to October is shown by the horizontal bar (see appendix 1 for data source). X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2.

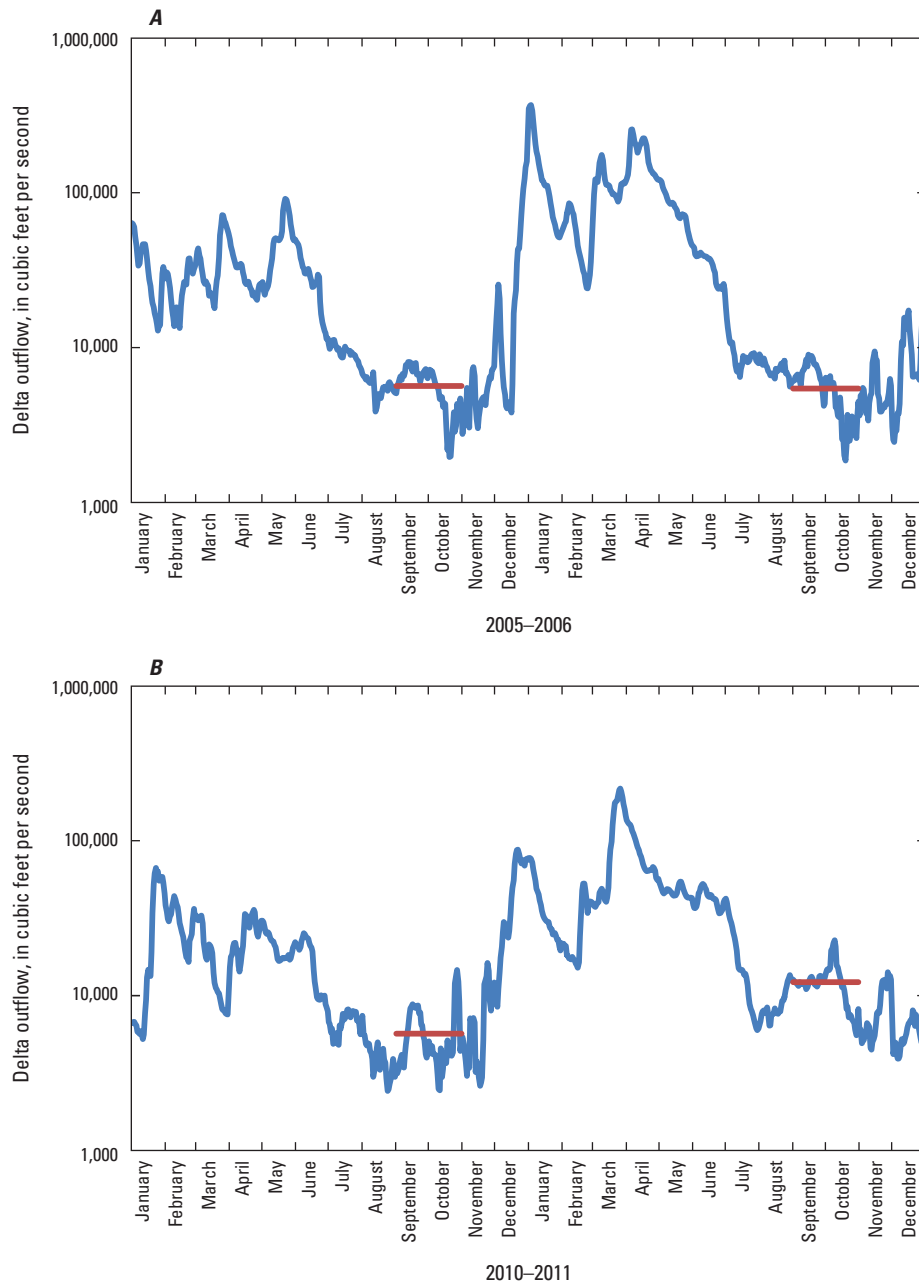


Figure 18. Daily Delta outflow for A, 2005–2006 and B, 2010–2011. Mean daily outflow during September to October are shown by the horizontal bar (see appendix 1 for data source).

than in comparison years. Outflows, during fall 2011, were relatively constant or increased compared to the other years; however, there was still a rapid decline in October (fig. 18). Increased flows in September–October are often influenced by water-management actions for migrating salmonids and to reduce reservoir volumes in anticipation of winter-stormflows for flood control.

Observed mean values of outflow (table 3) were somewhat similar to those predicted for scenarios with a similar X2 value (table 1). Predicted outflow with X2 at 74 km was 11,400 cubic feet per second (cfs) compared to the observed outflow of $12,710 \pm 3,679$ cfs (mean \pm standard deviation; table 3) for X2 at 75 km. There was uncertainty associated with the predictions of outflows for all the X2 scenarios (table 1) because X2 changes more slowly than outflow and depends on the preceding position of the LSZ as well as daily changes in outflow (Jassby and others, 1995). The observed values for outflow showed few differences for X2 varying between 82 and 85 km (table 3). This indicates 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 appeared to be correct within a standard deviation of the prediction. The observed values for X2 at 75 km in fall 2011 indicated that the predicted value was somewhat low to produce an X2 of 74 km; however, variability in the observed values was large, making an exact conclusion impossible. More consistent outflows during a managed action, if possible, could provide for a more definitive conclusion.

Not surprisingly, the daily surface area of the depth-averaged low-salinity zone (fig. 19) showed patterns similar to those of daily outflow (fig. 18). As noted earlier, outflow determines X2 and the location and size of the LSZ in the estuary. The areal size of the LSZ showed less variability than daily outflow (table 3). This is likely the case because outflow can be changed relatively quickly by changes in operations; however, the translation of changes in outflows to changes in the location of the LSZ depends on complex hydrodynamic processes that take place over a more extended period, which results in salinity changing in a more gradual and complex manner (Monismith and others, 2002).

There are some notable features of the general pattern of changes in surface area of the LSZ (fig. 19). First, the largest surface areas—above about 9,000 hectares—corresponded to outflows and X2 values that move the LSZ through Carquinez Strait and out into San Pablo Bay. These high flows occurred during the springs of wet years. Low spring X2 values for extended periods are not always associated with high production of delta smelt (Jassby and others, 1995; Kimmerer, 2002a, 2002b). The other notable result is that in late summer and September–October 2011, there was an extended period where the surface area of the LSZ was large and relatively constant compared to other years (fig. 19). In the other 3 years, the surface area of the LSZ decreased during the preceding summer months, then remained relatively small through the fall and early winter until the first rains.

The predicted surface areas of the LSZ (table 1) were approximately the same as those calculated (table 3). The prediction of about 9,000 hectares for the LSZ when X2 is at 74 km compares favorably with the 8,366 hectares estimated from the data. This is not surprising because both values were calculated from the same model (appendix 2). The difference is that, in fall 2011, average X2 was 75 km, and there was variability in the position of X2 through the fall. The estimated surface areas for X2 at 82–85 km were also similar to predicted values (table 3)—between 4,500 and 5,000 hectares. The surface area of the LSZ was expected to decrease when X2 ranged from 81 to 85 km, and the mean estimated surface area did decrease, as expected, but the standard deviations were approximately equal to the differences between the means (table 3). Given the variability in the values, no firm conclusions are justified concerning the surface area of the LSZ at the greater values for X2. The prediction that the surface area of low-salinity habitat increases with decreasing X2 values appears to be true when comparing an X2 of 75 km to the greater values considered; however, over the shorter range of X2 values, from 82 to 85 km, it is unclear if daily variability in X2 can be operationally controlled sufficiently, such that statistically different areal sizes of LSZ can be provided. Additional work is needed to better understand the operational limits of X2 location control.

The delta smelt abiotic habitat index was greater in September–October 2011 compared to the other years (table 3; fig. 20). The abiotic habitat index was lowest in September–October 2010; however, except for September–October 2011, differences between means were relatively small compared to standard deviations, particularly in 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 period of the FMWT survey (September–December), so the abiotic habitat index was not calculated for other months.

Generally, there appeared to be little contribution of San Joaquin River flow to Delta outflow through the confluence region and into the LSZ (fig. 21) as measured by the calculated net outflow from the San Joaquin River (QWEST). In 2005 and 2006, QWEST was never positive during September–October. In September–October 2010, 6 days of positive QWEST were observed. In September 2011, 11 days of positive QWEST were observed. QWEST data for October were not available for this report. Although the prediction for San Joaquin River contribution was qualitative, the available data indicated a very low contribution to total outflow even when X2 is at 74 km; however, 11 days of positive flow in September 2011 was indicative of a greater contribution to flow from the San Joaquin River. The outcome of this prediction could be better determined when water-year 2012 data are finalized.

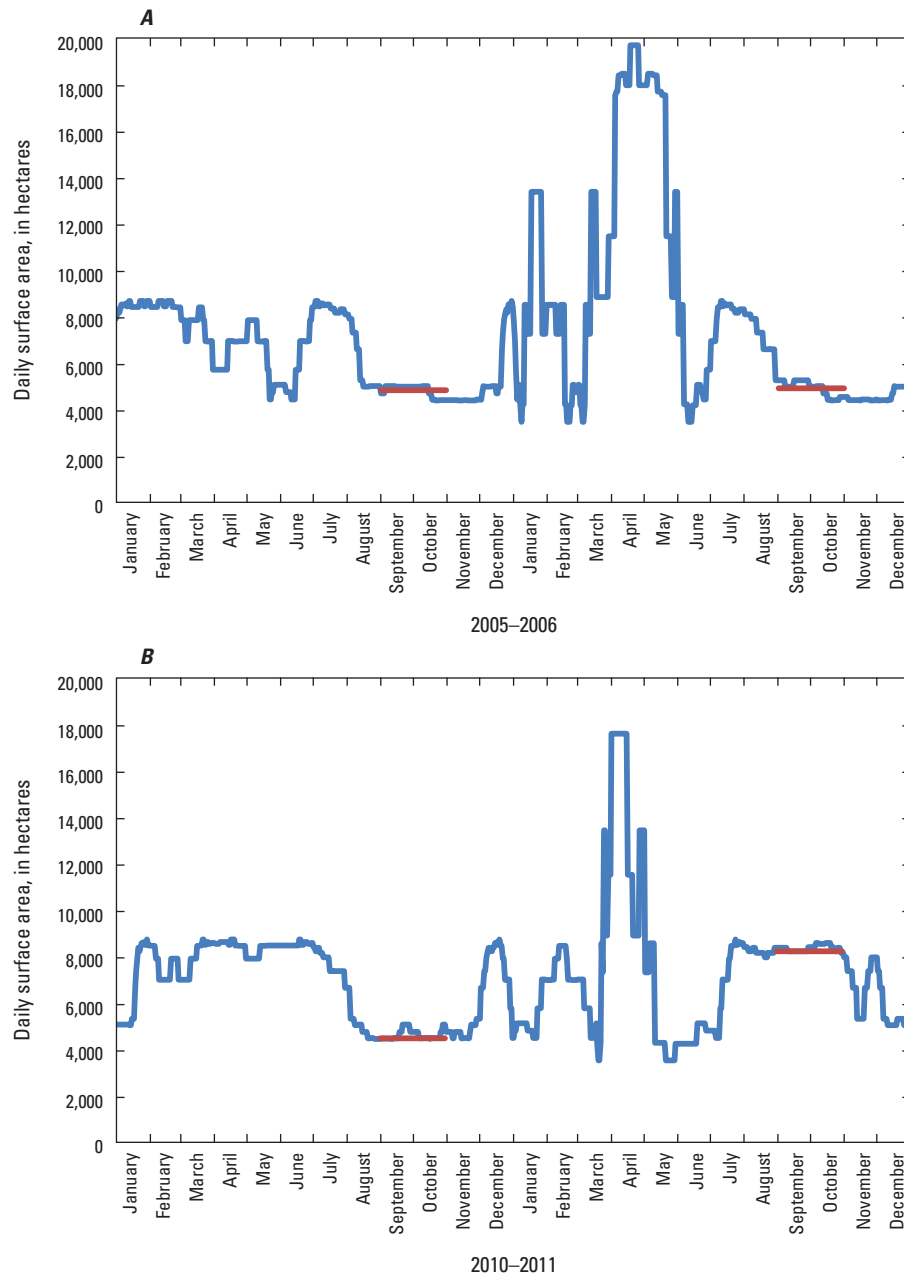


Figure 19. Daily surface area of the depth-averaged low-salinity zone (salinity 1–6) for *A*, 2005–2006 and *B*, 2010–2011 (data from table 2.1). Mean daily surface areas during September to October are shown by the horizontal bar.

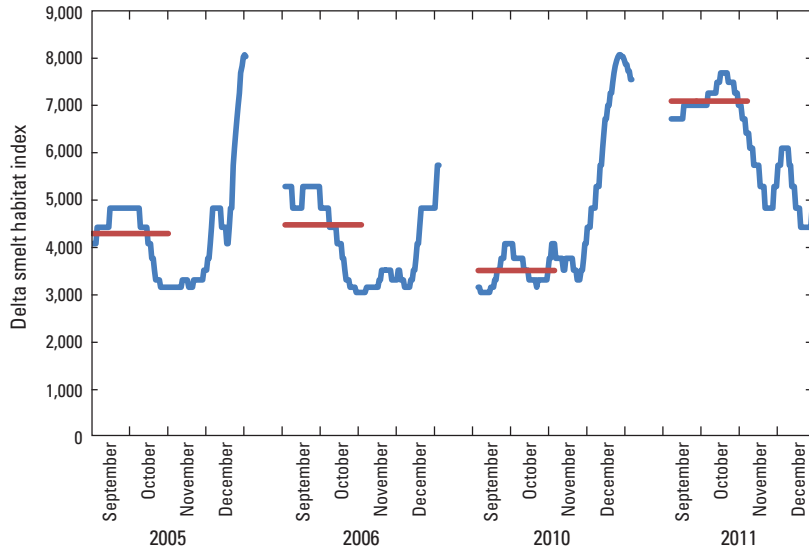


Figure 20. Daily delta smelt habitat index for the fall (September–December) for 2005, 2006, 2010, and 2011 (appendix 3). Mean daily delta smelt habitat index during September to October is shown by the horizontal bar.

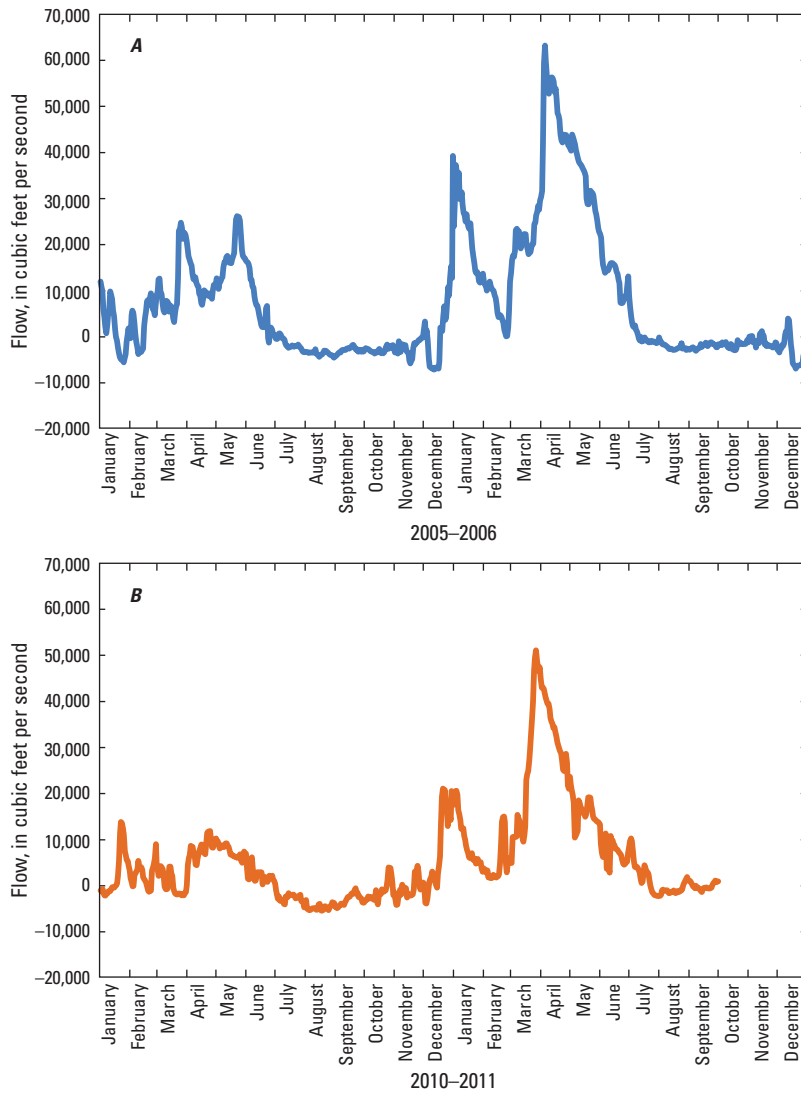


Figure 21. Daily net flow past Jersey Point on the San Joaquin River for A, 2005–2006 and B, 2010–2011 (appendix 1).

The prediction of little to no contribution to fall outflow from San Joaquin River flow with the greatest contribution when X2 is at 74 km appeared to be qualitatively correct over the range of X2 considered. The QWEST data are a relatively coarse test of this prediction, and hydrodynamic modeling might provide a more quantitative test.

The prediction about San Joaquin River flow (table 1) is potentially important to delta smelt because of the hypothesized relation 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 to evaluate this hypothesis. Although, September–October 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, QWEST flows were negative during the preceding months, generally July and August. In contrast, in 2011, positive QWEST flows persisted through most of July. The greater persistence of San Joaquin River contribution into the summer could have effects on productivity that could carry over into the fall.

The prediction regarding increased hydrodynamic complexity at lesser X2 (table 1) could not be evaluated. The FLaSH AMP did not link the prediction with a specific metric to quantify hydrodynamic complexity. Hydrodynamic modeling of SFE could allow for calculation and mapping of hydrodynamic qualities, such as velocity vectors, that could be useful in describing hydrodynamic complexity in a quantitative and easily explainable manner. Deployment of instrument packages, including current profilers, along with existing monitoring stations is likely to provide useful data for calibrating models and directly evaluating hydrodynamic conditions. Some combination of modeling and data collection is necessary to objectively evaluate this hypothesis as the FLaSH AMP continues.

The prediction that wind speed would be higher when X2 was at 74 km and lower for X2 at 85 km 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, suspended-sediment concentration 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. 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 to be a useful approach.

Because the predictions regarding Secchi depth and turbidity are both related to water clarity, we present those results together. The prediction is that turbidity will be greater and Secchi depth lesser at greater X2 (table 1). We first present results from data collected during the FMWT (appendix 4) and then results from detailed analyses of data from fixed sites (appendix 5). We also present additional analyses from fixed sites that are important to understanding the other results.

Secchi depth has a longer data record than turbidity in the FMWT and has been collected since the beginning of the program. In the LSZ, Secchi depth in September–October was lowest in the LSZ in 2011 and highest in 2010 (fig. 22). Overall, September–October Secchi depth was comparable across years and regions, except water clarity tended to be greater in freshwater. Another exception was Cache Slough and the SRDWSC, which had particularly shallow Secchi depth in 2005. The prediction that Secchi depth would be higher when X2 was at 85 km, and lower when it was at 74 km was supported for the LSZ.

Turbidity data were only available for the FMWT for 2010 and 2011 (fig. 23). Not surprisingly, differences in turbidity were similar to those for Secchi depth for the available data. Turbidity was greater in the LSZ during September–October 2011 compared to 2010. The freshwater region tended to be clearer than the other regions during September–October, although differences from the greater than salinity 6 region were small, especially in 2011. Turbidity in Cache Slough and SRDWSC tended to be greater than in the freshwater and greater than salinity 6 regions, but not as great as in the salinity 1–6 region. Except for the LSZ, turbidities were similar for 2010 and 2011.

The turbidity results were similar to those for Secchi depth for the LSZ in November–December 2011 (figs. 22 and 23). Measurements indicated the LSZ was more turbid in November–December 2011 compared to November–December 2010. The Secchi depth data had the same trend, but there was more variability in Secchi depth measurements. The prediction that water clarity of the LSZ would decrease (Secchi depth lesser and greater turbidity) with decreasing X2 values appeared to be true within the range of X2 values considered (75–85 km).

Continuous data from fixed sites supported the idea that Suisun Bay was more turbid than the confluence in the fall of 2011 (fig. 24). However, this regional difference in turbidity was independent of any direct influence of X2 or of salinity (appendix 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 indicates 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).

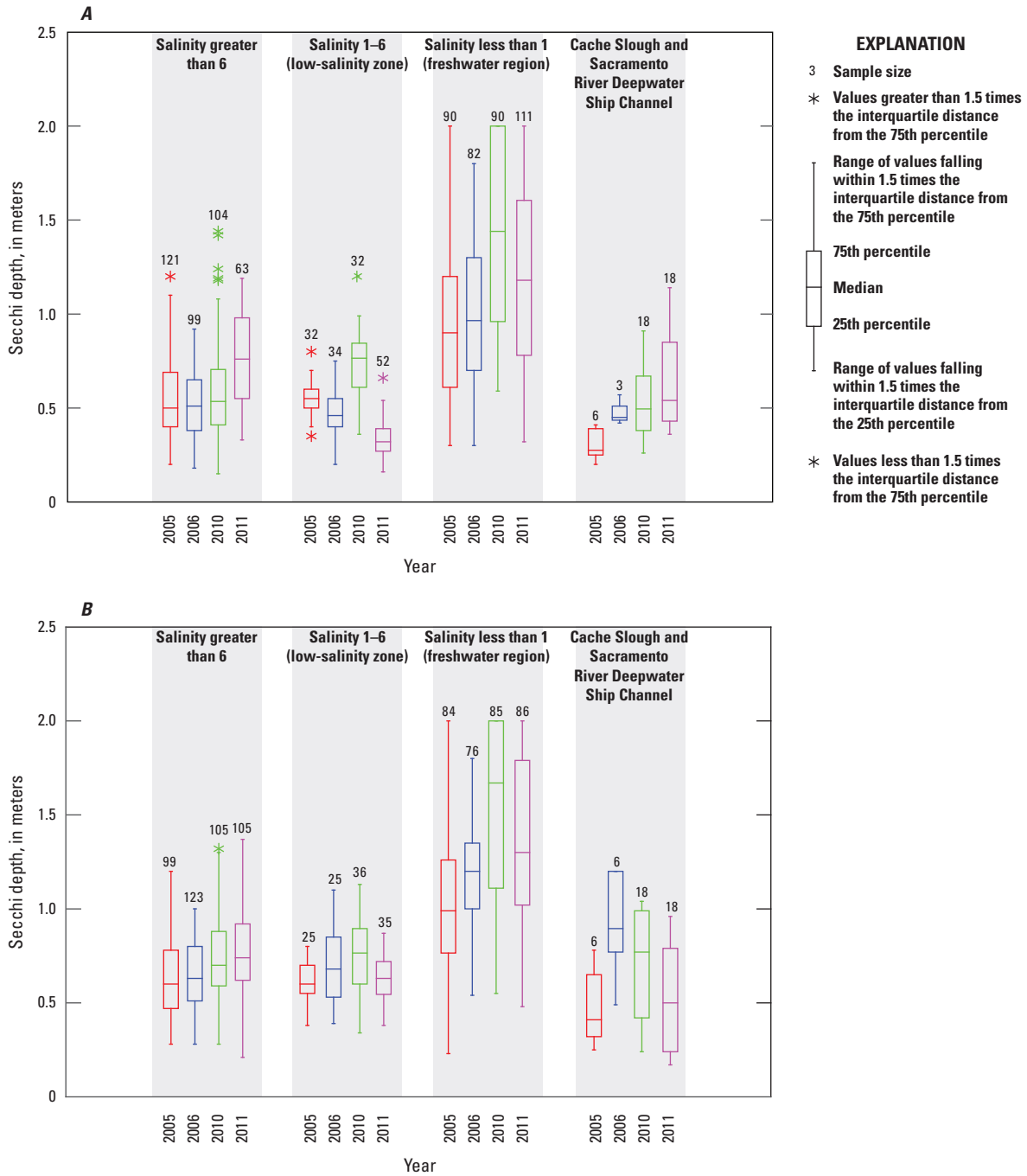


Figure 22. Graphs showing Secchi depth data collected during the fall midwater-trawl survey: *A*, September–October; and *B*, November–December (appendix 4).

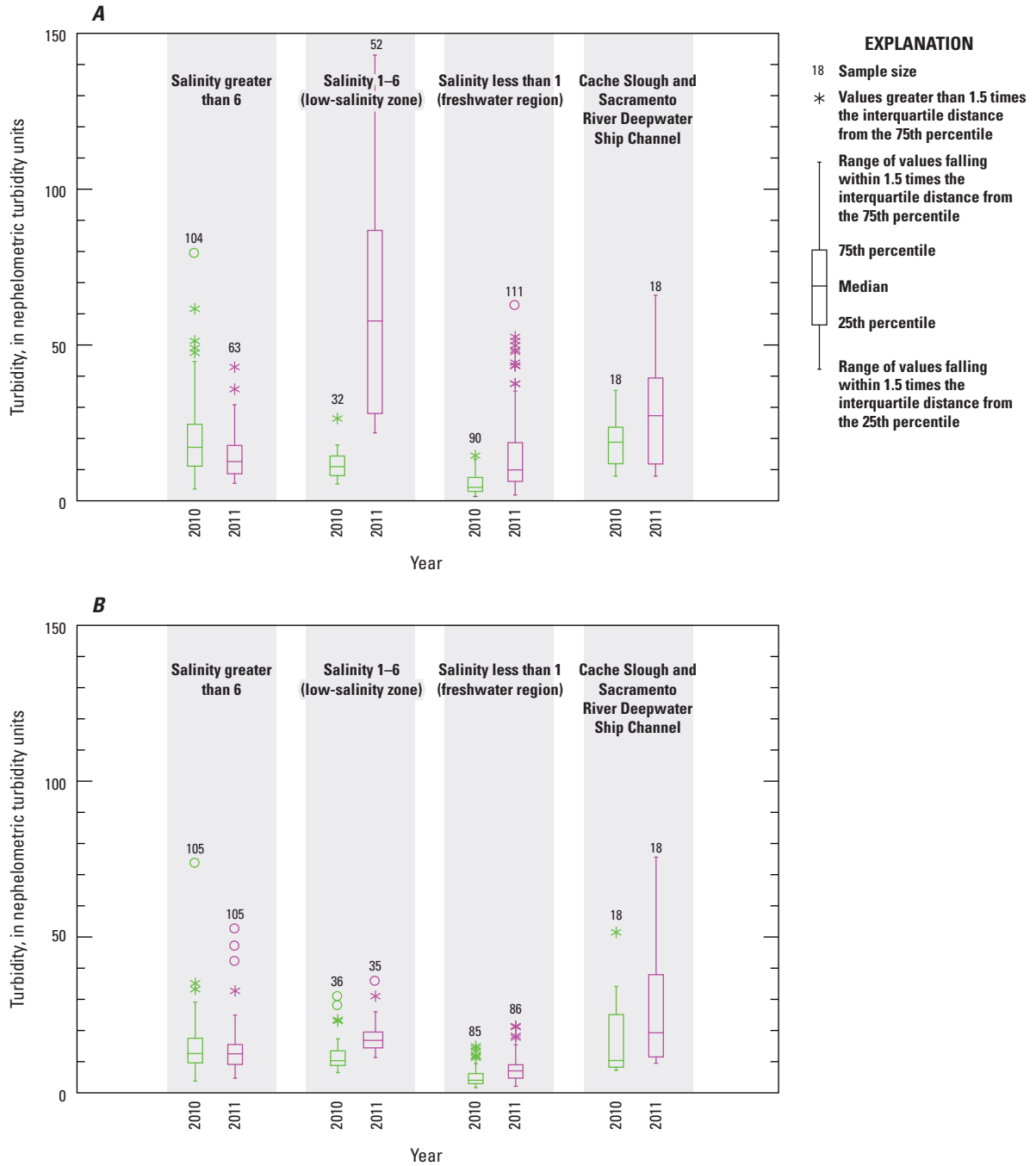


Figure 23. Turbidity data collected during the fall midwater-trawl survey: *A*, September–October; and *B*, November–December (appendix 4). These data were not collected in 2005 and 2006.

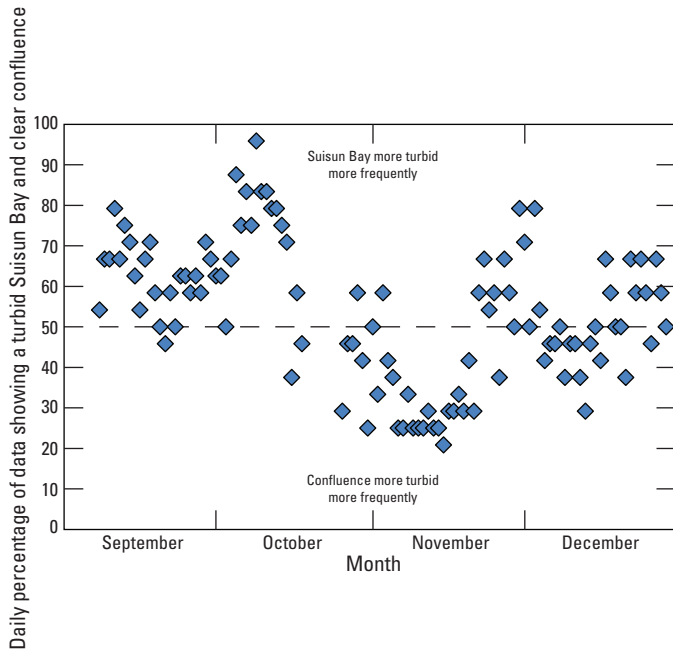


Figure 24. Percentage of data showing a turbid bay and clear confluence, September–December 2011, calculated from the product of hourly deviations of specific conductance and suspended-sediment concentration (SSC) from tidally averaged values. Values greater than 50 percent indicate specific conductance and SSC are either both positive (relatively turbid bay water) or negative (relatively clear confluence water). Values less than 50 percent indicate that deviations of conductance and SSC have opposite signs (relatively clear bay or relatively turbid confluence). See appendix 5 for details.

Although the prediction for turbidity 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. In the Cache Slough complex, however, the opposite was observed; turbidity was greater in fall 2010 than in 2011. Differences in turbidity between Mallard Island and the Cache Slough complex were not consistent between years (appendix 5).

Although the prediction that X2 at 74 km was associated with a more turbid LSZ was supported by the data, analysis of long-term trends indicate caution should be applied in assuming that actual turbidity levels 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 5). This is consistent with a 50 percent decrease in total suspended-solids concentration (equivalent to SSC in this estuary) in the Delta from 1975 to 1995 (Jassby and others, 2002). In 1999, there was a 36 percent step decrease in SSC in San Francisco Bay when the threshold from transport to supply regulation was crossed

because 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 increased water clarity in the SFE as a whole.

Although there was no specific prediction regarding water temperature, it can be an important explanatory variable through its effects on fish growth and physiology and other biological and physical processes. There was relatively little interannual 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 the greater than salinity 6 region in September, but not in the other months. Water temperatures in 2011 were generally cooler than water temperatures in 2010, except for September.

The major sources of ammonium in the system include point sources of treated wastewater, with the large treatment plant servicing Sacramento and discharging into the Sacramento River constituting a major source (Jassby, 2008). The prediction that ammonium concentrations will be greater when X2 is at 85 km compared to 74 km 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. On the basis of the Environmental Monitoring Program (EMP) data, concentrations in September–October did not show consistent patterns within or among years (fig. 27). In the LSZ, ammonium concentrations were higher in 2011 compared to 2010. Concentrations of ammonium were generally less than 0.1 milligrams per liter (mg/L) during September–October in all years. The EMP data indicated that there was little difference in ammonium concentrations for 2006, 2010, and 2011 in the LSZ during November–December (fig. 27). Ammonium concentrations appeared higher in 2005 compared to other years in the LSZ and greater than salinity 6 region. The prediction of lower concentrations of ammonium in the LSZ with lesser values for X2 was not supported by the EMP data.

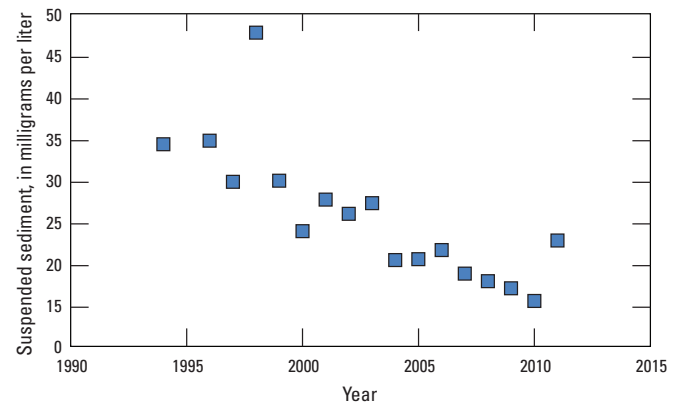


Figure 25. Near-surface suspended-sediment concentration (SSC) at Mallard Island, September–October mean values, 1994–2011. Measurements from 1995 are not included because there were insufficient SSC data. See appendix 5 for more detail on methods and data sources.

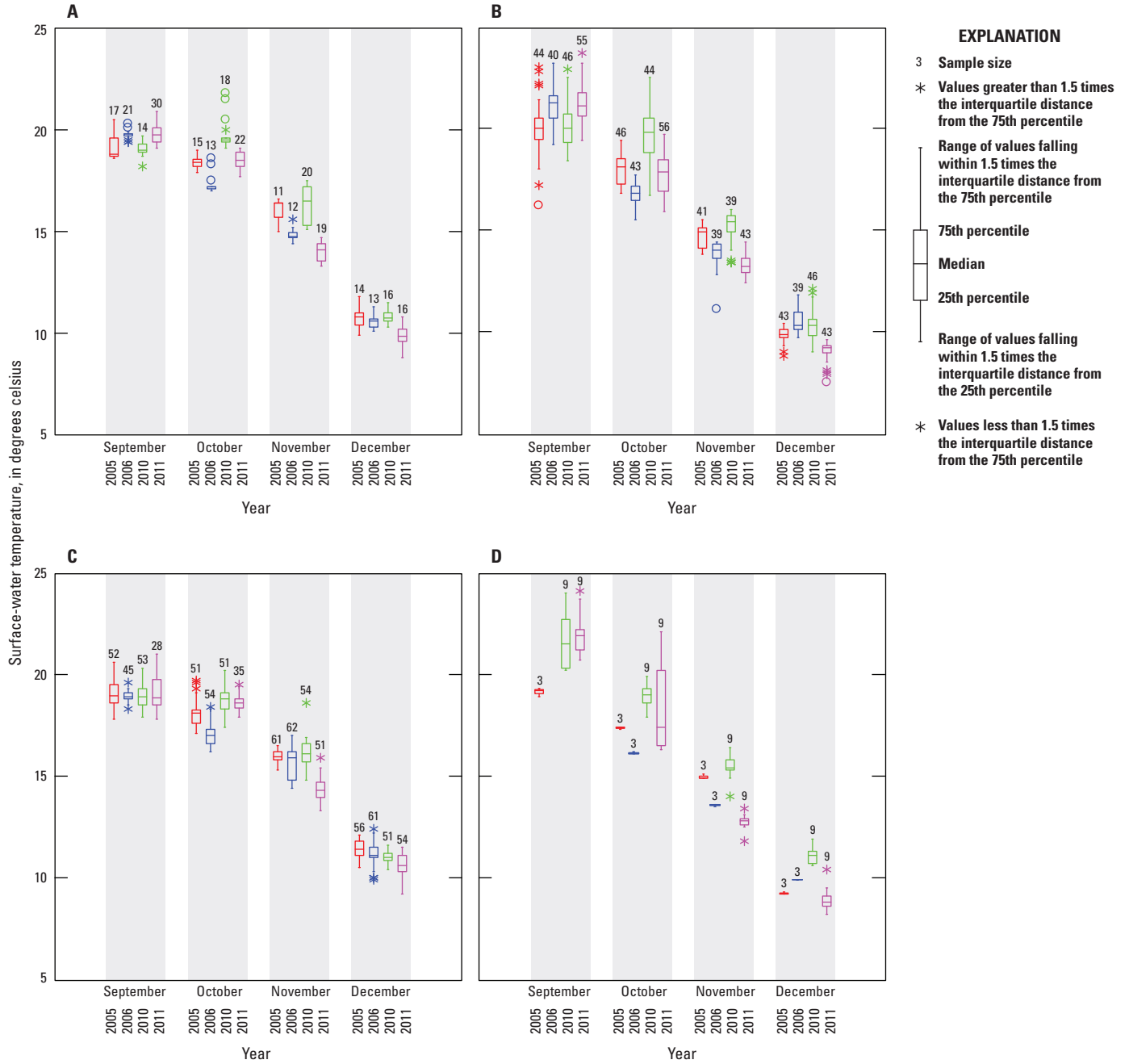


Figure 26. Surface-water temperature at fall midwater-trawl sampling sites during monthly sampling for the *A*, salinity 1–6, low-salinity zone; *B*, salinity less than 1, freshwater region; *C*, salinity greater than 6; and *D*, Cache Slough and Sacramento River Deep Water Ship Channel (see appendix 4 for data sources).

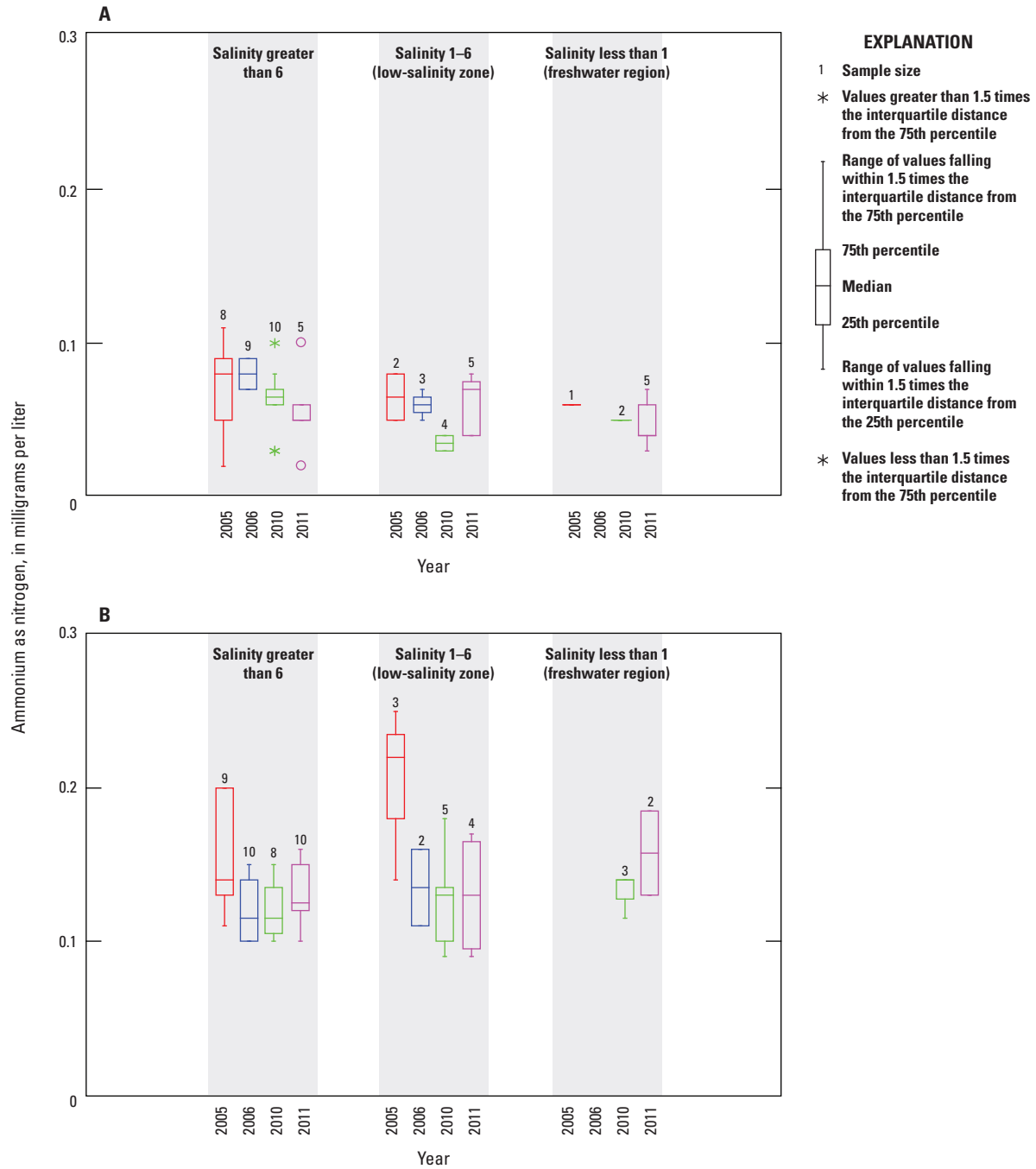


Figure 27. Ammonium concentrations as nitrogen from the Environmental Monitoring Program: *A*, September–October; and *B*, November–December (see appendix 6 for data sources).

Ammonium data collected during U.S. Geological Survey (USGS) Polaris cruises (fig. 28) differed somewhat from the EMP data (fig. 27). In September–October, the LSZ showed no clear trend among years. Median values in the LSZ and greater than salinity 6 region 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, but the USGS sampling program included more stations in the freshwaters of the Sacramento River compared to the EMP data set (appendixes 6 and 7). Similar to the EMP data, the USGS data showed higher concentrations of ammonium in November–December compared to September–October. As with the EMP data, the USGS data did not support the prediction of reduced ammonium concentrations for X2 at 74 km compared to 85 km.

Ammonium concentrations were measured at FMWT stations concurrent with fish sampling for the first time in 2011 (fig. 29). Unfortunately, time-series data are not yet available for comparison. The concentrations measured during FMWT were generally similar to those measured by the EMP and by the USGS. In September–October 2011, there were some relatively high and low concentrations measured in freshwater compared to the LSZ and greater than salinity 6 region. The interquartile range of the less than salinity 1 region contained the entire range of ammonium concentrations measured in the LSZ and greater than salinity 6 region. During November–December, ammonium concentrations in freshwater were higher than those measured in the LSZ and greater than salinity 6 region, except for one value (fig. 29). These results were similar to the USGS data (fig. 28). The EMP data also showed a slightly higher median value for the freshwater region in November–December 2011 (fig. 27), but the difference in values was not as great as in the other two data sets.

The EMP and USGS data that were used to assess the predictions in table 1 were from monthly sampling at fixed locations in the estuary. Studies of nitrogen cycling generally require 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 the research being done as part of FLaSH actually addresses the prediction as stated because nutrient cycling involves many processes other than the simple dilution that is the basis for the prediction. The differences among the EMP, USGS, and FMWT results in 2011 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 values and the LSZ require further research, including analysis of already collected data and continued data collection.

In the EMP data set, nitrite plus nitrate concentrations were generally between 0.2 and 0.4 mg/L during September–October across all regions in all years (fig. 30). In the LSZ, concentrations in 2011 were similar to 2010 and lower than 2005 and 2006. Overall, 2011 tended to have the lowest concentrations in all years and in all salinity regions.

The EMP data did not support the prediction (table 1) of higher LSZ nitrate concentrations when X2 is at 74 km compared to 85 km. The prediction was based on the assumption that at higher outflows, more nitrate would be contributed to the LSZ from the nitrate-rich smaller sloughs of the Cache Slough region, the San Joaquin River, or both.

Nitrite plus nitrate concentrations for September–October were generally between 0.2 and 0.4 mg/L and were similar in the USGS data set (fig. 31) and the EMP data set (fig. 30) with little difference across years and regions. In the LSZ, concentrations were generally lower during September–October 2011 than in other years. There was more variability among years in November–December; however, concentrations in 2011 were always similar to or lower than other years within each region. As with the EMP data, the USGS data did not support the prediction that nitrite plus nitrate concentrations would be higher when X2 was at 74 km compared to greater values of X2.

Similar to the ammonium measurements, 2011 was the first year that nitrite plus nitrate concentrations were determined during FMWT sampling. Concentrations during FMWT in September–October were lower in freshwater than in the LSZ or greater than salinity 6 region (fig. 32). The lowest concentrations were observed in the Cache Slough region. There was little difference among regions in November–December; however, there was a greater range of nitrite plus nitrate concentrations in the Cache Slough region (fig. 32).

Predictions for Dynamic Biotic Habitat Components

The concentration of chlorophyll- α is a common surrogate for phytoplankton biomass. The average concentration of chlorophyll- α in the LSZ was predicted to increase in response to X2 at 74 km compared to X2 at greater distances (phytoplankton biomass prediction; table 1) for several reasons, but this prediction does not include *Microcystis*, which is addressed in a separate section. If the assumed inhibitory effect of ammonium on diatom growth is lessened in the LSZ as a result of higher flows, production of diatoms would be expected to increase, as indicated by increased concentrations of chlorophyll- α . Increased nitrate concentrations in the LSZ would also tend to increase the biomass if the initial or subsequent production of phytoplankton was limited by available nitrate. Also, the location of the LSZ could influence the interaction between phytoplankton and grazers, including clams and zooplankton. The prediction that biomass of *Potamocorbula*, a major grazer of phytoplankton, would be lower when X2 is at 74 km compared to greater distances is based on this interaction. The hypotheses concerning phytoplankton and *Potamocorbula* biomass are relatively simplistic for several reasons. For example, nutrient concentrations are likely to depend on chemical processes (that is, nutrient cycling) other than simple dilution and transport. Also, it is assumed that chlorophyll- α , the selected indicator of biomass, provides an indication of primary production in the system.

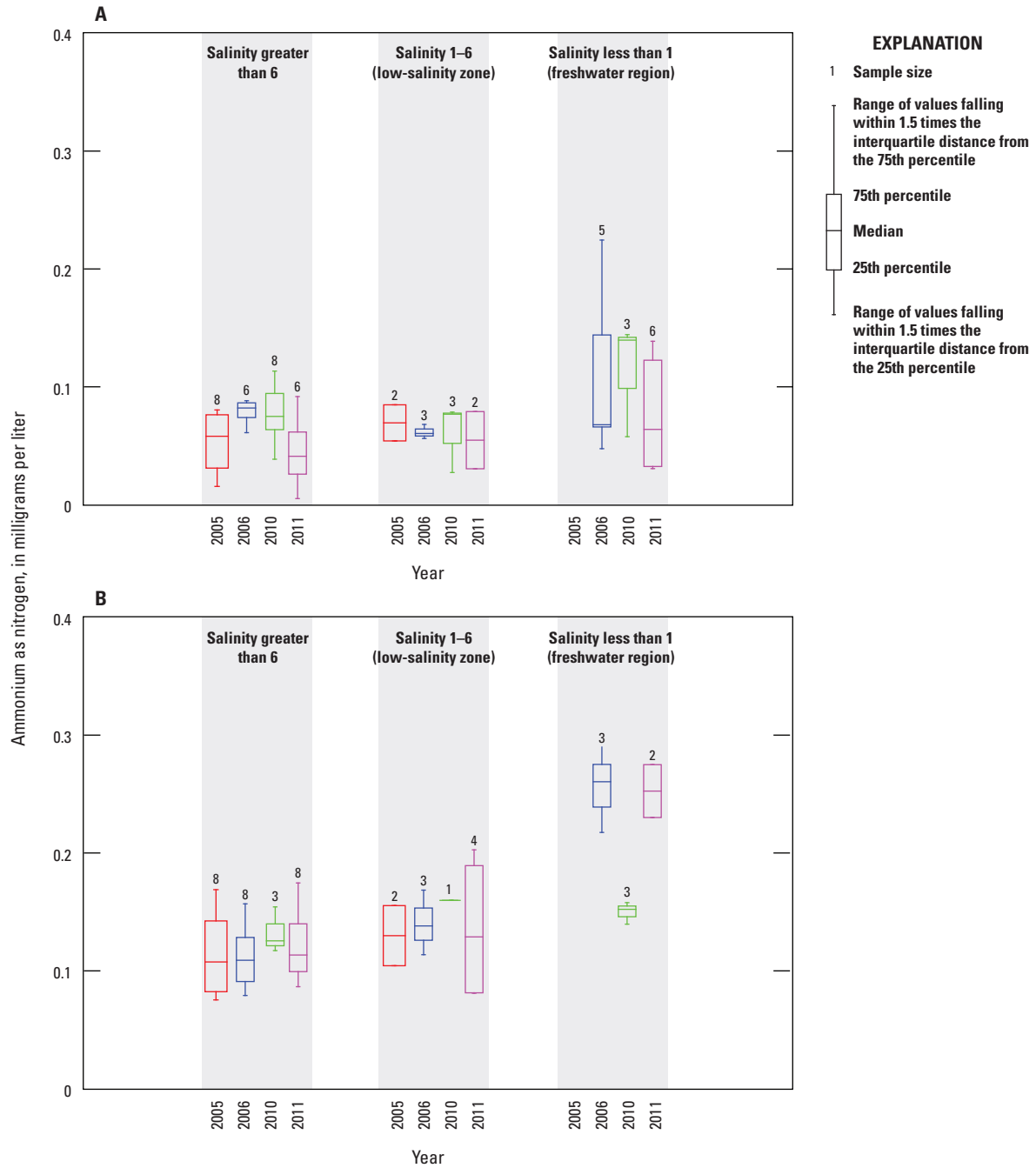


Figure 28. Ammonium as nitrogen data from U.S. Geological Survey monthly sampling cruises: *A*, September–October; and *B*, November–December (see appendix 7 for data sources).

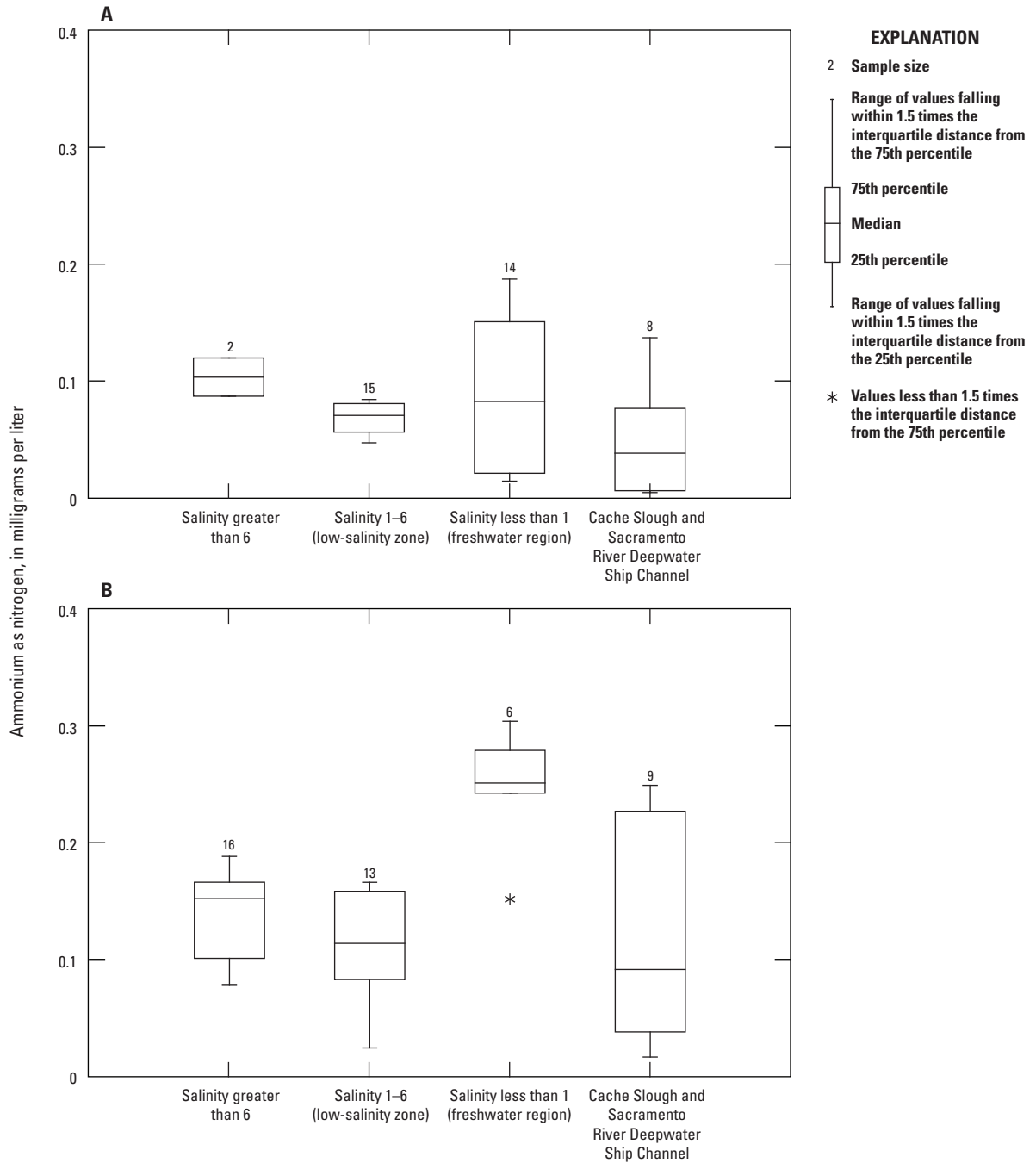


Figure 29. Ammonium as nitrogen concentrations in fall 2011 from samples collected during the fall midwater-trawl survey: *A*, September–October; and *B*, November–December (see appendix 4).

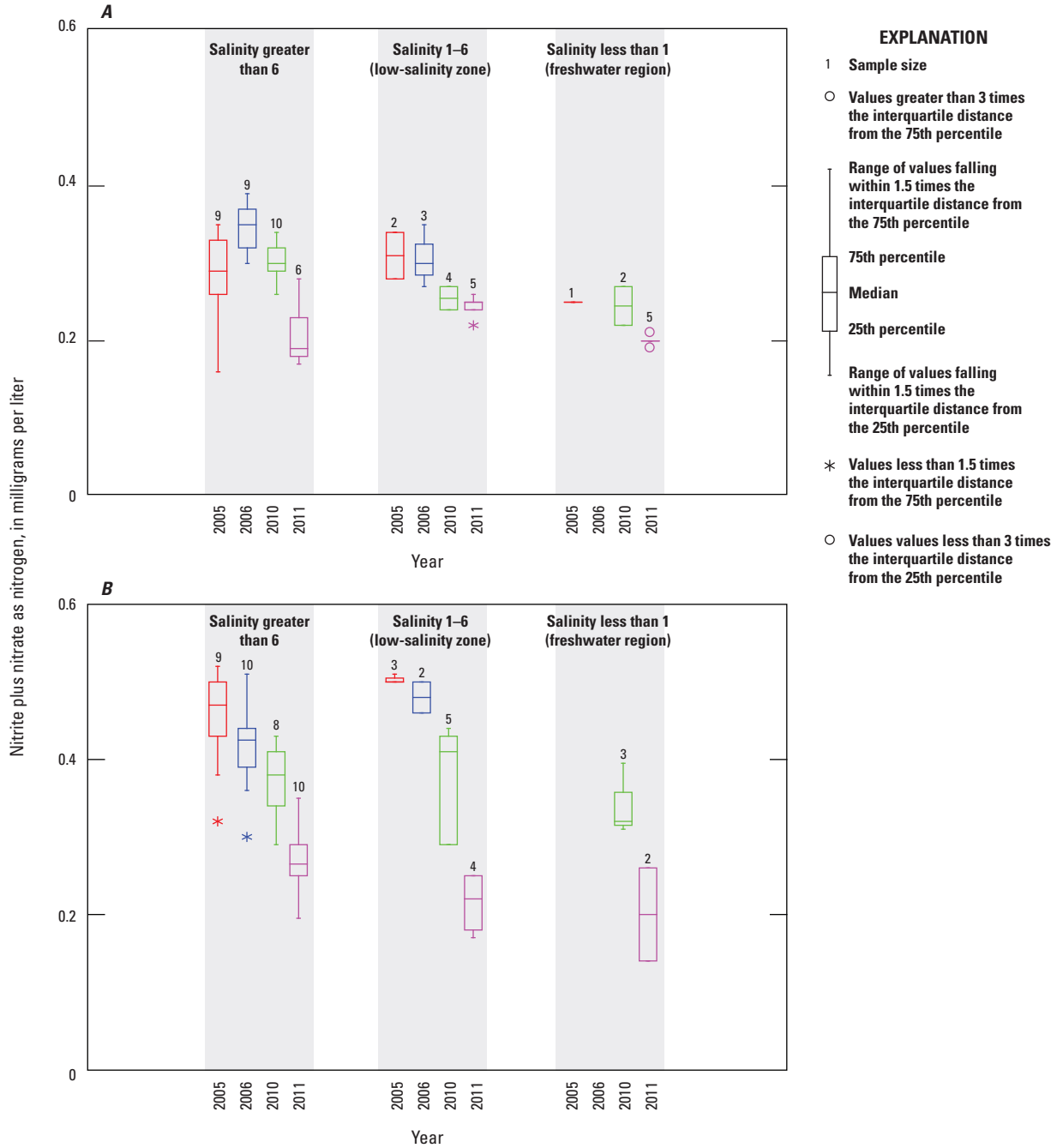


Figure 30. Nitrite plus nitrate as nitrogen concentrations in September–October and November–December from the Environmental Monitoring Program: *A*, September–October; and *B*, November–December (see appendix 6 for data sources).

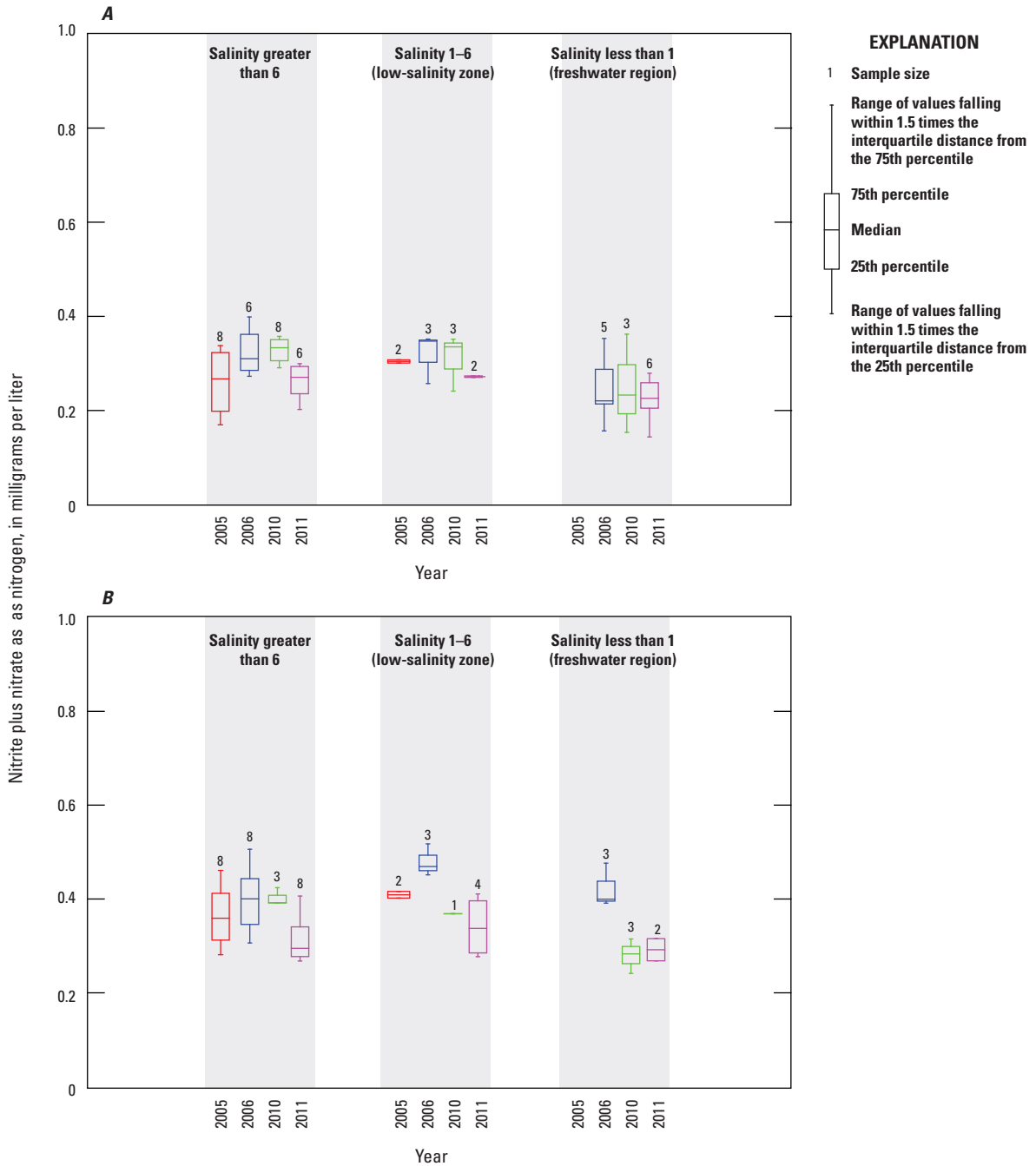


Figure 31. Nitrite plus nitrate as nitrogen concentrations from samples collected during monthly U.S. Geological Survey cruises: *A*, September–October; and *B*, November–December (see appendix 7 for data sources). Original concentrations of nitrite plus nitrate were measured in micromoles.

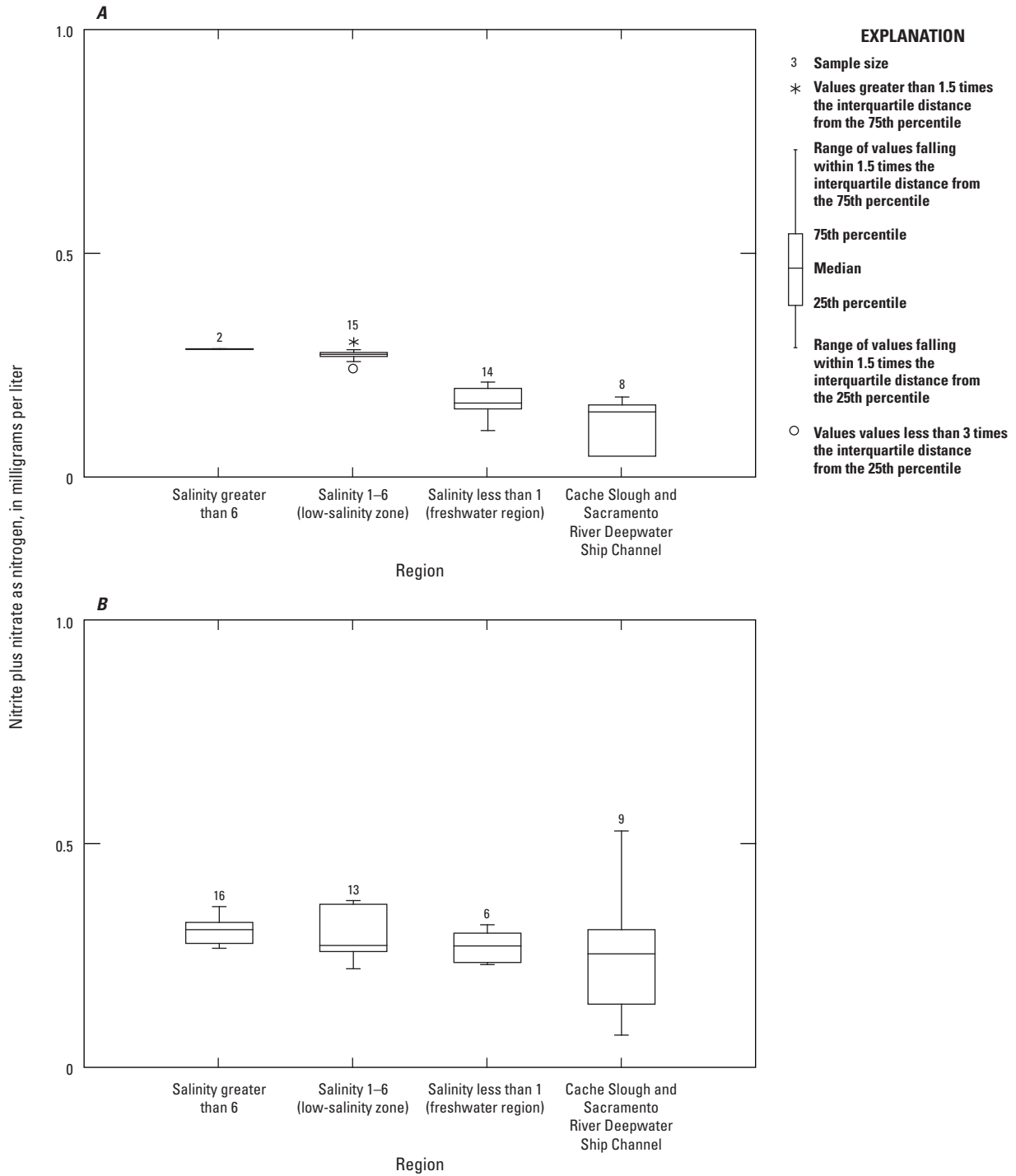


Figure 32. Nitrite plus nitrate as nitrogen concentrations in fall 2011 from the samples collected during the fall midwater-trawl survey: *A*, September–October; and *B*, November–December (see appendix 4 for data sources).

While production is certainly proportional to biomass, it also depends on the growth rate of the phytoplankton population. The population growth rate of phytoplankton can depend on nutrient concentrations, depth of the photic zone, and circulation of phytoplankton into and out of the photic zone. Furthermore, phytoplankton biomass can depend on complex interactions of factors affecting grazing, such as density of grazers, water temperature, channel characteristics (for example, depth), and hydrodynamics (Lucas and others, 2002; Lopez and others, 2006; Cloern, 2007; Lucas and Thompson, 2012). The basic hypothesis from which these individual predictions about phytoplankton responses were derived is that LSZ primary production (total carbon produced) increases when the LSZ is located in the shoals of the Suisun region (that is, X2 is at 74 km), mostly because of increased volume of the photic zone. Increased primary production might support organisms that are eaten by Delta Smelt and other organisms. We address each of the predictions in the AMP individually and on their own merits. We also recognize that the predictions concern a variable (biomass) that is relatively easy to measure, while rates of biological and chemical processes can be very difficult to measure. We expect that the predictions and hypotheses will become more sophisticated as the adaptive management cycle proceeds and the conceptual model is revised in response to research and monitoring results.

Chlorophyll- α concentrations were not particularly high in the LSZ in September–October 2011 based on EMP monthly sampling (fig. 33). In September–October 2011, concentrations were lowest in the LSZ and higher in the greater than salinity 6 and freshwater regions. One high observation in the greater than salinity 6 region could be indicative of a bloom. Median chlorophyll- α concentrations during September–October in the LSZ were generally low, but were higher in 2010 compared to 2011, and concentrations were lowest in 2005 and 2006. The EMP data did not support the hypothesis of greater average phytoplankton biomass as measured by chlorophyll- α at lower X2 values. 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 could not be applied to the available data.

In contrast to the EMP data, the data from USGS monthly cruises appeared to support the prediction of more LSZ phytoplankton biomass at lower X2 near 74 km (fig. 34). Chlorophyll- α concentrations were greatest in September–October 2011 when X2 was 75 km compared to other years across all salinity regions, when X2 was greater. High chlorophyll- α concentrations continued in the LSZ during November–December 2011. In the other salinity regions, chlorophyll- α concentrations were similar across the years.

Water samples collected during the 2011 FMWT were analyzed for chlorophyll- α (fig. 35). The FMWT samples showed a general trend toward higher concentrations of chlorophyll- α in freshwater habitats, particularly in the Cache Slough complex, in September–October and November–December 2011, although concentrations were higher in September–October. In the EMP data, the highest concentrations of chlorophyll- α were also found in freshwater (fig. 33). The USGS data showed similar median concentrations of chlorophyll- α 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. This could be due to spatial patchiness of phytoplankton and the different sampling dates of the three surveys, among other factors. The most interesting feature of the FMWT data is the high chlorophyll- α concentrations in the Cache Slough region (fig. 35).

Because the EMP and USGS data differed, we evaluated additional data for fall 2011, when X2 was 75 km. In particular, we looked at continuous fluorescence data, a method of estimating chlorophyll- α concentration in the water column, from EMP water-quality stations at Rio Vista and Mallard Island (fig. 36). The data discussed earlier were from chemical analyses of chlorophyll- α in water samples. Rio Vista represents freshwater conditions, and Mallard Island is between the confluence and Suisun Bay region (fig. 3). These data indicate that a bloom in freshwater was advected into the LSZ. Transport from freshwater could account for at least some of the chlorophyll- α observed in the LSZ. Given the conflict between the EMP and USGS data and the evidence for at least some contribution from a freshwater bloom, the prediction about chlorophyll- α production could not be evaluated with certainty.

Because the cyanobacteria *Microcystis* forms floating colonies that are difficult to quantify with standard sampling techniques, there was 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 did not include 2005–2006 (see appendix 4). In 2010 and 2011, the *Microcystis* ranking rarely exceeded the lowest rank for affirmative collections, so we compared the frequency of presence between years. In 2010, the most occurrences were in freshwater (fig. 37). In 2011, the results were similar, except for a high percentage of occurrences in the LSZ in September. Although occurrence data do not directly address the prediction that density is greater when X2 is at 85 km compared to 74 km, the prediction is neither supported nor rejected. The average occurrences of *Microcystis* in September–October of 2010 and 2011 were not particularly different, and there was high variability in 2011.

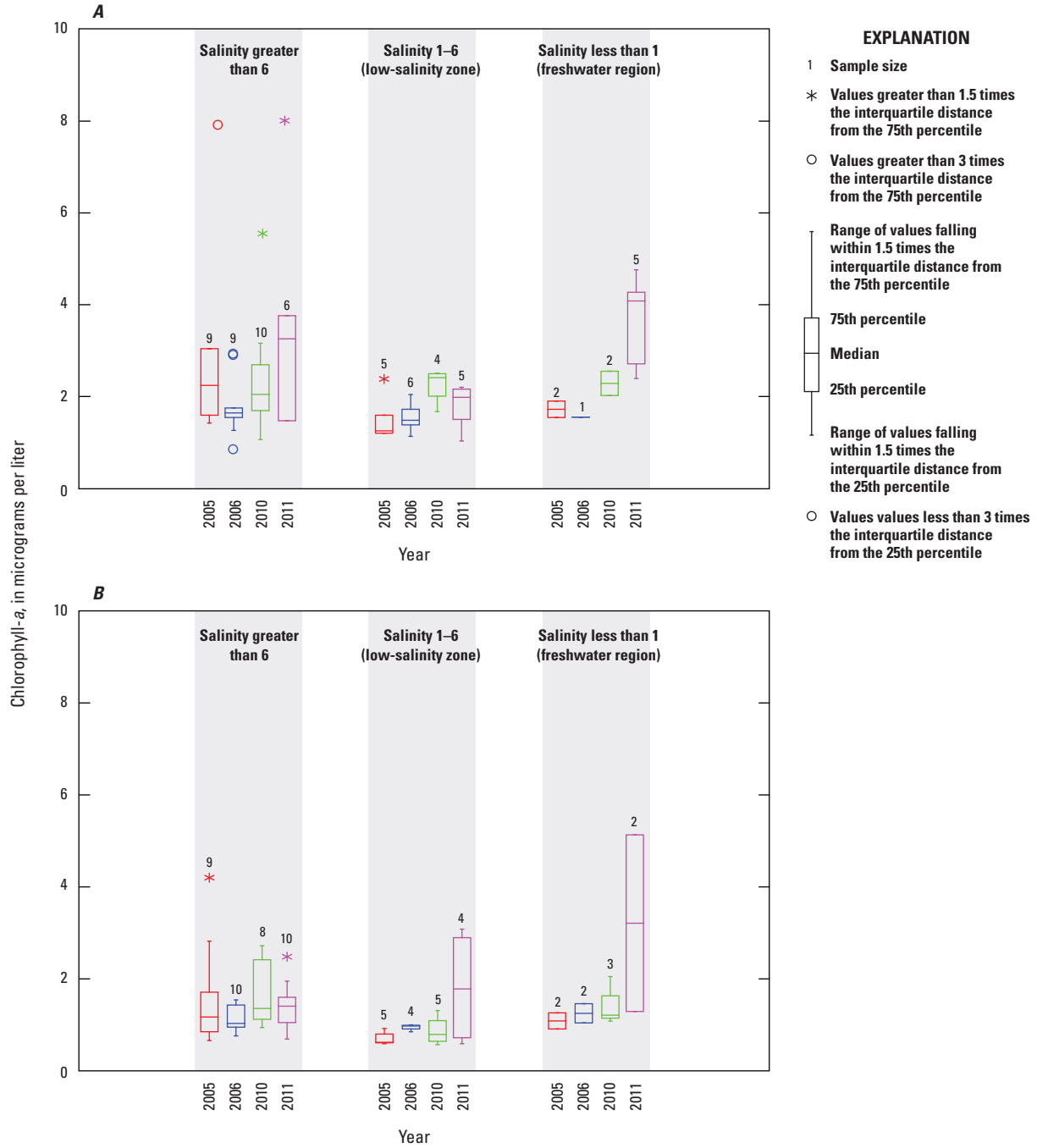


Figure 33. Chlorophyll- α concentrations from the Environmental Monitoring Program: *A*, September–October; and *B*, November–December (see appendix 6).

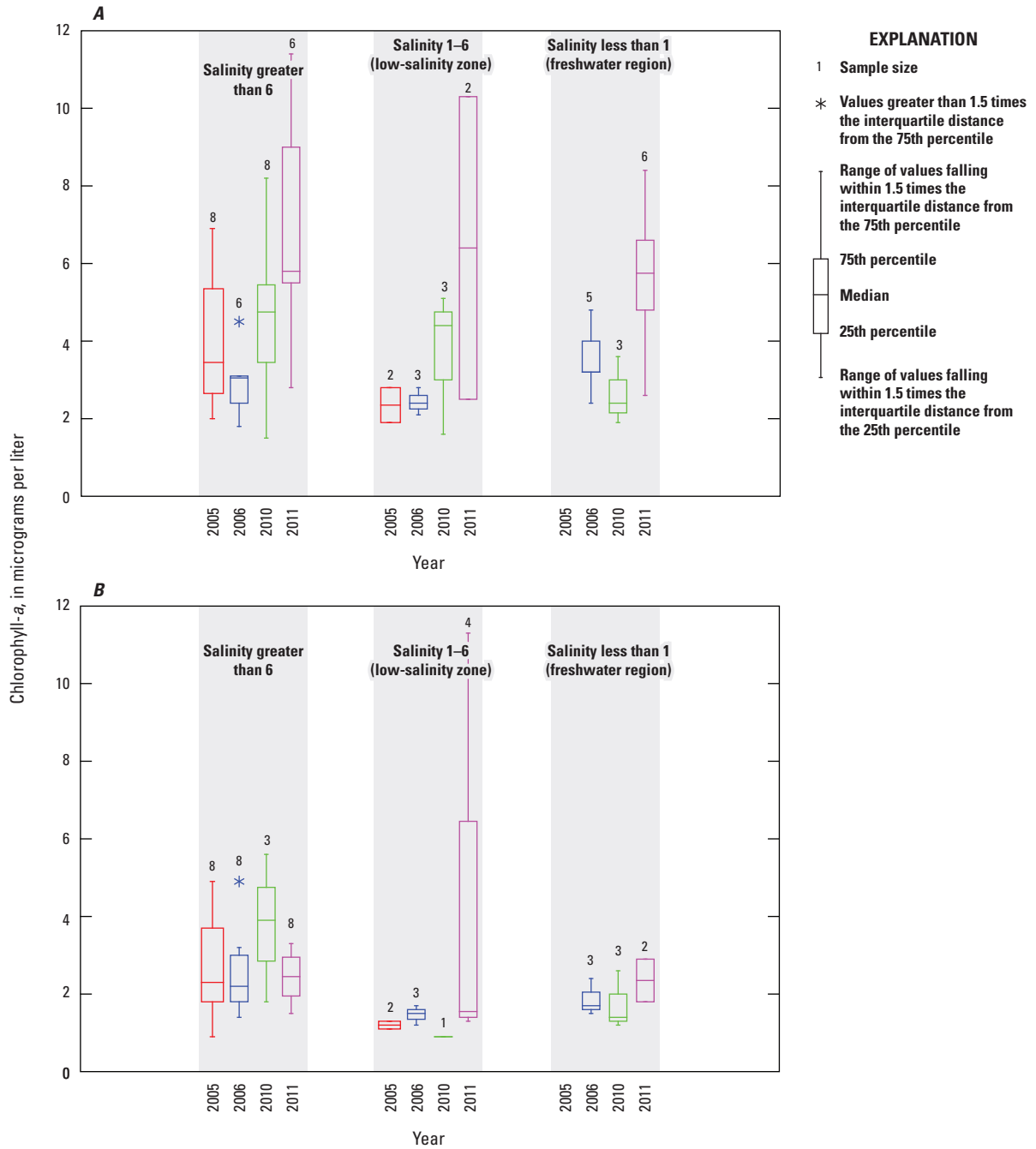


Figure 34. Chlorophyll- α concentrations from samples collected during monthly U.S. Geological Survey cruises: *A*, September–October; and *B*, November–December (see appendix 7).

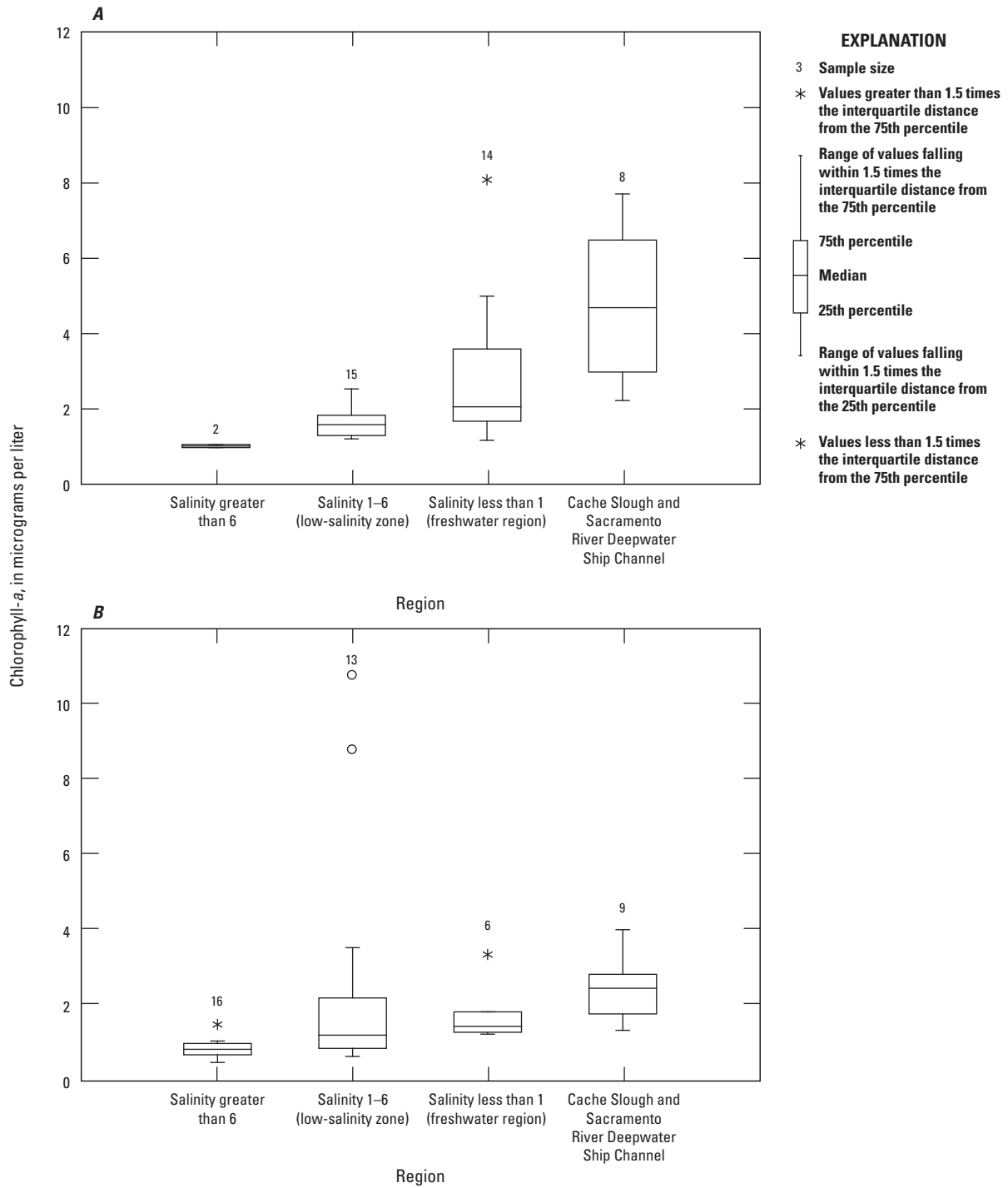


Figure 35. Chlorophyll- α concentration in 2011 from samples collected during the fall midwater-trawl: A, September–October; and B, November–December (see appendix 4).

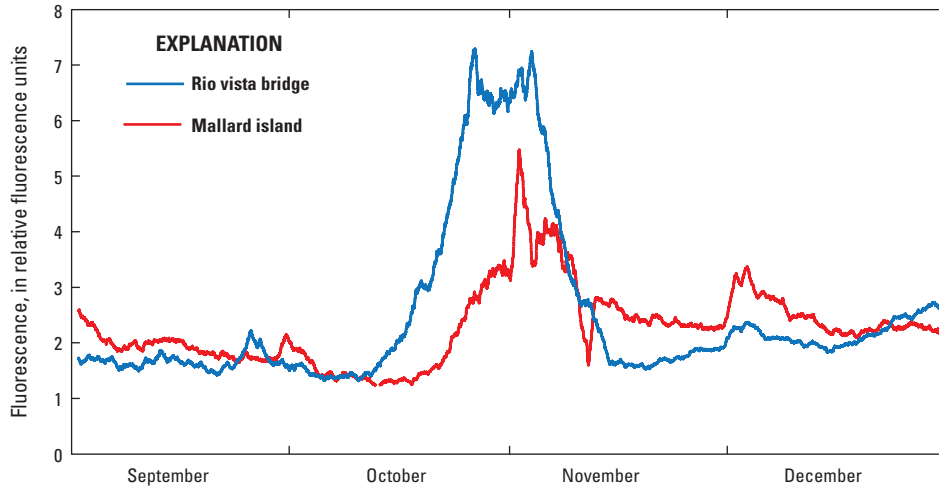


Figure 36. Continuous in-situ fluorescence measurements (a method to estimate chlorophyll- α concentrations) from September to December 2011 for Rio Vista Bridge and Mallard Island (appendix 6). The lines represent 24-hour running averages of data collected at 15-minute intervals.

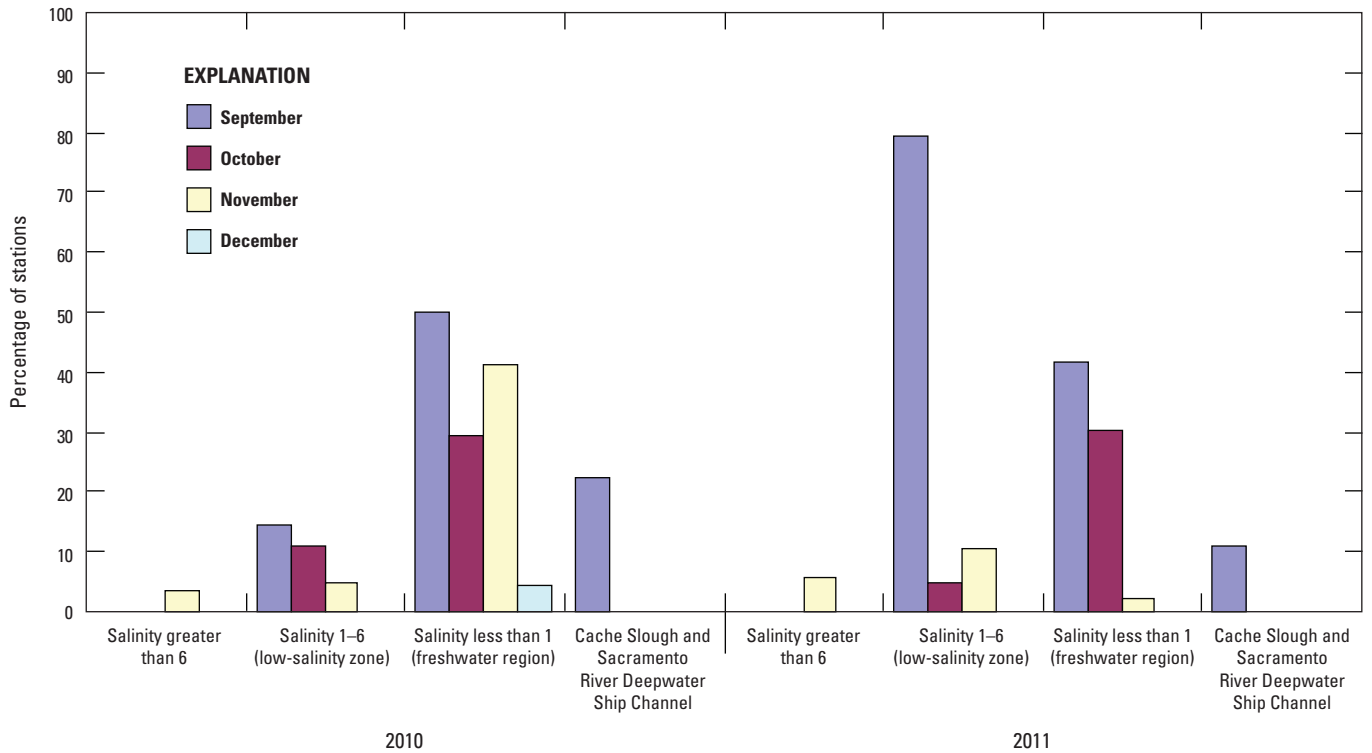


Figure 37. Occurrence of floating *Microcystis* at fall midwater-trawl sampling stations for September to December 2010 and 2011 (appendix 4 shows sampling locations).

Several predictions (table 1) concern copepods, a major food source of delta smelt. Calanoid copepods, particularly *Pseudodiaptomus forbesi*, *Eurytemora affinis*, and *Acartiella sinensis*, are generally recognized as important prey for delta smelt. Calanoid copepod biomass per unit effort (BPUE, in micrograms of carbon per cubic meter) tended to be slightly greater in September and October 2011 compared to other years in the LSZ and greater than salinity 6 region; however, standard deviations were large relative to the differences in means (fig. 38). This was not the case in freshwater, where September and October 2011 were similar to September and October of 2005 and 2010. In general, calanoid copepod BPUE tended to be greater in freshwater than in the other salinity regions, mostly because of greater densities of copepodids (juvenile copepods) in freshwater. The greater BPUE in freshwater during September and October was not apparent in November and December. Instead, BPUE was low and similar across all salinity groups in November and December. There was a tendency for November and December BPUE to be slightly greater in the LSZ during the wet years of 2006 and 2011, although standard deviations were large relative to the differences in means. The prediction was that calanoid copepod biomass would be greater in the LSZ at a low X2 value, and the data did show that trend; however, given the high variability in the data, a definite conclusion was not warranted.

Cyclopoid copepods, mainly represented numerically by *Limnoithona tetraspina*, can also be consumed by delta smelt; however, when calanoids are available, the delta smelt diet usually includes more of the larger calanoid copepods than the smaller cyclopoid copepods. 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. 38 and 39). There was a great deal of monthly variability in the BPUE of cyclopoid copepods, based on large standard deviations relative to the mean (fig. 39). In September and October 2011, the BPUE of cyclopoid copepods was both the greatest and the least during 2011. The BPUE of cyclopoid copepods was generally greater in November and December compared to September and October across years (fig. 38), except in freshwater. The prediction that cyclopoid biomass in the LSZ would be less when X2 was at 85 km is difficult to interpret because both X2 at 81 km and X2 at 74 km were expected to be moderate. The data indicated that when X2 was at 74 km, the BPUE of cyclopoid copepods could be greater than predicted in comparison to the other conditions, which is not consistent with the prediction; however, as with calanoid copepods, the differences in the mean values are small relative to the standard deviations. Thus, the data did not support the prediction as stated in table 1, and we defer making a definitive judgment.

Although there was not an explicit prediction for the food that delta smelt might actually consume, we compiled the available data on delta smelt diet 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. 40). This consumption corresponded to the greatest BPUE of cyclopoid copepods in the LSZ (fig. 39), presumably due to high abundance of this large species. In some months, a large proportion of the diet consisted of other organisms (fig. 41), in particular, mysids and amphipods. The mysids were mainly *Hyperacanthomysis longirostris*. Amphipods included *Americorophium spinicorne* and *Corophium alienense* in the LSZ and Cache Slough and SRDWSC region and included *Gammarus daiberi* in the Cache Slough and 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. 42). Individual mysids are larger than copepods and could be selected by delta smelt when available.

To 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 mean values of total zooplankton (fig. 42) were almost identical to the patterns apparent in the mean values of calanoid copepods (fig. 38). Zooplankton biomass tended to be higher in freshwater, but standard deviations were large relative to differences in means, making a firm conclusion unwarranted. There was no specific prediction for total zooplankton.

The prediction that *Potamocorbula* biomass would increase when X2 is at 85 km and decrease when X2 is at 74 km (table 1) is related to grazing rates on phytoplankton and zooplankton in the LSZ, which would channel primary and secondary production to clams rather than fishes and other consumers, such as delta smelt. The U.S. Bureau of Reclamation (2012) hypothesized that lower X2 values in wet years could result in decreased fall populations of *Potamocorbula* in the LSZ because of large shifts in the distribution of salinity in the estuary and subsequent effects on the recruitment and physiology of *Potamocorbula*. The prediction does not incorporate biomass of *Corbicula fluminea*, a freshwater invasive clam living on the freshwater side of the LSZ. *Corbicula* can also exert substantial grazing pressure on phytoplankton (Lucas and others, 2002; Lopez and others, 2006). For this reason, this prediction was addressed in terms of total biomass of *Potamocorbula* and *Corbicula*, with the percentage attributed to *Potamocorbula* identified and a measure of total grazing rate for both species (Thompson and others, 2012). We

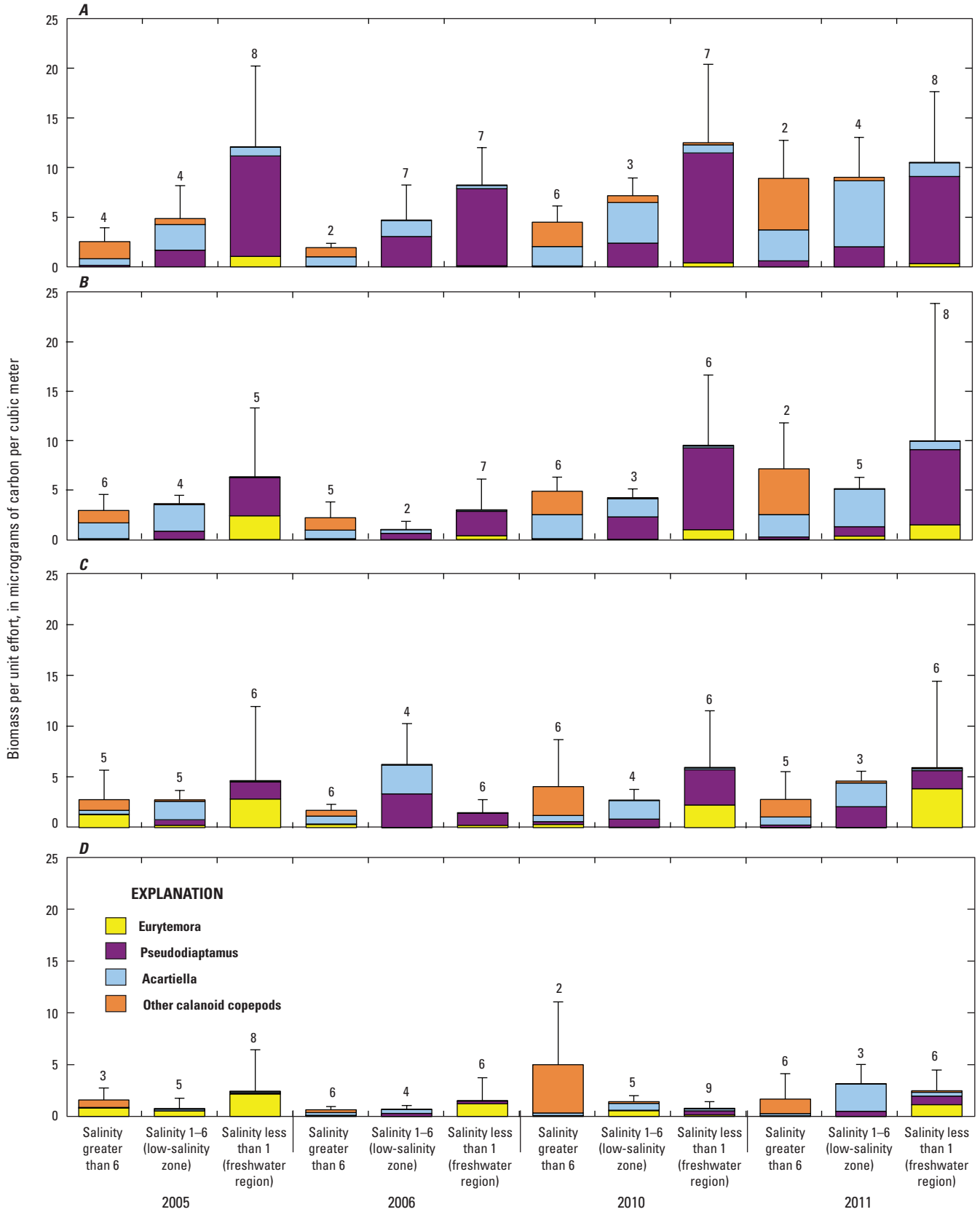


Figure 38. Mean biomass per unit effort of juvenile and adult calanoid copepods for Environmental Monitoring Program samples for: A, September; B, October; C, November; D, December (see appendix 6 for data sources). Vertical lines represent 1 standard deviation; numbers represent sample sizes for the associated bars.

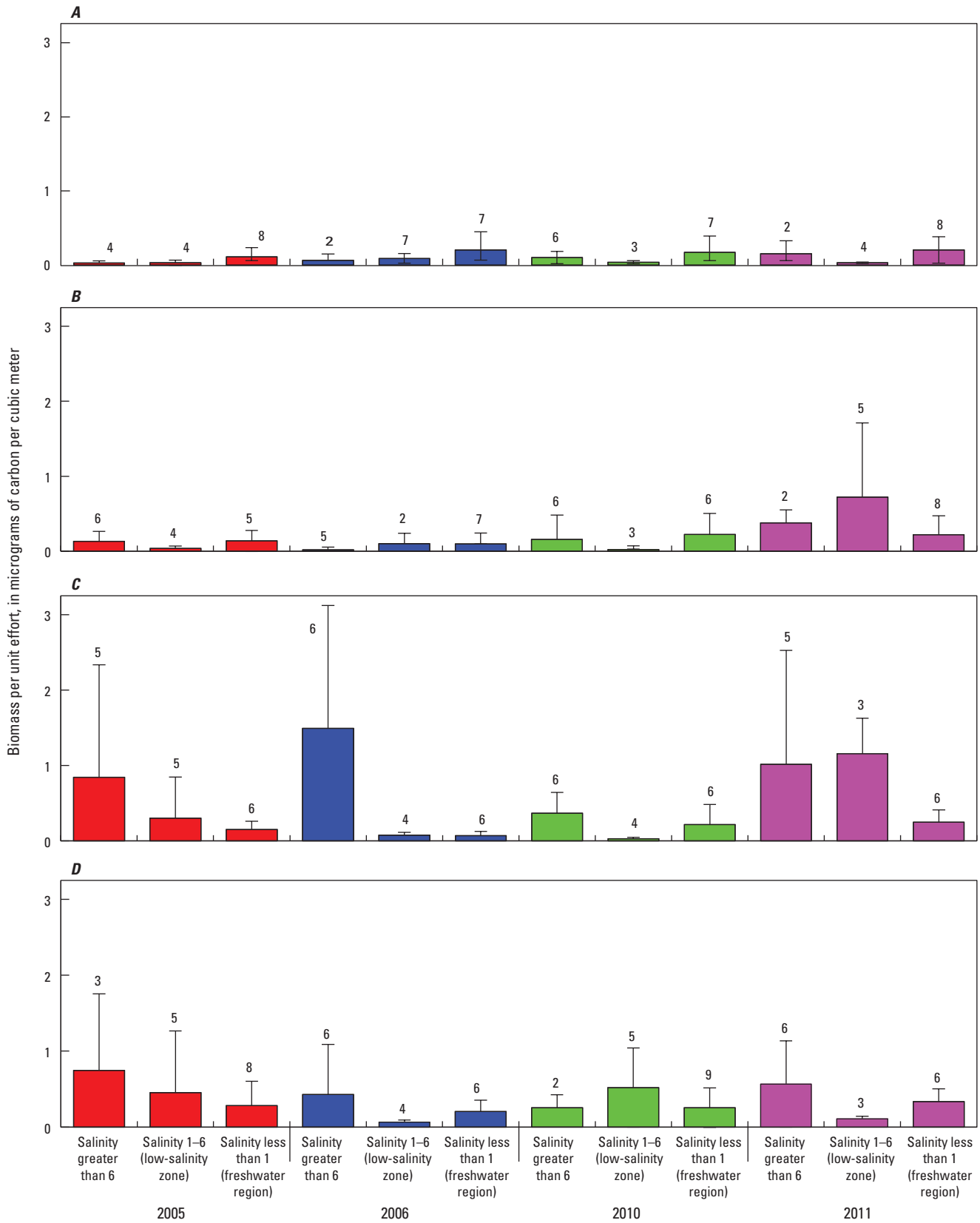


Figure 39. Mean biomass per unit effort of juvenile and adult cyclopoid copepods for Environmental Monitoring Program samples for: A, September; B, October; C, November; D, December (appendix 6). Vertical lines represent 1 standard deviation; numbers represent sample sizes for the associated bars.

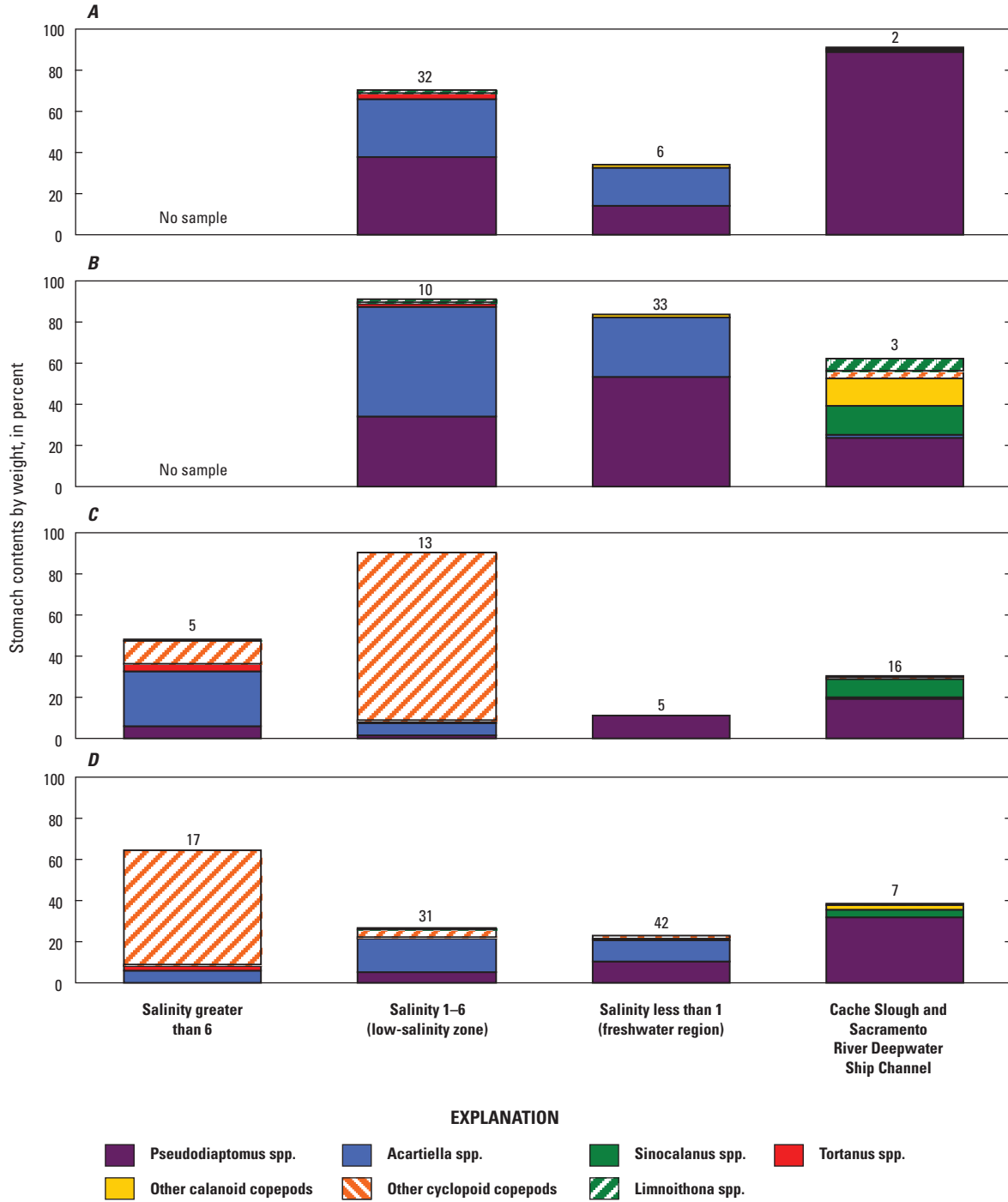


Figure 40. Stomach contents of delta smelt captured in the fall midwater-trawl survey in 2011 containing calanoid and cyclopoid copepods for: *A*, September; *B*, October; *C*, November; *D*, December (see appendix 4 for methods). The composition of the remaining portion of the diet is shown in figure 41. Numbers represent the number of delta smelt stomachs examined to generate the associated bars. Bars indicate means, and lines show 1 standard deviation.

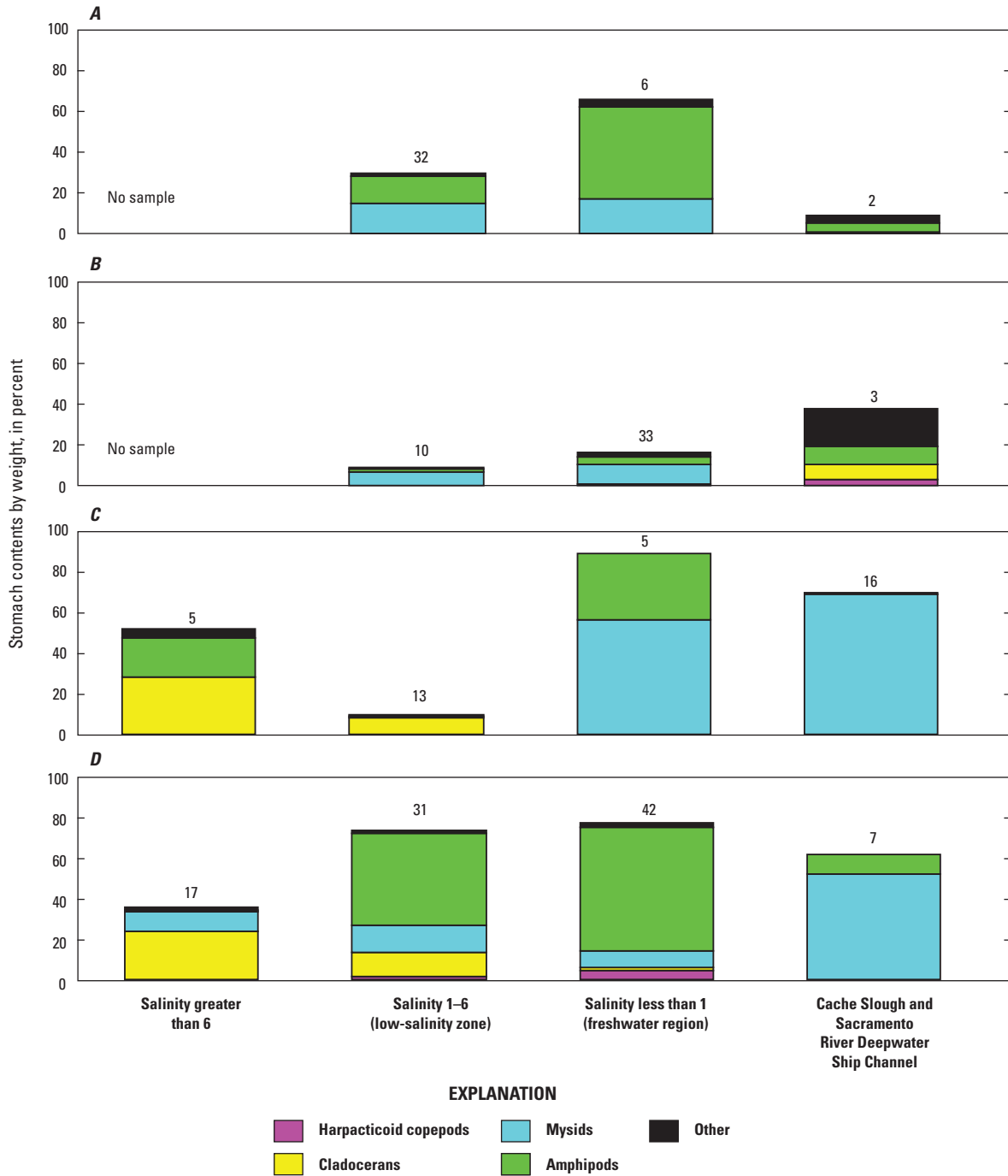


Figure 41. Stomach contents of delta smelt captured in the fall midwater-trawl survey in 2011 containing harpacticoid copepods, cladocerans, mysids, amphipods, and other prey for: *A*, September; *B*, October; *C*, November; *D*, December (see appendix 4 for methods). Numbers represent the number of delta smelt stomachs examined to generate the associated bars. Bars indicate means, and lines show 1 standard deviation.

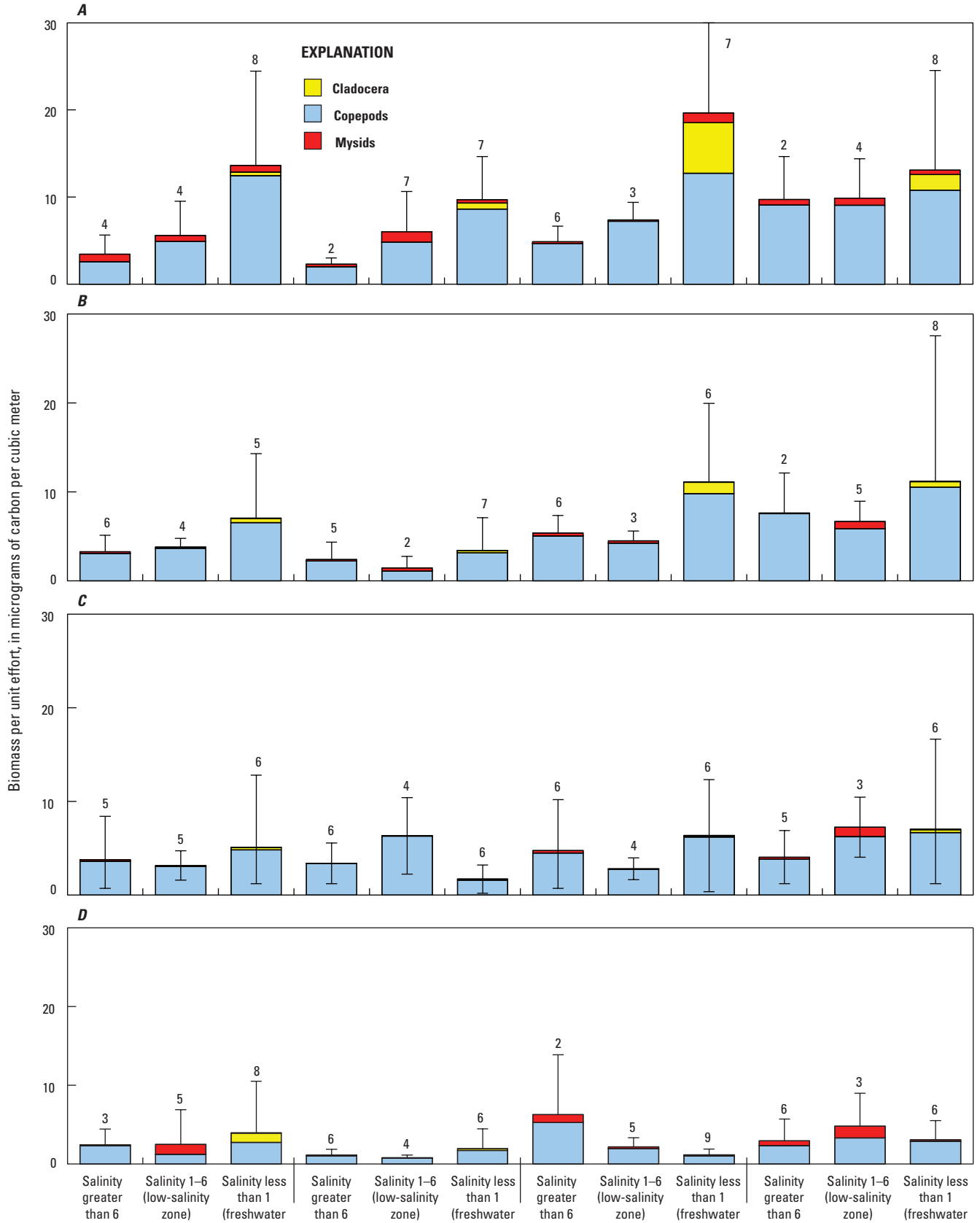


Figure 42. Mean biomass per unit effort of juvenile and adult calanoid copepods, cyclopoid copepods, cladocerans, and mysids for Environmental Monitoring Program samples (see appendix 6 for methods and data sources). Vertical lines represent 1 standard deviation; numbers represent sample sizes for the associated bars.

only address total grazing rate because the loss to the benthic food web is the important process, rather than which benthic species benefits most, and a specific prediction restricted to *Potamocorbula* was not made for this process. After young clams settle to the bottom and begin their sedentary, benthic existence, they do not move with the LSZ on tidal or seasonal time scales, as swimming organisms like delta smelt are capable of doing. Therefore, they were considered geographically. Grizzly and Honker Bays (Grizzly/Honker Bays), western Suisun Marsh, the confluence, and several flooded islands (Franks Tract, Big Break, and Sherman Lake) were areas considered by Thompson and others (2012). The first three areas are within the range of *Potamocorbula* and, in general, are most subject to movements of the LSZ and salinity gradient that results from tides and intra- and interannual flow conditions. The flooded islands are primarily fresh and dominated by *Corbicula*. Data were only available for October 2009, 2010, and 2011.

In October 2011, the *Potamocorbula* filtration rate, the volume of water filtered per day, was lower through much of its range compared to 2009 and 2010, except for two stations in the main channel of Suisun Bay (fig. 43). In 2011, X2 was seaward of Grizzly/Honker Bay and western Suisun Marsh for at least some of the time, indicating that those areas were fresher than in 2009 and 2010. In 2009 and 2010, X2 was mainly landward of these areas during the previous 6 months, so water was more brackish in those areas, which favors settlement and growth of *Potamocorbula*. Based on biomass, *Potamocorbula* were less abundant in Grizzly/Honker Bay and western Suisun Marsh during October 2011 compared to 2009 and 2010 (fig. 44); however, the hypothesis concerning *Potamocorbula* is based on the position and extent of the LSZ. In 2010, the LSZ was located in the confluence area on the basis of X2 at 85 km (fig. 16). In 2011, the LSZ was located in the Grizzly/Suisun Bay and western Suisun Marsh area on the basis of X2 at 74 km (fig. 14). In 2010, median biomass in the confluence region was about 5 g ash free dry mass per square meter (AFDM/m²), with 4 percent of biomass accounted for by *Potamocorbula*. Thus, median biomass of *Potamocorbula* was only about 0.2 g AFDM/m². In 2011, median biomass in the Grizzly/Honker Bay and Western Suisun Marsh regions was about 2 and 5 g AFDM/m², respectively, with 97 percent and 91 percent of biomass accounted for by *Potamocorbula*, respectively. Thus, the median biomass contribution of *Potamocorbula* for the two areas combined was greater than 2 g AFDM/m², and the median biomass of *Potamocorbula* in the LSZ was greater in 2011 compared to 2010. The prediction that *Potamocorbula* biomass would be greater when X2 was at 85 km compared to 74 km (table 1) was not supported by the data.

Because clam grazing on phytoplankton is the ecological process underlying the prediction concerning *Potamocorbula* biomass (table 1), we also considered grazing rates, in terms of turnover rate. In these calculations, grazing rate is different from filtration rate (above) because it assumes food in the water column is depleted by feeding, forming a boundary

layer. Thus grazing rates are lower than filtration rates. The turnover rate normalizes the grazing rates to the depth of the water column (fig. 45) and is the proportion of the water column a population of clams filters in a day. In all years, the turnover rate in the confluence was relatively low because of the greater depth of many of the confluence channels compared to the shoals of the bays and the greater biomass contribution of *Corbicula*, which has slower grazing rates than *Potamocorbula*. The high variability can be attributed to faster turnover rates in some shallower sample locations (fig. 45). Also, in all years, turnover rates were faster in Grizzly/Honker Bay and western Suisun Marsh, as compared to the confluence. These results are counter to the prediction (table 1) if the hypothesis about *Potamocorbula* biomass is considered in terms of total grazing pressure on the phytoplankton population; however, high variability made it difficult to draw definite conclusions.

In addition to species of grazer and depth, hydrodynamics, in terms of transport time and circulation of water and associated phytoplankton, can have important effects on grazing rates (Lucas and others, 2002; Lopez and others, 2006; Cloern, 2007; Lucas and Thompson, 2012). For example, tidal exchange between the confluence and flooded islands, which have different total biomasses of clams, and thus, different turnover rates (figs. 44 and 45), could have important effects on phytoplankton biomass that would not be obvious from a simple examination of conditions in specific geographic areas or the LSZ. Because of these uncertainties, we conclude the prediction that *Potamocorbula* biomass would be greater when X2 was at 85 km and less when it was at 74 km (table 1) was not supported and that the hypothesis was likely too simple to address the underlying process of interest, which was the effect of clam grazing on phytoplankton production. This prediction and the underlying hypotheses could be revisited and revised in an updated AMP.

The predictions about predator abundances and predation rates (table 1) 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 requires new sampling programs.

Predictions for Delta Smelt Responses

The prediction (table 1) of some delta smelt captured at the Suisun region power plants when X2 was at 74 km and no delta smelt captured when X2 values were greater than 74 km could not be directly assessed because no fish counts were available; however, the power plants only operated at about one-third of capacity for a limited number of days in September and October of 2011. The assumption behind this prediction is that capturing delta smelt near the power plants while they are in operation would indicate that entrainment was likely. At the plant near Pittsburgh, one or two of three generation units operated for 9 days from September

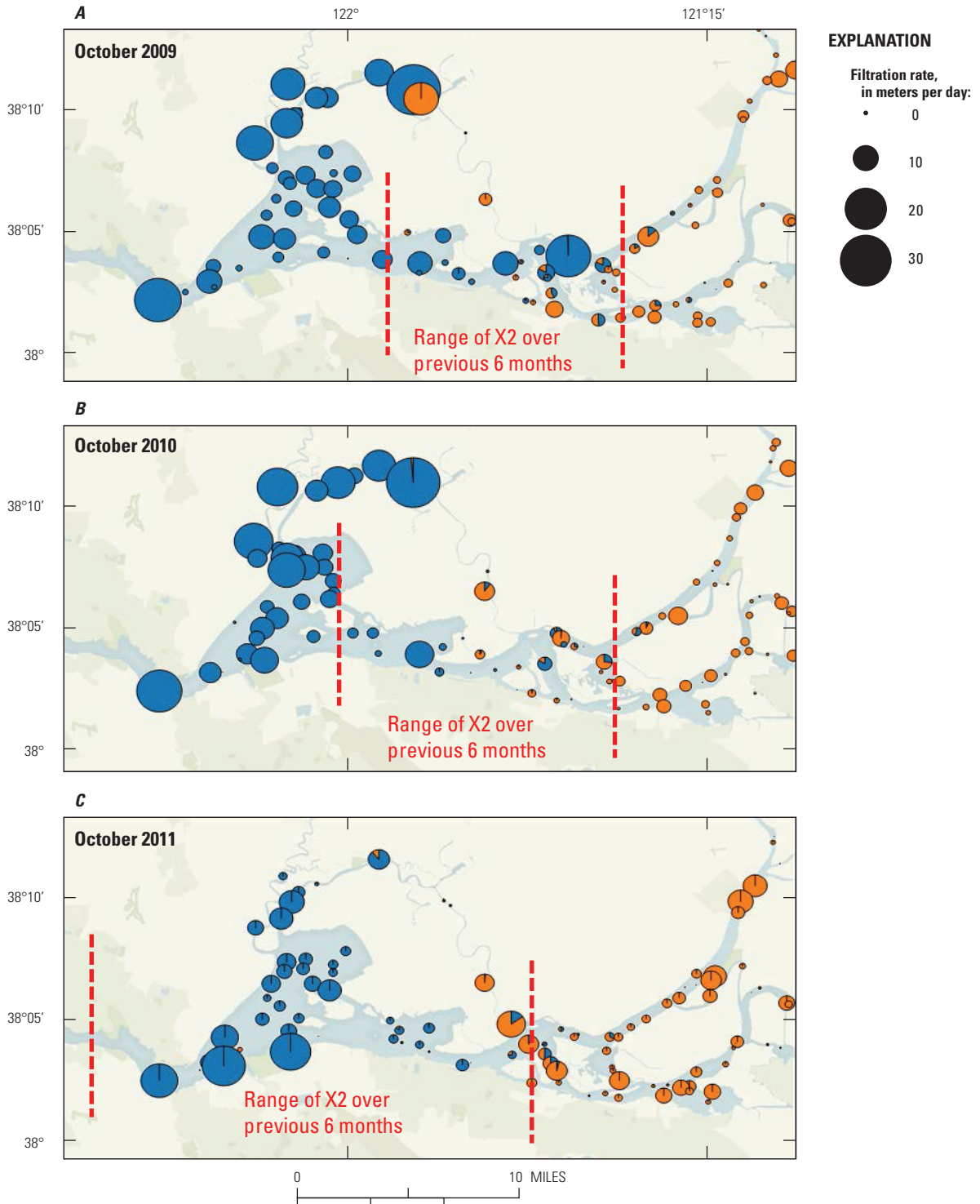


Figure 43. Filtration rates (a function of biomass and temperature) for *Potamocorbula amurensis* (blue) and *Corbicula fluminea* (orange) in **A**, October 2009; **B**, October 2010; and **C**, October 2011. Range of X2 during previous 6 months shown on map as range where bivalves were expected to overlap. Figure modified from Thompson and others (2012). X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2.

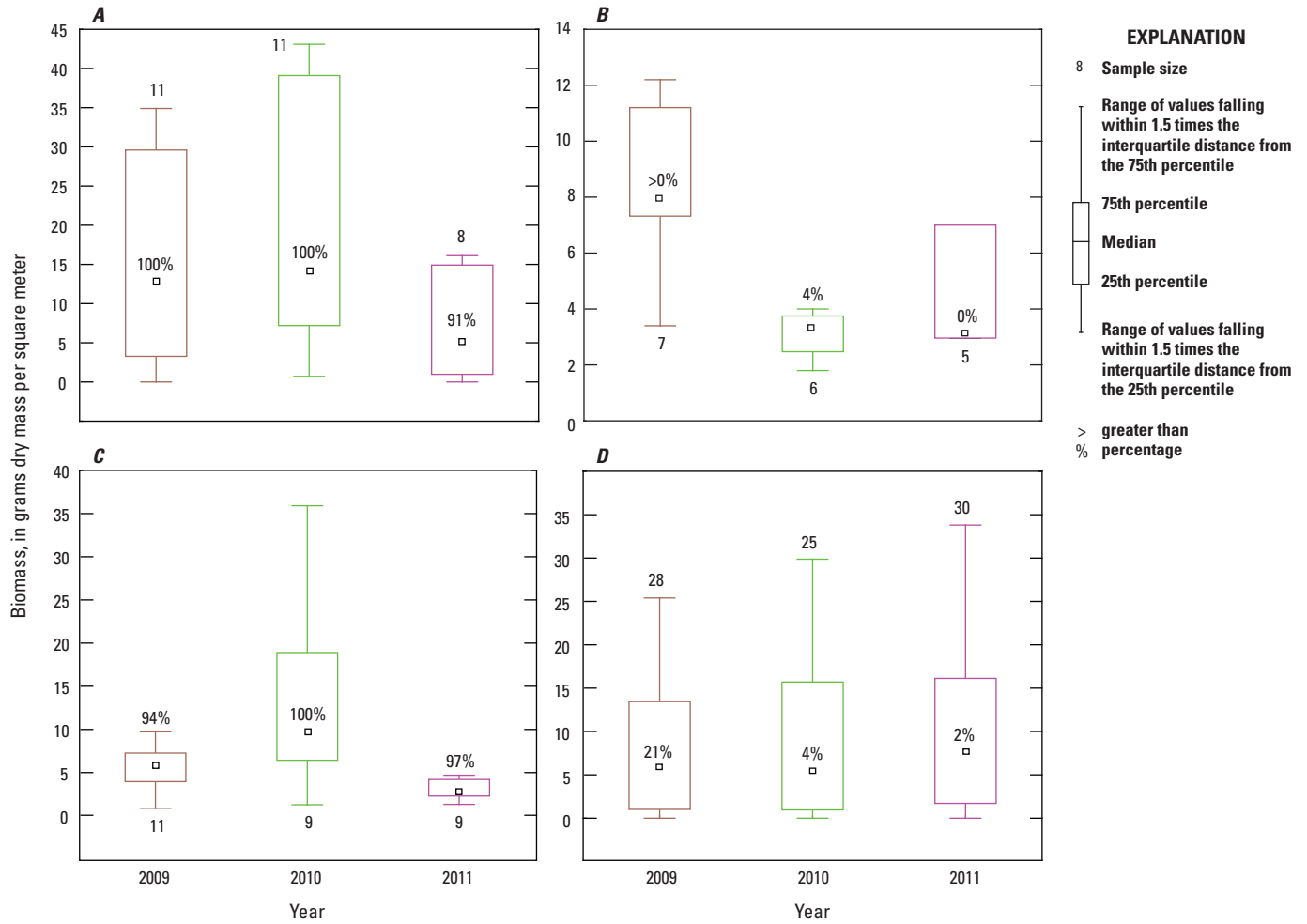


Figure 44. Biomass for *Potamocorbula amurensis* and *Corbicula fluminea* combined during the October sampling periods in *A*, western Suisun Marsh; *B*, the flooded islands; *C*, Grizzly/Honker Bay shallows; and *D*, the confluence region. Percentages (%) show proportion of biomass contributed by *Potamocorbula amurensis*. Figure modified from Thompson and others (2012).

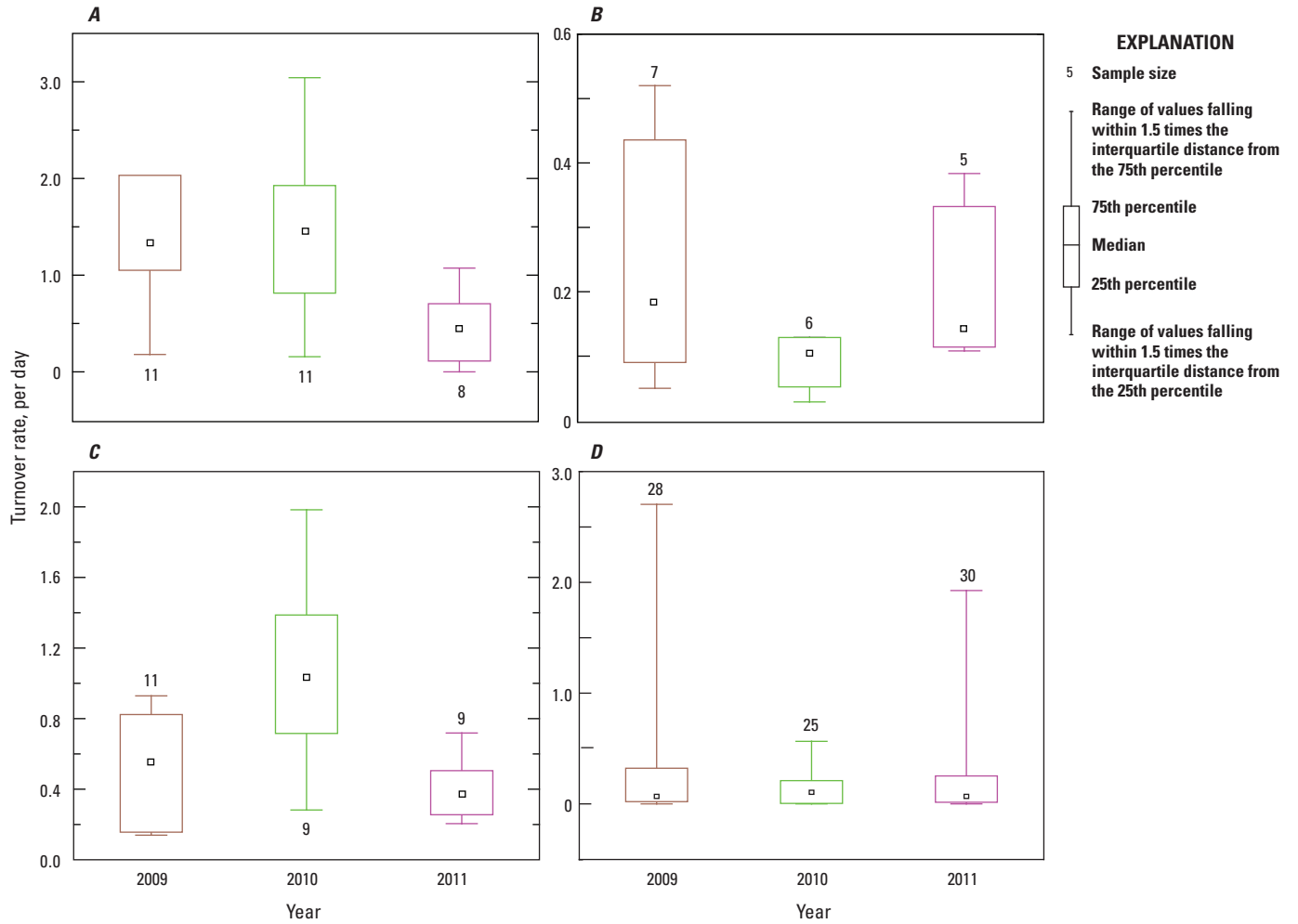


Figure 45. Turnover rates for *Potamocorbula amurensis* and *Corbicula fluminea* combined during the October in *A*, western Suisun Marsh; *B*, the flooded islands; *C*, Grizzly/Honker Bay shallows; and *D*, the confluence region. In western Suisun Marsh, turnover rates were not significantly different between 2009 and 2010, but were significantly different between 2010 and 2011 (Kruskal-Wallis test, P less than 0.05, Thompson and others, 2012). In Grizzly/Honker Bay shallows, turnover rates were not significantly different between 2009 and 2011, but the turnover rate in 2010 was significantly different than in 2009 and 2011 (Kruskal-Wallis test, P less than 0.05, Thompson and others, 2012). Figure modified from Thompson and others (2012).

to October. At the other plant, one of two generation units operated for 18 days, and both units operated for 4 days from September to October. It seems likely that entrainment was nil or very low; however, a definitive conclusion is not possible without fish counts. No delta smelt were salvaged at the CVP or SWP pumping plants from September to October in any of the years considered ([ftp://ftp.delta.dfg.ca.gov/salvage/](http://ftp.delta.dfg.ca.gov/salvage/)). Fish salvage is determined at fish collection facilities associated with each pumping plant where fish are removed from the diverted water, counted, and subsequently trucked to release points within the Delta. The prediction that there would be no delta smelt in the fall SWP and CVP salvage when X2 was at 74 or 81 km was supported by data; however, few, if any, delta smelt were expected to be salvaged even at greater values of X2 (table 1).

The center of distribution of delta smelt (median) appeared to be within the predicted range of X2 values (fig. 46) in September–October 2011 (table 1), although it was toward the lower end of the predicted range and many individuals were 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 except 2011. The available data appeared to support the prediction that the center of delta smelt distribution would approximate X2; however, the sparse data for years other than 2011 limited the strength of comparisons.

Preliminary data on delta smelt growth rates determined from otoliths were available for 2011 (Teh, 2012; table 4). The data indicate declining growth from August through December of 2011 in each of the salinity regions, as is expected with seasonally decreasing temperatures and a shift from growth in length to development of gonads. Growth in November and December was similar. Similar otolith-based growth data have been gathered as part of other studies in other years. These data need to be aggregated and the results compared among years before the prediction of greater growth when X2 is at 74 km compared to 85 km (table 1) can be evaluated.

Delta smelt survival was not calculated directly because only population abundance indices (fig. 47) rather than population estimates are available; however, some information can be inferred from ratios calculated from the summer totnet survey (TNS) and FMWT abundance indices (fig. 48). The ratio of the FMWT to the TNS can be used as an indicator of survival

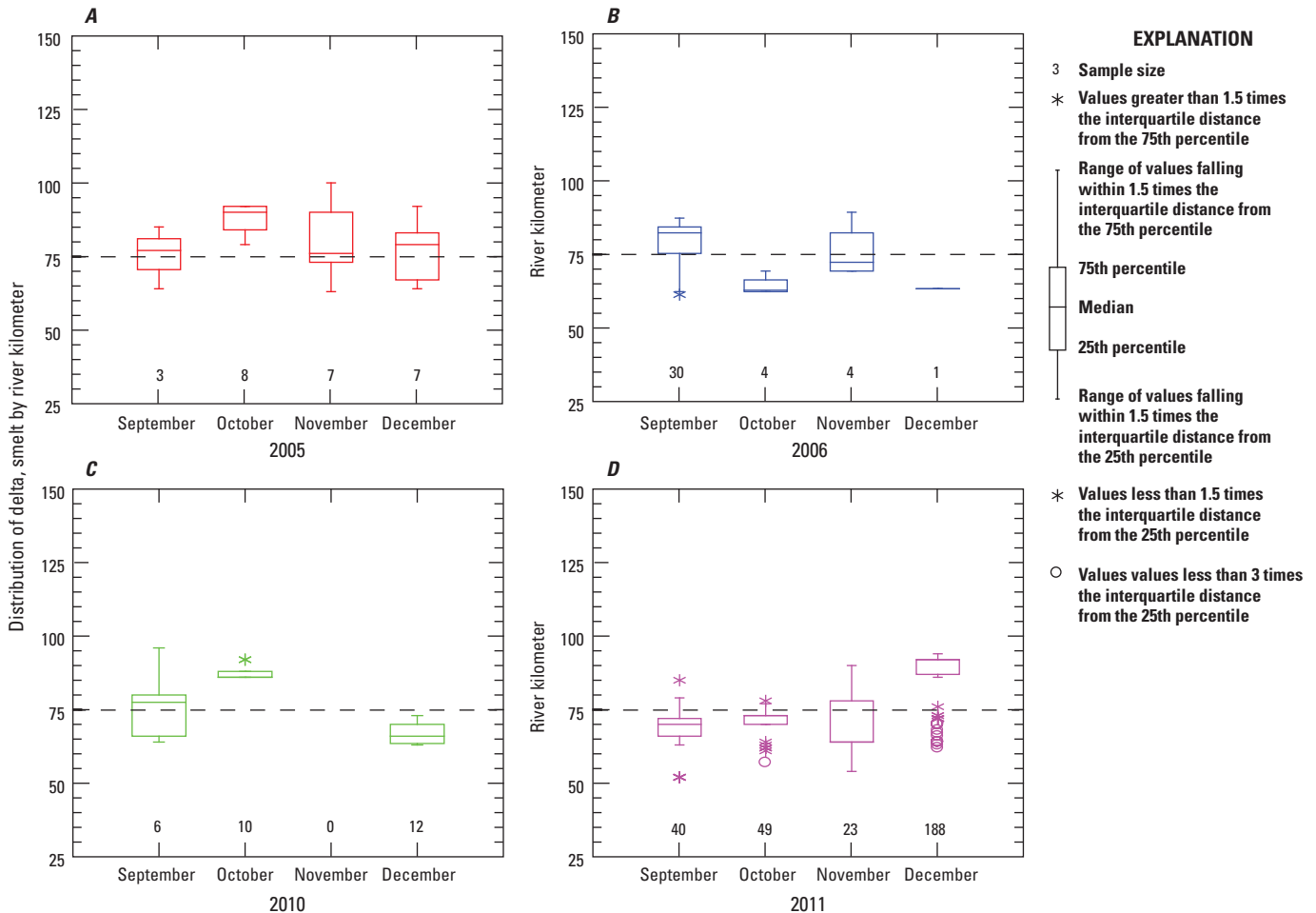


Figure 46. Distribution of delta smelt captured in the fall midwater-trawl survey for: *A*, 2005; *B*, 2006; *C*, 2010; *D*, 2011. The distance from the Golden Gate of each site where delta smelt were captured was weighted by the number of delta smelt caught. The number of delta smelt captured each month are shown. The dotted line indicates 75 kilometers for reference.

Table 4. Estimated mean and standard deviation of growth rates of delta smelt from August to December 2011 based on otolith analysis from four regions of the San Francisco Estuary: salinity less than 1, salinity 1–6, salinity greater than 6, and Cache Slough/Sacramento River Deepwater Ship Channel (SRDWSC; modified from Teh, 2012).

[**Abbreviation:** mm/day, millimeter per day]

Region	Month	Number aged	Growth rate (mm/day)	
			Mean	Standard deviation
Cache Slough/SRDWSC	August	37	0.41	0.06
Cache Slough/SRDWSC	September	2	0.39	0.05
Cache Slough/SRDWSC	October	3	0.29	0.01
Cache Slough/SRDWSC	November	16	0.28	0.01
Cache Slough/SRDWSC	December	7	0.28	0.03
Salinity less than 1	August	0	No data	No data
Salinity less than 1	September	5	0.42	0.04
Salinity less than 1	October	32	0.36	0.04
Salinity less than 1	November	1	0.27	No data
Salinity less than 1	December	69	0.29	0.02
Salinity 1–6	August	24	0.46	0.05
Salinity 1–6	September	25	0.38	0.04
Salinity 1–6	October	8	0.39	0.03
Salinity 1–6	November	5	0.28	0.01
Salinity 1–6	December	15	0.28	0.02
Salinity greater than 6	August	4	0.44	0.04
Salinity greater than 6	September	5	0.41	0.02
Salinity greater than 6	October	2	0.37	0.01
Salinity greater than 6	November	3	0.28	0.01
Salinity greater than 6	December	31	0.28	0.02

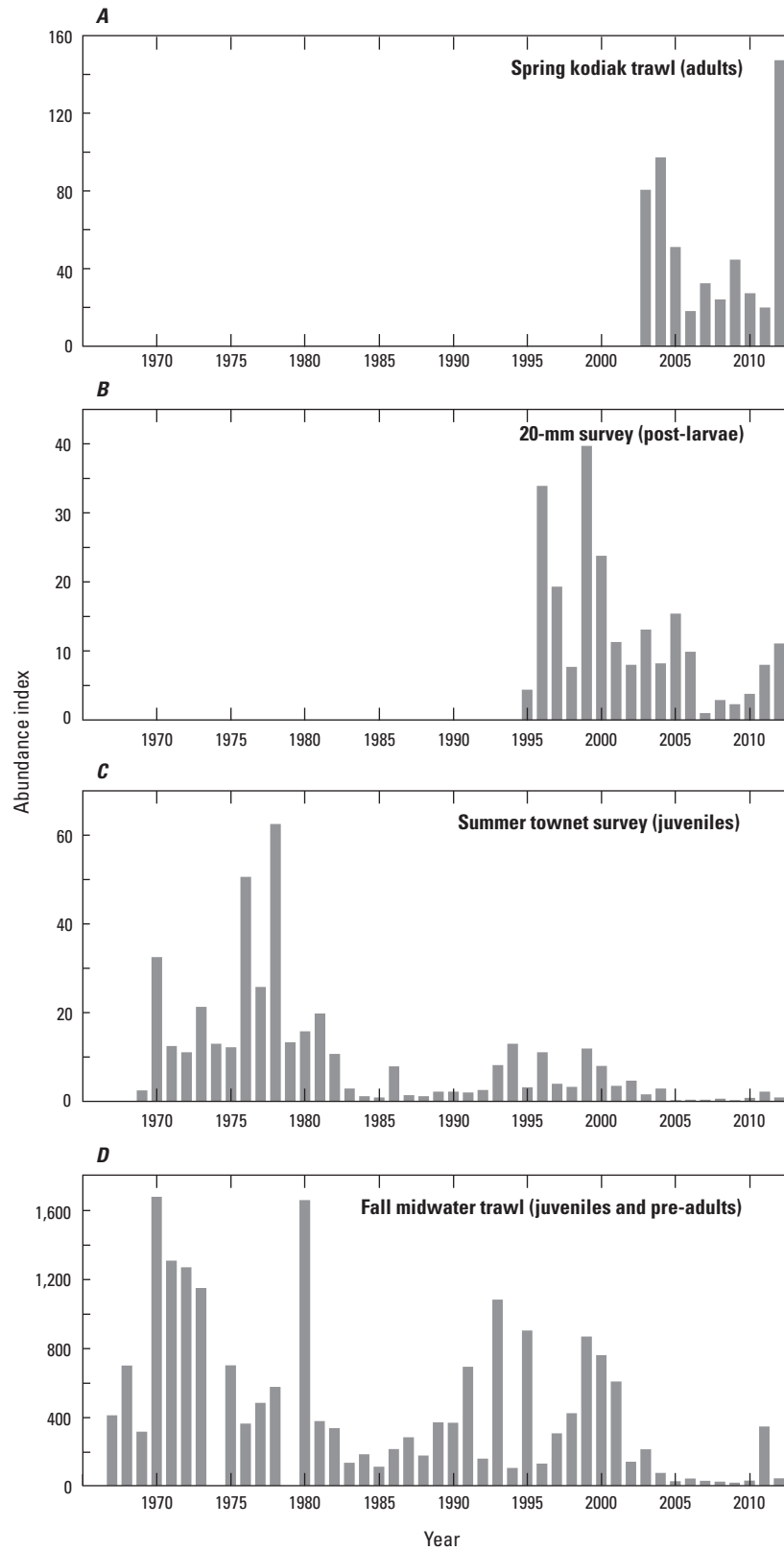


Figure 47. Plots of delta smelt abundance indices by year for *A*, the spring Kodiak-trawl survey (appendix table 8-1); *B*, 20-millimeter (mm) survey (appendix table 8-1); *C*, summer townet survey (appendix table 8-1); and *D*, fall midwater-trawl survey (appendix table 8-1). The fall midwater-trawl survey was not done in 1974 or 1979. The summer townet survey was not done from 1966 to 1968, and data from 1959 to 1965 are not shown.

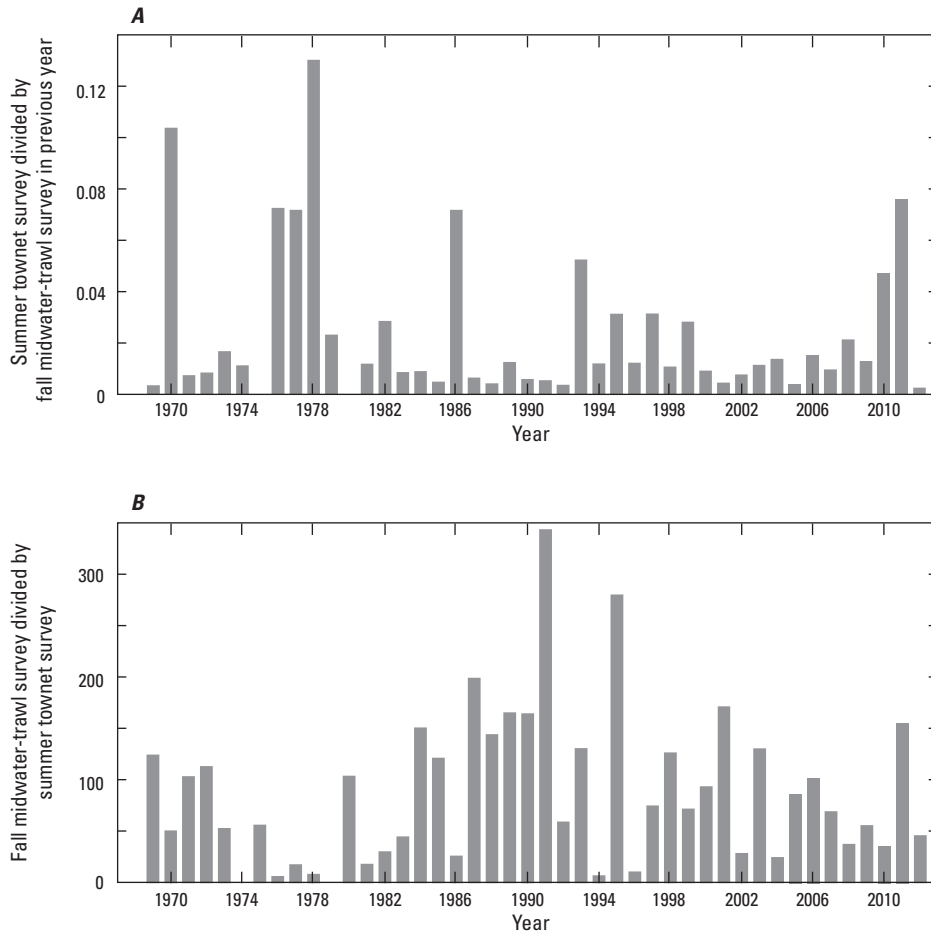


Figure 48. Ratios of delta smelt abundance indices used as indicators of survival by year for A, summer tonet survey divided by fall midwater-trawl survey in previous year; and B, fall midwater-trawl survey divided by summer tonet survey.

of delta smelt present in the summer (July–August) into the fall (fig. 48B). This ratio was well above the median (74.2) in 2011; however, this could be partially the result of favorable summer conditions and subsequent high survival rates, rather than only favorable fall conditions and survival. The ratio of TNS to the FMWT of the previous year (fig. 48A) can be used as an indicator of successful recruitment of juveniles from the maturing adults sampled by the FMWT. This ratio indicates that juvenile recruitment was high in 2010 and 2011 compared to the long-term median (0.012). The ratio in 2010 was the eighth highest on record, and in 2011, it was among the six highest values on record. This indicates 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 of 2011. The data indicated that survival in fall 2011, the preceding summer months, or both, was likely greater than in other years, which supports the prediction that delta smelt survival would be greater when X2 was at 74 km compared to greater values of X2 (table 1). The prediction about fecundity could not be addressed because samples were still being processed and, even if 2011 data were available, there are few data from preceding years for comparison.

The prediction that recruitment in the following year would be greater when X2 was at 74 km compared to 85 km can also be assessed by using values of abundance indices and ratios of abundance indices. For recruitment, in addition to the FMWT and TNS abundance indices, we used abundance indices from the spring Kodiak-trawl survey (SKT), which samples mature and spawning adults, and the 20-mm survey (20-mm), which samples post-larval to juvenile delta smelt (fig. 47). Recruitment from the fall into the next year includes two processes. Fish present in the fall must survive into the winter and spring of the following year ($SKT/FMWT_{year-1}$) and then reproduce. The resulting eggs and larvae must then survive. We assessed recruitment at two stages. We compared values from the 20-mm, TNS, and FMWT in 2012 to values in other years. We also assessed the contribution of spawning adults to recruitment by using ratios. Conceptually, this is equivalent to looking at recruits produced per spawning adult. The ratio of the 20-mm to SKT assesses recruitment to the larval stage from spawning adults. The ratio of the TNS to SKT assesses recruitment to the juvenile stage from spawning adults. In 2012, survival of pre-adults to mature adults was the lowest on record since the SKT began (fig. 49A) and was well below the median ratio of 0.70. The SKT abundance index in 2012 was the highest ever observed (fig. 47A). Thus, a large population of pre-adults in fall 2011 had proportionately poor survival into 2012, but still produced the largest population of adults since 2003, when these data were first collected.

The 2012 recruitment of post-larval to juvenile delta smelt in the 20-mm survey from the adults surviving after fall 2011 was an improvement from the previous 5 years and was the third greatest observed since the POD began in about 2002

(fig. 47B). The ratio of 20-mm to SKT was the third lowest observed since the SKT began in 2003 (fig. 49B), indicating that the increased recruitment was a result of the large spawning population rather than an increase in survival rate of the young of individual spawning adults. In 2012, recruitment of juveniles from the adults surviving from fall 2011 was less than the previous year and was the fifth greatest observed since the POD began in about 2002 (fig. 47C). The ratio of the TNS to SKT was the second lowest observed since the SKT began in 2003 (fig. 49C), which is consistent with a decrease in survival of the young of individual spawning adults. The 2012 recruitment of pre-adults from the adults surviving from fall 2011 was less than the previous year and was the fifth greatest observed since the POD began in about 2002 (fig. 47D). The prediction that recruitment the following year would be greater when X2 was at 74 km in 2011 compared to 85 km in 2010 was not supported, except at the earliest assessed life stage.

Results for recruitment of post-larval to juvenile delta smelt (20-mm survey) and juveniles (TNS) from the adults surviving from fall 2010 were not always lowest (fig. 47), as predicted for X2 of 85 km (table 1), so the prediction that recruitment would be less at greater X2 values was not fully supported. Note that there were no estimates of variability for either the population indices or ratios, so caution is warranted when interpreting these results.

The prediction that fish health would be better when X2 was at 74 km compared to 85 km (table 1) cannot be assessed at this time. Assessments of delta smelt health and condition are ongoing, including new measurements that have not been previously performed 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, sodium-potassium adenosine triphosphatase, histopathology, and pathogens). Preliminary results are available in Teh (2012). Results from fall 2011 will be used as the basis for comparisons with values for future years.

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 isotope 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 few fish also showed mixed signatures, indicating movement between different salinity regions through the year. However, there were no comparable data available from other years for assessment of the prediction that life history variability would be greater when X2 was at 74 km compared to 85 km.

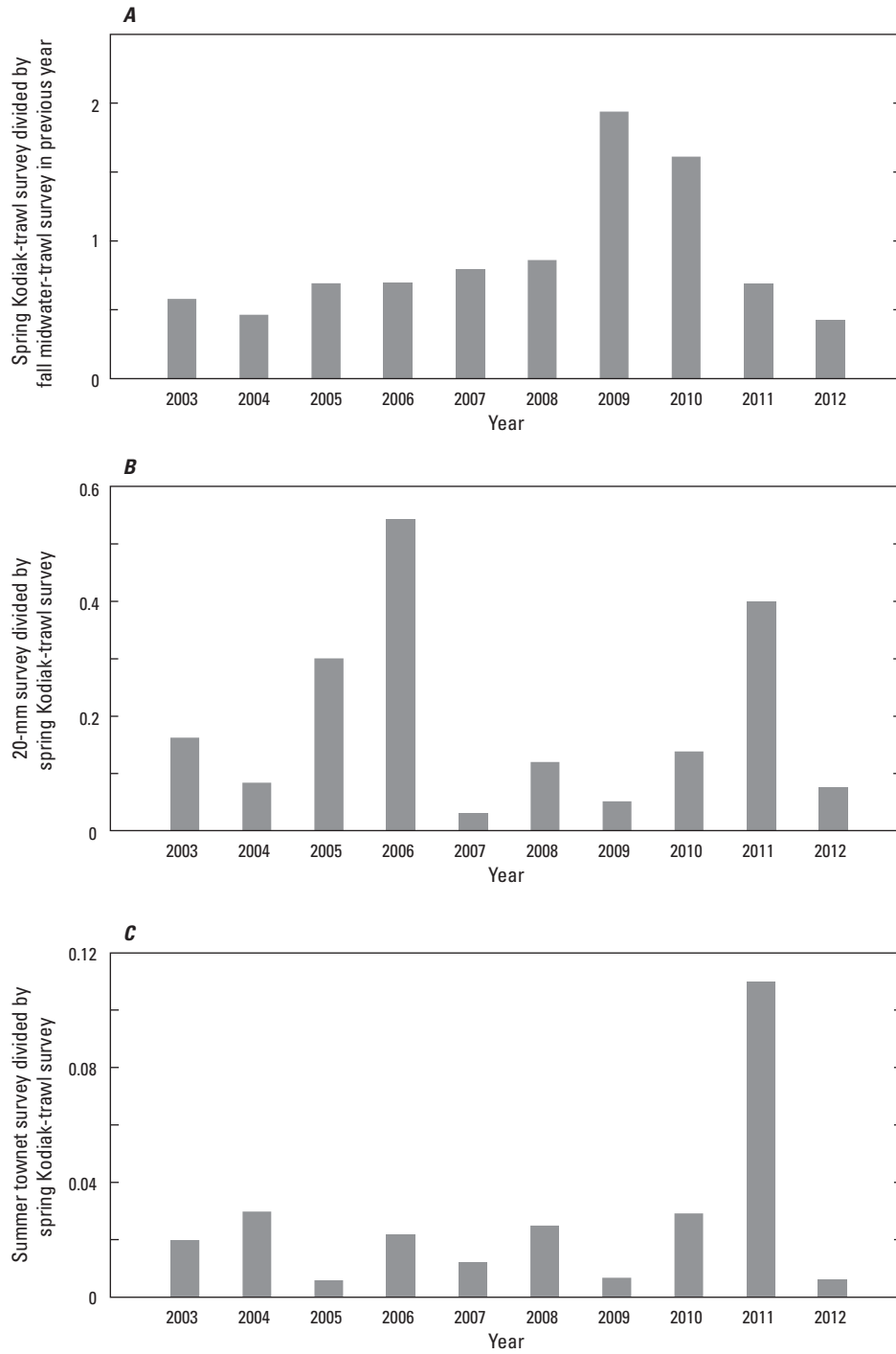


Figure 49. Ratios of delta smelt abundance indices used as indicators of survival and recruitment: *A*, spring Kodiak-trawl survey divided by fall midwater-trawl survey in previous year; *B*, 20-millimeter (mm) survey divided by spring Kodiak-trawl survey; and *C*, summer townet survey divided by spring Kodiak-trawl survey.

Discussion

There was an increase in the FMWT abundance index in the wet year of 2011 (fig. 4) when September–October X2 was at 75 km, which is near the objective of X2 at 74 km identified in the fall low-salinity habitat component of the RPA (U.S. Bureau of Reclamation, 2012). The greater FMWT abundance index in 2011 was followed in early 2012 by the highest winter abundance index for delta smelt since the beginning of the SKT survey in 2003 (fig. 47). The scientific challenge is to understand the degree to which the changes in delta smelt abundances and fall X2 are connected. The conceptual model, developed as part of the FLASH AMP (fig. 13), formalized the hypotheses associating X2 at 74 km (or 81 km) with improved conditions for delta smelt, which presumably lead to an increase in the population. This conceptual model led directly to the predictions in table 1. However, the greater numbers of delta smelt present in fall 2011 did not result in more recruitment in the following year, except for post-larvae (fig. 47). High variability in recruitment is not unexpected, particularly in an annual fish. Conditions must be favorable in every season of each year for high survival and recruitment.

Many of the predictions either could not be evaluated with the data available or the needed data were not being collected (table 5). In some cases, the available data were not sufficient to provide a reasonable assessment of the hypothesis at hand. It is unclear if precise water operations can provide the desired mean X2s with sufficiently low variability for assessment of hypotheses related to X2 at 81 and 85 km. Additional data will become available as results from research and monitoring are released. Incorporating these data into future reports, as part of the adaptive management cycle, assuming the FLASH investigations continue, could provide additional opportunities for improvement of our understanding of the factors affecting delta smelt.

Most of the predictions that could be addressed involved either abiotic habitat components or delta smelt responses (table 5). It is not surprising that abiotic components were relatively easy to assess because many of them are 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 highlighted differences between conditions when X2 was at 75 km and the other X2 values assessed. Variability in results at X2 between 82 and 85 km made the finer-scale comparisons difficult. Such variability leaves some question as to whether meaningful comparisons can be made between an X2 at 81 and at 85 km. It is notable that the two abiotic factors where the predictions were not supported concerned the nutrients ammonium and nitrite plus nitrate. These were included in the abiotic factors because they are considered potential contaminants and drivers of phytoplankton productivity and biomass, 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 based only on considerations of sources and transport.

The available data on delta smelt responses were limited to long-term data that were previously analyzed. Salvage data from the SWP and CVP were most recently addressed by Grimaldo and others (2009), and since the POD, managers have been very careful to minimize salvage. The center of distribution for delta smelt was most recently addressed by Sommer and others (2011b). Relationships among the various delta smelt population indices have also been explored (for example, Baxter and others, 2010). Thus, these predictions were based on previous empirical assessments. The data being collected on growth, fecundity, health, and condition in 2011 (Teh, 2012) could not be used to assess the predictions because there were no previous data for comparison; however, these data will be important in the future as a benchmark for a relatively “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 that biomass of *Potamocorbula* would be greater in the LSZ at X2 of 85 km compared to other values was not supported to the extent data were available, and the prediction that average phytoplankton biomass would be greater in the LSZ at X2 of 74 compared to greater values of X2 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, 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. The biotic habitat components are also known to interact with each other and with abiotic components. The prediction for *Potamocorbula*, which is functionally directed at grazing rates of clams on phytoplankton, does not include *Corbicula*, a clam which is an important grazer in freshwater. Understanding the effect of clam grazing on phytoplankton available to organisms that delta smelt consume will require modeling of grazing by both clam species in relation to phytoplankton production, hydrodynamics, and channel characteristics (for example, depth; Lucas and others, 2002; Lopez and others, 2006; Cloern, 2007; Lucas and Thompson, 2012). Further, benthic clam distributions do not shift as quickly in response to salinity changes as the distribution of pelagic organisms, and the predictions about clams would be more robust by taking these differences into consideration. Predation on delta smelt could also be a factor, but there are no quantitative data on predation rates to objectively evaluate the importance of predation to the delta smelt population.

In general, the FLASH investigation of the mechanisms linking X2 and delta smelt abundance has been somewhat inconclusive as of the writing of this report. That is not to be unexpected in the first year of a multi-year adaptive

Table 5. Assessments of predicted qualitative and quantitative outcomes for September to October of the fall low-salinity habitat component of the Reasonable and Prudent Alternative based on three levels of the action (modified from U.S. Bureau of Reclamation, 2012). The years considered representative of the three levels of action are indicated.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Green shading means that data supported the prediction; orange shading means the prediction was not supported; gray shading means that data were not yet available to support a conclusion; no shading means there were no data to assess **Abbreviations:** CVP, Central Valley Project; DS, delta smelt; ha, hectares; km, kilometer; LSZ, low-salinity zone with salinity 1–6; SWP, State Water Project; ~, approximately]

Variable (September–October)	Predictions for X2 scenarios		
	85 km	81 km	74 km
	Year used to test prediction		
	2010 (X2 at 85 km)	2005, 2006 (X2 at 83 and 82 km, respectively)	2011 (X2 at 75 km)
Dynamic abiotic habitat components			
Average daily net delta outflow	~5,000 cfs	~8,000 cfs	11,400
Surface area of the fall LSZ	~4,000 ha	~5,000 ha	~9,000 ha
Delta smelt abiotic habitat index	3,523	4,835	7,261
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 <i>Microcystis</i>)	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 <i>Microcystis</i> 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
<i>Potamocorbula</i> 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 and 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

management effort. Substantial knowledge was gained as a result of the work done in fall 2011 and will provide the basis for reassessing some hypotheses that could be too simplistic in the current conceptual model. This report can be viewed as the first chapter of a “living document” to be continually updated as part of the adaptive management cycle. As part of that cycle, the results of this report can be used to revise the conceptual model and predictions based on the conceptual model, perhaps through an annual or biannual update of the adaptive management plan.

The results of this report, especially predictions with insufficient data for evaluation, indicate a number of science-based approaches 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 would be needed to determine if hydrodynamic complexity creates the dynamic, biotic habitat components hypothesized, including variability in phytoplankton and zooplankton biomass, and whether those biotic habitat components contribute to greater abundances of delta smelt.
- 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 to determining turbidity. If important goals are the understanding of the processes generating turbidity and the ability to predict turbidity, then development of a suspended-sediment and turbidity model that incorporates wind and other important factors is warranted.
- Determine the correct spatial and temporal scales necessary for monitoring, and identify other studies to address the predicted abiotic and biotic responses. 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 daily.
- Develop a phytoplankton-production model, if feasible. At a minimum, develop a mechanistic conceptual model to support more process-based interpretations of data or the design of new studies, rather than making simple predictions of increase or decrease of nutrient concentrations or the biomass of phytoplankton and grazers. Such a model could include components of nutrient cycling and grazing, which would highlight any needs for additional research and understanding of those processes.

- Refine predictions about delta smelt prey availability and quality by using data on delta smelt diet and other information on delta smelt prey characteristics.
- Determine if studies of predation are feasible in areas occupied by delta smelt.

As noted previously, a major limitation of this report is that many of the key analyses from the FLaSH studies were not completed at the time that this report was prepared. Even when these analyses are completed, rigorous inter-year comparisons will not be possible because there are not other years with comparable levels of effort dedicated to understanding the same features of the LSZ. Such comparisons, therefore, will 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 only addressed selected months in selected years to limit the need to incorporate larger data sets in the limited time available to prepare the report and because the FLaSH investigation focuses only on the fall. Future iterations of this report can incorporate additional data as they become available, including data from seasons other than the fall. There are fewer available data from earlier years to compare to recent years because additional types of data have been collected as management of delta smelt became important. Differences in overall habitat conditions and status of delta smelt were greater in earlier years before the POD (Thomson and others, 2010; Baxter and others, 2010). This makes comparisons with earlier years more difficult and less likely to be conclusive. Inclusion of data from all seasons, not just fall, is critical to our understanding of factors affecting delta smelt. 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 conditions during the preceding spring affected spawning success of adults and the subsequent survival of larvae. Understanding the relative importance of such events is the basis of life-cycle models, which could be useful tools for managing delta smelt in the future. A broader analysis that incorporates the results of the FLaSH investigation is one of the objectives of the newly formed IEP Management, Analysis, and Synthesis Team. The Management, Analysis, and Synthesis Team is intended to provide a broader analysis of factors affecting delta smelt and could serve as a template for formation of a FLaSH team as part of the AMP that would prepare future versions of this report.

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Appendixes

Appendix 1. Dayflow

Dayflow was the source for basic flow data used in this report. Full documentation and data for Dayflow are available at <http://www.water.ca.gov/dayflow/>. The following description is directly from the website with minimal editing.

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 Bay estuary.

The Dayflow program also estimates the following flow and parameter values as daily averages:

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

The Dayflow estimate of Delta outflow is referred to as the “net Delta outflow index” (NDOI) because it does not 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 (about ±150,000 cfs), aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much more or less than the Dayflow estimate.

Dayflow is computed for each year following completion of the water year (October 1). At that time, we request official quality assured and controlled data from several sources (table 1-1). Once all input data are received, we compute the Dayflow estimate of Delta outflow. Our goal is to provide data for the previous water year by January 1.

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

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

The stations used in Dayflow calculations are shown in figure 1-1. We utilized three calculated outputs from Dayflow. We utilize the net Delta outflow index; however, for simplicity, we refer to it as 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:

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

where

- t is current day, and
- t-1 is previous day.

We also used 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 same as quantity WEST in Dayflow data output files.

Table 1-1. Responsible agencies and data used as input to the Dayflow program.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. **Abbreviation:** ID, Irrigation District]

Responsible agency	Input data
U.S. Geological Survey	Flow: Sacramento River at Freeport, Yolo Bypass at Woodland, Cosumnes River at Michigan Bar, San Joaquin River at Vernalis, Delta Cross Channel, Georgiana Slough.
U.S. Army Corps of Engineers	Flow: Calaveras River.
East Bay Municipal Utility District	Flow: Mokelumne River at Woodbridge.
California Department of Water Resources Operations and Maintenance	Precipitation at Stockton Fire Department, Clifton Court Forebay gate flow, Barker Slough export, Byron Bethany ID depletion, X2 (only when outflow is negative).
California Department of Water Resources Bay-Delta	Estimated delta island consumptive use.
California Department of Water Resources Planning and Local Assistance	Sacramento Weir spill, Lisbon Weir flow.
Reclamation	Delta cross-channel gate status, Tracy export, Contra Costa export.
Solano County Water District	Lake Barryessa releases, Lake Solano inflow, Putah Creek.

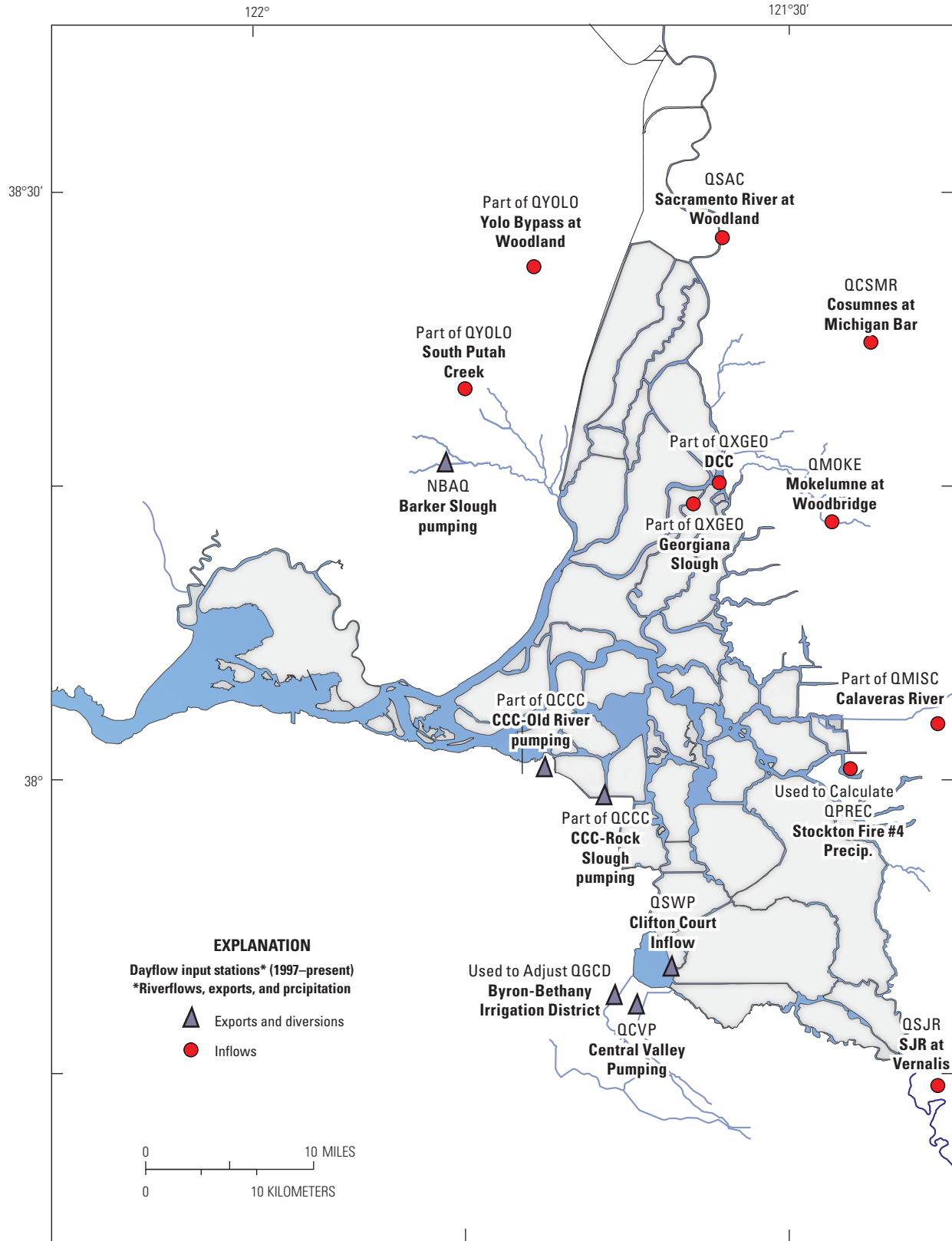


Figure 1-1. Sites used in Dayflow calculations (<http://www.water.ca.gov/dayflow/>).

Appendix 2. Surface Area and Maps of the Low-Salinity Zone

Our calculations of area of the LSZ were based on conversions of X2 (the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2) 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 14–16 of the report. The results were also used to create a table (table 2-1) for conversion of X2 to surface area of the LSZ. Dr. MacWilliams cautions that the distribution of salinity in the estuary for the same X2 can differ depending on whether X2 is moving seaward or landward and on the exact flow conditions in the year of interest. Therefore, the maps and calculated surface areas are to be considered estimates rather than exact values.

Low-Salinity Zone Area and Depth Analysis

Figure references have been updated in the following text, dated January 23, 2012, provided by Michael L. MacWilliams, Ph.D. The text has been edited for this appendix.

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 from April 1, 1994, to October 1, 1995. Model validation of predicted salinity for this period will be documented 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 and 6.0 (similar analyses have used a slightly wider salinity range, from 0.5 to 6.0). This analysis focuses specifically on the relationship between X2 and the areal extent and average depth of the LSZ.

LSZ Habitat Area and Depth Calculation Approach

In this analysis, the LSZ habitat area is calculated by using the predicted depth-averaged daily averaged salinity for the simulation of a historic period 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 that has

depth-averaged daily averaged salinity between 1 and 6 and is 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 figure 2-1. Area within the salinity range of the LSZ that is not within the model domain is 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 on the basis of the daily averaged water level within each cell that is within the LSZ. Water levels are only averaged during periods when the cells are wet, so that the average depth of intertidal cells is calculated on the basis of the average depth during the time each cell was wet during each day.

Table 2-1. Estimates of the area of the low-salinity zone (LSZ) for specified X2.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. **Abbreviations:** km, kilometers]

X2 (km)	Area of LSZ (hectares)	X2 (km)	Area of LSZ (hectares)
30	18,324	64	6,981
31	10,933	65	6,999
32	9,544	66	7,912
33	12,675	67	8,467
34	15,432	68	8,474
35	11,423	69	8,743
36	7,413	70	8,500
37	14,905	71	8,632
38	20,693	72	8,539
39	14,154	73	8,585
40	17,138	74	8,408
41	19,969	75	8,231
42	19,421	76	8,380
43	19,131	77	8,162
44	21,651	78	7,959
45	19,746	79	7,369
46	18,021	80	6,653
47	18,525	81	5,313
48	18,450	82	5,051
49	17,743	83	5,075
50	17,590	84	4,753
51	11,525	85	4,483
52	8,908	86	4,492
53	13,429	87	4,456
54	7,313	88	4,463
55	8,576	89	4,604
56	4,284	90	4,635
57	3,530	91	4,653
58	4,244	92	4,655
59	5,127	93	4,953
60	4,813	94	5,000
61	4,498	95	5,025
62	5,773	96	4,996
63	7,007		

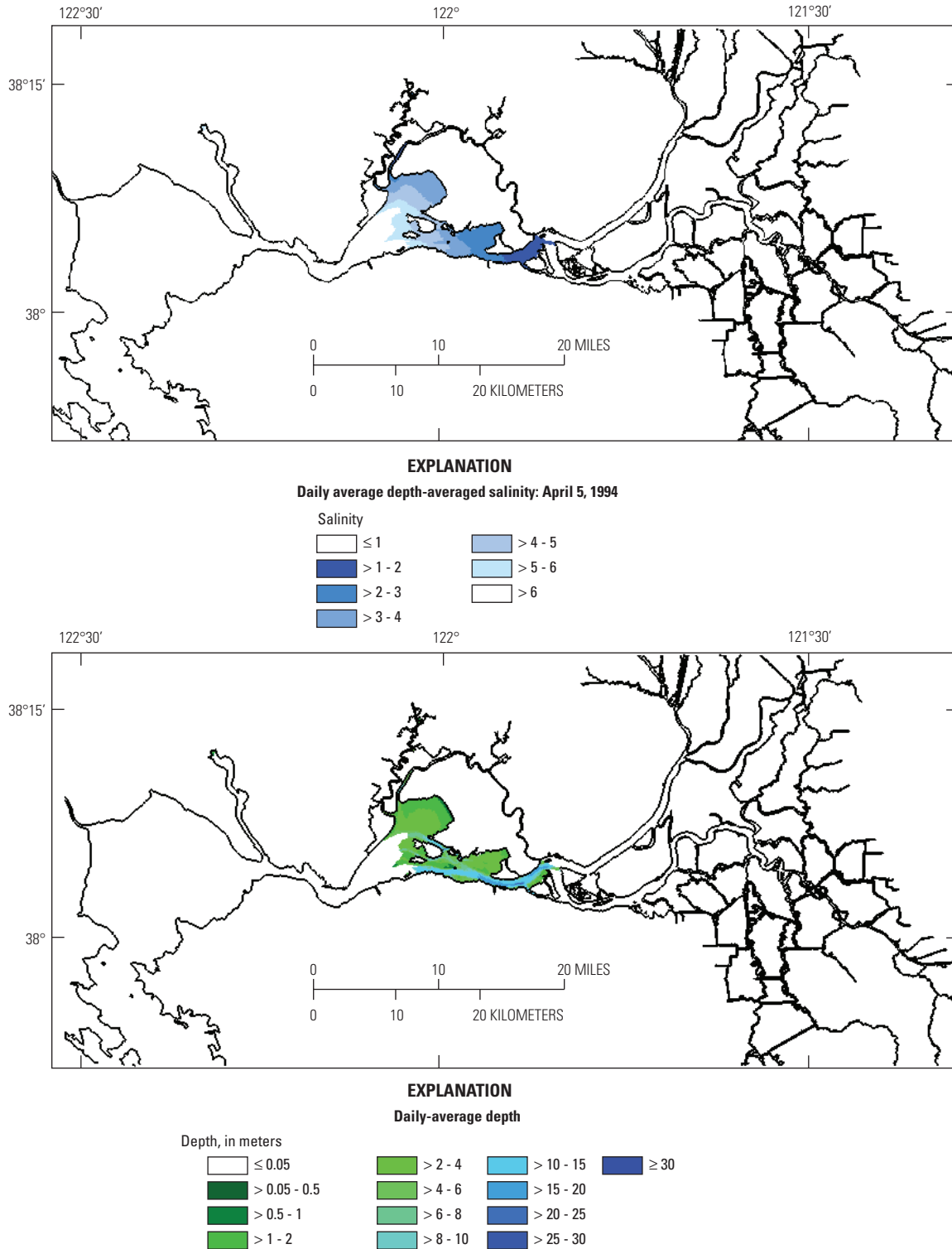


Figure 2-1. Model domain (entire mapped region) showing daily averaged depth-averaged salinity (top) and daily averaged depth (bottom) of the low-salinity zone (salinity 1–6) on April 5, 1994, when X2 was approximately 75. Area not within the LSZ is shown in white. X2 is the horizontal distance from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. Symbols are: ≤, less than or equal to; and >, greater than.

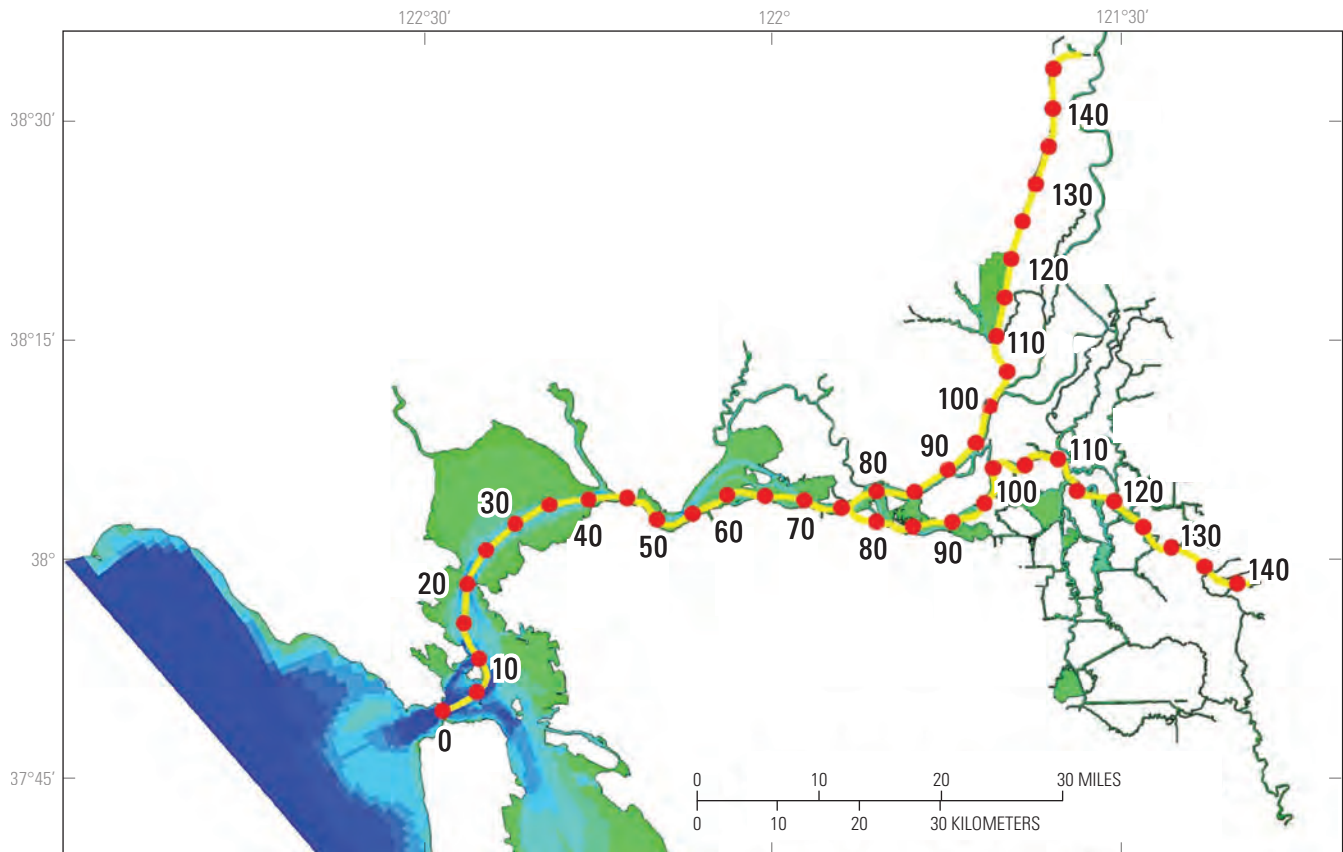


Figure 2-2. Transects along the axis of northern San Francisco Bay used to measure X2 in the UnTRIM Bay-Delta model.

X2 Calculation Approach

By definition, X2 is the horizontal distance from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. 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 (<http://www.water.ca.gov/dayflow/documentation/dayflowDoc.cfm#Introduction>). 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 and others, 1995), although recent studies indicate that some of these relationships have changed (Sommer and others, 2007).

Jassby and others (1995) provide a graphical depiction of X2 (see fig. 2 of report), showing selected values of X2. The inset in the 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 at the transects shown in figure 2-2. For X2 greater than 75 km, the distance from the Golden Gate to the location of near-bottom salinity 2 isohaline is measured along both the Sacramento

and San Joaquin transects, and the reported predicted “average X2” is the average of the Sacramento and San Joaquin X2 distances. Use of an average over a number of years, within water-year types, could perhaps provide a consistent basis for conversion or modeling future areas.

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Appendix 3. Delta Smelt Habitat Index

We used a table (table 3-1) to convert daily X2 (the horizontal distance from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2) 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 fall midwater-trawl (FMWT) station by the 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 turbidity measured at the time fish were sampled. The habitat index was calculated as the average habitat index for the 4 months of the FMWT, September–December. The annual habitat index was then related to mean X2 from September to December by 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 table.

References Cited

Feyrer, Frederick, Newman, Ken, Nobriga, Matthew, and Sommer, Ted, 2010, Modeling the effects of future freshwater flow on the abiotic habitat of an imperiled estuarine fish: *Estuaries and Coasts*, v. 34, p. 120–128.

Table 3-1. Delta smelt habitat index values for specified X2.

[X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2. **Abbreviations:** km, kilometer]

X2 (km)	Predicted habitat index	X2 (km)	Predicted habitat index
61	7,343	78	6,099
62	7,551	79	5,735
63	7,724	80	5,292
64	7,863	81	4,835
65	7,967	82	4,430
66	8,036	83	4,081
67	8,069	84	3,777
68	8,067	85	3,523
69	8,027	86	3,314
70	7,950	87	3,160
71	7,837	88	3,054
72	7,685	89	2,996
73	7,491	90	2,987
74	7,261	91	3,028
75	7,000	92	3,116
76	6,716	93	3,252
77	6,414		

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Appendix 4. Fall Midwater-Trawl Survey

A description of the fall midwater-trawl survey (FMWT) and data for fish abundance indices are available at <http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT>. The FMWT is carried out by the California Department of Fish and Wildlife under the umbrella of Interagency Ecological Program monitoring activities. For convenience, in this appendix, we present an edited version of the general description of the FMWT sampling and provide additional details. We also include a map (fig. 4-1) and latitude and longitude (table 4-1) of the sampling stations. Values of the FMWT delta smelt abundance index are provided in appendix 8 with abundance indices from other sampling programs.

The fall midwater-trawl survey (FMWT) has been completed annually since its inception in 1967, with the exceptions of 1974 and 1979, when sampling was not performed. The FMWT was initiated to determine the relative abundance and distribution of age-0 striped bass (*Morone saxatilis*) in the estuary, but the data have 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. The 122 stations are located from San Pablo Bay upstream to Stockton on the San Joaquin River and to Hood on the Sacramento River, including locations in the Sacramento Deep Water Ship Channel. Sampling takes approximately 9 days a 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 performed 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 by 12 ft when stretched taut, but mouth dimensions tend to 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 it is towed through the water. At each station, the net is towed for 12 minutes as it is retrieved obliquely through the water column from bottom to surface, after which, all fish, shrimp, and jellyfish are identified and enumerated. In addition, the crew measures water temperature, electrical conductivity (specific conductance), Secchi depth, and turbidity.

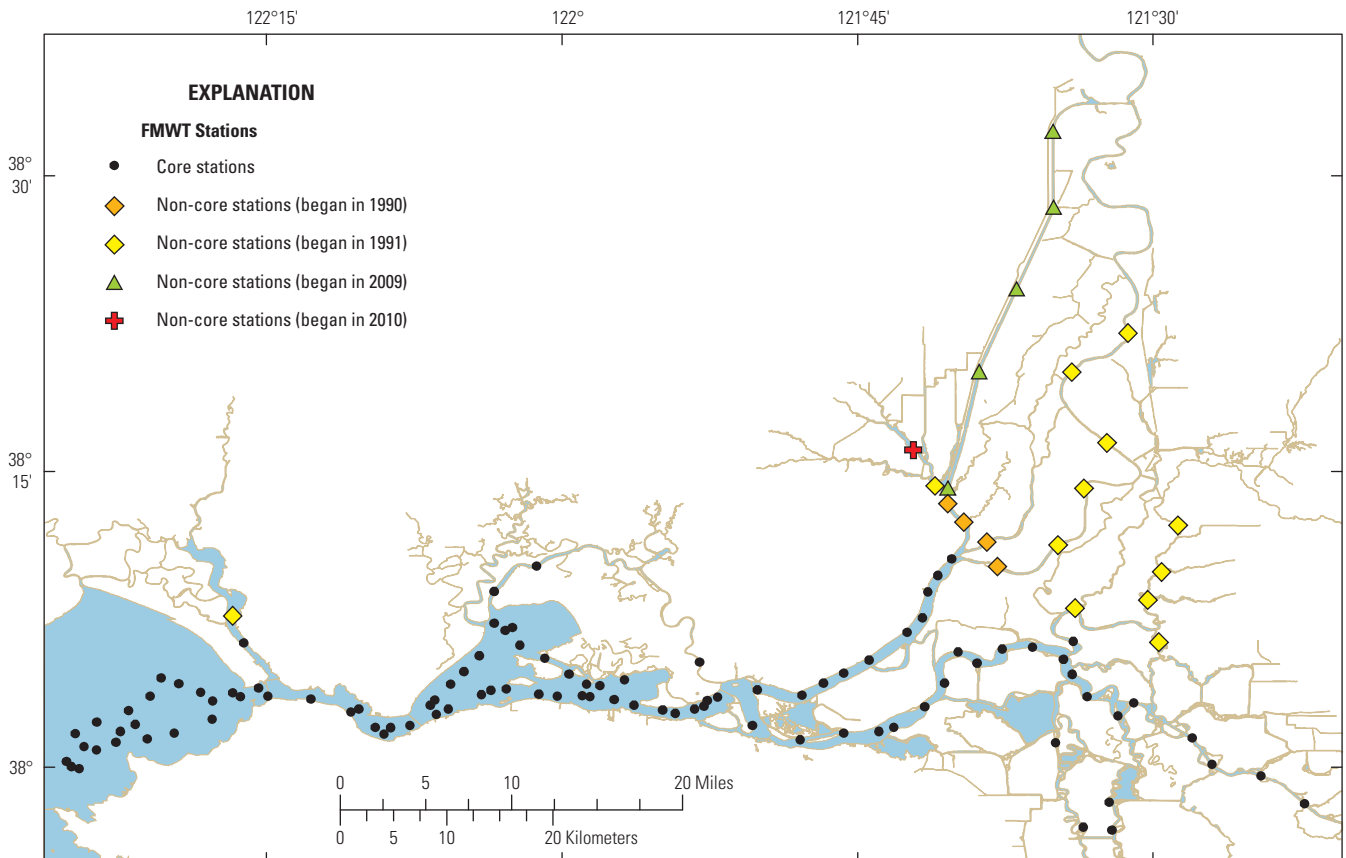


Figure 4-1. Locations of fall midwater-trawl sampling (FMWT) stations in the San Francisco Bay estuary.

Table 4-1. Locations of fall midwater-trawl sampling stations in the San Francisco estuary.

Station	North latitude (decimal degrees)	West longitude (decimal degrees)	Station	North latitude (decimal degrees)	West longitude (decimal degrees)	Station	North latitude (decimal degrees)	West longitude (decimal degrees)	Station	North latitude (decimal degrees)	West longitude (decimal degrees)
72	38.18775	121.58057	416	38.07020	122.09415	717	38.17017	121.63138			
73	38.27433	121.53937	417	38.08075	122.08300	719	38.33428	121.64733			
305	37.99870	122.40860	418	38.09383	122.06973	723	38.23615	121.67348			
306	38.00042	122.41488	501	38.06167	122.01955	724	38.23578	121.55878			
307	38.00472	122.41920	502	38.05997	122.00397	735	38.33343	121.56968			
308	38.01745	122.40438	503	38.06022	121.98320	736	38.36737	121.52140			
309	38.01442	122.39387	504	38.05945	121.97670	795	38.53770	121.58468			
310	38.02970	122.37355	505	38.05713	121.95597	796	38.47387	121.58440			
311	38.02087	122.37743	507	38.05228	121.93900	797	38.40462	121.61560			
314	38.02812	122.41167	508	38.04813	121.91492	721	38.26815	121.70277			
315	38.03815	122.39360	509	38.04547	121.90412	802	38.03528	121.83875			
321	38.03612	122.36103	510	38.04888	121.88783	804	38.02308	121.79868			
322	38.02363	122.35078	511	38.05130	121.88000	806	38.02872	121.76170			
323	38.02853	122.32817	512	38.05638	121.87722	807	38.02995	121.73203			
325	38.05605	122.29550	513	38.05920	121.86842	808	38.03337	121.71942			
326	38.04038	122.29592	515	38.09200	122.01472	809	38.05120	121.69305			
327	38.04772	122.36672	516	38.07867	121.99408	810	38.07083	121.67622			
328	38.06005	122.34842	517	38.07022	121.97938	811	38.09742	121.66487			
329	38.06312	122.30588	518	38.06875	121.96802	812	38.08792	121.64883			
334	38.07553	122.33933	519	38.07378	121.94725	813	38.09978	121.62767			
335	38.07050	122.32430	601	38.10310	122.03560	814	38.10128	121.60220			
336	38.06275	122.27875	602	38.11783	122.04183	815	38.09130	121.57587			
337	38.05950	122.27232	603	38.11552	122.04805	902	38.02050	121.58255			
338	38.06003	122.24892	604	38.12163	122.05717	903	38.10628	121.56747			
339	38.06670	122.25680	605	38.14853	122.05738	904	38.07828	121.56847			
340	38.10508	122.26988	606	38.16980	122.02177	905	38.05953	121.55573			
341	38.12828	122.28020	608	38.08870	121.88332	906	38.05412	121.51653			
401	38.05758	122.21245	701	38.06505	121.83475	908	38.04308	121.52980			
403	38.04883	122.17192	703	38.06087	121.79692	909	38.02442	121.46705			
404	38.04645	122.17887	704	38.07087	121.77892	910	38.00228	121.45037			
405	38.03353	122.15815	705	38.07925	121.76180	911	37.99247	121.40875			
406	38.02800	122.15057	706	38.09030	121.74000	912	37.96883	121.37172			
407	38.03298	122.14515	707	38.11397	121.70797	913	37.97012	121.53705			
408	38.03513	122.12897	708	38.12608	121.69670	914	37.94662	121.53475			
409	38.04455	122.10637	709	38.14787	121.69048	915	37.94900	121.55908			
410	38.04883	122.09647	710	38.16200	121.68228	919	38.10572	121.49525			
411	38.06117	122.06828	711	38.17595	121.67028	920	38.14138	121.50475			
412	38.06462	122.06007	712	38.19042	121.64095	921	38.16513	121.49303			
413	38.06595	122.04730	713	38.20712	121.66008	922	38.20438	121.47890			
414	38.05213	122.11128	715	38.22295	121.67362	923	38.13445	121.56625			
415	38.05678	122.10772	716	38.23787	121.68438						

The FMWT equipment and methods have remained consistent since the survey's inception, which allows annual abundance indices to be compared. Monthly and annual abundance indices are calculated by 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 (that is, 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 four (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.

In addition to the FMWT delta smelt abundance index, we assessed water-quality data collected during sampling, specifically, water temperature, electrical conductivity (converted to salinity), Secchi depth, and turbidity (table 4-2). Turbidity has only been measured since 2010. Estimates of *Microcystis* abundance have been made since 2008 by using a visual ranking system (fig. 4-2). 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 FMWT. Stomachs were dissected and inspected, and prey items were identified to the lowest practical taxon. Data were recorded as number of each prey taxon and weight of each taxon in the diet. We present data as percentage of the weight of all prey items in the diet. The center of distribution of the delta smelt population was determined by weighting the distance (kilometers) 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. We used data on chlorophyll- α , ammonia as nitrogen, and nitrite plus nitrate as nitrogen (table 4-3).

Algal pigments were determined by using method SM10200-H (Clesceri and others, 1998). Samples were filtered by using a Whatman GF/F glass-fiber filter within 12 hours of delivery, and the filters were frozen prior to extraction. The method was altered by using 90 percent ethanol for extraction instead of 90 percent acetone, and the glass-fiber

filters were freeze-dried but not ground (Sartory and Grobbelaar, 1984). Samples were analyzed by fluorometric determination; the limit of detection was generally about 0.5 $\mu\text{g/L}$, but it varied depending on the volume of water filtered (200 to 1,000 mL).

A subsample was filtered through a pre-rinsed 0.45-micrometer polycarbonate membrane (Millipore) for quantification of ammonium as nitrogen ($\text{NH}_4\text{-N}$). $\text{NH}_4\text{-N}$ was determined spectroscopically with the Berthelot reaction using a salicylate analog of indophenol blue (limit of detection is about 0.010 milligrams per liter; Forster 1995). Analysis of $\text{NH}_4\text{-N}$ was completed within 48 hours of sample collection. The vanadium chloride method was used to spectroscopically determine nitrate plus nitrite as nitrogen (limit of detection is 0.01 milligrams per liter).

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).

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Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
72	09/19/2005	<1	19.0	1.05	—	—	505	09/15/2005	1–6	18.7	0.70	—	—
73	09/19/2005	<1	19.2	0.90	—	—	507	09/15/2005	1–6	18.7	0.60	—	—
305	09/06/2005	>6	18.7	0.47	—	—	508	09/08/2005	1–6	19.5	0.60	—	—
306	09/06/2005	>6	18.8	0.78	—	—	509	09/15/2005	1–6	18.6	0.60	—	—
307	09/06/2005	>6	18.8	0.92	—	—	510	09/15/2005	1–6	18.7	0.35	—	—
308	09/06/2005	>6	18.7	0.80	—	—	511	09/15/2005	1–6	18.8	0.42	—	—
309	09/06/2005	>6	18.7	0.89	—	—	512	09/15/2005	1–6	19.0	0.45	—	—
310	09/06/2005	>6	19.0	0.94	—	—	513	09/15/2005	1–6	18.9	0.40	—	—
311	09/06/2005	>6	18.7	0.81	—	—	515	09/08/2005	>6	19.2	0.45	—	—
314	09/06/2005	>6	18.8	0.45	—	—	516	09/08/2005	>6	19.7	0.48	—	—
315	09/06/2005	>6	19.8	0.46	—	—	517	09/08/2005	>6	19.7	0.45	—	—
321	09/06/2005	>6	19.5	0.82	—	—	518	09/08/2005	1–6	19.7	0.56	—	—
322	09/06/2005	>6	18.7	0.70	—	—	519	09/08/2005	1–6	19.6	0.50	—	—
323	09/06/2005	>6	18.5	0.50	—	—	601	09/08/2005	>6	18.8	0.30	—	—
325	09/06/2005	>6	19.8	0.84	—	—	602	09/08/2005	>6	19.3	0.23	—	—
326	09/06/2005	>6	19.0	0.44	—	—	603	09/08/2005	>6	19.1	0.35	—	—
327	09/06/2005	>6	18.7	0.39	—	—	604	09/08/2005	>6	19.8	0.40	—	—
328	09/06/2005	>6	18.7	0.49	—	—	605	09/08/2005	>6	20.4	0.41	—	—
329	09/06/2005	>6	17.9	0.49	—	—	606	09/08/2005	>6	20.6	0.39	—	—
334	09/06/2005	>6	18.9	0.35	—	—	608	09/08/2005	1–6	20.5	0.42	—	—
335	09/06/2005	>6	18.8	0.45	—	—	701	09/12/2005	1–6	19.8	0.49	—	—
336	09/06/2005	>6	19.8	0.40	—	—	703	09/12/2005	<1	19.9	0.40	—	—
337	09/06/2005	>6	19.8	0.50	—	—	704	09/12/2005	<1	20.0	0.42	—	—
338	09/06/2005	>6	19.9	0.85	—	—	705	09/12/2005	<1	20.1	0.30	—	—
339	09/06/2005	>6	19.9	0.28	—	—	706	09/12/2005	<1	19.9	0.40	—	—
340	09/07/2005	>6	19.5	0.31	—	—	707	09/12/2005	<1	19.8	0.58	—	—
341	09/07/2005	>6	19.7	0.54	—	—	708	09/12/2005	<1	19.8	0.50	—	—
401	09/07/2005	>6	19.0	0.60	—	—	709	09/12/2005	<1	19.6	0.50	—	—
403	09/07/2005	>6	18.5	0.36	—	—	710	09/12/2005	<1	19.5	0.45	—	—
404	09/07/2005	>6	19.3	0.49	—	—	711	09/12/2005	<1	19.5	0.60	—	—
405	09/07/2005	>6	19.5	0.48	—	—	712	09/12/2005	<1	19.4	0.90	—	—
406	09/08/2005	>6	19.1	0.90	—	—	713	09/12/2005	CS/ SDWSC	19.2	0.39	—	—
407	09/08/2005	>6	19.3	0.72	—	—							
408	09/08/2005	>6	19.3	0.50	—	—	715	09/12/2005	CS/ SDWSC	19.3	0.41	—	—
409	09/15/2005	>6	18.5	0.50	—	—							
410	09/15/2005	>6	18.5	0.60	—	—	716	09/12/2005	CS/ SDWSC	18.9	0.30	—	—
411	09/15/2005	>6	18.4	0.50	—	—							
412	09/15/2005	>6	18.4	0.50	—	—	717	09/19/2005	<1	19.1	0.70	—	—
413	09/15/2005	>6	18.5	0.50	—	—	724	09/19/2005	<1	19.3	0.80	—	—
414	09/15/2005	>6	17.8	0.20	—	—	735	09/19/2005	<1	19.2	0.85	—	—
415	09/15/2005	>6	18.0	0.25	—	—	736	09/19/2005	<1	19.3	0.95	—	—
416	09/15/2005	>6	18.0	0.20	—	—	802	09/19/2005	1–6	18.7	0.50	—	—
417	09/15/2005	>6	18.0	0.30	—	—	804	09/12/2005	1–6	19.9	0.60	—	—
418	09/15/2005	>6	18.0	0.30	—	—	806	09/19/2005	<1	20.0	0.72	—	—
501	09/15/2005	1–6	18.6	0.65	—	—	807	09/13/2005	<1	20.0	0.65	—	—
502	09/15/2005	1–6	18.6	0.55	—	—	808	09/13/2005	<1	20.2	0.75	—	—
503	09/15/2005	1–6	18.6	0.60	—	—	809	09/13/2005	<1	20.1	0.80	—	—
504	09/08/2005	>6	19.2	0.60	—	—	810	09/13/2005	<1	20.3	0.85	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
811	09/13/2005	<1	20.4	0.90	—	—	340	10/04/2005	>6	17.6	0.50	—	—
812	09/13/2005	<1	20.4	1.00	—	—	341	10/04/2005	>6	17.2	0.48	—	—
813	09/13/2005	<1	20.3	0.90	—	—	401	10/04/2005	>6	18.2	0.60	—	—
814	09/13/2005	<1	20.4	1.00	—	—	403	10/04/2005	>6	18.0	0.50	—	—
815	09/13/2005	<1	20.5	1.10	—	—	404	10/04/2005	>6	18.2	0.62	—	—
902	09/14/2005	<1	20.5	1.80	—	—	405	10/04/2005	>6	18.2	0.59	—	—
903	09/14/2005	<1	19.7	0.80	—	—	406	10/04/2005	>6	18.2	0.59	—	—
904	09/13/2005	<1	20.6	1.10	—	—	407	10/04/2005	>6	18.3	0.68	—	—
905	09/13/2005	<1	20.9	1.20	—	—	408	10/04/2005	>6	18.3	0.55	—	—
906	09/13/2005	<1	21.3	1.50	—	—	409	10/04/2005	>6	19.1	0.65	—	—
908	09/14/2005	<1	20.1	1.40	—	—	410	10/04/2005	>6	19.3	0.60	—	—
909	09/13/2005	<1	22.2	0.95	—	—	411	10/04/2005	>6	18.3	0.50	—	—
910	09/13/2005	<1	22.8	0.95	—	—	412	10/04/2005	>6	19.0	0.61	—	—
911	09/13/2005	<1	23.0	0.60	—	—	413	10/06/2005	>6	17.4	0.50	—	—
912	09/13/2005	<1	22.1	0.65	—	—	414	10/05/2005	>6	17.5	0.50	—	—
913	09/14/2005	<1	21.4	1.15	—	—	415	10/05/2005	>6	17.7	0.30	—	—
914	09/14/2005	<1	21.1	1.40	—	—	416	10/05/2005	>6	17.5	0.30	—	—
915	09/14/2005	<1	20.8	1.50	—	—	417	10/05/2005	>6	17.6	0.40	—	—
919	09/14/2005	<1	18.0	1.10	—	—	418	10/05/2005	>6	17.4	0.30	—	—
920	09/14/2005	<1	17.2	0.90	—	—	501	10/06/2005	>6	17.5	0.48	—	—
921	09/14/2005	<1	18.0	1.00	—	—	502	10/06/2005	>6	17.5	0.55	—	—
922	09/14/2005	<1	16.2	0.90	—	—	503	10/06/2005	>6	17.1	0.68	—	—
923	09/14/2005	<1	19.8	0.90	—	—	504	10/06/2005	1–6	17.9	0.60	—	—
72	10/11/2005	<1	16.8	1.10	—	—	505	10/06/2005	1–6	17.9	0.60	—	—
73	10/11/2005	<1	16.8	1.20	—	—	507	10/06/2005	1–6	18.2	0.42	—	—
305	10/03/2005	>6	17.6	0.90	—	—	508	10/06/2005	1–6	18.2	0.58	—	—
306	10/03/2005	>6	17.9	1.10	—	—	509	10/06/2005	1–6	18.5	0.59	—	—
307	10/03/2005	>6	17.9	1.20	—	—	510	10/06/2005	1–6	18.4	0.50	—	—
308	10/03/2005	>6	18.1	0.78	—	—	511	10/06/2005	1–6	18.4	0.55	—	—
309	10/03/2005	>6	19.7	1.10	—	—	512	10/06/2005	1–6	18.5	0.60	—	—
310	10/03/2005	>6	17.8	0.70	—	—	513	10/06/2005	1–6	18.6	0.52	—	—
311	10/03/2005	>6	18.1	1.00	—	—	515	10/05/2005	1–6	18.2	0.50	—	—
314	10/03/2005	>6	18.2	0.75	—	—	516	10/05/2005	1–6	18.4	0.57	—	—
315	10/03/2005	>6	18.3	0.95	—	—	517	10/05/2005	1–6	19.0	0.80	—	—
321	10/03/2005	>6	17.8	0.85	—	—	518	10/05/2005	1–6	18.7	0.55	—	—
322	10/03/2005	>6	18.1	0.90	—	—	519	10/05/2005	1–6	18.4	0.50	—	—
323	10/03/2005	>6	18.2	0.90	—	—	601	10/05/2005	>6	18.1	0.35	—	—
325	10/03/2005	>6	18.8	0.40	—	—	602	10/05/2005	>6	17.4	0.33	—	—
326	10/03/2005	>6	18.3	0.70	—	—	603	10/05/2005	>6	17.6	0.38	—	—
327	10/03/2005	>6	18.4	0.60	—	—	604	10/05/2005	>6	17.4	0.45	—	—
328	10/03/2005	>6	18.2	0.38	—	—	605	10/05/2005	>6	17.4	0.30	—	—
329	10/03/2005	>6	18.3	0.40	—	—	606	10/05/2005	>6	19.6	0.35	—	—
334	10/03/2005	>6	18.0	0.40	—	—	608	10/05/2005	1–6	18.6	0.50	—	—
335	10/03/2005	>6	18.0	0.30	—	—	701	10/06/2005	<1	19.4	0.50	—	—
336	10/04/2005	>6	18.1	0.60	—	—	703	10/06/2005	<1	18.2	0.50	—	—
337	10/04/2005	>6	17.4	0.80	—	—	704	10/06/2005	<1	18.5	0.55	—	—
338	10/04/2005	>6	18.2	0.55	—	—	705	10/11/2005	<1	18.6	0.35	—	—
339	10/04/2005	>6	18.0	0.35	—	—	706	10/11/2005	<1	18.4	0.30	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
707	10/11/2005	<1	17.0	0.61	—	—	306	10/31/2005	>6	15.6	1.00	—	—
708	10/11/2005	<1	17.0	0.73	—	—	307	10/31/2005	>6	15.6	1.20	—	—
709	10/11/2005	<1	17.1	0.68	—	—	308	10/31/2005	>6	15.3	0.90	—	—
710	10/11/2005	<1	17.1	0.50	—	—	309	10/31/2005	>6	15.9	0.90	—	—
711	10/11/2005	<1	17.2	0.50	—	—	310	10/31/2005	>6	15.9	1.00	—	—
712	10/11/2005	<1	18.0	0.90	—	—	311	10/31/2005	>6	16.2	0.93	—	—
713	10/11/2005	CS/ SDWSC	17.3	0.25	—	—	314	10/31/2005	>6	15.6	0.45	—	—
715	10/11/2005	CS/ SDWSC	17.4	0.25	—	—	315	10/31/2005	>6	15.8	1.20	—	—
716	10/11/2005	CS/ SDWSC	17.4	0.20	—	—	321	10/31/2005	>6	15.5	1.16	—	—
717	10/11/2005	<1	16.8	0.90	—	—	322	10/31/2005	>6	16.0	0.85	—	—
724	10/11/2005	<1	17.0	1.20	—	—	323	10/31/2005	>6	16.0	0.85	—	—
735	10/11/2005	<1	17.0	1.35	—	—	325	11/01/2005	>6	16.0	1.10	—	—
736	10/11/2005	<1	16.9	1.40	—	—	326	10/31/2005	>6		0.85	—	—
802	10/06/2005	<1	18.7	0.50	—	—	327	10/31/2005	>6	16.1	1.20	—	—
804	10/12/2005	<1	18.6	0.40	—	—	328	10/31/2005	>6	15.9	0.90	—	—
806	10/12/2005	<1	18.1	0.50	—	—	329	10/31/2005	>6	15.7	0.60	—	—
807	10/12/2005	<1	18.6	0.80	—	—	334	10/31/2005	>6	15.9	0.70	—	—
808	10/12/2005	<1	18.4	0.80	—	—	335	10/31/2005	>6	15.9	0.70	—	—
809	10/12/2005	<1	1.00	—	—	—	336	11/01/2005	>6		0.65	—	—
810	10/12/2005	<1	18.4	0.70	—	—	337	11/01/2005	>6	16.1	0.90	—	—
811	10/12/2005	<1	18.5	1.09	—	—	338	11/01/2005	>6	16.0	1.00	—	—
812	10/12/2005	<1	18.3	0.80	—	—	339	11/01/2005	>6	16.2	0.65	—	—
813	10/12/2005	<1	18.1	1.25	—	—	340	11/01/2005	>6	16.2	0.30	—	—
814	10/12/2005	<1	18.1	0.90	—	—	341	11/01/2005	>6	16.4	0.39	—	—
815	10/17/2005	<1	17.9	1.14	—	—	401	11/01/2005	>6	16.3	0.70	—	—
902	10/17/2005	<1		1.51	—	—	403	11/01/2005	>6	16.4	0.78	—	—
903	10/17/2005	<1	17.8	2.00	—	—	404	11/01/2005	>6	16.3	0.90	—	—
904	10/12/2005	<1	18.2	1.40	—	—	405	11/01/2005	>6	16.2	0.90	—	—
905	10/12/2005	<1	18.1	0.98	—	—	406	11/01/2005	>6	16.0	0.80	—	—
906	10/17/2005	<1	18.4	1.88	—	—	407	11/01/2005	>6	16.5	0.82	—	—
908	10/17/2005	<1	18.4	2.00	—	—	408	11/01/2005	>6	16.5	0.68	—	—
909	10/12/2005	<1	18.7	0.70	—	—	409	11/02/2005	>6		0.75	—	—
910	10/12/2005	<1	18.6	0.70	—	—	410	11/02/2005	>6	16.1	0.72	—	—
911	10/12/2005	<1	18.6	0.55	—	—	411	11/02/2005	>6	16.2	0.70	—	—
912	10/12/2005	<1	18.5	0.50	—	—	412	11/02/2005	>6	16.1	0.81	—	—
913	10/17/2005	<1	18.5	2.00	—	—	413	11/02/2005	>6	16.1	0.80	—	—
914	10/17/2005	<1	18.1	2.00	—	—	414	11/03/2005	>6	15.9	0.65	—	—
915	10/17/2005	<1	17.9	1.42	—	—	415	11/03/2005	>6	15.7	0.50	—	—
919	10/17/2005	<1	17.4	1.53	—	—	416	11/03/2005	>6	15.5	0.50	—	—
920	10/17/2005	<1	17.3	1.86	—	—	417	11/03/2005	>6	15.5	0.70	—	—
921	10/17/2005	<1	17.4	1.77	—	—	418	11/03/2005	>6	15.5	0.50	—	—
923	10/17/2005	<1	17.6	2.00	—	—	501	11/02/2005	>6	16.2	0.76	—	—
72	11/09/2005	<1	14.0	1.49	—	—	502	11/02/2005	>6	16.3	0.90	—	—
73	11/09/2005	<1	14.0	0.87	—	—	503	11/02/2005	>6	16.3	0.65	—	—
305	10/31/2005	>6	15.4	0.90	—	—	504	11/02/2005	>6	16.4	0.75	—	—
							505	11/02/2005	>6	16.5	0.80	—	—
							507	11/02/2005	1–6	16.4	0.70	—	—
							508	11/02/2005	1–6	16.4	0.75	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro-cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro-cystis (0–5)
509	11/02/2005	1–6	16.4	0.80	—	—	814	11/10/2005	<1	14.8	1.20	—	—
510	11/02/2005	>6	16.5	0.65	—	—	815	11/10/2005	<1	14.9	0.99	—	—
511	11/02/2005	>6	16.5	0.55	—	—	902	11/14/2005	<1	14.6	2.00	—	—
512	11/02/2005	>6	16.3	0.40	—	—	903	11/14/2005	<1	14.0	1.04	—	—
513	11/07/2005	1–6	15.7	0.80	—	—	904	11/10/2005	<1	14.8	1.60	—	—
515	11/03/2005	>6	15.9	0.57	—	—	905	11/10/2005	<1	15.0	1.30	—	—
516	11/03/2005	>6	15.8	0.68	—	—	906	11/10/2005	<1	15.2	1.40	—	—
517	11/03/2005	>6	15.8	0.55	—	—	908	11/14/2005	<1	14.6	1.50	—	—
518	11/03/2005	>6	15.9	0.39	—	—	909	11/10/2005	<1	15.2	1.30	—	—
519	11/03/2005	>6	15.9	0.42	—	—	910	11/10/2005	<1	15.0	1.00	—	—
601	11/03/2005	>6	15.8	0.50	—	—	911	11/10/2005	<1	14.9	0.75	—	—
602	11/03/2005	>6	15.9	0.57	—	—	912	11/10/2005	<1	15.0	0.50	—	—
603	11/03/2005	>6	15.3	0.69	—	—	913	11/14/2005	<1	14.7	1.39	—	—
604	11/03/2005	>6	15.4	0.55	—	—	914	11/14/2005	<1	14.7	1.70	—	—
605	11/03/2005	>6	15.4	0.30	—	—	915	11/14/2005	<1	14.6	1.80	—	—
606	11/03/2005	>6	15.9	0.50	—	—	919	11/14/2005	<1	13.9	1.56	—	—
608	11/02/2005	1–6	16.4	0.39	—	—	920	11/14/2005	<1	13.8	1.35	—	—
701	11/07/2005	1–6	15.9	0.60	—	—	921	11/14/2005	<1	13.9	1.19	—	—
703	11/07/2005	1–6	15.7	0.55	—	—	922	11/14/2005	<1	13.9	0.87	—	—
704	11/07/2005	1–6	15.7	0.40	—	—	923	11/14/2005	<1	13.9	1.10	—	—
705	11/07/2005	1–6	15.0	0.45	—	—	73	12/13/2005	<1	9.9	1.01	—	—
706	11/07/2005	<1	15.5	0.50	—	—	305	12/05/2005	>6	11.8	0.65	—	—
707	11/07/2005	<1	15.3	0.43	—	—	306	12/05/2005	>6	11.7	0.70	—	—
708	11/07/2005	<1	15.3	0.65	—	—	307	12/05/2005	>6	11.5	0.80	—	—
709	11/07/2005	<1	15.1	0.70	—	—	308	12/05/2005	>6	11.9	0.72	—	—
710	11/07/2005	<1	15.0	0.75	—	—	309	12/05/2005	>6	11.9	0.70	—	—
711	11/07/2005	<1	15.0	0.80	—	—	310	12/05/2005	>6	12.0	0.80	—	—
712	11/09/2005	<1	14.3	0.93	—	—	311	12/05/2005	>6	12.0	0.78	—	—
713	11/07/2005	CS/ SDWSC	14.9	0.78	—	—	314	12/05/2005	>6	11.6	0.80	—	—
715	11/07/2005	CS/ SDWSC	14.9	0.65	—	—	315	12/05/2005	>6	11.7	0.60	—	—
716	11/07/2005	CS/ SDWSC	15.1	0.25	—	—	321	12/05/2005	>6	12.0	0.50	—	—
717	11/07/2005	<1	15.0	0.90	—	—	322	12/05/2005	>6	12.0	0.35	—	—
724	11/09/2005	<1	14.0	1.31	—	—	323	12/05/2005	>6	12.1	0.60	—	—
735	11/09/2005	<1	14.1	1.39	—	—	325	12/06/2005	>6	11.2	0.35	—	—
736	11/09/2005	<1	14.1	1.40	—	—	326	12/06/2005	>6	11.2	0.46	—	—
802	11/02/2005	1–6	16.5	0.68	—	—	327	12/05/2005	>6	11.4	0.58	—	—
804	11/02/2005	1–6	16.6	0.50	—	—	328	12/05/2005	>6	11.3	0.48	—	—
806	11/10/2005	<1	15.2	0.80	—	—	329	12/05/2005	>6	11.8	0.28	—	—
807	11/10/2005	<1	15.1	0.80	—	—	334	12/05/2005	>6	11.5	0.60	—	—
808	11/10/2005	<1	15.1	0.92	—	—	335	12/05/2005	>6	11.1	0.39	—	—
809	11/10/2005	<1	15.1	1.05	—	—	336	12/06/2005	>6	11.2	0.46	—	—
810	11/10/2005	<1	15.2	0.80	—	—	337	12/06/2005	>6	11.7	0.60	—	—
811	11/10/2005	<1	15.1	1.20	—	—	338	12/06/2005	>6	11.6	0.60	—	—
812	11/10/2005	<1	15.1	1.10	—	—	339	12/06/2005	>6	11.8	0.30	—	—
813	11/10/2005	<1	15.1	1.10	—	—	340	12/06/2005	>6	11.2	0.30	—	—
							341	12/06/2005	>6	10.8	0.45	—	—
							401	12/06/2005	>6	11.8	0.60	—	—
							403	12/06/2005	>6	11.9	0.40	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
404	12/06/2005	>6	11.8	0.48	—	—	711	12/08/2005	<1	9.3	0.39	—	—
405	12/06/2005	>6	11.8	0.55	—	—	712	12/08/2005	<1	9.0	0.30	—	—
406	12/06/2005	>6	11.8	0.51	—	—	713	12/08/2005	CS/ SDWSC	9.2	0.42	—	—
407	12/06/2005	>6	11.8	0.75	—	—	715	12/08/2005	CS/ SDWSC	9.2	0.32	—	—
408	12/06/2005	>6	11.7	0.70	—	—	716	12/08/2005	CS/ SDWSC	9.3	0.40	—	—
409	12/07/2005	>6	11.4	0.32	—	—	717	12/08/2005	<1	8.8	0.30	—	—
410	12/07/2005	>6	11.4	0.36	—	—	717	12/13/2005	<1	9.8	1.10	—	—
411	12/07/2005	>6	11.4	0.42	—	—	724	12/13/2005	<1	9.8	0.99	—	—
412	12/07/2005	>6	10.9	0.48	—	—	735	12/13/2005	<1	9.8	0.92	—	—
413	12/07/2005	>6		0.40	—	—	736	12/13/2005	<1	9.9	0.83	—	—
414	12/12/2005	>6		0.47	—	—	802	12/13/2005	1–6	10.3	0.70	—	—
415	12/12/2005	>6	11.1	0.60	—	—	804	12/15/2005	1–6	9.9	0.60	—	—
416	12/12/2005	>6	11.1	0.57	—	—	806	12/15/2005	1–6	10.1	0.74	—	—
417	12/12/2005	>6	11.0	0.49	—	—	807	12/15/2005	<1	10.2	0.72	—	—
418	12/12/2005	>6	11.0	0.32	—	—	808	12/15/2005	<1	10.1	0.73	—	—
501	12/07/2005	>6	11.9	0.49	—	—	809	12/15/2005	<1	10.2	0.82	—	—
502	12/07/2005	>6	11.1	0.60	—	—	810	12/15/2005	<1	10.1	0.94	—	—
503	12/07/2005	>6	11.0	0.65	—	—	811	12/15/2005	<1	10.1	0.81	—	—
504	12/07/2005	>6	10.9	0.60	—	—	812	12/15/2005	<1	10.0	0.87	—	—
505	12/07/2005	1–6	11.2	0.65	—	—	813	12/15/2005	<1	10.1	0.92	—	—
507	12/07/2005	1–6	11.0	0.60	—	—	814	12/15/2005	<1	10.1	0.94	—	—
508	12/07/2005	1–6	10.9	0.65	—	—	815	12/15/2005	<1	10.2	0.87	—	—
509	12/07/2005	1–6	11.1	0.69	—	—	902	12/14/2005	<1	10.1	1.80	—	—
510	12/07/2005	1–6	11.0	0.70	—	—	903	12/14/2005	<1	10.2	0.92	—	—
511	12/07/2005	1–6	10.8	0.60	—	—	904	12/16/2005	<1	9.8	1.30	—	—
512	12/07/2005	1–6	10.8	0.70	—	—	905	12/16/2005	<1	9.8	1.27	—	—
513	12/07/2005	1–6	10.8	0.55	—	—	906	12/16/2005	<1	9.7	1.55	—	—
515	12/12/2005	>6	11.2	0.45	—	—	908	12/14/2005	<1	10.2	1.11	—	—
516	12/12/2005	>6	11.0	0.57	—	—	909	12/16/2005	<1	9.7	1.36	—	—
517	12/12/2005	>6	11.1	0.40	—	—	910	12/16/2005	<1	9.9	1.07	—	—
518	12/12/2005	>6	11.3	0.60	—	—	911	12/16/2005	<1	10.1	1.20	—	—
519	12/12/2005	1–6	11.8	0.58	—	—	912	12/16/2005	<1	10.1	1.10	—	—
601	12/12/2005	>6	11.3	0.43	—	—	913	12/14/2005	<1	10.4	1.12	—	—
602	12/12/2005	>6	11.1	0.48	—	—	914	12/14/2005	<1	10.3	1.25	—	—
603	12/12/2005	>6	11.1	0.32	—	—	915	12/14/2005	<1	10.2	1.57	—	—
604	12/12/2005	>6	11.1	0.43	—	—	919	12/14/2005	<1	9.4	1.09	—	—
605	12/12/2005	>6	10.5	0.44	—	—	920	12/14/2005	<1	9.6	0.78	—	—
606	12/12/2005	>6	10.9	0.30	—	—	921	12/14/2005	<1	9.7	0.63	—	—
608	12/13/2005	1–6	10.4	0.38	—	—	922	12/14/2005	<1	9.8	1.21	—	—
701	12/08/2005	1–6	10.5	0.55	—	—	923	12/14/2005	<1	9.8	1.05	—	—
703	12/08/2005	<1		0.53	—	—	305	09/05/2006	>6	19.1	0.59	—	—
704	12/08/2005	<1	9.8	0.54	—	—	306	09/05/2006	>6	19.6	0.60	—	—
705	12/08/2005	<1	9.7	0.48	—	—	307	09/05/2006	>6	19.2	0.58	—	—
706	12/08/2005	<1	9.5	0.30	—	—	308	09/05/2006	>6	19.2	0.77	—	—
707	12/08/2005	<1	9.3	0.23	—	—	309	09/05/2006	>6	18.5	0.65	—	—
708	12/08/2005	<1	9.3	0.45	—	—							
709	12/08/2005	<1	9.9	0.40	—	—							
710	12/08/2005	<1	9.7	0.38	—	—							

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0-5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0-5)
310	09/05/2006	>6	18.5	0.70	—	—	513	09/12/2006	1-6	19.8	0.45	—	—
311	09/05/2006	>6	18.8	0.44	—	—	515	09/08/2006	>6	18.9	0.22	—	—
314	09/05/2006	>6	19.0	0.45	—	—	516	09/11/2006	>6	18.5	0.42	—	—
315	09/05/2006	>6	19.1	0.40	—	—	517	09/11/2006	>6	18.7	0.35	—	—
321	09/06/2006	>6	19.2	0.40	—	—	518	09/11/2006	1-6	19.4	0.40	—	—
322	09/06/2006	>6	18.6	0.43	—	—	519	09/11/2006	1-6	19.6	0.42	—	—
323	09/06/2006	>6	18.5	0.49	—	—	601	09/08/2006	>6	18.9	0.22	—	—
325	09/06/2006	>6	18.8	0.52	—	—	602	09/08/2006	>6	18.7	0.21	—	—
326	09/06/2006	>6	18.8	0.47	—	—	603	09/08/2006	>6	18.3	0.23	—	—
327	09/05/2006	>6	19.0	0.60	—	—	604	09/08/2006	1-6	19.7	0.23	—	—
328	09/05/2006	>6	18.9	0.51	—	—	605	09/08/2006	1-6	20.1	0.24	—	—
329	09/05/2006	>6	18.9	0.27	—	—	606	09/08/2006	1-6	20.3	0.20	—	—
334	09/05/2006	>6	18.9	0.45	—	—	608	09/12/2006	1-6	19.9	0.35	—	—
335	09/05/2006	>6	18.8	0.40	—	—	701	09/14/2006	<1	20.2	0.50	—	—
336	09/06/2006	>6	18.7	0.52	—	—	703	09/14/2006	<1	20.4	0.64	—	—
337	09/06/2006	>6	18.8	0.53	—	—	704	09/14/2006	<1	20.4	0.46	—	—
338	09/06/2006	>6	19.2	0.63	—	—	705	09/14/2006	<1	20.4	0.74	—	—
339	09/06/2006	>6	18.8	0.62	—	—	706	09/14/2006	<1	20.5	0.30	—	—
340	09/06/2006	>6	18.8	0.47	—	—	707	09/14/2006	<1	20.5	0.60	—	—
341	09/06/2006	>6	19.3	0.42	—	—	708	09/14/2006	<1	20.5	—	—	—
401	09/06/2006	>6	19.2	0.66	—	—	709	09/14/2006	<1	20.5	0.50	—	—
403	09/07/2006	>6	18.8	0.20	—	—	710	09/14/2006	<1	20.5	0.70	—	—
404	09/06/2006	>6	19.1	0.38	—	—	711	09/14/2006	<1	20.5	0.85	—	—
405	09/07/2006	>6	18.9	0.18	—	—	802	09/12/2006	<1	20.4	0.48	—	—
406	09/07/2006	>6	18.9	0.25	—	—	804	09/12/2006	<1	21.0	0.65	—	—
407	09/07/2006	>6	19.0	0.18	—	—	806	09/12/2006	<1	21.4	0.68	—	—
408	09/07/2006	>6	19.0	0.28	—	—	807	09/12/2006	<1	21.3	0.78	—	—
409	09/07/2006	>6	19.1	0.35	—	—	808	09/12/2006	<1	21.3	0.80	—	—
410	09/07/2006	>6	19.3	0.38	—	—	809	09/12/2006	<1	21.4	0.95	—	—
411	09/07/2006	1-6	19.4	0.38	—	—	810	09/12/2006	<1	21.2	0.90	—	—
412	09/07/2006	1-6	19.6	0.38	—	—	811	09/12/2006	<1	21.8	0.89	—	—
413	09/07/2006	1-6	19.7	0.39	—	—	812	09/12/2006	<1	22.0	0.95	—	—
414	09/08/2006	>6	18.9	0.35	—	—	813	09/13/2006	<1	21.5	1.35	—	—
415	09/08/2006	>6	19.0	0.27	—	—	814	09/13/2006	<1	21.5	0.95	—	—
416	09/08/2006	>6	19.0	0.35	—	—	815	09/13/2006	<1	21.6	1.20	—	—
417	09/08/2006	>6	18.9	0.25	—	—	902	09/15/2006	<1	21.4	1.60	—	—
418	09/08/2006	>6	19.0	0.24	—	—	903	09/18/2006	<1	19.2	1.18	—	—
501	09/07/2006	1-6	19.7	0.50	—	—	904	09/13/2006	<1	21.6	1.06	—	—
502	09/07/2006	1-6	19.8	0.48	—	—	905	09/13/2006	<1	21.9	0.94	—	—
503	09/07/2006	1-6	19.8	0.46	—	—	906	09/13/2006	<1	22.4	0.97	—	—
504	09/07/2006	1-6	19.8	0.46	—	—	908	09/15/2006	<1	21.4	1.00	—	—
505	09/11/2006	1-6	19.8	0.42	—	—	909	09/13/2006	<1	22.9	0.96	—	—
507	09/11/2006	1-6	19.5	0.36	—	—	910	09/13/2006	<1	23.2	0.66	—	—
508	09/11/2006	1-6	19.9	0.45	—	—	911	09/13/2006	<1	23.0	0.75	—	—
509	09/12/2006	1-6	19.8	0.48	—	—	912	09/13/2006	<1	20.9	0.56	—	—
510	09/12/2006	1-6	19.7	0.41	—	—	913	09/15/2006	<1	21.6	1.20	—	—
511	09/12/2006	1-6	19.8	0.45	—	—	914	09/15/2006	<1	21.6	1.00	—	—
512	09/12/2006	1-6	19.8	0.40	—	—	915	09/15/2006	<1	21.4	1.60	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-				Station	Date (mm/dd/yyyy)	Salinity group	Surface-			
			water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)				water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
919	09/15/2006	<1	20.6	0.97	—	—	501	10/12/2006	>6	18.4	0.60	—	—
920	09/15/2006	<1	20.3	0.85	—	—	502	10/12/2006	>6	18.3	0.78	—	—
921	09/15/2006	<1	20.1	1.15	—	—	503	10/12/2006	1–6	18.3	0.65	—	—
922	09/15/2006	<1	20.5	1.18	—	—	504	10/13/2006	1–6	17.1	0.75	—	—
923	09/15/2006	<1	20.3	1.09	—	—	505	10/12/2006	1–6	18.6	0.65	—	—
73	10/19/2006	<1	16.3	1.40	—	—	507	10/13/2006	1–6	17.2	0.55	—	—
305	10/06/2006	>6	16.4	0.89	—	—	508	10/13/2006	1–6	17.2	0.58	—	—
306	10/06/2006	>6	16.5	0.92	—	—	509	10/13/2006	1–6	17.2	0.60	—	—
307	10/06/2006	>6	16.5	0.79	—	—	510	10/13/2006	1–6	17.1	0.52	—	—
308	10/06/2006	>6	16.4	0.90	—	—	511	10/13/2006	1–6	17.0	0.55	—	—
309	10/06/2006	>6	16.2	0.74	—	—	512	10/13/2006	1–6	17.1	0.50	—	—
310	10/06/2006	>6	16.2	0.75	—	—	513	10/13/2006	1–6	17.2	0.55	—	—
311	10/06/2006	>6	16.3	0.65	—	—	515	10/12/2006	>6	17.1	0.38	—	—
314	10/06/2006	>6	16.6	0.56	—	—	516	10/12/2006	>6	17.0	0.50	—	—
315	10/06/2006	>6	16.6	0.52	—	—	517	10/12/2006	>6	17.2	0.60	—	—
321	10/10/2006	>6	16.5	0.80	—	—	518	10/12/2006	>6	17.2	0.58	—	—
322	10/10/2006	>6	16.6	0.65	—	—	519	10/12/2006	1–6	17.0	0.60	—	—
323	10/10/2006	>6	16.4	0.65	—	—	601	10/12/2006	>6	17.2	0.30	—	—
325	10/10/2006	>6	17.0	0.72	—	—	602	10/12/2006	>6	17.2	0.29	—	—
326	10/10/2006	>6	16.7	0.76	—	—	603	10/12/2006	>6	17.3	0.28	—	—
327	10/06/2006	>6	16.5	0.78	—	—	604	10/11/2006	>6	16.9	0.40	—	—
328	10/06/2006	>6	16.8	0.54	—	—	605	10/11/2006	>6	17.4	0.42	—	—
329	10/06/2006	>6	16.9	0.41	—	—	606	10/11/2006	>6	17.4	0.40	—	—
334	10/06/2006	>6	16.8	0.58	—	—	608	10/13/2006	1–6	17.0	0.48	—	—
335	10/06/2006	>6	16.8	0.31	—	—	701	10/16/2006	<1	16.6	0.62	—	—
336	10/10/2006	>6	17.0	0.40	—	—	703	10/16/2006	<1	16.6	0.68	—	—
337	10/10/2006	>6	17.0	0.40	—	—	704	10/16/2006	<1	16.6	0.72	—	—
338	10/10/2006	>6	17.1	0.70	—	—	705	10/16/2006	<1	16.7	0.89	—	—
339	10/10/2006	>6	17.2	0.39	—	—	706	10/16/2006	<1	16.7	0.88	—	—
340	10/10/2006	>6	17.3	0.30	—	—	707	10/16/2006	<1	16.7	1.08	—	—
341	10/10/2006	>6	17.3	0.22	—	—	708	10/19/2006	<1	16.5	0.58	—	—
401	10/10/2006	>6	17.1	0.80	—	—	709	10/19/2006	<1	16.8	0.56	—	—
403	10/10/2006	>6	17.4	0.68	—	—	710	10/19/2006	<1	16.5	0.67	—	—
404	10/10/2006	>6	17.2	0.50	—	—	711	10/19/2006	<1	16.4	0.64	—	—
405	10/10/2006	>6	17.5	0.60	—	—	712	10/19/2006	<1	15.9	1.20	—	—
406	10/10/2006	>6	17.2	0.68	—	—	713	10/19/2006	CS/ SDWSC	16.2	0.42	—	—
407	10/11/2006	>6	17.0	0.70	—	—							
408	10/11/2006	>6	16.9	0.65	—	—	715	10/19/2006	CS/ SDWSC	16.1	0.57	—	—
409	10/12/2006	>6	17.6	0.60	—	—							
410	10/12/2006	>6	18.2	0.68	—	—	716	10/19/2006	CS/ SDWSC	16.1	0.45	—	—
411	10/12/2006	>6	18.1	0.68	—	—							
412	10/12/2006	>6	18.2	0.70	—	—	724	10/19/2006	<1	16.4	1.30	—	—
413	10/12/2006	>6	18.3	0.70	—	—	735	10/19/2006	<1	16.2	1.20	—	—
414	10/11/2006	>6	16.7	0.64	—	—	802	10/13/2006	1–6	17.5	0.68	—	—
415	10/11/2006	>6	16.9	0.59	—	—	804	10/13/2006	<1	17.7	0.65	—	—
416	10/11/2006	>6	17.1	0.54	—	—	806	10/16/2006	<1	17.0	0.71	—	—
417	10/11/2006	>6	17.1	0.50	—	—	807	10/16/2006	<1	17.1	0.92	—	—
418	10/11/2006	>6	16.6	0.40	—	—	808	10/16/2006	<1	17.1	1.15	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)
809	10/16/2006	<1	17.2	0.98	—	—	338	11/07/2006	>6	16.6	0.50	—	—
810	10/16/2006	<1	17.2	1.50	—	—	339	11/07/2006	>6	16.7	0.50	—	—
811	10/18/2006	<1	16.9	0.99	—	—	340	11/07/2006	>6	16.2	0.58	—	—
812	10/18/2006	<1	16.9	1.78	—	—	341	11/07/2006	>6	16.6	0.60	—	—
813	10/18/2006	<1	16.8	1.80	—	—	401	11/08/2006	>6	16.2	0.50	—	—
814	10/18/2006	<1	16.9	1.80	—	—	403	11/08/2006	>6	16.3	0.40	—	—
815	10/18/2006	<1	16.9	1.41	—	—	404	11/08/2006	>6	16.2	0.54	—	—
902	10/17/2006	<1	17.2	1.80	—	—	405	11/08/2006	>6	16.4	0.82	—	—
903	10/18/2006	<1	16.1	1.80	—	—	406	11/08/2006	>6	16.5	0.79	—	—
904	10/17/2006	<1	17.1	1.15	—	—	407	11/08/2006	>6	16.4	0.82	—	—
905	10/17/2006	<1	17.3	1.20	—	—	408	11/08/2006	>6	16.5	0.88	—	—
906	10/17/2006	<1	17.4	1.70	—	—	409	11/13/2006	>6	14.9	0.70	—	—
908	10/17/2006	<1	17.3	1.25	—	—	410	11/13/2006	>6	15.0	0.72	—	—
909	10/17/2006	<1	17.4	0.88	—	—	411	11/13/2006	>6	15.1	0.87	—	—
910	10/17/2006	<1	17.0	0.69	—	—	412	11/13/2006	>6	15.0	0.58	—	—
911	10/17/2006	<1	16.8	0.75	—	—	413	11/13/2006	>6	15.0	0.76	—	—
912	10/17/2006	<1	16.7	0.68	—	—	414	11/13/2006	>6	15.0	0.60	—	—
913	10/17/2006	<1	17.6	1.80	—	—	415	11/13/2006	>6	15.0	0.73	—	—
914	10/17/2006	<1	17.6	1.75	—	—	416	11/13/2006	>6	15.0	0.70	—	—
915	10/17/2006	<1	17.4	1.80	—	—	417	11/13/2006	>6	15.0	0.47	—	—
919	10/18/2006	<1	16.2	1.80	—	—	418	11/13/2006	>6	14.7	0.40	—	—
920	10/18/2006	<1	15.9	1.56	—	—	501	11/13/2006	>6	14.8	0.77	—	—
921	10/18/2006	<1	15.5	1.37	—	—	502	11/13/2006	>6	14.8	0.89	—	—
922	10/18/2006	<1	15.7	1.32	—	—	503	11/14/2006	>6	14.7	0.83	—	—
923	10/18/2006	<1	15.9	1.80	—	—	504	11/14/2006	>6	14.7	0.84	—	—
72	11/16/2006	<1	13.1	1.80	—	—	505	11/14/2006	>6	14.7	0.77	—	—
73	11/16/2006	<1	13.0	1.80	—	—	507	11/14/2006	>6	14.7	0.78	—	—
305	11/06/2006	>6	15.7	0.76	—	—	508	11/14/2006	1–6	14.7	0.72	—	—
306	11/06/2006	>6	16.1	0.75	—	—	509	11/14/2006	1–6	14.8	0.85	—	—
307	11/06/2006	>6	15.3	0.82	—	—	510	11/14/2006	>6	14.7	0.59	—	—
308	11/06/2006	>6	16.2	0.80	—	—	511	11/14/2006	>6	14.7	0.57	—	—
309	11/06/2006	>6	15.8	1.00	—	—	512	11/14/2006	>6	14.6	0.47	—	—
310	11/07/2006	>6	16.0	0.70	—	—	513	11/14/2006	>6	14.7	0.60	—	—
311	11/06/2006	>6	16.1	0.89	—	—	515	11/08/2006	>6	16.4	0.59	—	—
314	11/06/2006	>6	15.6	0.50	—	—	516	11/08/2006	>6	16.4	0.61	—	—
315	11/06/2006	>6	16.0	0.53	—	—	517	11/08/2006	>6	16.4	0.62	—	—
321	11/07/2006	>6	16.0	0.77	—	—	518	11/13/2006	1–6	14.7	0.54	—	—
322	11/07/2006	>6	16.0	0.58	—	—	519	11/13/2006	>6	14.7	0.45	—	—
323	11/07/2006	>6	16.1	0.38	—	—	601	11/13/2006	>6	14.5	0.39	—	—
325	11/07/2006	>6	16.2	0.82	—	—	602	11/13/2006	>6	14.5	0.74	—	—
326	11/07/2006	>6	16.8	0.82	—	—	603	11/13/2006	>6	14.5	0.46	—	—
327	11/06/2006	>6	16.2	0.94	—	—	604	11/13/2006	>6	14.4	0.38	—	—
328	11/06/2006	>6	16.0	0.59	—	—	605	11/08/2006	>6	16.4	0.47	—	—
329	11/06/2006	>6	15.6	0.42	—	—	606	11/08/2006	>6	16.2	0.49	—	—
334	11/06/2006	>6	16.0	0.56	—	—	608	11/14/2006	1–6	14.4	0.39	—	—
335	11/06/2006	>6	15.8	0.52	—	—	701	11/14/2006	1–6	14.8	0.57	—	—
336	11/07/2006	>6	16.6	0.50	—	—	703	11/15/2006	1–6	15.2	0.51	—	—
337	11/07/2006	>6	17.0	0.91	—	—	704	11/15/2006	1–6	15.6	0.49	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)
705	11/15/2006	1–6	15.0	0.53	—	—	923	11/21/2006	<1	13.8	1.30	—	—
706	11/15/2006	1–6	14.6	0.52	—	—	72	12/15/2006	<1	11.3	0.90	—	—
707	11/15/2006	<1	14.1	0.54	—	—	73	12/15/2006	<1	11.6	0.68	—	—
708	11/16/2006	<1	13.8	1.13	—	—	305	12/04/2006	>6	12.0	0.78	—	—
709	11/16/2006	<1	13.6	1.14	—	—	306	12/04/2006	>6	12.0	0.53	—	—
710	11/16/2006	<1	13.6	0.98	—	—	307	12/04/2006	>6	11.9	0.45	—	—
711	11/16/2006	<1	13.5	1.07	—	—	308	12/04/2006	>6	12.1	0.52	—	—
712	11/16/2006	<1	12.8	1.80	—	—	309	12/04/2006	>6	12.1	0.52	—	—
713	11/16/2006	CS/ SDWSC	13.6	0.99	—	—	310	12/04/2006	>6	12.1	0.51	—	—
715	11/16/2006	CS/ SDWSC	13.6	0.80	—	—	311	12/04/2006	>6	12.0	0.52	—	—
716	11/16/2006	CS/ SDWSC	13.5	0.49	—	—	314	12/04/2006	>6	12.0	0.32	—	—
717	11/16/2006	<1	13.7	1.40	—	—	315	12/04/2006	>6	12.2	0.54	—	—
724	11/16/2006	<1	12.9	1.68	—	—	321	12/04/2006	>6	12.4	0.48	—	—
735	11/16/2006	<1	12.8	1.60	—	—	322	12/04/2006	>6	12.2	0.48	—	—
736	11/16/2006	<1	12.8	1.80	—	—	323	12/05/2006	>6	11.3	0.37	—	—
802	11/14/2006	1–6	14.9	0.77	—	—	325	12/05/2006	>6	11.4	0.53	—	—
804	11/14/2006	1–6	14.7	0.68	—	—	326	12/05/2006	>6	11.1	0.63	—	—
806	11/14/2006	1–6	14.7	0.60	—	—	327	12/04/2006	>6	11.5	0.51	—	—
807	11/15/2006	<1	14.4	0.62	—	—	328	12/04/2006	>6	11.1	0.71	—	—
808	11/15/2006	<1	14.3	0.79	—	—	329	12/04/2006	>6	11.0	0.44	—	—
809	11/15/2006	<1	14.4	0.79	—	—	334	12/04/2006	>6	11.3	0.73	—	—
810	11/15/2006	<1	14.3	0.96	—	—	335	12/04/2006	>6	11.3	0.72	—	—
811	11/21/2006	<1	14.4	1.05	—	—	336	12/05/2006	>6	11.1	0.53	—	—
812	11/21/2006	<1	14.3	1.25	—	—	337	12/05/2006	>6	11.1	0.65	—	—
813	11/21/2006	<1	14.3	1.12	—	—	338	12/05/2006	>6	11.4	0.48	—	—
814	11/21/2006	<1	14.0	1.25	—	—	339	12/05/2006	>6	11.2	0.52	—	—
815	11/21/2006	<1	14.0	1.38	—	—	340	12/05/2006	>6	11.6	0.28	—	—
902	11/17/2006	<1	14.1	1.80	—	—	341	12/05/2006	>6	11.5	0.32	—	—
903	11/21/2006	<1	13.5	1.35	—	—	401	12/05/2006	>6	11.4	0.56	—	—
904	11/17/2006	<1	14.2	1.46	—	—	403	12/05/2006	>6	11.6	0.48	—	—
905	11/17/2006	<1	14.2	1.80	—	—	404	12/05/2006	>6	11.5	0.39	—	—
906	11/17/2006	<1	14.3	1.60	—	—	405	12/05/2006	>6	11.5	0.51	—	—
908	11/17/2006	<1	14.3	1.80	—	—	406	12/06/2006	>6	10.8	0.70	—	—
909	11/17/2006	<1	14.4	1.32	—	—	407	12/06/2006	>6	11.1	0.79	—	—
910	11/17/2006	<1	14.1	1.00	—	—	408	12/06/2006	>6	11.1	0.80	—	—
911	11/17/2006	<1	13.7	1.17	—	—	409	12/06/2006	>6	10.8	0.60	—	—
912	11/17/2006	<1	13.7	0.74	—	—	410	12/06/2006	>6	10.9	0.83	—	—
913	11/17/2006	<1	14.3	1.80	—	—	411	12/06/2006	>6	10.9	0.65	—	—
914	11/17/2006	<1	11.1	1.80	—	—	412	12/06/2006	>6	10.9	0.78	—	—
915	11/17/2006	<1	14.1	1.80	—	—	413	12/06/2006	>6	10.9	0.65	—	—
919	11/17/2006	<1	14.2	1.80	—	—	414	12/07/2006	>6	11.1	0.80	—	—
920	11/21/2006	<1	14.0	1.35	—	—	415	12/07/2006	>6	11.1	0.83	—	—
921	11/21/2006	<1	13.8	1.30	—	—	416	12/07/2006	>6	10.6	0.72	—	—
922	11/21/2006	<1	14.2	1.15	—	—	417	12/07/2006	>6	10.8	0.62	—	—
							418	12/07/2006	>6	10.3	0.86	—	—
							501	12/06/2006	>6	11.1	0.80	—	—
							502	12/06/2006	>6	11.1	0.80	—	—

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
503	12/06/2006	>6	11.1	0.80	—	—	808	12/08/2006	<1	10.5	1.25	—	—
504	12/06/2006	>6	11.1	0.75	—	—	809	12/08/2006	<1	10.4	1.60	—	—
505	12/06/2006	>6	11.2	0.86	—	—	810	12/11/2006	<1	10.4	1.20	—	—
507	12/06/2006	1–6	11.3	0.96	—	—	811	12/11/2006	<1	10.2	1.15	—	—
508	12/06/2006	>6	11.1	0.92	—	—	812	12/11/2006	<1	10.4	1.20	—	—
509	12/06/2006	>6	11.4	0.99	—	—	813	12/11/2006	<1	10.3	1.20	—	—
510	12/08/2006	1–6	10.7	0.67	—	—	814	12/11/2006	<1	10.2	1.30	—	—
511	12/08/2006	1–6	10.6	0.68	—	—	815	12/11/2006	<1	10.1	1.25	—	—
512	12/08/2006	1–6	10.7	0.80	—	—	902	12/13/2006	<1	10.3	1.35	—	—
513	12/08/2006	1–6	10.6	0.97	—	—	903	12/14/2006	<1	10.9	1.30	—	—
515	12/07/2006	>6	11.1	0.86	—	—	904	12/11/2006	<1	10.0	1.30	—	—
516	12/07/2006	>6	11.2	0.82	—	—	905	12/11/2006	<1	10.1	1.30	—	—
517	12/07/2006	>6	11.3	0.93	—	—	906	12/13/2006	<1	10.3	1.30	—	—
518	12/07/2006	>6	11.3	0.96	—	—	908	12/13/2006	<1	10.1	1.30	—	—
519	12/07/2006	>6	11.4	0.95	—	—	909	12/13/2006	<1	10.1	1.20	—	—
601	12/07/2006	>6	10.9	0.82	—	—	910	12/13/2006	<1	10.2	1.09	—	—
602	12/07/2006	>6	11.0	0.75	—	—	911	12/13/2006	<1	10.5	0.90	—	—
603	12/07/2006	>6	10.7	0.86	—	—	912	12/13/2006	<1	10.3	0.81	—	—
604	12/07/2006	>6	10.4	0.87	—	—	913	12/13/2006	<1	10.3	1.30	—	—
605	12/07/2006	>6	10.0	0.58	—	—	914	12/13/2006	<1	10.3	1.40	—	—
606	12/07/2006	>6	9.9	0.52	—	—	915	12/13/2006	<1	10.3	1.30	—	—
608	12/08/2006	>6	10.0	0.45	—	—	919	12/14/2006	<1	10.8	1.17	—	—
701	12/08/2006	1–6	10.7	0.82	—	—	920	12/14/2006	<1	11.0	0.90	—	—
703	12/12/2006	1–6	10.2	0.44	—	—	921	12/14/2006	<1	11.1	1.00	—	—
704	12/12/2006	1–6	10.2	0.50	—	—	922	12/14/2006	<1	11.0	0.92	—	—
705	12/12/2006	1–6	10.1	0.66	—	—	923	12/14/2006	<1	10.9	1.20	—	—
706	12/12/2006	<1	10.0	0.64	—	—	72	09/23/2010	<1	18.9	1.38	6.3	1
707	12/12/2006	<1	9.8	0.95	—	—	73	09/23/2010	<1	19.0	1.18	10.6	1
708	12/12/2006	<1	9.8	1.15	—	—	305	09/09/2010	>6	18.1	0.70	11.9	1
709	12/12/2006	<1	9.8	1.20	—	—	306	09/09/2010	>6	18.3	0.69	15.8	1
710	12/12/2006	<1	9.7	1.20	—	—	307	09/09/2010	>6	18.3	0.45	27.2	1
711	12/12/2006	<1	9.8	1.30	—	—	308	09/09/2010	>6	18.6	0.61	16.6	1
712	12/15/2006	<1	11.4	0.80	—	—	309	09/09/2010	>6	18.3	0.70	11.7	1
713	12/12/2006	CS/ SDWSC	9.9	1.20	—	—	310	09/09/2010	>6	19.0	0.67	10.6	1
715	12/12/2006	CS/ SDWSC	9.9	1.20	—	—	311	09/09/2010	>6	18.8	0.49	13.9	1
716	12/12/2006	CS/ SDWSC	9.9	0.77	—	—	314	09/09/2010	>6	18.4	0.30	36.3	1
717	12/15/2006	<1	11.2	1.00	—	—	315	09/09/2010	>6	18.0	0.28	33.4	1
724	12/15/2006	<1	11.6	0.77	—	—	321	09/09/2010	>6	18.9	0.80	12.1	1
735	12/15/2006	<1	11.8	0.60	—	—	322	09/09/2010	>6	18.5	0.19	40.2	1
736	12/15/2006	<1	11.8	0.77	—	—	323	09/09/2010	>6	18.7	0.15	38.9	1
802	12/08/2006	1–6	10.6	0.96	—	—	325	09/13/2010	>6	18.2	0.44	24.5	1
804	12/08/2006	1–6	10.3	0.94	—	—	326	09/09/2010	>6	18.8	0.41	22.2	1
806	12/08/2006	1–6	10.5	1.04	—	—	327	09/09/2010	>6	18.9	0.20	49.0	1
807	12/08/2006	1–6	10.6	1.10	—	—	328	09/08/2010	>6	19.1	0.32	23.9	1
							329	09/13/2010	>6	17.9	0.60	19.4	1
							334	09/08/2010	>6	18.9	0.17	79.3	1
							335	09/08/2010	>6	18.9	0.21	51.3	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)
336	09/07/2010	>6	19.3	0.46	24.8	1	701	09/20/2010	1–6	19.4	0.67	11.0	1
337	09/07/2010	>6	19.2	0.50	18.6	1	703	09/20/2010	<1	19.2	0.69	14.5	1
338	09/07/2010	>6	19.6	0.71	31.1	1	704	09/20/2010	<1	19.3	0.67	13.4	1
339	09/07/2010	>6	19.5	0.20	61.6	1	705	09/20/2010	<1	19.6	0.87	9.3	1
340	09/07/2010	>6	19.5	0.46	37.5	1	706	09/20/2010	<1	19.7	0.88	12.1	1
341	09/07/2010	>6	20.3	0.31	44.7	1	707	09/20/2010	<1	19.8	0.85	11.1	1
401	09/07/2010	>6	19.6	0.56	17.1	1	708	09/20/2010	<1	19.8	0.94	8.2	1
403	09/07/2010	>6	19.7	0.44	23.0	1	709	09/20/2010	<1	19.9	0.82	10.0	1
404	09/07/2010	>6	19.3	0.52	17.2	1	710	09/20/2010	<1	19.9	0.77	10.1	1
405	09/07/2010	>6	20.0	0.63	19.0	1	711	09/20/2010	<1	19.9	0.86	10.8	1
406	09/07/2010	>6	20.3	0.51	11.8	1	712	09/20/2010	<1	20.0	1.09	5.5	1
407	09/07/2010	>6	20.2	0.43	20.7	1	713	09/20/2010	CS/ SDWSC	20.3	0.48	16.0	1
408	09/13/2010	>6	18.7	0.70	11.5	1	715	09/20/2010	CS/ SDWSC	20.3	0.43	21.9	2
409	09/13/2010	>6	19.2	0.66	11.4	1	716	09/20/2010	CS/ SDWSC	20.2	0.40	22.6	1
410	09/13/2010	>6	19.3	0.55	15.3	1	717	09/23/2010	<1	18.4	1.34	4.8	1
411	09/13/2010	>6	19.1	0.50	20.0	1	719	09/29/2010	CS/ SDWSC	21.5	0.28	27.2	1
412	09/13/2010	>6	19.1	0.55	17.9	1	721	09/29/2010	CS/ SDWSC	24.0	0.44	18.7	1
413	09/13/2010	>6	19.5	0.68	11.0	1	723	09/29/2010	CS/ SDWSC	20.9	0.91	8.7	2
414	09/14/2010	>6	19.3	0.52	17.1	1	724	09/23/2010	<1	18.9	1.10	6.4	1
415	09/14/2010	>6	19.3	0.67	14.1	1	735	09/23/2010	<1	19.2	1.45	5.4	1
416	09/14/2010	>6	19.0	0.58	15.7	1	736	09/23/2010	<1	19.2	1.26	5.9	1
417	09/14/2010	>6	19.0	0.42	17.9	1	795	09/29/2010	CS/ SDWSC	22.7	0.67	8.9	1
418	09/14/2010	>6	18.5	0.34	26.7	1	796	09/29/2010	CS/ SDWSC	22.7	0.38	23.6	1
501	09/15/2010	>6	19.0	0.77	9.7	1	797	09/29/2010	CS/ SDWSC	22.3	0.26	29.9	1
502	09/15/2010	>6	18.8	0.85	11.3	1	802	09/16/2010	1–6	19.7	0.88	7.3	2
503	09/15/2010	1–6	18.7	0.91	7.8	1	804	09/16/2010	<1	20.0	1.07	5.2	2
504	09/15/2010	1–6	19.0	0.94	7.8	1	806	09/16/2010	<1	20.1	1.20	6.8	2
505	09/15/2010	1–6	18.8	0.92	8.8	1	807	09/16/2010	<1	20.0	0.95	6.6	2
507	09/15/2010	1–6	19.4	0.58	12.1	1	808	09/16/2010	<1	20.1	1.60	5.1	2
508	09/15/2010	1–6	19.3	0.82	10.4	1	809	09/16/2010	<1	20.3	1.40	4.5	2
509	09/16/2010	1–6	18.9	0.77	10.6	1	810	09/16/2010	<1	20.2	1.30	5.5	2
510	09/16/2010	1–6	18.9	0.82	10.9	1	811	09/16/2010	<1	20.7	1.30	5.5	2
511	09/16/2010	1–6	19.0	0.77	11.0	1	812	09/16/2010	<1	20.6	1.47	4.6	2
512	09/16/2010	1–6	18.2	0.73	9.7	1	813	09/16/2010	<1	20.6	1.50	4.3	2
513	09/16/2010	<1	18.8	0.71	11.5	2	814	09/16/2010	<1	20.7	1.50	4.2	2
515	09/15/2010	>6	18.4	0.32	28.2	1	815	09/16/2010	<1	20.6	1.60	3.1	2
516	09/15/2010	>6	18.5	0.52	20.6	1	902	09/21/2010	<1	20.4	2.00	1.6	3
517	09/15/2010	>6	18.5	0.38	23.1	1	903	09/22/2010	<1	19.2	1.40	3.4	1
518	09/15/2010	1–6	19.1	0.85	14.3	1							
519	09/15/2010	1–6	19.1	0.76	11.4	1							
601	09/14/2010	>6	18.7	0.27	47.5	1							
602	09/14/2010	>6	18.3	0.25	35.0	1							
603	09/14/2010	>6	18.4	0.26	32.6	1							
604	09/14/2010	>6	18.2	0.31	22.6	1							
605	09/14/2010	>6	18.2	0.48	16.1	1							
606	09/14/2010	>6	18.9	0.37	22.9	1							
608	09/14/2010	1–6	18.9	0.49	15.4	2							

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
904	09/16/2010	<1	20.8	1.85	3.1	2	406	10/06/2010	>6	18.6	0.42	22.9	1
905	09/16/2010	<1	20.5	1.75	3.6	2	407	10/06/2010	>6	18.5	0.40	24.6	1
906	09/21/2010	<1	21.6	2.00	1.8	2	408	10/06/2010	>6	18.9	0.65	14.8	1
908	09/21/2010	<1	21.4	2.00	1.8	3	409	10/06/2010	>6	18.9	0.60	12.3	1
909	09/21/2010	<1	22.9	2.00	2.9	2	410	10/06/2010	>6	18.8	0.64	10.6	1
910	09/21/2010	<1	22.4	1.70	3.2	2	411	10/06/2010	>6	19.0	0.60	11.2	1
911	09/21/2010	<1	22.5	1.25	4.4	2	412	10/06/2010	>6	19.1	0.80	10.8	1
912	09/21/2010	<1	22.2	1.00	6.5	1	413	10/06/2010	>6	19.2	0.72	8.5	1
913	09/21/2010	<1	21.4	2.00	1.5	3	414	10/06/2010	>6	19.1	0.55	24.6	1
914	09/21/2010	<1	21.3	2.00	1.5	2	415	10/06/2010	>6	19.3	0.42	19.6	1
915	09/21/2010	<1	20.9	2.00	2.5	2	416	10/06/2010	>6	19.0	0.50	10.8	1
919	09/22/2010	<1	19.9	2.00	2.4	1	417	10/06/2010	>6	19.4	0.36	25.0	1
920	09/22/2010	<1	19.7	1.40	3.7	1	418	10/06/2010	>6	19.5	0.42	22.1	1
921	09/22/2010	<1	19.3	1.33	3.7	1	501	10/06/2010	>6	19.3	0.82	8.6	1
922	09/22/2010	<1	19.2	1.71	3.6	1	502	10/06/2010	1–6	19.5	0.80	8.3	1
923	09/22/2010	<1	19.0	2.00	3.3	1	503	10/06/2010	1–6	19.5	0.82	7.3	1
72	10/18/2010	<1	18.0	1.76	3.2	1	504	10/06/2010	1–6	19.5	0.84	6.4	1
73	10/18/2010	<1	17.9	1.58	3.9	1	505	10/06/2010	1–6	20.0	0.86	6.4	1
305	10/04/2010	>6	18.2	1.02	4.3	1	507	10/07/2010	1–6	19.4	0.63	16.0	1
306	10/04/2010	>6	18.2	1.05	5.2	1	508	10/07/2010	1–6	19.6	0.53	13.4	1
307	10/04/2010	>6	17.9	0.77	6.1	1	509	10/07/2010	1–6	19.4	0.64	14.4	1
308	10/04/2010	>6	18.1	1.24	4.1	1	510	10/07/2010	1–6	19.3	0.59	16.1	1
309	10/04/2010	>6	17.7	1.08	7.2	1	511	10/07/2010	1–6	19.4	0.57	17.9	1
310	10/04/2010	>6	18.3	1.42	3.9	1	512	10/07/2010	1–6	19.4	0.59	17.2	1
311	10/04/2010	>6	17.9	1.19	4.8	1	513	10/07/2010	1–6	19.6	0.64	15.1	1
314	10/04/2010	>6	18.4	0.76	16.7	1	515	10/07/2010	>6	19.0	0.53	14.7	1
315	10/04/2010	>6	18.3	0.54	14.8	1	516	10/07/2010	1–6	19.3	0.63	9.4	1
321	10/04/2010	>6	18.3	1.44	3.8	1	517	10/07/2010	>6	19.1	0.41	28.9	1
322	10/04/2010	>6	18.9	1.02	5.4	1	518	10/07/2010	1–6	19.4	0.68	11.4	1
323	10/04/2010	>6	19.4	1.04	5.6	1	519	10/07/2010	1–6	19.5	0.52	13.0	1
325	10/05/2010	>6	18.7	0.81	12.6	1	601	10/07/2010	>6	18.7	0.52	35.7	1
326	10/04/2010	>6	19.0	1.18	5.7	1	602	10/07/2010	>6	18.1	0.42	32.7	1
327	10/04/2010	>6	18.5	0.86	7.5	1	603	10/07/2010	>6	17.4	0.38	31.6	1
328	10/05/2010	>6	18.3	0.70	12.0	1	604	10/07/2010	>6	18.1	0.39	22.9	1
329	10/05/2010	>6	18.7	0.60	17.6	1	605	10/07/2010	>6	18.3	0.51	20.4	1
334	10/05/2010	>6	18.5	0.50	26.5	1	606	10/07/2010	>6	18.4	0.58	23.9	1
335	10/05/2010	>6	18.4	0.50	22.2	1	608	10/12/2010	1–6	19.1	0.36	26.4	1
336	10/05/2010	>6	19.0	0.93	10.1	1	701	10/12/2010	1–6	20.5	0.82	8.9	1
337	10/05/2010	>6	19.0	0.81	7.4	1	703	10/12/2010	<1	20.0	0.67	10.7	1
338	10/05/2010	>6	19.0	0.86	9.4	1	704	10/12/2010	<1	19.8	0.59	13.3	1
339	10/05/2010	>6	18.9	0.60	13.3	1	705	10/12/2010	<1	20.0	0.96	11.4	1
340	10/05/2010	>6	19.6	0.40	15.8	1	706	10/12/2010	<1	19.6	0.62	10.2	1
341	10/05/2010	>6	19.7	0.40	17.3	1	707	10/12/2010	<1	19.5	0.77	10.9	1
401	10/05/2010	>6	19.2	0.89	7.6	1	708	10/12/2010	<1	19.2	0.74	7.5	1
403	10/05/2010	>6	20.2	0.95	8.0	1	709	10/12/2010	<1	19.6	0.67	8.7	1
404	10/05/2010	>6	19.2	0.70	9.8	1	710	10/12/2010	<1	19.4	0.79	8.0	1
405	10/06/2010	>6	18.2	0.32	24.0	1	711	10/12/2010	<1	19.2	0.84	7.9	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
712	10/12/2010	<1	18.8	1.59	5.3	1	915	10/13/2010	<1	20.3	2.00	2.0	2
713	10/12/2010	CS/ SDWSC	19.0	0.82	7.9	1	919	10/14/2010	<1	18.5	2.00	1.7	1
715	10/12/2010	CS/ SDWSC	18.8	0.80	8.4	1	920	10/14/2010	<1	18.3	2.00	1.8	1
716	10/12/2010	CS/ SDWSC	19.3	0.51	14.5	1	921	10/14/2010	<1	17.8	1.85	2.3	1
717	10/18/2010	<1	17.4	1.85	2.7	1	922	10/14/2010	<1	16.7	0.74	2.9	1
719	10/19/2010	CS/ SDWSC	18.6	0.35	35.4	1	923	10/14/2010	<1	18.8	2.00	2.7	1
721	10/19/2010	CS/ SDWSC	18.3	0.55	25.5	1	72	11/08/2010	<1	15.5	1.38	4.3	1
723	10/19/2010	CS/ SDWSC	17.9	0.64	12.1	1	73	11/08/2010	<1	15.7	1.95	2.7	1
724	10/18/2010	<1	17.7	1.75	4.0	1	305	11/01/2010	>6	15.1	1.22	4.8	1
735	10/18/2010	<1	18.0	2.00	3.0	1	306	11/01/2010	>6	15.0	1.15	7.1	1
736	10/18/2010	<1	17.7	1.74	3.2	1	307	11/01/2010	>6	15.1	1.04	7.2	1
795	10/19/2010	CS/ SDWSC	19.9	0.75	11.9	1	308	11/01/2010	>6	15.1	1.19	5.5	1
796	10/19/2010	CS/ SDWSC	19.3	0.55	18.9	1	309	11/01/2010	>6	15.2	1.20	4.4	1
797	10/19/2010	CS/ SDWSC	19.3	0.35	22.9	1	310	11/01/2010	>6	15.5	1.30	3.8	1
802	10/14/2010	1–6	21.5	0.99	5.9	2	311	11/01/2010	>6	15.7	1.00	5.3	1
804	10/14/2010	1–6	21.8	1.20	5.4	2	314	11/01/2010	>6	14.8	0.88	9.8	1
806	10/13/2010	<1	19.8	0.90	7.9	1	315	11/01/2010	>6	15.0	0.48	14.1	1
807	10/13/2010	<1	19.8	0.86	8.4	1	321	11/01/2010	>6	15.7	1.32	3.7	1
808	10/13/2010	<1	19.9	1.22	5.9	1	322	11/01/2010	>6	16.1	1.16	5.0	1
809	10/13/2010	<1	19.7	1.04	6.8	1	323	11/01/2010	>6	15.8	1.02	7.9	1
810	10/14/2010	<1	21.3	1.40	4.9	3	325	11/02/2010	>6	15.4	1.00	6.8	1
811	10/14/2010	<1	20.8	1.40	5.8	2	326	11/01/2010	>6	15.9	0.98	6.0	1
812	10/14/2010	<1	20.7	1.41	4.0	3	327	11/01/2010	>6	15.1	0.58	19.5	1
813	10/14/2010	<1	20.3	1.44	4.7	3	328	11/02/2010	>6	15.3	0.54	15.1	1
814	10/14/2010	<1	20.4	1.65	3.6	2	329	11/02/2010	>6	15.7	0.82	13.2	1
815	10/14/2010	<1	19.9	1.56	3.6	1	334	11/02/2010	>6	15.5	0.68	17.4	1
902	10/13/2010	<1	22.0	2.00	2.0	1	335	11/02/2010	>6	15.5	0.66	14.9	1
903	10/14/2010	<1	18.9	2.00	4.1	1	336	11/02/2010	>6	15.7	0.58	16.6	1
904	10/14/2010	<1	20.0	2.00	3.8	2	337	11/02/2010	>6	15.8	0.61	11.9	1
905	10/14/2010	<1	19.9	1.88	3.3	2	338	11/02/2010	>6	15.8	0.72	13.7	1
906	10/13/2010	<1	20.7	2.00	1.8	2	339	11/02/2010	>6	15.8	0.59	19.4	1
908	10/13/2010	<1	20.0	2.00	2.1	2	340	11/02/2010	>6	16.7	0.65	10.4	1
909	10/13/2010	<1	21.2	2.00	1.8	1	341	11/02/2010	>6	16.8	0.88	6.6	1
910	10/13/2010	<1	21.5	2.00	1.9	2	401	11/02/2010	>6	16.2	0.96	10.7	1
911	10/13/2010	<1	21.4	1.80	3.3	1	403	11/02/2010	>6	16.7	0.70	8.8	1
912	10/13/2010	<1	22.5	1.44	10.5	1	404	11/02/2010	>6	16.2	0.90	7.9	1
913	10/13/2010	<1	20.6	2.00	1.4	2	405	11/03/2010	>6	15.9	0.76	11.2	1
914	10/13/2010	<1	20.7	2.00	1.6	2	406	11/03/2010	>6	16.0	0.72	11.2	1
							407	11/03/2010	>6	16.0	0.87	9.4	2
							408	11/03/2010	>6	15.9	0.81	10.5	1
							409	11/03/2010	>6	16.1	1.09	7.2	1
							410	11/03/2010	>6	16.3	1.16	7.4	1
							411	11/03/2010	>6	16.7	0.77	14.2	1
							412	11/03/2010	>6	16.9	0.47	22.1	1
							413	11/03/2010	>6	16.6	0.64	12.9	1
							414	11/03/2010	>6	16.7	0.90	10.3	1
							415	11/03/2010	>6	16.5	0.93	9.6	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
416	11/03/2010	>6	16.6	0.72	12.0	1	721	11/09/2010	CS/ SDWSC	16.0	0.50	15.6	1
417	11/03/2010	>6	16.7	0.72	12.5	1							
418	11/03/2010	>6	18.6	0.42	19.4	1	723	11/16/2010	CS/ SDWSC	14.0	1.02	7.1	1
501	11/03/2010	>6	16.6	0.73	14.6	1							
502	11/03/2010	>6	16.6	0.98	7.0	1	724	11/08/2010	<1	15.5	1.72	3.4	1
503	11/03/2010	>6	16.6	1.22	6.8	2	735	11/08/2010	<1	15.9	2.00	3.9	1
504	11/03/2010	1–6	16.5	1.13	6.4	1	736	11/08/2010	<1	15.8	1.87	5.4	1
505	11/03/2010	1–6	16.5	1.09	6.6	1	795	11/16/2010	CS/ SDWSC	15.8	0.82	9.3	1
507	11/04/2010	1–6	17.1	0.86	7.3	1							
508	11/04/2010	1–6	17.5	0.88	10.5	1	796	11/16/2010	CS/ SDWSC	15.3	0.58	13.3	1
509	11/04/2010	1–6	17.3	1.12	7.3	1							
510	11/04/2010	1–6	17.5	1.05	8.6	1	797	11/16/2010	CS/ SDWSC	14.9	0.40	10.0	1
511	11/04/2010	1–6	17.3	0.95	10.2	1							
512	11/04/2010	1–6	17.3	0.90	9.6	1	802	11/08/2010	1–6	15.5	0.82	8.5	1
513	11/04/2010	>6	16.9	0.85	9.4	1	804	11/08/2010	1–6	15.1	0.80	8.2	1
515	11/04/2010	>6	16.6	0.78	8.5	1	806	11/10/2010	1–6	15.1	0.78	9.8	1
516	11/04/2010	1–6	16.8	0.98	6.9	1	807	11/10/2010	1–6	15.4	1.04	8.7	2
517	11/04/2010	>6	16.7	0.72	10.6	1	808	11/10/2010	<1	15.4	1.20	6.3	2
518	11/04/2010	1–6	16.8	0.78	9.5	1	809	11/10/2010	<1	15.3	1.11	6.6	1
519	11/04/2010	1–6	17.0	0.94	9.1	1	810	11/15/2010	<1	15.7	1.25	5.1	2
601	11/04/2010	>6	16.6	0.70	13.6	1	811	11/15/2010	<1	15.9	1.32	6.0	1
602	11/04/2010	>6	16.7	0.70	10.6	1	812	11/15/2010	<1	15.4	1.50	4.6	2
603	11/04/2010	>6	16.4	0.75	12.1	1	813	11/15/2010	<1	15.2	1.40	5.3	2
604	11/04/2010	>6	16.4	0.64	13.0	1	814	11/15/2010	<1	15.2	1.42	4.5	2
605	11/04/2010	>6	16.1	0.56	14.4	1	815	11/15/2010	<1	14.7	1.75	3.2	2
606	11/04/2010	>6	16.2	0.55	18.2	1	902	11/10/2010	<1	15.1	2.00	4.6	2
608	11/08/2010	1–6	15.5	0.50	13.8	1	903	11/15/2010	<1	13.4	2.00	3.3	2
701	11/09/2010	1–6	15.1	0.51	12.0	1	904	11/15/2010	<1	14.5	2.00	3.4	2
703	11/09/2010	1–6	15.4	0.62	11.8	1	905	11/15/2010	<1	14.6	2.00	3.4	2
704	11/09/2010	1–6	15.1	0.46	17.2	1	906	11/10/2010	<1	15.7	2.00	2.2	2
705	11/09/2010	1–6	15.2	0.55	14.2	1	908	11/10/2010	<1	15.7	2.00	2.3	2
706	11/09/2010	<1	15.1	0.55	13.4	1	909	11/10/2010	<1	15.9	2.00	2.3	1
707	11/09/2010	<1	15.1	0.95	8.4	2	910	11/10/2010	<1	16.0	2.00	2.8	2
708	11/09/2010	<1	15.2	1.00	8.3	1	911	11/10/2010	<1	16.0	1.70	2.8	1
709	11/09/2010	<1	15.4	0.98	6.4	1	912	11/10/2010	<1	16.0	1.55	3.7	1
710	11/09/2010	<1	15.3	1.15	6.7	1	913	11/10/2010	<1	15.7	2.00	2.2	2
711	11/09/2010	<1	15.5	1.15	6.0	1	914	11/10/2010	<1	15.7	2.00	2.1	2
712	11/16/2010	<1	14.2	1.67	4.0	1	915	11/10/2010	<1	15.4	2.00	2.4	1
713	11/09/2010	CS/ SDWSC	15.3	0.99	7.4	1	919	11/15/2010	<1	13.4	2.00	2.6	1
							920	11/15/2010	<1	13.4	2.00	2.7	1
715	11/09/2010	CS/ SDWSC	15.4	1.00	7.7	1	921	11/15/2010	<1	13.5	1.95	3.8	1
							922	11/15/2010	<1	14.0	1.86	4.8	1
716	11/09/2010	CS/ SDWSC	15.5	0.82	10.5	1	923	11/15/2010	<1	13.4	2.00	3.0	1
							72	12/07/2010	<1	11.2	0.78	11.6	1
717	11/08/2010	<1	15.2	1.45	4.7	1	73	12/07/2010	<1	11.5	0.63	14.2	1
719	11/09/2010	CS/ SDWSC	16.4	0.24	34.0	1	305	12/01/2010	>6	11.3	0.63	27.0	1
							306	12/01/2010	>6	11.3	0.98	8.5	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
307	12/01/2010	>6	11.3	0.76	9.8	1	509	12/07/2010	1–6	10.7	0.67	12.1	1
308	12/01/2010	>6	11.2	0.37	27.0	1	510	12/07/2010	1–6	10.8	0.64	12.9	1
309	12/01/2010	>6	11.4	0.50	33.1	1	511	12/07/2010	1–6	10.8	0.72	11.1	1
310	12/02/2010	>6	10.9	1.21	9.5	1	512	12/07/2010	1–6	11.1	0.69	9.4	1
311	12/02/2010	>6	11.0	0.70	15.9	1	513	12/07/2010	1–6	10.7	0.76	13.8	1
314	12/01/2010	>6	11.2	0.64	10.3	1	515	12/06/2010	>6	11.6	0.58	12.9	1
315	12/01/2010	>6	11.3	0.71	10.5	1	516	12/07/2010	1–6	10.3	0.68	11.5	1
321	12/02/2010	>6	11.0	1.24	6.5	1	517	12/07/2010	1–6	10.6	0.51	22.9	1
322	12/02/2010	>6	10.7	0.78	13.2	1	518	12/07/2010	1–6	10.9	0.51	27.8	1
323	12/02/2010	>6	11.1	0.82	14.5	1	519	12/07/2010	1–6	10.4	0.77	9.6	1
325	12/02/2010	>6	10.5	0.59	13.8	1	601	12/06/2010	>6	11.4	0.62	14.5	1
326	12/02/2010	>6	11.1	0.58	20.7	1	602	12/06/2010	>6	11.4	0.43	25.5	1
327	12/01/2010	>6	11.0	0.88	9.3	1	603	12/06/2010	>6	11.2	0.59	17.8	1
328	12/01/2010	>6	11.0	0.71	9.0	1	604	12/06/2010	>6	11.5	0.61	19.6	1
329	12/02/2010	>6	10.8	0.52	20.0	1	605	12/06/2010	1–6	11.3	0.47	23.3	1
334	12/01/2010	>6	11.0	0.68	11.3	1	606	12/06/2010	1–6	11.5	0.34	30.7	1
335	12/01/2010	>6	11.1	0.70	11.0	1	608	12/07/2010	1–6	11.3	0.59	16.6	1
336	12/02/2010	>6	10.4	0.59	13.4	1	701	12/06/2010	1–6	10.5	0.61		1
337	12/02/2010	>6	11.1	0.77	11.5	1	703	12/06/2010	<1	10.4	0.76		1
338	12/02/2010	>6	11.0	0.68	10.7	1	704	12/06/2010	<1	10.3	0.67		1
339	12/02/2010	>6	11.2	0.54	23.0	1	705	12/06/2010	<1	10.1	0.78		1
340	12/02/2010	>6	11.0	0.28	73.5	1	706	12/06/2010	<1	10.4	0.92		1
341	12/02/2010	>6	11.0	0.38	35.0	1	707	12/06/2010	<1	10.4	1.11		1
401	12/03/2010	>6	10.8	0.77	11.5	1	708	12/06/2010	<1	10.7	0.95		1
403	12/03/2010	>6	10.8	0.75	12.2	1	709	12/06/2010	<1	10.5	1.04		1
404	12/03/2010	>6	10.7	0.77	11.7	1	710	12/06/2010	<1	10.6	1.16		1
405	12/03/2010	>6	10.8	0.87	11.4	1	711	12/06/2010	<1	11.1	0.92		1
406	12/03/2010	>6	10.8	0.89	10.9	1	712	12/07/2010	<1	12.1	0.98	6.3	1
407	12/03/2010	>6	10.8	0.58	21.3	1	713	12/06/2010	CS/ SDWSC	10.6	0.97		1
408	12/03/2010	>6	10.9	0.52	19.5	1							
409	12/03/2010	>6	10.9	0.68	15.0	1	715	12/06/2010	CS/ SDWSC	10.7	1.00		1
410	12/03/2010	>6	11.0	0.71	14.8	1							
411	12/03/2010	>6	11.0	0.58	19.2	1	716	12/06/2010	CS/ SDWSC	10.7	0.98		1
412	12/03/2010	>6	10.9	0.39	29.0	1							
413	12/03/2010	>6	10.9	0.50	23.2	1	717	12/07/2010	<1	10.9	0.72	9.2	1
414	12/06/2010	>6	11.0	0.62	18.8	1	719	12/08/2010	CS/ SDWSC	10.9	0.38	26.4	1
415	12/06/2010	>6	11.1	0.60	19.7	1							
416	12/06/2010	>6	11.0	0.59	16.7	1	721	12/06/2010	CS/ SDWSC	11.3	0.72		1
417	12/06/2010	>6	11.0	0.69	13.5	1							
418	12/06/2010	>6	11.2	0.53	14.8	1	723	12/08/2010	CS/ SDWSC	11.1	1.04	8.1	1
501	12/03/2010	>6	11.0	0.52	18.8	1							
502	12/03/2010	>6	10.8	0.49	22.5	1	724	12/07/2010	<1	11.3	0.66	14.8	1
503	12/03/2010	>6	10.7	0.59	17.2	1	735	12/07/2010	<1	11.9	0.70	11.1	2
504	12/03/2010	>6	10.6	0.42	27.2	1	736	12/07/2010	<1	11.7	0.65	11.9	2
505	12/07/2010	1–6	10.6	0.89	7.6	1	795	12/08/2010	CS/ SDWSC	11.9	0.68	9.7	1
507	12/07/2010	1–6	10.7	0.79	9.0	1							
508	12/07/2010	1–6	10.8	0.67	10.7	1							

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
519	09/13/2011	1–6	19.6	0.20	91.4	2	810	09/16/2011	<1	21.7	1.22	8.3	2
601	09/12/2011	1–6	20.1	0.26	23.0	2	811	09/16/2011	<1	21.8	1.72	8.2	2
602	09/12/2011	1–6	20.2	0.18	142.0	1	812	09/16/2011	<1	21.9	1.52	10.0	2
603	09/12/2011	1–6	19.9	0.26	120.0	2	813	09/16/2011	<1	21.6	1.52	9.2	2
604	09/12/2011	1–6	19.9	0.29	97.8	2	814	09/16/2011	<1	21.6	1.52	8.9	1
605	09/12/2011	1–6	20.6	0.19	143.0	2	815	09/16/2011	<1	21.6	1.60	8.9	2
606	09/12/2011	1–6	20.9	0.27	67.2	2	902	09/15/2011	<1	21.8	2.00	10.5	2
608	09/13/2011	<1	21.0	0.32	62.6	1	903	09/16/2011	<1	20.6	1.82	10.1	1
701	09/14/2011	<1	20.2	0.53	37.5	1	904	09/16/2011	<1	21.8	1.61	6.8	2
703	09/14/2011	<1	20.5	0.76	31.2	1	905	09/16/2011	<1	21.7	1.79	6.1	2
704	09/14/2011	<1	20.2	0.68	37.6	1	906	09/15/2011	<1	23.1	1.65	6.9	2
705	09/14/2011	<1	20.7	0.85	23.3	1	908	09/15/2011	<1	22.6	1.61	6.2	2
706	09/14/2011	<1	20.8	0.70	19.2	1	909	09/15/2011	<1	22.9	0.99	13.9	2
707	09/14/2011	<1	21.1	0.85	17.5	1	910	09/15/2011	<1	22.7	0.88	21.2	1
708	09/19/2011	<1	20.5	1.15	15.2	2	911	09/15/2011	<1	23.2	0.71	23.9	1
709	09/14/2011	<1	21.3	0.83	22.8	1	912	09/15/2011	<1	23.7	0.74	19.8	1
710	09/14/2011	<1	21.4	0.84	16.2	1	913	09/15/2011	<1	23.2	2.00	6.0	1
711	09/14/2011	<1	21.3	0.67	20.3	1	914	09/15/2011	<1	22.6	2.00	7.5	2
712	09/19/2011	<1	19.4	1.31	10.5	1	915	09/15/2011	<1	22.3	2.00	6.3	2
713	09/14/2011	CS/ SDWSC	21.2	0.78	17.5	1	919	09/16/2011	<1	20.6	1.45	6.5	1
715	09/14/2011	CS/ SDWSC	21.2	0.52	39.4	1	920	09/16/2011	<1	20.8	1.59	9.9	1
716	09/14/2011	CS/ SDWSC	21.2	0.49	41.6	1	921	09/16/2011	<1	20.6	1.27	12.5	1
717	09/19/2011	<1	21.1	1.26	11.4	1	922	09/16/2011	<1	20.4	1.18	13.2	1
719	09/20/2011	CS/ SDWSC	21.9	0.56	48.3	1	923	09/16/2011	<1	20.6	1.64	10.5	1
721	09/14/2011	CS/ SDWSC	21.9	0.38	65.9	1	72	10/13/2011	<1	17.2	1.10	5.9	1
723	09/20/2011	CS/ SDWSC	20.7	0.67	30.6	2	73	10/13/2011	<1	17.1	1.50	4.5	1
724	09/19/2011	<1	22.3	1.07	10.7	1	305	10/03/2011	>6	18.1	1.02	8.9	1
735	09/19/2011	<1	19.9	1.08	21.7	1	306	10/03/2011	>6	18.1	1.12	6.5	1
736	09/19/2011	<1	19.6	1.02	19.3	1	307	10/03/2011	>6	18.1	1.16	7.3	1
795	09/20/2011	CS/ SDWSC	24.1	1.14	10.2	1	308	10/03/2011	>6	18.1	1.19	8.2	1
796	09/20/2011	CS/ SDWSC	23.7	0.48	31.0	1	309	10/03/2011	>6	18.2	1.01	8.6	1
797	09/20/2011	CS/ SDWSC	22.2	0.39	41.3	1	310	10/03/2011	>6	18.5	1.08	10.0	1
802	09/12/2011	<1	21.2	0.38	49.9	2	311	10/03/2011	>6	18.4	1.04	8.7	1
804	09/12/2011	<1	21.5	0.51	51.3	2	314	10/03/2011	>6	17.9	0.98	10.2	1
806	09/15/2011	<1	20.6	0.79	24.6	1	315	10/03/2011	>6	17.9	0.86	11.4	1
807	09/15/2011	<1	20.9	0.98	20.0	1	321	10/03/2011	>6	18.8	0.82	7.4	1
808	09/15/2011	<1	21.0	0.99	20.1	1	322	10/03/2011	>6	18.6	1.18	9.7	1
809	09/15/2011	<1	21.1	1.24	12.3	1	323	10/03/2011	>6	18.8	0.99	9.1	1
							325	10/04/2011	>6	18.6	0.82	13.6	1
							326	10/03/2011	>6	19.0	0.87	11.1	1
							327	10/03/2011	>6	18.4	0.41	27.2	1
							328	10/04/2011	>6	18.2	0.51	22.9	1
							329	10/04/2011	>6	18.7	0.76	12.4	1
							334	10/04/2011	>6	18.5	0.50	27.9	1
							335	10/04/2011	>6	18.7	0.74	11.2	1
							336	10/04/2011	>6	18.5	0.62	23.4	1
							337	10/04/2011	>6	18.5	0.60	15.7	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
338	10/04/2011	>6	18.6	0.88	9.2	1	704	10/10/2011	<1	16.4	1.02	11.1	1
339	10/04/2011	>6	18.6	0.52	19.4	1	705	10/10/2011	<1	16.1	1.19	8.8	1
340	10/04/2011	>6	19.0	0.58	14.6	1	706	10/10/2011	<1	16.0	1.21	7.4	1
341	10/04/2011	>6	19.2	0.64	16.2	1	707	10/10/2011	<1	15.9	1.33	7.9	1
401	10/04/2011	>6	19.4	0.71	14.6	1	708	10/10/2011	<1	16.0	1.51	8.5	1
403	10/04/2011	>6	19.5	0.46	22.2	1	709	10/10/2011	<1	16.0	1.37	9.6	1
404	10/04/2011	>6	19.4	0.67	13.0	1	710	10/10/2011	<1	16.0	1.12	8.3	1
405	10/05/2011	>6	18.3	0.62	17.5	1	711	10/10/2011	<1	16.1	1.16	9.2	1
406	10/05/2011	>6	18.7	0.65	15.8	1	712	10/13/2011	<1	16.5	1.50	4.9	1
407	10/05/2011	>6	18.7	0.68	17.3	1	713	10/10/2011	CS/ SDWSC	16.3	0.87	11.7	1
408	10/05/2011	>6	18.7	0.84	18.0	1							
409	10/05/2011	>6	18.7	0.41	23.8	1	715	10/10/2011	CS/ SDWSC	16.5	0.87	11.8	1
410	10/05/2011	>6	18.9	0.75	21.6	1							
411	10/05/2011	1–6	18.6	0.48	28.7	1	716	10/10/2011	CS/ SDWSC	16.5	0.75	14.4	1
412	10/05/2011	>6	19.2	0.33	42.9	1							
413	10/05/2011	1–6	19.1	0.34	40.3	1	717	10/13/2011	<1	17.4	1.40	5.4	1
414	10/06/2011	1–6	17.7	0.48	23.5	1	719	10/14/2011	CS/ SDWSC	19.1	0.47	24.0	1
415	10/06/2011	1–6	18.1	0.50	23.8	1							
416	10/06/2011	1–6	18.1	0.41	26.4	1	721	10/10/2011	CS/ SDWSC	17.4	0.43	30.7	1
417	10/06/2011	1–6	18.4	0.34	38.3	1							
418	10/06/2011	1–6	18.1	0.16	116.0	1	723	10/14/2011	CS/ SDWSC	17.1	0.99	8.6	1
501	10/05/2011	1–6	18.9	0.52	21.8	1							
502	10/05/2011	1–6	18.9	0.54	22.3	1	724	10/13/2011	<1	17.6	1.50	7.8	1
503	10/05/2011	1–6	18.5	0.49	24.8	1	735	10/13/2011	<1	16.9	1.75	5.6	1
504	10/05/2011	1–6	18.6	0.42	28.6	1	736	10/13/2011	<1	16.8	1.65	4.6	1
505	10/05/2011	1–6	18.9	0.46	26.0	1	795	10/14/2011	CS/ SDWSC	22.1	0.85	7.9	1
507	10/07/2011	<1	18.8	0.33	35.2	1							
508	10/07/2011	<1	18.3	0.46	17.1	1	796	10/14/2011	CS/ SDWSC	20.6	0.42	21.6	1
509	10/07/2011	<1	18.2	0.57	18.1	2							
510	10/07/2011	<1	17.9	0.62	10.8	2	797	10/14/2011	CS/ SDWSC	20.2	0.36	32.0	1
511	10/07/2011	<1	17.5	0.65	9.1	1							
512	10/07/2011	<1	17.1	0.78	9.5	1	802	10/07/2011	<1	19.7	0.69	14.3	2
513	10/07/2011	<1	17.5	0.61	13.0	1	804	10/11/2011	<1	18.2	0.89	9.4	2
515	10/07/2011	1–6	18.9	0.39	24.1		806	10/11/2011	<1	18.5	1.03	7.7	1
516	10/07/2011	1–6	18.8	0.39	27.1	2	807	10/11/2011	<1	18.5	1.18	7.9	1
517	10/07/2011	1–6	18.5	0.32	33.4	1	808	10/11/2011	<1	18.4	1.32	11.1	1
518	10/07/2011	1–6	19.0	0.30	27.8	1	809	10/11/2011	<1	18.4	1.45	5.9	1
519	10/07/2011	<1	18.8	0.40	28.8	1	810	10/12/2011	<1	18.6	2.00	4.9	2
601	10/06/2011	1–6	18.2	0.22	61.7	1	811	10/12/2011	<1	19.2	2.00	3.7	2
602	10/06/2011	1–6	18.2	0.29	53.2	1	812	10/12/2011	<1	18.4	2.00	3.8	2
603	10/06/2011	1–6	19.1	0.31	37.1	1	813	10/12/2011	<1	18.3	2.00	2.9	2
604	10/06/2011	1–6	18.5	0.38	28.0	1	814	10/12/2011	<1	18.2	1.90	3.4	2
605	10/06/2011	1–6	18.0	0.39	28.0	1	815	10/12/2011	<1	18.4	2.00	3.7	2
606	10/06/2011	1–6	18.2	0.37	25.1	1	902	10/11/2011	<1	18.8	2.00	1.9	1
608	10/07/2011	<1	17.1	0.42	24.9	1	903	10/12/2011	<1	16.6	1.50	5.3	1
701	10/10/2011	<1	17.6	0.85	11.4	2	904	10/12/2011	<1	18.4	1.75	4.3	2
703	10/10/2011	<1	16.7	1.06	12.0	2	905	10/12/2011	<1	18.4	2.00	4.3	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface- water temper- ature (°C)	Secchi depth (m)	Turbidity (NTU)	Micro- cystis (0–5)
713	11/15/2011	CS/ SDWSC	12.7	0.85	10.9	1	919	11/17/2011	<1	12.9	1.60	5.0	1
715	11/15/2011	CS/ SDWSC	12.8	0.79	12.7	1	920	11/17/2011	<1	13.2	1.75	5.6	1
716	11/15/2011	CS/ SDWSC	13.1	0.66	14.7	1	921	11/17/2011	<1	13.4	2.00	2.0	1
717	11/18/2011	<1	12.5	2.00	5.3	1	922	11/17/2011	<1	14.1	2.00	3.6	1
719	11/21/2011	CS/ SDWSC	12.6	0.21	54.2	1	923	11/17/2011	<1	12.8	2.00	2.4	1
721	11/15/2011	CS/ SDWSC	12.9	0.48	24.6	1	72	12/15/2011	<1	9.1	1.17	8.0	1
723	11/21/2011	CS/ SDWSC	11.8	0.48	18.5	1	73	12/15/2011	<1	9.2	1.00	8.3	1
724	11/18/2011	<1	12.8	1.90	4.3	1	305	12/05/2011	>6	11.2	1.34	6.5	1
735	11/18/2011	<1	12.9	1.47	5.0	1	306	12/05/2011	>6	11.0	1.26	7.2	1
736	11/18/2011	<1	12.9	1.48	4.7	1	307	12/05/2011	>6	11.0	1.17	8.4	1
795	11/21/2011	CS/ SDWSC	13.4	0.42	21.9	1	308	12/05/2011	>6	11.3	1.18	6.2	1
796	11/21/2011	CS/ SDWSC	12.8	0.23	49.3	1	309	12/05/2011	>6	11.4	1.21	6.9	1
797	11/21/2011	CS/ SDWSC	12.5	0.21	75.5	1	310	12/05/2011	>6	11.4	0.88	12.3	1
802	11/10/2011	1–6	14.7	0.48	20.1	1	311	12/05/2011	>6	11.3	0.66	21.3	1
804	11/10/2011	1–6	14.6	0.46	24.6	1	314	12/05/2011	>6	11.1	1.02	9.6	1
806	11/16/2011	<1	13.4	0.61	17.6	1	315	12/05/2011	>6	10.9	0.90	10.1	1
807	11/16/2011	<1	13.7	0.72	15.3	1	321	12/05/2011	>6	11.3	1.13	7.9	1
808	11/16/2011	<1	13.8	0.65	14.6	1	322	12/05/2011	>6	11.5	0.38	42.0	1
809	11/16/2011	<1	13.9	0.73	14.9	1	323	12/05/2011	>6	11.5	0.28	46.9	1
810	11/17/2011	<1	13.6	0.90	8.3	1	325	12/06/2011	>6	10.4	0.82	9.0	1
811	11/17/2011	<1	13.6	1.20	9.3	1	326	12/05/2011	>6	11.3	0.31	24.8	1
812	11/17/2011	<1	13.5	1.10	7.3	2	327	12/05/2011	>6	10.6	1.20	7.8	1
813	11/17/2011	<1	13.4	1.30	7.1	1	328	12/06/2011	>6	9.8	1.02	14.3	1
814	11/17/2011	<1	13.2	1.40	4.6	1	329	12/06/2011	>6	10.5	1.02	8.9	1
815	11/17/2011	<1	13.2	1.70	4.8	1	334	12/06/2011	>6	10.3	0.88	9.5	1
902	11/16/2011	<1	13.5	2.00	5.0	1	335	12/06/2011	>6	10.1	0.99	9.0	1
903	11/17/2011	<1	12.8	2.00	2.6	1	336	12/06/2011	>6	10.3	0.57	19.7	1
904	11/17/2011	<1	13.0	2.00	3.6	1	337	12/06/2011	>6	10.5	1.02	11.0	1
905	11/17/2011	<1	13.1	1.90	3.5	1	338	12/06/2011	>6	10.6	0.68	18.1	1
906	11/16/2011	<1	13.4	2.00	3.6	1	339	12/06/2011	>6	10.6	0.88	13.8	1
908	11/16/2011	<1	13.4	2.00	3.5	1	340	12/06/2011	>6	11.0	0.59	13.1	1
909	11/16/2011	<1	13.9	1.63	4.2	1	341	12/06/2011	>6	11.1	0.21	52.4	1
910	11/16/2011	<1	14.4	1.40	6.1	1	401	12/06/2011	>6	11.0	0.62	14.6	1
911	11/16/2011	<1	14.1	1.11	7.3	1	403	12/06/2011	>6	11.3	0.57	13.2	1
912	11/16/2011	<1	13.8	1.07	7.4	1	404	12/06/2011	>6	11.1	0.69	12.3	1
913	11/16/2011	<1	13.8	2.00	3.9	1	405	12/07/2011	>6	9.9	0.79	11.9	1
914	11/16/2011	<1	13.6	2.00	2.9	1	406	12/07/2011	>6	9.2	0.77	12.0	1
915	11/16/2011	<1	13.8	2.00	4.2	1	407	12/07/2011	>6	10.0	0.76	11.5	1
							408	12/07/2011	>6	10.3	0.84	12.1	1
							409	12/07/2011	>6	10.4	0.81	12.3	1
							410	12/07/2011	>6	10.5	0.77	11.6	1
							411	12/07/2011	>6	10.6	0.74	13.3	1
							412	12/07/2011	>6	10.3	0.64	15.3	1
							413	12/07/2011	>6	10.3	0.57	19.6	1
							414	12/08/2011	>6	10.5	0.72	11.3	1
							415	12/08/2011	>6	10.1	0.77	11.2	1
							416	12/08/2011	>6	10.0	0.69	11.6	1

Table 4-2. Surface-water temperature, Secchi depth, turbidity, and *Microcystis* rating data collected during the fall midwater-trawl sampling survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 4-1. *Microcystis*: see figure 5 for visual rating system. Data were analysed within salinity group. Data were analyzed within salinity groups. **Abbreviations:** CS, Cache Slough; SDWSC, Sacramento River Deepwater Ship Channel; m, meter; mm/dd/yyyy, month/day/year; NTU, nephelometric turbidity unit; °C, degree Celsius; —, missing data; <, less than; >, greater than]

Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)	Station	Date (mm/dd/yyyy)	Salinity group	Surface-water temperature (°C)	Secchi depth (m)	Turbidity (NTU)	Microcystis (0–5)
417	12/08/2011	>6	10.3	0.63	12.5	1	719	12/16/2011	CS/ SDWSC	8.9	0.32	37.8	1
418	12/08/2011	>6	10.6	0.59	32.6	1	721	12/12/2011	CS/ SDWSC	8.2	0.52	19.8	1
501	12/07/2011	>6	10.4	0.74	20.7	1	723	12/16/2011	CS/ SDWSC	8.6	0.83	10.1	1
502	12/07/2011	>6	10.6	0.72	10.6	1	724	12/15/2011	<1	9.2	1.00	7.9	1
503	12/07/2011	>6	10.9	0.52	15.6	1	735	12/15/2011	<1	9.5	1.10	8.5	1
504	12/07/2011	>6	10.6	0.58	13.5	1	736	12/15/2011	<1	9.2	1.09	9.3	1
505	12/07/2011	>6	10.6	0.66	12.6	1	795	12/16/2011	CS/ SDWSC	10.4	0.77	9.4	1
507	12/09/2011	1–6	9.8	0.65	15.1	1	796	12/16/2011	CS/ SDWSC	9.5	0.24	37.8	1
508	12/09/2011	1–6	10.0	0.68	15.9	1	797	12/16/2011	CS/ SDWSC	9.1	0.17	72.7	1
509	12/09/2011	1–6	10.2	0.72	12.9	1	802	12/09/2011	1–6	10.8	0.78	14.4	1
510	12/09/2011	1–6	10.1	0.79	12.9	1	804	12/13/2011	1–6	8.8	0.73	12.6	1
511	12/09/2011	1–6	10.2	0.78	16.7	1	806	12/13/2011	<1	8.5	0.84	10.4	1
512	12/09/2011	1–6	10.3	0.70	17.8	1	807	12/13/2011	<1	8.9	0.99	8.1	1
513	12/09/2011	1–6	10.5	0.63	13.4	1	808	12/13/2011	<1	9.2	1.02	8.8	1
515	12/09/2011	>6	9.3	0.63	21.3	1	809	12/13/2011	<1	9.3	0.98	8.7	1
516	12/09/2011	1–6	9.5	0.61	21.8	1	810	12/14/2011	<1	9.5	1.34	8.1	1
517	12/09/2011	1–6	9.4	0.53	12.8	1	811	12/14/2011	<1	9.3	1.22	7.6	1
518	12/09/2011	1–6	9.8	0.63	18.5	1	812	12/14/2011	<1	9.3	1.08	8.3	1
519	12/09/2011	1–6	9.6	0.62	16.7	1	813	12/14/2011	<1	9.3	1.28	7.6	1
601	12/08/2011	>6	11.3	0.73	13.9	1	814	12/14/2011	<1	9.3	1.22	6.8	1
602	12/08/2011	>6	10.9	0.49	21.2	1	815	12/14/2011	<1	9.3	1.41	6.5	1
603	12/08/2011	>6	10.7	0.39	23.7	1	902	12/13/2011	<1	9.0	2.00	3.2	1
604	12/08/2011	>6	11.2	0.48	12.0	1	903	12/14/2011	<1	8.6	2.00	6.2	1
605	12/08/2011	>6	10.2	0.49	15.2	1	904	12/14/2011	<1	9.4	1.38	6.0	1
606	12/08/2011	>6	10.1	0.41	23.0	1	905	12/14/2011	<1	9.2	1.42	6.2	1
608	12/09/2011	1–6	9.6	0.38	35.6	1	906	12/13/2011	<1	9.3	1.69	4.3	1
701	12/12/2011	1–6	9.9	0.82	11.9	1	908	12/13/2011	<1	9.4	1.21	6.8	1
703	12/12/2011	1–6	9.7	0.48	30.9	1	909	12/13/2011	<1	9.3	2.00	4.1	1
704	12/12/2011	<1	9.5	0.82	12.3	1	910	12/13/2011	<1	9.5	1.30	5.7	1
705	12/12/2011	<1	9.3	0.91	11.6	1	911	12/13/2011	<1	9.6	1.39	5.1	1
706	12/12/2011	<1	9.4	0.83	10.5	1	912	12/13/2011	<1	9.4	1.62	4.3	1
707	12/12/2011	<1	9.0	1.13	10.3	1	913	12/13/2011	<1	9.4	1.76	3.7	1
708	12/12/2011	<1	8.9	1.09	9.3	1	914	12/13/2011	<1	9.2	2.00	3.4	1
709	12/12/2011	<1	9.0	1.12	8.6	1	915	12/13/2011	<1	9.0	2.00	4.3	1
710	12/12/2011	<1	8.9	1.03	9.7	1	919	12/14/2011	<1	8.0	1.04	9.4	1
711	12/12/2011	<1	8.9	1.12	9.1	1	920	12/14/2011	<1	8.1	0.78	12.6	1
712	12/15/2011	<1	9.0	1.39	7.7	1	921	12/14/2011	<1	7.9	1.79	4.7	1
713	12/12/2011	CS/ SDWSC	8.8	0.96	11.4	1	922	12/14/2011	<1	7.5	2.00	4.9	1
715	12/12/2011	CS/ SDWSC	8.7	0.90	11.1	1	923	12/14/2011	<1	8.7	1.60	6.2	1
716	12/12/2011	CS/ SDWSC	8.6	0.75	13.8	1							
717	12/15/2011	<1	9.0	1.23	7.5	1							

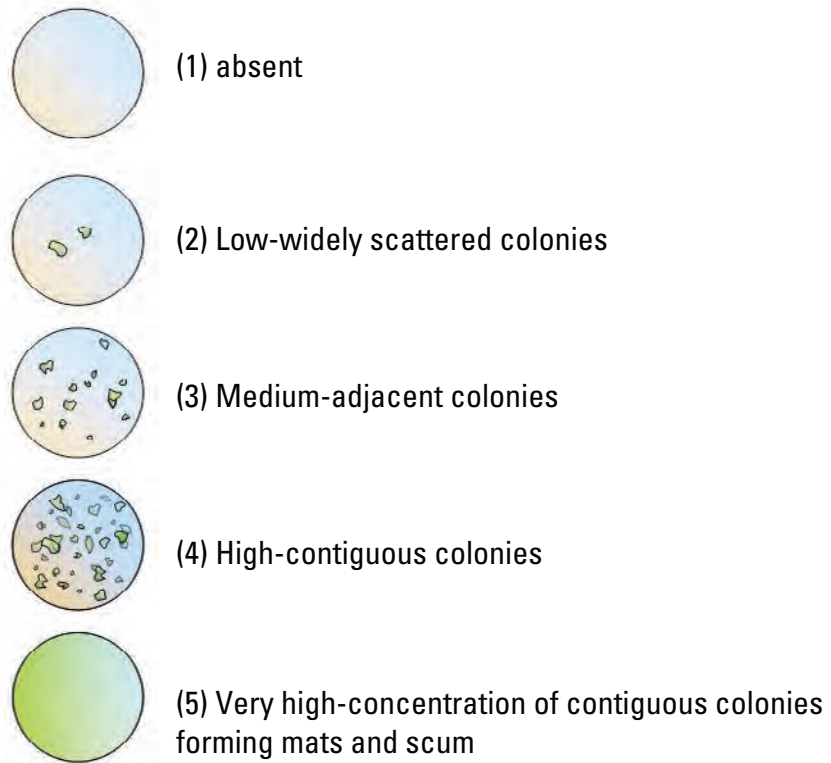


Figure 4-2. *Microcystis* abundance visual-ranking system utilized during the fall midwater-trawl sampling.

Table 4-3. Nitrite plus nitrate as nitrogen, ammonium as nitrogen, and chlorophyll- α , by salinity group, from water samples collected during the fall midwater-trawl sampling survey in 2011.

[Latitude and longitude of sampling stations are in table 4-1. **Abbreviations:** CS-SRDWSC, Cache Slough-Sacramento River Deep Water Ship Channel; mg/L, milligrams per liter; mm/dd/yyyy, month/day/year; N, nitrogen; $\mu\text{g/L}$, micrograms per liter; <, less than; >, greater than; +, plus]

Station	Date (mm/dd/yyyy)	Salinity group	Nitrite+ nitrate as N (mg/L)	Ammonium as N (mg/L)	Chlorophyll- α ($\mu\text{g/L}$)	Station	Date (mm/dd/yyyy)	Salinity group	Nitrite+ nitrate as N (mg/L)	Ammonium as N (mg/L)	Chlorophyll- α ($\mu\text{g/L}$)
405	09/08/2011	1–6	0.28	0.08	1.8	504	11/09/2011	>6	0.28	0.09	0.9
411	09/08/2011	1–6	0.28	0.08	1.4	416	11/10/2011	>6	0.27	0.13	1.0
502	09/08/2011	1–6	0.27	0.07	1.4	418	11/10/2011	>6	0.26	0.08	0.9
504	09/08/2011	1–6	0.26	0.05	1.6	602	11/10/2011	>6	0.27	0.10	0.6
416	09/12/2011	1–6	0.28	0.08	1.9	606	11/10/2011	1–6	0.25	0.11	2.1
418	09/12/2011	1–6	0.28	0.05	1.3	802	11/10/2011	1–6	0.23	0.05	10.7
602	09/12/2011	1–6	0.27	0.05	1.3	804	11/10/2011	1–6	0.22	0.02	8.8
606	09/12/2011	1–6	0.30	0.05	1.6	508	11/14/2011	1–6	0.26	0.08	1.0
802	09/12/2011	<1	0.21	0.02	3.6	513	11/14/2011	1–6	0.26	0.09	2.1
804	09/12/2011	<1	0.18	0.01	4.7	519	11/14/2011	>6	0.27	0.10	0.9
809	09/15/2011	<1	0.16	0.01	5.0	608	11/14/2011	1–6	0.26	0.08	2.1
704	09/16/2011	<1	0.21	0.09	2.5	704	11/15/2011	1–6	0.27	0.09	3.5
711	09/16/2011	<1	0.15	0.13	1.7	706	11/15/2011	<1	0.30	0.15	3.3
716	09/16/2011	CS-SRDWSC	0.14	0.06	6.0	707	11/15/2011	<1	0.32	0.25	1.8
712	09/16/2011	<1	0.12	0.02	8.1	711	11/15/2011	<1	0.29	0.30	1.4
405	10/05/2011	>6	0.29	0.12	1.0	716	11/15/2011	CS-SRDWSC	0.29	0.25	1.8
411	10/05/2011	>6	0.28	0.09	1.1	721	11/15/2011	CS-SRDWSC	0.51	0.09	4.0
501	10/05/2011	1–6	0.27	0.08	1.8	719	11/21/2011	CS-SRDWSC	0.20	0.05	3.1
504	10/05/2011	1–6	0.26	0.06	2.5	723	11/21/2011	CS-SRDWSC	0.31	0.23	1.7
416	10/06/2011	1–6	0.27	0.08	1.8	795	11/21/2011	CS-SRDWSC	0.07	0.04	2.8
418	10/06/2011	1–6	0.27	0.07	1.2	796	11/21/2011	CS-SRDWSC	0.09	0.02	2.6
602	10/06/2011	1–6	0.27	0.08	1.2	797	11/21/2011	CS-SRDWSC	0.14	0.03	2.4
606	10/06/2011	1–6	0.27	0.07	1.3	405	12/07/2011	>6	0.31	0.15	0.7
508	10/07/2011	<1	0.20	0.07	1.2	411	12/07/2011	>6	0.30	0.16	0.9
513	10/07/2011	<1	0.18	0.07	2.0	416	12/08/2011	>6	0.32	0.19	0.8
519	10/07/2011	1–6	0.24	0.07	2.1	418	12/08/2011	>6	0.32	0.17	0.4
608	10/07/2011	<1	0.16	0.10	2.1	501	12/07/2011	>6	0.33	0.16	0.5
802	10/07/2011	<1	0.21	0.06	2.3	504	12/07/2011	>6	0.33	0.16	0.6
704	10/10/2011	<1	0.17	0.15	1.8	602	12/08/2011	>6	0.32	0.18	0.7
706	10/10/2011	<1	0.10	0.18	1.3	606	12/08/2011	>6	0.32	0.17	1.4
707	10/10/2011	<1	0.15	0.19	1.4	508	12/09/2011	1–6	0.37	0.16	0.8
711	10/10/2011	<1	0.15	0.18	1.9	513	12/09/2011	1–6	0.36	0.16	0.7
716	10/10/2011	CS-SRDWSC	0.16	0.14	2.2	519	12/09/2011	>6	0.36	0.15	0.7
721	10/10/2011	CS-SRDWSC	0.16	0.06	6.9	608	12/09/2011	1–6	0.36	0.16	1.2
719	10/14/2011	CS-SRDWSC	0.15	0.02	3.0	704	12/12/2011	1–6	0.37	0.16	0.9
723	10/14/2011	CS-SRDWSC	0.18	0.09	3.0	706	12/12/2011	<1	0.25	0.25	1.2
795	10/14/2011	CS-SRDWSC	0.00	0.00	4.3	707	12/12/2011	<1	0.23	0.28	1.2
796	10/14/2011	CS-SRDWSC	0.02	0.01	7.7	711	12/12/2011	<1	0.23	0.24	1.3
797	10/14/2011	CS-SRDWSC	0.07	0.01	5.1	716	12/12/2011	CS-SRDWSC	0.25	0.23	1.3
405	11/09/2011	>6	0.28	0.13	1.0	721	12/12/2011	CS-SRDWSC	0.53	0.16	1.5
411	11/09/2011	1–6	0.27	0.13	0.6	802	12/12/2011	1–6	0.37	0.17	0.6
501	11/09/2011	>6	0.29	0.09	0.7						

Appendix 5. U.S. Geological Survey Sediment Monitoring and Analysis

Foreward

The material presented in this appendix was provided by David Schoellhamer and others specifically for this report. Only the major points related to the predictions in the report were excerpted from the provided material. These major points are summarized at the beginning of the material presented in this appendix. The original material from Schoellhamer and others consisted largely of a series of figures with results and interpretive text provided in extensive figure captions. The material presented here has been edited to move text out of the captions and into regular text where possible.

Data sources and site identifiers are provided in table 5-1. Generally, data were collected with continuously recording instruments at fixed stations. At the Mallard Island site (USGS station 11185185), turbidity and suspended-sediment concentrations at 1-meter below the surface were recorded at 15-minute intervals, according to methods in Buchanan and Morgan (2012). Turbidity instruments were calibrated by using prepared standards. Suspended-sediment concentrations determined from water samples and analyzed at the U.S. Geological Survey (USGS) sediment laboratory, Marina, Calif., were used to calibrate the suspended-sediment sensors. See Buchanan and Morgan (2012) for additional detail. Specific-conductance measurements at Mallard Island were obtained from the California Department of Water Resources, which has instruments co-located with USGS instruments at this site. Methods used at Grizzly Bay (USGS station 380605122012101) and Suisun Cutoff (USGS station 380530122003501) were similar and are documented in Cuetera and others (2001); however, instruments at these sites were positioned 1.2 meters above the bottom in 1995 and 0.8 meters above the bottom in 2011. Methods used at Cache Slough sites, including lower Cache Slough (USGS station 11455350), upper Cache Slough (USGS station 11455280), Deep Water Ship Channel adjacent shallows (USGS station 11455335), and Liberty Island shallows (USGS station 381504121404001) are described in detail by Morgan-King and Schoellhamer (2013). Methods were essentially the same as for Buchanan and Morgan (2012); however, instruments were located 1.2 meters above the bottom, except at Deep Water Ship Channel adjacent shallows, where the instrument was located 0.6 m above the bottom because of the shallowness of the water at the site.

Preliminary Analysis of Suspended-Sediment Concentration and Turbidity in the Fall Low-Salinity Zone of the San Francisco Estuary

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

Summary

- X2, the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2, 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, and turbidity was greater in fall 2010 than 2011.

Does X2 Position Affect Suspended-Sediment Concentration?

A plot of suspended-sediment concentration relative to X2 (fig. 5-1) does not indicate an obvious effect of X2 on near-surface suspended-sediment concentration at Mallard Island.

Has Suspended-Sediment Concentration Changed Between 1994 and 2011?

September–October SSC decreased about 50 percent from 1994–2011 (fig. 5-2). Total suspended-solids concentration (equivalent to SSC in this estuary) in the Delta decreased 50 percent from 1975 to 1995 (Jassby and others, 2002). In 1999, there was a 36-percent step decrease in SSC in San Francisco Bay as the threshold from transport to supply regulation was crossed because 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.

Table 5-1. Station names, site identifiers, site codes, and data sources for analyses presented in this appendix.

[Abbreviations: CDEC, California data exchange center; USGS, U.S. Geological Survey]

Site name	USGS site code	Abbreviation	Time period of data used	Type of data	Data availability
Mallard Island	11185185	MI	September to October, 1994–2011	Near-surface suspended sediment concentration	2007 and earlier, http://ca.water.usgs.gov/grapher/baydelta/
Mallard Island	11185185	MI	September to October, 1994–2011	Near-surface suspended sediment concentration	2008 and later, http://waterdata.usgs.gov/ca/nwis/tv/?site_no=11185185&agency_cd=USGS&amp
Mallard Island	CDEC site	MI	September to October, 1994–2011	Near-surface specific conductance	http://cdec.water.ca.gov/cgi-progs/selectQuery?station_id=mal
Mallard Island	CDEC site	MI	September to December, 2011	Turbidity	http://cdec.water.ca.gov/cgi-progs/selectQuery?station_id=mal
Grizzly Bay	380605122012101	GS	September to October, 1994 and 2011	Near-bottom suspended sediment concentration	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Suisun Cutoff	380530122003501	Cut	September to October, 1994 and 2011	Near-bottom suspended sediment concentration	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Lower Cache Slough, mid-depth	11455350	LCS	September to December, 2011	Turbidity	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Deep Water Ship Channel, adjacent shallows	11455335	DWSC	September to December, 2011	Turbidity	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Liberty Island, shallows	381504121404001	LIW	September to December, 2011	Turbidity	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Upper Cache Slough, near-bottom	11455280	UCS	September to December, 2011	Turbidity	For these data contact the California Water Science Center at: GS-W-CAdist_www@usgs.gov
Travis Air Force Base	CDEC site	None	September to December, 2011	Wind speed	http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=TAF

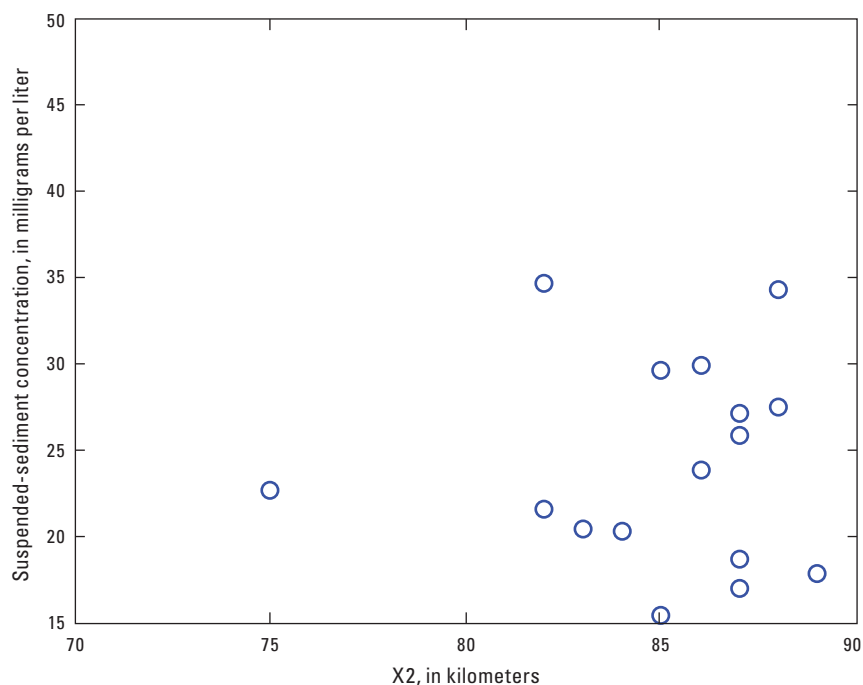


Figure 5-1. Near-surface suspended-sediment concentration (SSC) at Mallard Island (USGS station 11185185) as a function of X2, September–October mean values, 1994–2011 (sample number is 5,856 each year). SSC data are collected at a 15-minute interval 1 meter below the water surface (Buchanan and Morgan, 2012). The year 1995 is not included as a result of insufficient SSC data. X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2.

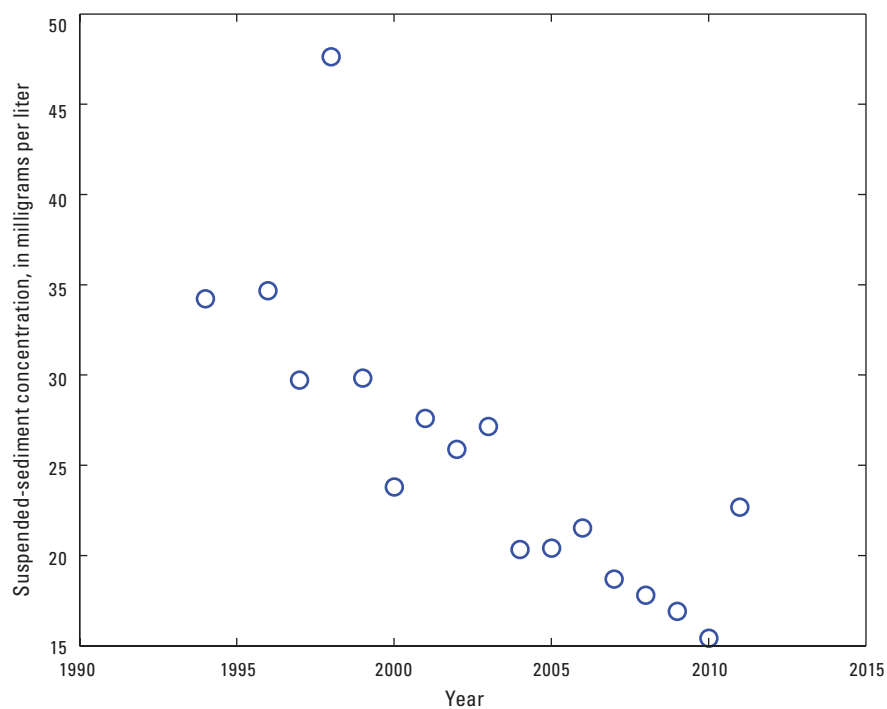


Figure 5-2. Near-surface suspended-sediment concentration (SSC) at Mallard Island (USGS station 11185185), September–October mean values, 1994–2011 (sample number is 5,856 each year). SSC data were collected at a 15-minute interval 1 meter below the water surface (Buchanan and Morgan, 2012). 1995 is not included because of insufficient SSC data.

Data collected at Suisun Cutoff (fig. 5-3) and Grizzly Bay (fig. 5-4) also support the trend of decreasing SSC, although there was less change at Suisun Cutoff compared to Grizzly Bay. For Suisun Cutoff, mean SSC in 2011 (66 mg/L) was 94 percent less than in 1995 (121 mg/L). For Grizzly Bay, the lower quartile decreased the most with 69 mg/L in 1995 and 52 mg/L in 2011, a decrease of 25 percent. For Grizzly Bay, the upper quartile decreased the least with 101 mg/L in 1995 and 97 mg/L in 2011, a decrease of 4 percent. Brennan and others (2002) found that tidal asymmetry in Suisun Cutoff caused greater SSC during flood tide. The highs were comparably high, perhaps because the tidal asymmetry mechanism was still present, but the lows were lower than before (SSC in Grizzly Bay and at Mallard Island have decreased almost one-half from the mid-1990s to 2011), perhaps because clearer water from elsewhere was transported into Suisun Cutoff. SSC decreases with distance from the bed, and 2011 data were collected 0.4 meters closer to the bottom than in 1995, which could account for some of the decrease in SSC observed from 1995 to 2011. Overall, data from multiple sites indicated that fall SSC declined from 1994 to 2011.

Is the Confluence or Suisun Bay More Turbid?

Determining whether the confluence or Suisun Bay was more turbid during the fall was addressed by evaluating deviations from tidally averaged mean values of specific conductance and suspended-sediment concentration at Mallard Island (fig. 5-5). 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 percent for specific conductance and 47.6 percent 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 percent of variability for specific conductance, 12.4 percent for SSC), indicating that advection was the most important tidal process. For SSC, quarter diurnal modes, which are indicative of tidal

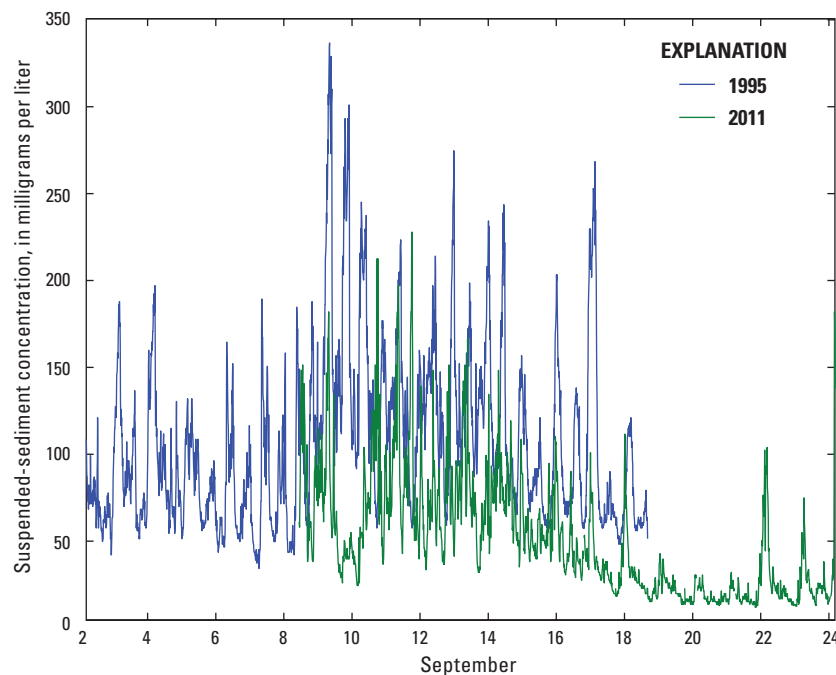


Figure 5-3. Suspended-sediment concentration (SSC) near the bottom of Suisun Cutoff (USGS station 380530122003501), September–October 1995 (sample number is 1,475) and 2011 (sample number is 984). Data were collected at a 15-minute intervals 1.2 meters above the bottom in 1995, and 0.8 meters above the bottom in 2011 (Cuetara and others, 2001). The period for which data have overlapping calendar dates is 33 days.

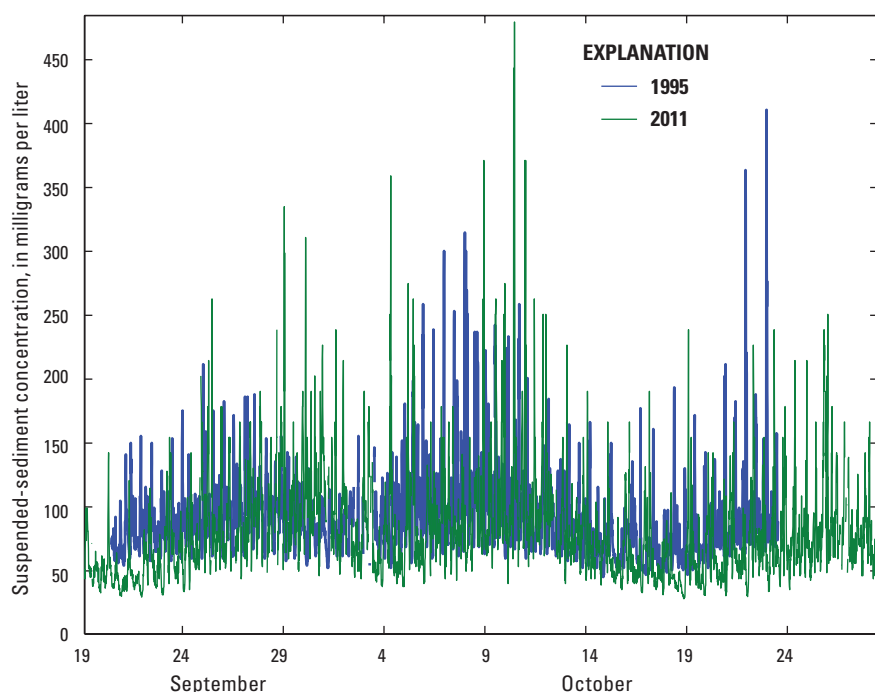


Figure 5-4. Suspended-sediment concentration (SSC) in Grizzly Bay (USGS station 380605122012101), September 1995 (sample number is 4,759) and 2011 (sample number is 2,172). Data were collected at a 15-minute interval, 0.6 meters above the bottom in 1995 and 0.5 meters above the bottom in 2011 (Cuetara and others, 2001). The period for which data have overlapping calendar dates spans 10.2 days.

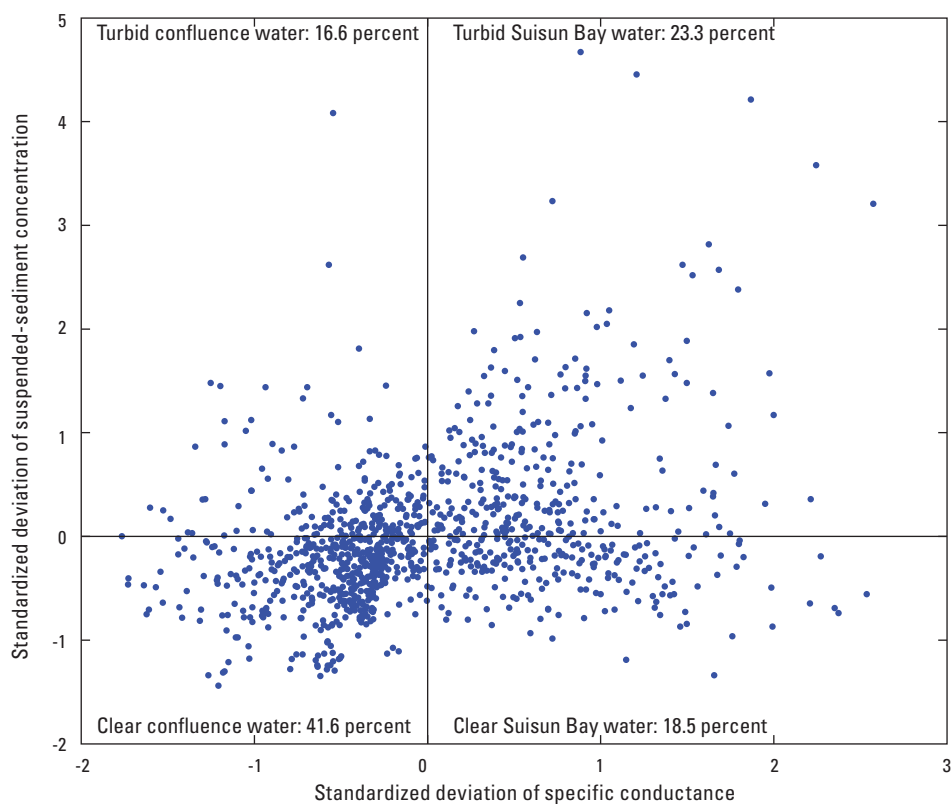


Figure 5-5. Standardized deviations of near-surface hourly specific conductance and suspended-sediment concentration (SSC) from tidally averaged values at Mallard Island (USGS station 11185185), September–October 2011 ($n=1,464$). SSC data are collected at a 15-minute interval 1 meter below the water surface (Buchanan and Morgan, 2012). Specific conductance data were collected by the California Department of Water Resources (<http://cdec.water.ca.gov/>).

resuspension, accounted for only 7.4 percent of the variability. About 65 percent of the data fell in the upper right or lower left quadrants (fig. 5-5), indicating relatively turbid water from Suisun Bay or relatively clear water from the confluence present at Mallard Island, respectively. Thus, Suisun Bay usually was more turbid than the confluence. This analysis assumes that advection is the dominant sediment transport mechanism.

The results depicted in figure 5-5 are for hourly data; however, consideration of these data on a daily time step could be more useful as an indicator of general water-quality conditions. This was accomplished by calculating the product of signs (positive or negative) of the hourly deviations of specific conductance and suspended-sediment concentration from tidally averaged values. Positive values of the product 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). The number of positive hourly values per day was then divided by 24 to determine the daily percentage shown in figure 5-6. 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, such that Suisun Bay is more turbid than the confluence in the early fall, September to mid-October. Several factors can affect this percentage, including wind-wave resuspension, the salinity field, river discharge, and the spring-neap tidal cycle.

The results shown in figure 5-5 appear to be independent of X2 (fig. 5-7), specific conductance (fig. 5-8) and windspeed (fig. 5-9). In general, 50–65 percent of the data indicated that Suisun Bay is more turbid than the confluence annually, and this percentage appears to be independent of X2 (fig. 5-7). Similarly, the percentage appears to be independent of specific conductance (fig. 5-8). A possible decrease in the percentage at 6,000–9,000 microsiemens per centimeter ($\mu\text{S}/\text{cm}$) could be due to formation of a small estuarine turbidity maximum (ETM) landward of Mallard Island during neap tides around salinity 0–2 (0–4,000 $\mu\text{S}/\text{cm}$; 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 4,000 $\mu\text{S}/\text{cm}$ at Mallard Island, the ETM would be centered at or seaward of Mallard Island. For specific conductance greater than 9,000 $\mu\text{S}/\text{cm}$, 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. The percentage also did not show an obvious relation to wind speed at Travis Airforce Base (fig. 5-9); however, the range of mean wind speed was only 4 miles per hour (mph), which could 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. Overall, the data indicated that Suisun Bay is usually more turbid than the confluence during the fall. However, this is not true every year, and in some years, the difference is not great.

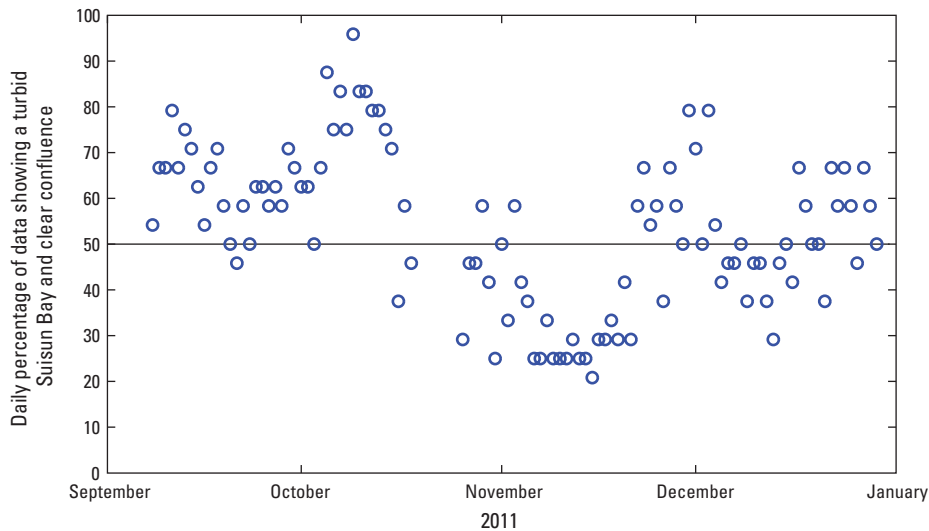


Figure 5-6. Percentage of data showing a turbid Suisun Bay and clear confluence, September–December 2011 (n=122).

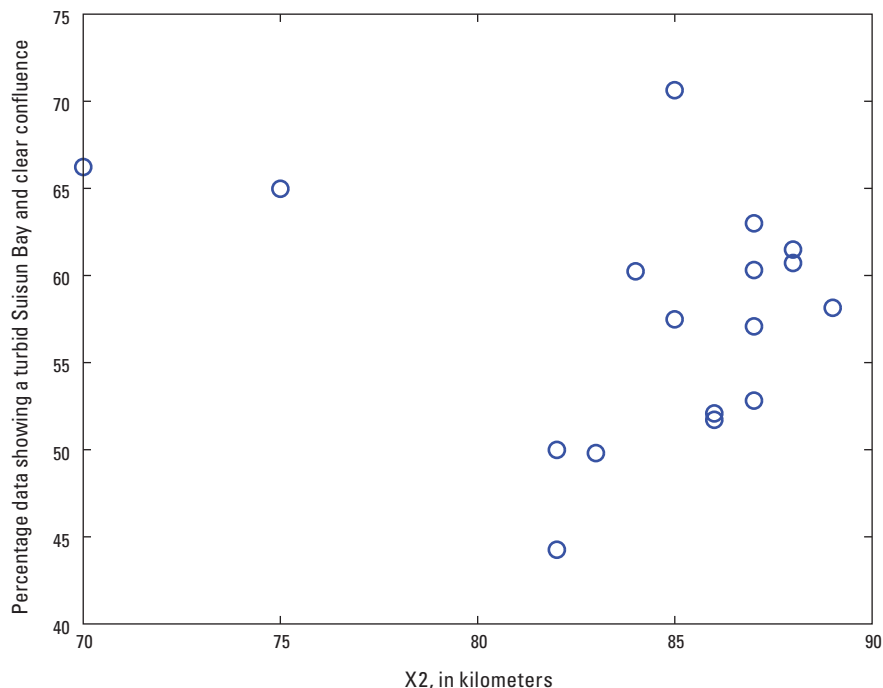


Figure 5-7. Annual percentage of specific conductance and suspended-sediment concentration (SSC) data from Mallard Island (USGS station 11185185) within the upper right and lower left quadrants of figure 5-5 showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence), as a function of X2, September and October 1994–2011. 1995 is not included because of insufficient SSC data. X2 is the mean for September and October. X2 is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2.

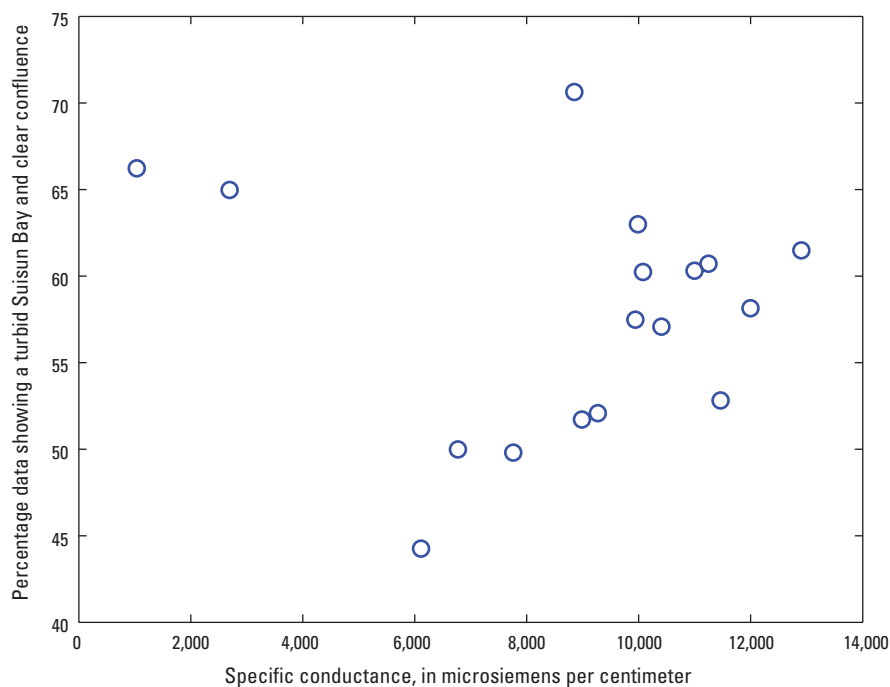


Figure 5-8. Annual percentage of specific conductance and suspended-sediment concentration (SSC) data from Mallard Island (USGS station 11185185) within the upper right and lower left quadrants of figure 5-5 showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence), as a function of mean specific conductance, September–October 1994–2011. 1995 is not included because of insufficient SSC data.

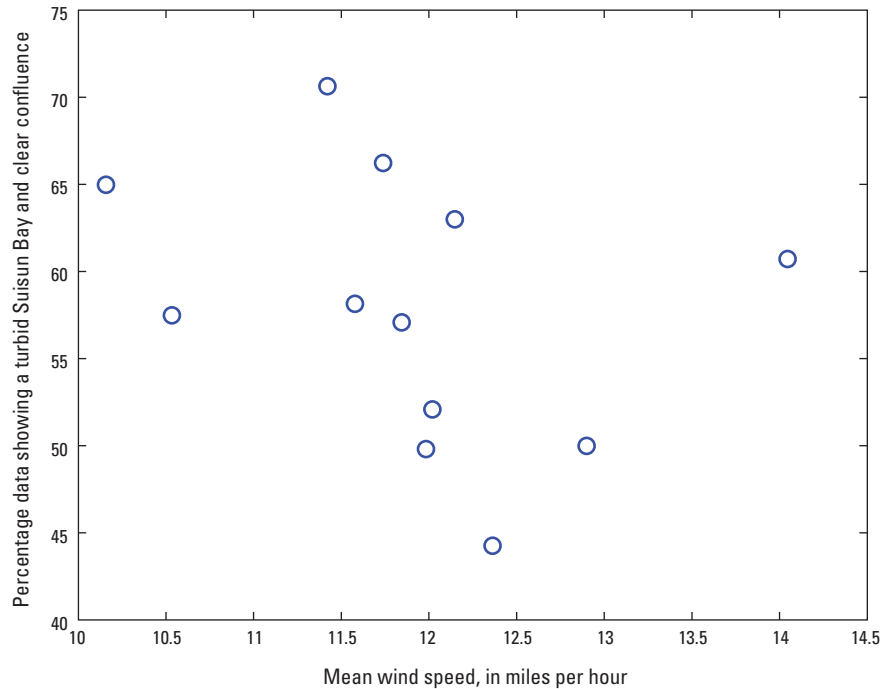


Figure 5-9. Annual percentage of specific conductance and suspended-sediment concentration (SSC) data from Mallard Island (USGS station 11185185) within the upper right and lower left quadrants of figure 5-5 showing turbid waters to the west of Mallard Island (Suisun Bay) and clear waters to the east (confluence), as a function of mean wind speed, September–October 1994–2011. 1995 is not included because of insufficient SSC data. Wind speed was measured hourly at Travis Air Force Base. No wind-speed data were available for 2000–2004.

Is Suisun Bay or the Cache Slough/Liberty Island Complex More Turbid?

Suspended-sediment concentration and, therefore, turbidity increase with water depth at a given site, so sensor position in the water column is important to consider when comparing turbidities among sites. For shallow sites during September–December 2011, Grizzly Bay was more turbid than Liberty Island (LIW) and the Deep Water Ship Channel (DWSC; fig. 5-10). For near-bottom sites, Suisun Cutoff (Cut) was more turbid than Upper Cache Slough (UCS). And for near-surface and mid-depth sites, Mallard Island (MI) was more turbid than Lower Cache Slough (LCS). For all these comparisons, Suisun Bay sites were more turbid than Cache Slough complex sites. The same pattern was observed when only September–October 2011 data were considered (fig. 5-11). Wind speed does appear to affect this pattern (fig. 5-12). Turbidity at Mallard Island is usually greater than in the Cache Slough complex, except during some windy events when wind-wave resuspension in Liberty Island increases turbidity in the Deep Water Ship Channel and Lower Cache Slough. Wind direction was not considered in this initial analysis.

There were differences in suspended-sediment concentration, and therefore turbidity, between 2010 and 2011, when data were available (fig. 5-13). As noted above, suspended-sediment concentration, and therefore turbidity, increase with water depth at a given site, so sensor position in the water column is important to consider when analyzing these results. Mallard Island was more turbid in 2011 than 2010, and Cache Slough complex sites were less turbid in 2011 compared to 2010. In 2010, Mallard Island was about as turbid as Lower Cache Slough and less turbid than the remaining Cache Slough complex sites. In 2011, Mallard Island was more turbid than all Cache Slough complex sites, except Upper Cache Slough. A hypothesis for the difference between 2010 and 2011 is that Yolo Bypass flow, in 2011, reduced sediment deposition in the Cache Slough complex, and greater watershed sediment supply in 2011 increased deposition in Suisun Bay, and this more seaward deposition in 2011 accounts for the observed turbidity. Another hypothesis is that, in 2010, the estuarine turbidity maximum (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. Overall, Suisun Bay was usually more turbid than the Cache Slough complex in Fall 2011, and turbidity at Mallard Island was greater in fall 2011 than 2010, but in the Cache Slough complex, turbidity was greater in fall 2010 than 2011.

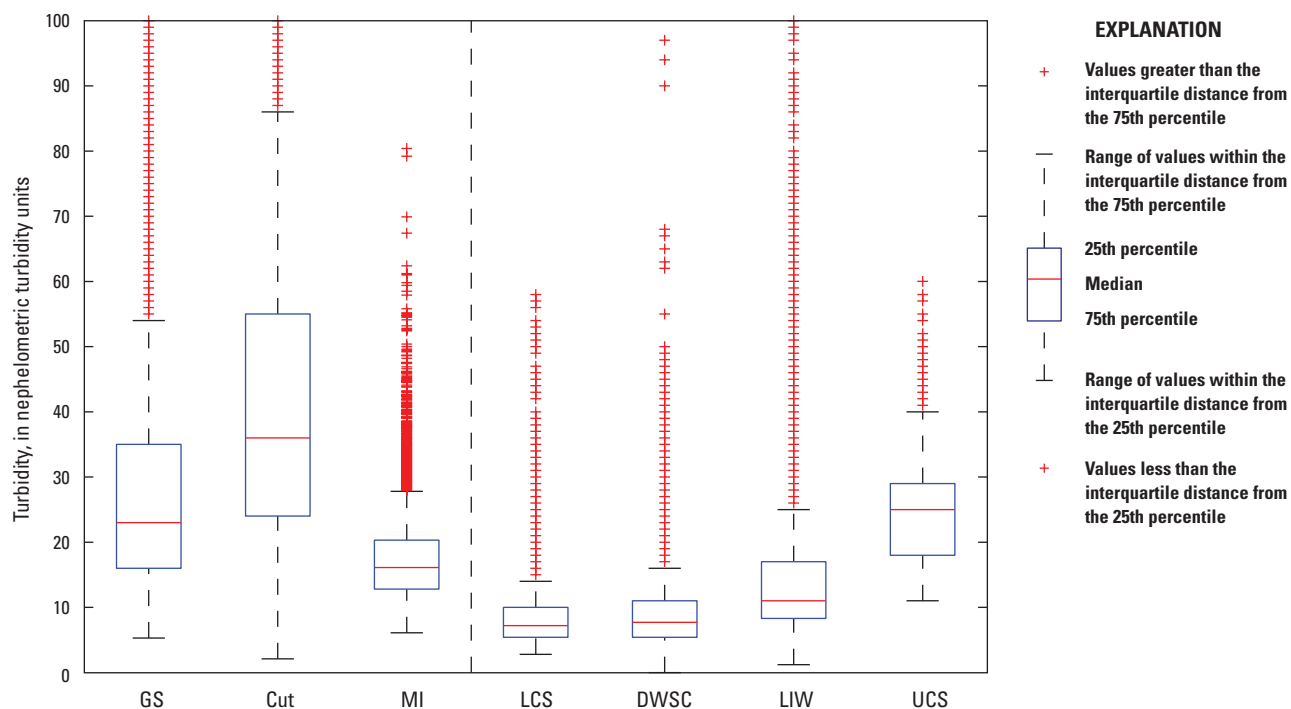


Figure 5-10. Boxplots of turbidity in Suisun Bay and the Cache Slough complex, September–December 2011. Data were collected every 15 minutes, and only times for which all seven sites had valid data are considered (sample number is 8,257 for each boxplot). Data points with turbidity greater than 100 nephelometric turbidity units are not shown. Suisun Bay sites are Grizzly Bay shallows (GS, USGS station 380605122012101), Suisun Cutoff near-bottom (Cut, USGS station 380530122003501), and Mallard Island near-surface (MI, USGS station 11185185). Mallard Island turbidity data are from California Data Exchange Center (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=MAL). 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, USGS station 11455350), Deep Water Ship Channel adjacent shallows (DWSC, USGS station 11455335), Liberty Island shallows (LIW, USGS station 381504121404001), and upper Cache Slough near-bottom (UCS, USGS station 11455280). Morgan-King and Schoellhamer (2013) described data collection in Cache Slough.

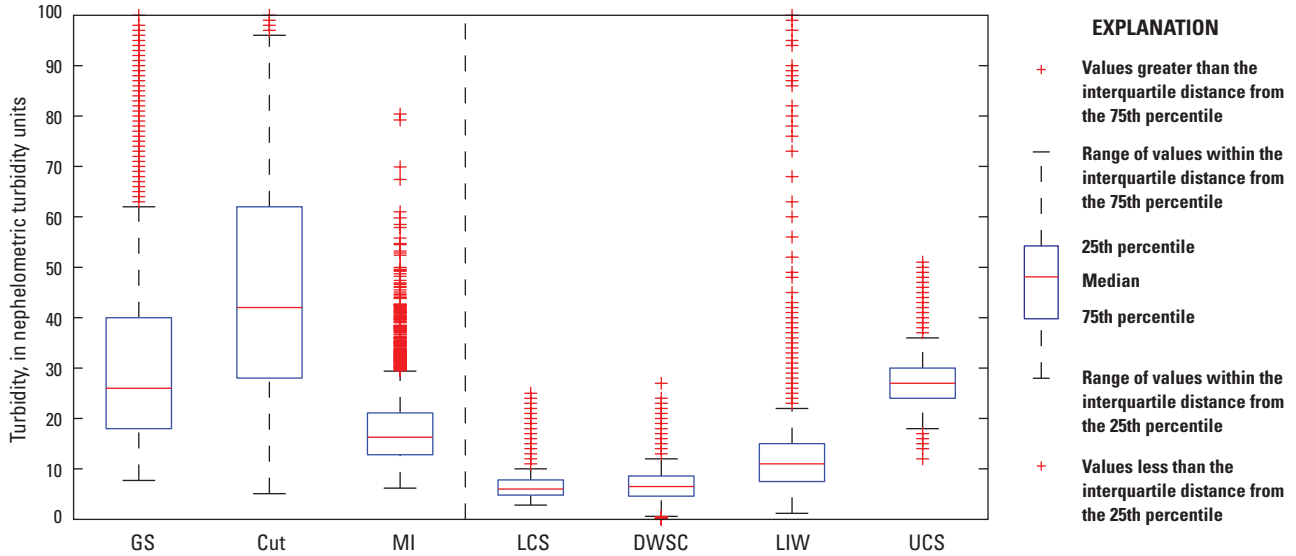


Figure 5-11. Boxplots of turbidity in Suisun Bay and the Cache Slough complex, September–October 2011. This figure is a subset of the previous figure. Data were collected every 15 minutes, and only times for which all seven sites had valid data are considered (sample number is 4557 for each boxplot). Data points with turbidity greater than 100 nephelometric turbidity units are not shown. Suisun Bay sites are Grizzly Bay shallows (GS, USGS station 380605122012101), Suisun Cutoff near-bottom (Cut, USGS station 380530122003501), and Mallard Island near-surface (MI, USGS station 11185185). Mallard Island turbidity data are from California Data Exchange Center (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=MAL). 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, USGS station 11455350), Deep Water Ship Channel adjacent shallows (DWSC, USGS station 11455335), Liberty Island shallows (LIW, USGS station 381504121404001), and Upper Cache Slough near-bottom (UCS, USGS station 11455280). Morgan-King and Schoellhamer (2013) described data collection in Cache Slough.

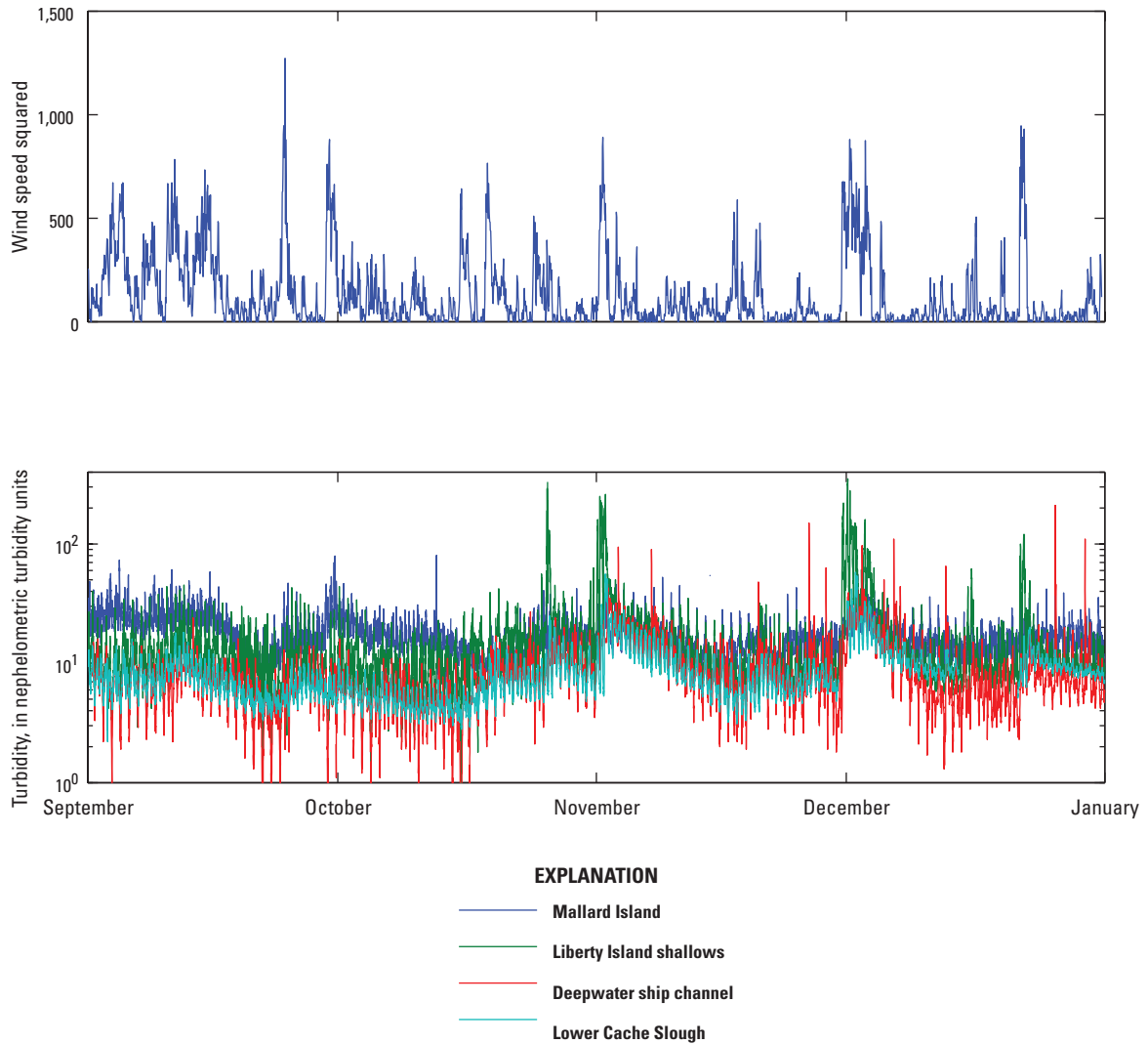


Figure 5-12. Wind-speed squared and turbidity, September–December 2011. Wind speed was measured hourly in miles per hour at Travis Air Force Base (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=TAF) (sample number is 2,928). Wind-shear stress on the water surface is roughly proportional to the square of the wind speed. Turbidity is shown at four sites: Mallard Island (USGS station 11185185), Liberty Island shallows (USGS station 381504121404001), Deepwater ship channel (USGS station 11455335), and Lower Cache Slough (USGS station 11455350). Morgan-King and Schoellhamer (2013) described data collection in Cache Slough. Note that a logarithmic scale is used for turbidity.

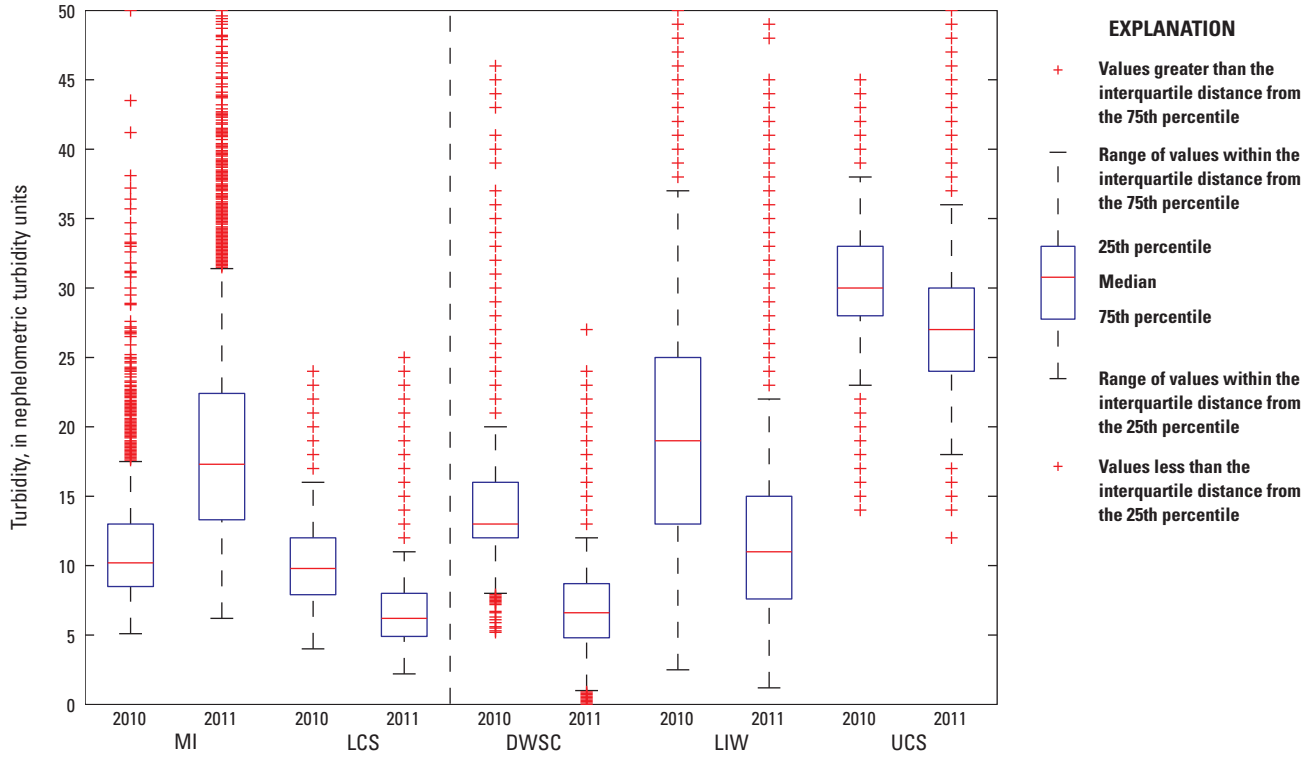


Figure 5-13. Boxplots of turbidity at Mallard Island and the Cache Slough complex, September–October 2010 and 2011. Data were collected every 15 minutes, and only times for which all five sites in a given water year had valid data are considered (sample number is 2,418 for each boxplot in 2010 and sample number is 5,452 for each boxplot in 2011). Data points with turbidity greater than 50 nephelometric turbidity units are not shown. Mallard Island (MI) turbidity data are from the California Data Exchange Center (http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=MAL). USGS measured turbidity at all the other sites. Cache Slough complex sites are Lower Cache Slough mid-depth (LCS, USGS station 11455350), Deep Water Ship Channel adjacent shallows (DWSC, USGS station 11455335), Liberty Island shallows (LIW, USGS station 381504121404001), and Upper Cache Slough near-bottom (UCS, USGS station 11455280). Morgan-King and Schoellhamer (2013) described data collection in Cache Slough. Gray shading is used to delineate sites.

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Appendix 6. Environmental Monitoring Program

The Environmental Monitoring Program (EMP) is carried out cooperatively by several IEP agencies. Sampling is performed monthly. The following information is excerpted from this web site: <http://www.water.ca.gov/iep/activities/emp.cfm>. Additional information on zooplankton sampling can be obtained at the following website: <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 carried out 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 (CDWR). Assistance is provided by the California Department of Fish and Wildlife (CDFW) 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 provides information on a wide range of chemical, physical, and biological baseline variables. EMP's discrete water-quality stations are sampled monthly by 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 the Department of Water Resources (DWR).

We used data from six discrete sites in the EMP sampling network (fig. 6-1). Latitude and longitude of sites are provided in table 6-1. We also included data from two "floating" sites, EZ2 and EZ6. These samples were taken at locations where near-bottom specific conductances were 2,000 and 6,000 $\mu\text{S}/\text{cm}$, respectively. We used data for ammonium as nitrogen (N), nitrite plus nitrate as N, and chlorophyll-*a*, (table 6-2). Water-quality data were determined from samples collected 1 meter below the surface. Details of methods are available at <http://www.water.ca.gov/bdma/meta/discrete.cfm>. We also used continuous 15-minute fluorescence measurements from two continuous monitoring sites, Rio Vista Bridge, and Mallard Island (table 6-3), which are near discrete sites D10 and D24, respectively (fig. 6-1, table 6-1). Data were provided by Mike Dempsey, California Department of Water Resources.

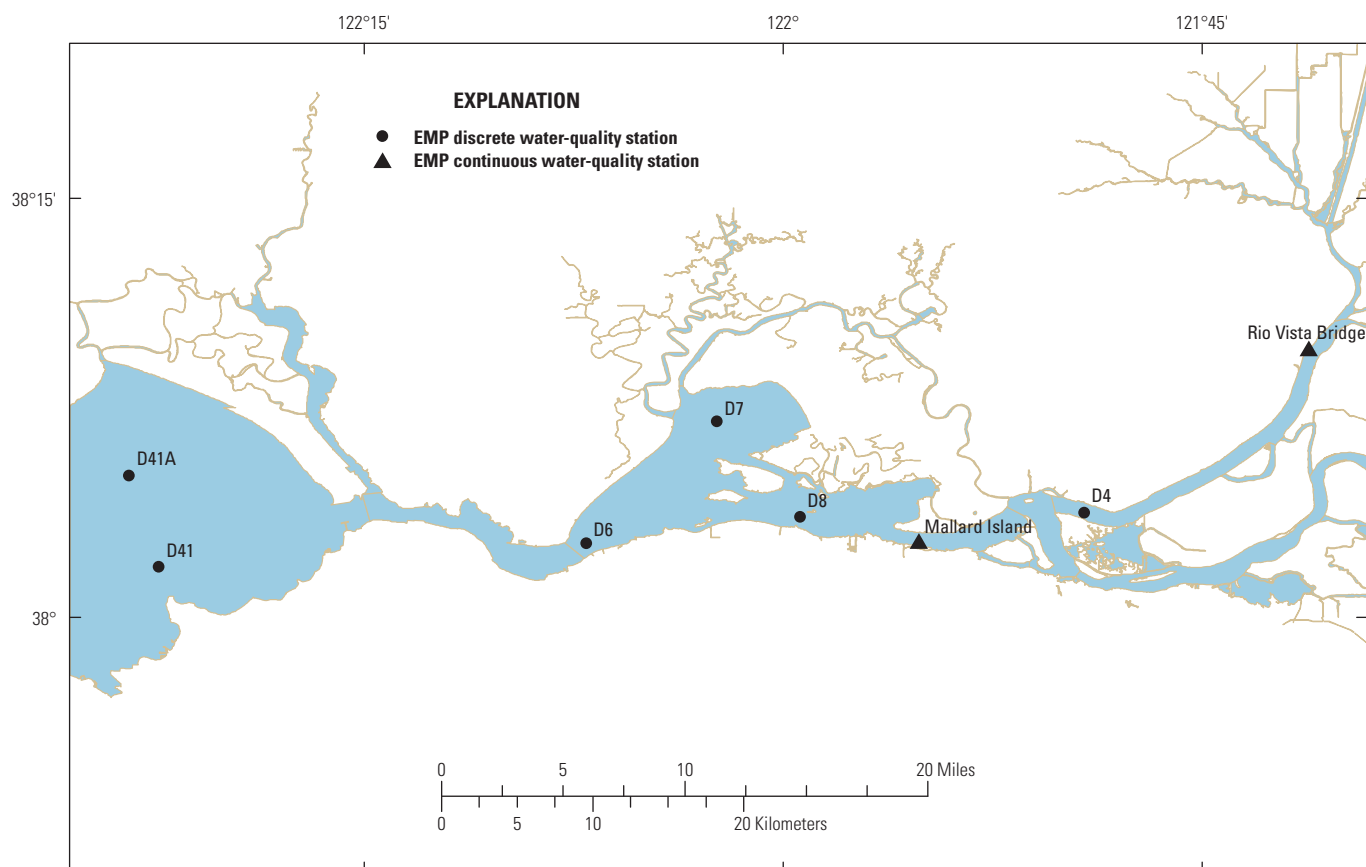


Figure 6-1. Sites sampled by the Environmental Monitoring Program for water-quality constituents that were included in data analysis for this report. See table 6-1 for latitude and longitude of each site.

Table 6-1. Latitude and longitude of Environmental Monitoring Program discrete and continuous water-quality monitoring sites utilized in this report.

Station	North latitude (decimal degrees)	West longitude (decimal degrees)
D7	38.1171	122.0397
D4	38.0625	121.8205
D6	38.0444	122.1177
D8	38.0599	121.9900
D41	38.0302	122.3729
D41A	38.0847	122.3907
Rio Vista Bridge	38.1597	121.6864
Mallard Island	38.0440	121.9190

Table 6-2. Nitrite plus nitrate as nitrogen, ammonium as nitrogen, and chlorophyll- α , by salinity group, from water samples collected during Environmental Monitoring Program sampling in 2005, 2006, 2010, and 2011.

[Latitude and longitude of sampling stations are in table 6-1, except for EZ2 and EZ6. These samples were taken at locations where near-bottom specific conductances were 2,000 and 6,000 $\mu\text{S}/\text{cm}$, respectively. **Abbreviations:** mg/L, milligram per liter; mm/dd/yyyy, month/day/year; N, nitrogen; $\mu\text{g}/\text{L}$, microgram per liter; —, missing data; <, less than; >, greater than; +, plus]

Station	Date (mm/dd/yyyy)	Salinity group	Ammonia as N (mg/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α ($\mu\text{g}/\text{L}$)	Station	Date (mm/dd/yyyy)	Salinity group	Ammonia as N (mg/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α ($\mu\text{g}/\text{L}$)
D7	09/23/2005	>6	0.05	0.32	1.84	D6	09/14/2006	>6	0.09	0.34	1.60
D4	09/26/2005	<1	0.06	0.25	1.54	D8	09/14/2006	1–6	0.07	0.30	1.13
D6	09/26/2005	>6	0.05	0.26	2.24	EZ2	09/14/2006	1–6	—	—	2.04
D8	09/26/2005	1–6	0.05	0.28	1.20	EZ6	09/14/2006	1–6	—	—	1.38
EZ2	09/26/2005	<1	—	—	1.90	D41	09/15/2006	>6	0.08	0.32	1.75
EZ6	09/26/2005	1–6	—	—	1.59	D41A	09/15/2006	>6	0.09	0.35	2.92
D41	09/27/2005	>6	0.02	0.21	3.04	D7	10/12/2006	>6	0.07	0.37	1.26
D41A	09/27/2005	>6	—	0.16	7.90	D4	10/16/2006	1–6	0.06	0.35	1.72
D7	10/24/2005	>6	0.09	0.35	1.42	D6	10/16/2006	>6	0.09	0.39	1.70
D4	10/25/2005	1–6	0.08	0.34	1.25	D8	10/16/2006	>6	0.07	0.37	1.54
D6	10/25/2005	>6	0.11	0.33	1.45	EZ2	10/16/2006	<1	—	—	1.55
D8	10/25/2005	>6	0.09	0.35	1.59	EZ6	10/16/2006	1–6	—	—	1.58
EZ2	10/25/2005	1–6	—	—	2.38	D41	10/17/2006	>6	0.08	0.30	1.64
EZ6	10/25/2005	1–6	—	—	1.20	D41A	10/17/2006	>6	0.07	0.36	2.88
D41	10/26/2005	>6	0.07	0.26	2.72	D7	11/13/2006	>6	0.10	0.43	0.76
D41A	10/26/2005	>6	0.09	0.29	3.04	D4	11/14/2006	1–6	0.11	0.46	0.85
D7	11/21/2005	>6	0.14	0.47	1.14	D6	11/14/2006	>6	0.12	0.41	0.79
D4	11/22/2005	1–6	0.14	0.51	0.61	D8	11/14/2006	>6	0.11	0.44	1.00
D6	11/22/2005	>6	0.14	0.44	1.17	EZ2	11/14/2006	<1	—	—	1.46
D8	11/22/2005	>6	0.13	0.48	0.85	EZ6	11/14/2006	1–6	—	—	0.97
EZ2	11/22/2005	<1	—	—	1.26	D41	11/15/2006	>6	0.10	0.30	1.43
EZ6	11/22/2005	1–6	—	—	0.62	D41A	11/15/2006	>6	0.10	0.36	1.54
D41	11/23/2005	>6	0.11	0.32	2.82	D7	12/11/2006	>6	0.14	0.51	0.95
D41A	11/23/2005	>6	0.13	0.38	1.71	D4	12/12/2006	1–6	0.16	0.50	1.00
D7	12/21/2005	>6	0.20	0.52	0.68	D6	12/12/2006	>6	0.15	0.47	1.00
D4	12/22/2005	1–6	0.25	0.50	0.92	D8	12/12/2006	>6	0.12	0.42	1.22
D6	12/22/2005	>6	0.20	0.50	0.66	EZ2	12/12/2006	<1	—	—	1.04
D8	12/22/2005	1–6	0.22	0.50	0.59	EZ6	12/12/2006	1–6	—	—	0.98
EZ2	12/22/2005	<1	—	—	0.91	D41	12/13/2006	>6	0.11	0.39	1.51
EZ6	12/22/2005	1–6	—	—	0.80	D41A	12/13/2006	>6	0.14	0.43	1.06
D41	12/23/2005	>6	0.17	0.43	4.20	D4	09/15/2010	1–6	0.03	0.24	2.51
D41A	12/23/2005	>6	0.20	0.50	1.40	D8	09/15/2010	>6	0.03	0.26	2.56
D7	09/13/2006	>6	0.07	0.32	0.83	EZ2	09/15/2010	<1	0.05	0.22	2.55
D4	09/14/2006	1–6	0.05	0.27	1.38	EZ6	09/15/2010	1–6	0.03	0.24	2.48

Table 6-2. Nitrite plus nitrate as nitrogen, ammonium as nitrogen, and chlorophyll- α , by salinity group, from water samples collected during Environmental Monitoring Program sampling in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 6-1. **Abbreviations:** mg/L, milligram per liter; mm/dd/yyyy, month/day/year; N, nitrogen; $\mu\text{g/L}$, microgram per liter; —, missing data; <, less than; >, greater than; +, plus]

Station	Date (mm/dd/yyyy)	Salinity group	Ammonia as N (mg/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α ($\mu\text{g/L}$)	Station	Date (mm/dd/yyyy)	Salinity group	Ammonia as N (mg/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α ($\mu\text{g/L}$)
D7	09/16/2010	>6	0.03	0.29	5.55	EZ2	09/21/2011	<1	0.04	0.20	4.76
D41	09/17/2010	>6	0.06	0.29	3.16	EZ6	09/21/2011	<1	0.03	0.20	2.71
D41A	09/17/2010	>6	0.08	0.34	1.69	D7	09/22/2011	>6	0.05	0.20	1.47
D6	09/17/2010	>6	0.07	0.32	2.69	D41	09/23/2011	>6	0.02	0.18	3.76
D4	10/14/2010	1–6	0.04	0.27	1.67	D41A	09/23/2011	>6	—	0.18	3.66
D8	10/14/2010	>6	0.06	0.28	1.64	D6	09/23/2011	>6	0.06	0.28	2.85
EZ2	10/14/2010	<1	0.05	0.27	2.02	D4	10/19/2011	<1	0.06	0.21	4.08
EZ6	10/14/2010	1–6	0.04	0.27	2.34	D8	10/19/2011	1–6	0.08	0.25	1.50
D7	10/15/2010	>6	0.07	0.29	1.83	EZ2	10/19/2011	<1	0.07	0.19	2.39
D41	10/18/2010	>6	0.06	0.31	2.26	EZ6	10/19/2011	1–6	0.07	0.25	2.20
D41A	10/18/2010	>6	0.07	0.32	1.83	D7	10/20/2011	1–6	0.08	0.26	1.03
D6	10/18/2010	>6	0.10	0.31	1.06	D41	10/21/2011	>6	0.05	0.17	8.01
D4	11/15/2010	1–6	0.10	0.43	1.09	D41A	10/21/2011	1–6	0.04	0.22	1.98
D8	11/15/2010	>6	0.11	0.43	1.24	D6	10/21/2011	>6	0.10	0.23	1.47
EZ2	11/15/2010	<1	0.12	0.40	2.05	D4	11/18/2011	1–6	0.09	0.25	3.08
EZ6	11/15/2010	1–6	0.09	0.44	1.31	D8	11/18/2011	>6	0.10	0.26	1.05
D7	11/16/2010	>6	0.11	0.41	0.94	EZ2	11/18/2011	<1	0.13	0.26	5.13
D41	11/17/2010	>6	0.10	0.29	2.52	EZ6	11/18/2011	1–6	0.10	0.25	2.71
D41A	11/17/2010	>6	0.10	0.38	2.72	D7	11/21/2011	>6	0.12	0.27	1.50
D6	11/17/2010	>6	0.12	0.38	1.47	D41	11/22/2011	>6	0.10	0.25	1.95
D4	12/15/2010	<1	0.14	0.32	1.21	D41A	11/22/2011	>6	0.12	0.27	2.48
D8	12/15/2010	1–6	0.14	0.29	0.57	D6	11/22/2011	>6	0.13	0.29	1.31
EZ2	12/15/2010	<1	0.14	0.31	1.08	D4	12/19/2011	1–6	0.16	0.17	0.59
EZ6	12/15/2010	1–6	0.13	0.29	0.79	D8	12/19/2011	>6	0.16	0.20	0.69
D7	12/16/2010	1–6	0.18	0.41	0.64	EZ2	12/19/2011	<1	0.19	0.14	1.29
D41	12/17/2010	>6	0.13	0.36	2.31	EZ6	12/19/2011	1–6	0.17	0.19	0.85
D41A	12/17/2010	>6	0.15	0.41	1.07	D7	12/20/2011	>6	0.15	0.22	1.52
D6	12/17/2010	>6	0.14	0.32	1.17	D41	12/21/2011	>6	0.12	0.25	1.60
D4	09/21/2011	<1	0.04	0.20	4.27	D41A	12/21/2011	>6	0.14	0.33	1.07
D8	09/21/2011	1–6	0.04	0.24	2.16	D6	12/21/2011	>6	0.16	0.35	1.05

Table 6-3. In-situ fluorescence at Rio Vista Bridge and Mallard Island for September–December 2011.

This table is provided separately as a Microsoft Excel® file.

Appendix 7. U.S. Geological Survey Water-Quality Monitoring

The U.S. Geological Survey (USGS) maintains a comprehensive database documenting the methods and results for long-term monitoring of the San Francisco estuary (<http://sfbay.wr.usgs.gov/access/wqdata/index.html>). Sampling is performed monthly. We used data from seven sites (fig. 7-1; table 7-1) where discrete water samples were taken for analysis of chlorophyll-*a* and nutrients. 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. We utilized data from water samples collected 2 meters below the surface to be comparable with samples collected near the surface by the Environmental Monitoring Program (EMP) and during the fall midwater trawl (FMWT). We used data for ammonium as nitrogen, nitrite plus nitrate as nitrogen, and chlorophyll-*a* (table 7-2). Ammonium and nitrite plus nitrate are presented in terms of micromoles in the USGS database. For purposes of comparison, we converted these molar concentrations to

milligrams per liter (mg/L) of ammonium as nitrogen and nitrite plus nitrate as nitrogen. Water samples were analyzed in the laboratory of Dr. Richard Dugdale of the Romberg-Tiburon Center of San Francisco State University.

Chlorophyll-*a* samples were filtered onto glass microfiber (GF/F) filters and immediately frozen. Filters were then stored at -80°C for less than 1 month until analyzed. Samples were extracted for 24 hours in acetone prior to determination of chlorophyll-*a* concentration by using a Turner laboratory fluorometer (Parsons and others, 1984). Chlorophyll-*a* was reported as milligrams per cubic meter in the original database, which is equivalent to values of micrograms per liter reported in this report.

Nutrient samples were filtered through 0.4-micron polycarbonate filters and frozen until analyzed for nitrite plus nitrate, and ammonium. Nitrite plus nitrate concentrations were determined by using a Bran and Lubbe AutoAnalyzer II (Whitledge and others, 1981), and ammonium was determined by using a spectrophotometer according to Solorzano (1969). Water samples were prefiltered by using precombusted GF/F filters before ammonium analysis.

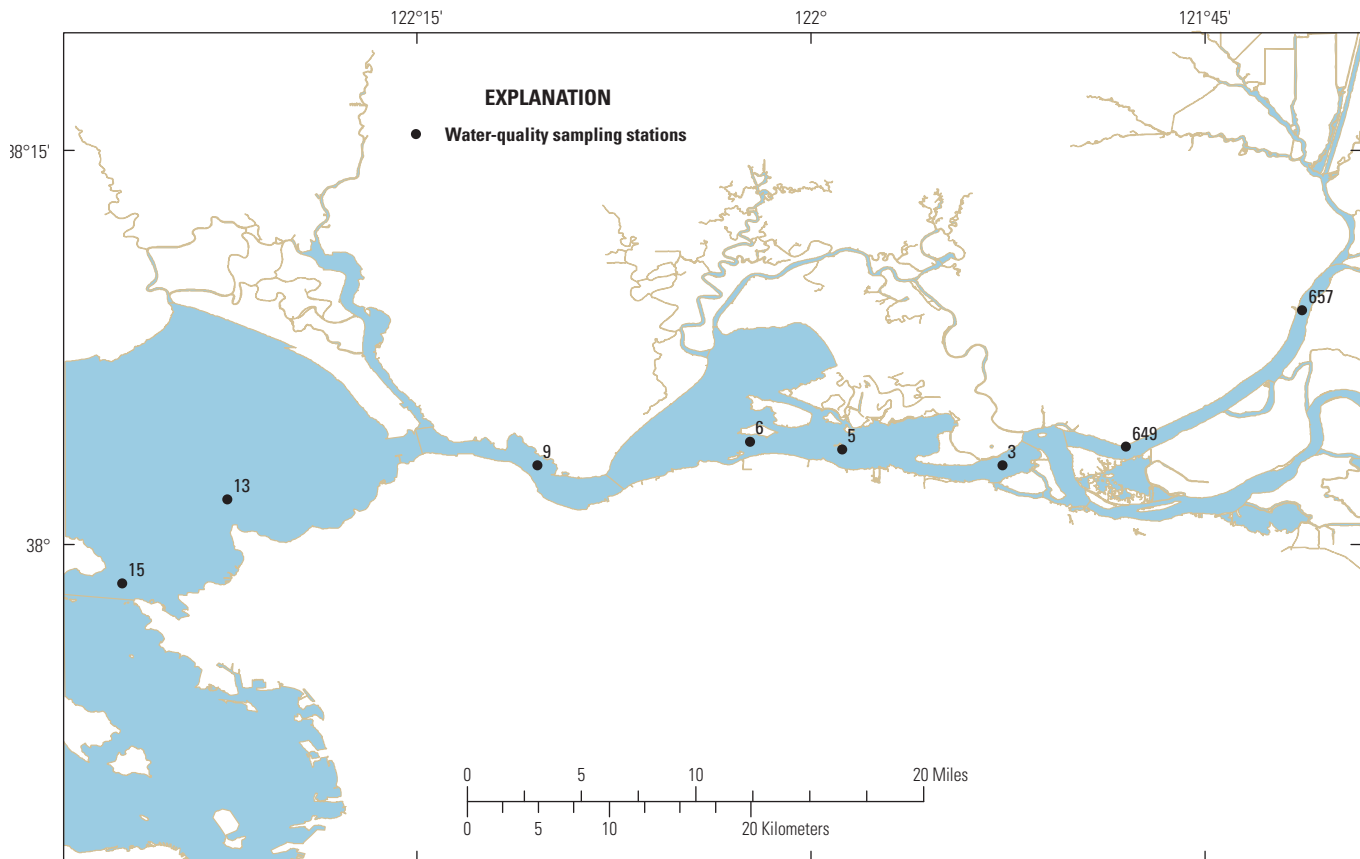


Figure 7-1. Sites sampled by the U.S. Geological Survey water-quality monitoring program for water-quality constituents.

Table 7-1. Latitude and longitude of U.S. Geologic Survey water-quality monitoring sites utilized in this report.

[Abbreviations: °, degree; ', minute]

Station	North latitude	West longitude
657	38° 8.9'	121° 41.3'
649	38° 3.7'	121° 48.0'
3	38° 3.0'	121° 52.7'
5	38° 3.6'	121° 58.8'
6	38° 3.9'	122° 2.3'
9	38° 3.0'	122° 10.4'
13	38° 1.7'	122° 22.2'
15	37° 58.5'	122° 26.2'

Table 7-2. Ammonium, ammonium as nitrogen, nitrite plus nitrate, nitrite plus nitrate as nitrogen, and chlorophyll- α , by salinity group, from water samples collected by the U.S. Geological Survey in 2005, 2006, 2010, and 2011.

[Latitude and longitude of sampling stations are in table 7-1. Chlorophyll- α determined from fluorescence data rather than analysis of pigments from discrete water samples. **Abbreviations:** hh:mm, hour:minute; mg/L, milligram per liter; mm/dd/yyyy, month/day/year; N, nitrogen; μ g/L, microgram per liter; μ M/L, micromole per liter; +, plus]

Station	Date (mm/dd/yyyy)	Time (hh:mm)	Salinity region	Ammonium (μ M/L)	Ammonium as N (mg/L)	Nitrite + nitrate (μ M/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α (μ g/L)
15	09/07/2005	11:38	>6	3.71	0.05	14.68	0.21	3.6a
13	09/07/2005	12:14	>6	4.48	0.06	18.75	0.26	2.3
9	09/07/2005	13:31	>6	5.34	0.07	24.11	0.34	3.0
6	09/07/2005	14:30	>6	2.7	0.04	23.44	0.33	4.0
3	09/07/2005	15:22	1–6	3.81	0.05	21.48	0.30	2.8
15	10/12/2005	12:13	>6	1.05	0.01	12.10	0.17	6.9
13	10/12/2005	13:00	>6	1.62	0.02	13.65	0.19	6.7
9	10/12/2005	14:29	>6	5.69	0.08	19.38	0.27	2.0
6	10/12/2005	15:45	>6	5.45	0.08	22.69	0.32	3.3
3	10/12/2005	16:52	1–6	6	0.08	21.96	0.31	1.9
15	11/08/2005	11:59	>6	5.24	0.07	20.07	0.28	4.9
13	11/08/2005	12:38	>6	5.87	0.08	20.60	0.29	3.3
9	11/08/2005	14:08	>6	8.03	0.11	24.42	0.34	1.7
6	11/08/2005	15:21	>6	7.12	0.10	27.10	0.38	2.2
3	11/08/2005	16:27	1–6	7.34	0.10	28.69	0.40	1.3
15	12/07/2005	11:43	>6	5.62	0.08	23.99	0.34	4.1
13	12/07/2005	12:24	>6	8.77	0.12	26.84	0.38	2.4
9	12/07/2005	14:07	>6	12.02	0.17	31.74	0.44	1.9
6	12/07/2005	15:19	>6	11.42	0.16	32.90	0.46	0.9
3	12/07/2005	16:21	1–6	11.04	0.15	29.71	0.42	1.1
15	09/12/2006	11:38	>6	5.23	0.07	20.36	0.29	4.5
13	09/12/2006	12:14	>6	6.12	0.09	19.46	0.27	3.0
9	09/12/2006	13:33	>6	5.93	0.08	23.70	0.33	3.1
6	09/12/2006	14:46	1–6	3.96	0.06	18.36	0.26	2.8
3	09/12/2006	15:41	<1	3.34	0.05	15.74	0.22	3.2
649	09/12/2006	16:21	<1	4.66	0.07	15.26	0.21	4.8
657	09/12/2006	17:12	<1	10.24	0.14	11.18	0.16	4.0
15	10/17/2006	11:53	<1	4.79	0.07	20.52	0.29	3.2a
13	10/17/2006	12:31	>6	4.31	0.06	20.57	0.29	3.1
9	10/17/2006	13:50	>6	5.69	0.08	25.82	0.36	2.4
6	10/17/2006	14:58	>6	6.25	0.09	28.46	0.40	1.8
3	10/17/2006	15:58	1–6	4.26	0.06	25.11	0.35	2.1
649	10/17/2006	16:38	1–6	4.81	0.07	24.80	0.35	2.4
657	10/17/2006	17:38	<1	16	0.22	25.20	0.35	2.4
15	11/14/2006	11:53	>6	6.27	0.09	21.86	0.31	2.1
13	11/14/2006	12:34	>6	6.47	0.09	23.11	0.32	3.2
9	11/14/2006	14:14	>6	7.48	0.10	26.25	0.37	2.2
6	11/14/2006	15:33	>6	7.87	0.11	30.15	0.42	1.4
3	11/14/2006	16:48	1–6	8.02	0.11	32.23	0.45	1.2
649	11/14/2006	17:29	1–6	9.79	0.14	33.50	0.47	1.7
657	11/14/2006	18:29	<1	20.79	0.29	28.53	0.40	1.5
15	12/12/2006	11:59	>6	5.51	0.08	28.60	0.40	4.9
13	12/12/2006	12:41	>6	7.88	0.11	28.56	0.40	2.8
9	12/12/2006	14:28	>6	11.15	0.16	33.14	0.46	2.2
6	12/12/2006	15:45	>6	10.28	0.14	36.13	0.51	1.5
3	12/12/2006	16:56	1–6	11.99	0.17	36.94	0.52	1.5
649	12/12/2006	17:31	<1	15.54	0.22	34.01	0.48	1.7
657	12/12/2006	18:29	<1	18.66	0.26	27.92	0.39	2.4
15	09/14/2010	11:59	>6	4.27	0.06	20.98	0.29	8.2
13	09/14/2010	12:39	>6	4.72	0.07	22.66	0.32	5.6

Table 7-2. Ammonium, ammonium as nitrogen, nitrite plus nitrate, nitrite plus nitrate as nitrogen, and chlorophyll- α , by salinity group, from water samples collected by the U.S. Geological Survey in 2005, 2006, 2010, and 2011.—Continued

[Latitude and longitude of sampling stations are in table 7-1. Chlorophyll- α determined from fluorescence data rather than analysis of pigments from discrete water samples. **Abbreviations:** hh:mm, hour:minute; mg/L, milligram per liter; mm/dd/yyyy, month/day/year; N, nitrogen; μ g/L, microgram per liter; μ M/L, micromole per liter; +, plus]

Station	Date (mm/dd/yyyy)	Time (hh:mm)	Salinity region	Ammonium (μ M/L)	Ammonium as N (mg/L)	Nitrite + nitrate (μ M/L)	Nitrite + nitrate as N (mg/L)	Chlorophyll- α (μ g/L)
9	09/14/2010	14:00	>6	4.96	0.07	23.57	0.33	4.7
6	09/14/2010	15:09	>6	2.7	0.04	20.75	0.29	5.3
3	09/14/2010	16:11	1-6	1.89	0.03	17.21	0.24	5.1
649	09/14/2010	16:43	<1	4.07	0.06	16.61	0.23	3.6
657	09/14/2010	17:37	<1	9.93	0.14	10.95	0.15	2.4
15	10/26/2010	12:13	>6	5.64	0.08	24.01	0.34	4.8
13	10/26/2010	12:47	>6	5.75	0.08	24.56	0.34	4.3
9	10/26/2010	13:56	>6	7.63	0.11	25.52	0.36	1.5
6	10/26/2010	14:57	>6	8.05	0.11	25.49	0.36	2.6
3	10/26/2010	15:50	1-6	5.56	0.08	23.93	0.34	4.4a
649	10/26/2010	16:26	1-6	5.43	0.08	25.09	0.35	1.6
657	10/26/2010	17:15	<1	10.26	0.14	25.85	0.36	1.9
657	12/16/2010	05:32	<1	10.81	0.15	17.22	0.24	2.6a
649	12/16/2010	06:27	<1	11.22	0.16	20.20	0.28	1.4
3	12/16/2010	07:02	<1	9.9	0.14	22.46	0.31	1.2
5	12/16/2010	07:49	1-6	11.36	0.16	26.31	0.37	0.9
9	12/16/2010	09:29	>6	10.96	0.15	30.28	0.42	1.8
13	12/16/2010	10:46	>6	8.87	0.12	27.94	0.39	5.6
15	12/16/2010	11:22	>6	8.27	0.12	27.97	0.39	3.9
15	09/20/2011	11:48	>6	0.31	0.00	19.11	0.27	15.8
13	09/20/2011	12:25	>6	1.86	0.03	20.95	0.29	11.4
9	09/20/2011	13:39	>6	3.9	0.05	21.38	0.30	5.5
6	09/20/2011	15:06	1-6	2.12	0.03	19.29	0.27	10.3a
3	09/20/2011	16:10	<1	2.26	0.03	17.30	0.24	5.7
649	09/20/2011	16:45	<1	2.13	0.03	14.93	0.21	5.8a
657	09/20/2011	17:37	<1	8.71	0.12	10.26	0.14	2.6
15	10/18/2011	11:54	>6	1.79	0.03	14.43	0.20	9.0
13	10/18/2011	12:37	>6	4.35	0.06	16.81	0.24	5.8
9	10/18/2011	13:58	>6	6.5	0.09	19.50	0.27	2.8
6	10/18/2011	15:02	1-6	5.59	0.08	19.52	0.27	2.5
3	10/18/2011	16:00	<1	4.36	0.06	19.93	0.28	4.8
649	10/18/2011	16:32	<1	4.66	0.07	18.49	0.26	8.4
657	10/18/2011	17:22	<1	9.86	0.14	14.62	0.20	6.6
15	11/15/2011	12:03	>6	6.17	0.09	19.37	0.27	3.3
13	11/15/2011	12:42	>6	6.05	0.08	19.12	0.27	2.7
9	11/15/2011	13:54	>6	7.97	0.11	20.49	0.29	1.5
6	11/15/2011	14:54	>6	8.03	0.11	20.20	0.28	2.2
3	11/15/2011	15:50	1-6	5.7	0.08	19.77	0.28	1.5
649	11/15/2011	16:23	1-6	5.65	0.08	20.91	0.29	11.3
657	11/15/2011	17:14	<1	19.71	0.28	22.52	0.32	2.9
15	12/13/2011	10:27	>6	7.79	0.11	21.60	0.30	3.1
13	12/13/2011	10:56	>6	8.09	0.11	22.19	0.31	2.8
9	12/13/2011	11:50	>6	11.75	0.16	26.44	0.37	2.0
6	12/13/2011	12:41	>6	12.43	0.17	29.00	0.41	1.9
3	12/13/2011	13:27	1-6	12.53	0.18	29.32	0.41	1.3
649	12/13/2011	13:53	1-6	14.47	0.20	27.24	0.38	1.6
657	12/13/2011	14:41	<1	16.46	0.23	19.14	0.27	1.8

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Appendix 8. California Department of Fish and Wildlife Fish Sampling

In addition to the fall midwater-trawl survey (appendix 4), the California Department of Fish and Wildlife (CDFW) performs other surveys of the delta smelt population. The spring Kodiak trawl (SKT) samples mature and spawning adults. For convenience, we are providing here the general description of the SKT sampling available at <http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SKT>. The text has been edited from the original to be consistent with format and usage in this report. We also include a map (fig. 8-1) of the sampling sites. Values of the SKT delta smelt abundance index are given in table 8-1.

The spring Kodiak-trawl survey (SKT) has sampled annually since its inception in 2002. The SKT determines the relative abundance and distribution of spawning delta smelt (*Hypomesus transpacificus*). The SKT samples 40 stations each month from January to May. These 40 stations range in location from the Napa River upstream to Stockton on the San Joaquin River, Walnut Grove on the Sacramento River, and the Sacramento Deep Water Ship Channel. Each ‘Delta-wide’ survey takes approximately 4–5 days per month to complete.

Historically, ‘Delta-wide’ surveys were followed by a ‘Supplemental’ survey two weeks later to intensively sample areas of the highest delta smelt concentration to estimate the proportion of male and female delta smelt that were in pre-spawning, spawning, and spent maturation stages. Beginning in 2008, in an effort to minimize take of spawning adults, routine ‘Supplemental’ surveys were discontinued and are now only done under the recommendation of the Smelt Working Group and the approval of managers. ‘Delta-wide’ surveys are numbered consecutively, beginning with number 1, and ‘Supplemental’ surveys are numbered consecutively beginning with number 11.

The Kodiak-trawl net has mouth dimensions of 25-ft wide by 6-ft high when stretched taught. Net mesh sizes graduate in five sections from 2-inch stretch-mesh at the mouth to 0.25-inch stretch-mesh at the cod-end. A 10-minute surface tow is carried out at each station with two boats that spread the net mouth fully open. All fish, shrimp, and jellyfish collected in the tow are identified and enumerated. Delta smelt are further processed to identify gender and maturity. Water temperature, electrical conductivity (specific conductance), Secchi depth, and turbidity are collected at the beginning of each tow.

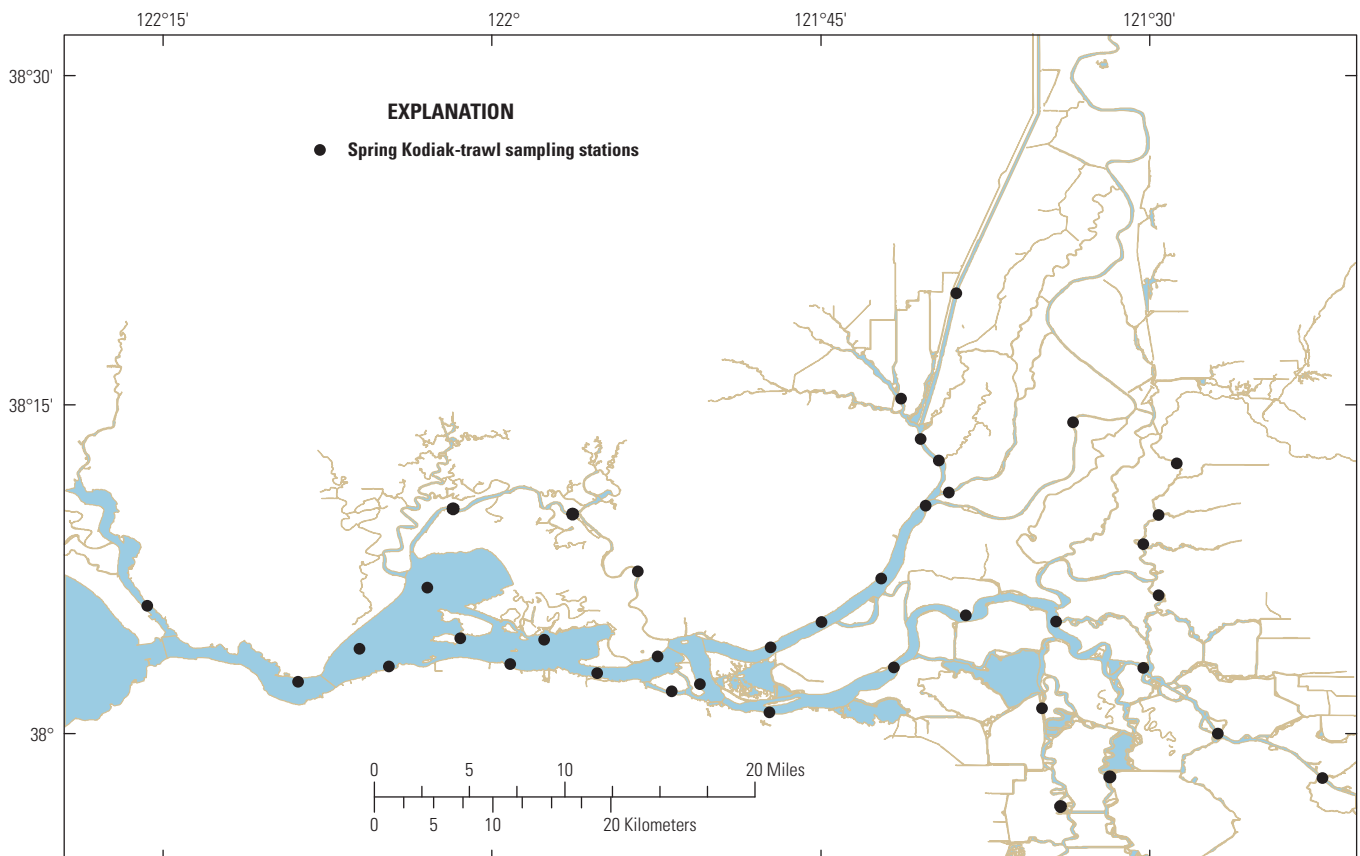


Figure 8-1. Sites sampled by the California Department of Fish and Wildlife spring Kodiak-trawl survey

Table 8-1. Annual values of delta smelt abundance indices for the fall midwater-trawl survey, spring Kodiak-trawl survey, 20-millimeter (mm) survey, and summer townet survey and values for selected ratios of abundance indices.[Abbreviations: FMT, fall midwater trawl; FMT_{previous year}, fall midwater trawl index from previous year; SKT, spring kodiak trawl; TNS, summer townet survey; —, none]

Year	FMT	SKT	20-mm	TNS	FMT/TNS	SKT/FMT _{previous year}	20-mm/SKT	TNS/SKT	TNS/FMT _{previous year}
1959	—	—	—	12.1	—	—	—	—	—
1960	—	—	—	25.4	—	—	—	—	—
1961	—	—	—	21.3	—	—	—	—	—
1962	—	—	—	24.9	—	—	—	—	—
1963	—	—	—	1.8	—	—	—	—	—
1964	—	—	—	24.6	—	—	—	—	—
1965	—	—	—	6	—	—	—	—	—
1966	—	—	—	—	—	—	—	—	—
1967	408	—	—	—	—	—	—	—	—
1968	696	—	—	—	—	—	—	—	—
1969	313	—	—	2.5	125.2000	—	—	—	0.0036
1970	1,673	—	—	32.5	51.4769	—	—	—	0.1038
1971	1,303	—	—	12.5	104.2400	—	—	—	0.0075
1972	1,265	—	—	11.1	113.9640	—	—	—	0.0085
1973	1,145	—	—	21.3	53.7559	—	—	—	0.0168
1974	—	—	—	13	—	—	—	—	0.0114
1975	697	—	—	12.2	57.1311	—	—	—	—
1976	359	—	—	50.6	7.0949	—	—	—	0.0726
1977	480	—	—	25.8	18.6047	—	—	—	0.0719
1978	572	—	—	62.5	9.1520	—	—	—	0.1302
1979	—	—	—	13.3	—	—	—	—	0.0233
1980	1,654	—	—	15.8	104.6835	—	—	—	—
1981	374	—	—	19.8	18.8889	—	—	—	0.0120
1982	333	—	—	10.7	31.1215	—	—	—	0.0286
1983	132	—	—	2.9	45.5172	—	—	—	0.0087
1984	182	—	—	1.2	151.6667	—	—	—	0.0091
1985	110	—	—	0.9	122.2222	—	—	—	0.0049
1986	212	—	—	7.9	26.8354	—	—	—	0.0718
1987	280	—	—	1.4	200.0000	—	—	—	0.0066
1988	174	—	—	1.2	145.0000	—	—	—	0.0043
1989	366	—	—	2.2	166.3636	—	—	—	0.0126
1990	364	—	—	2.2	165.4545	—	—	—	0.0060
1991	689	—	—	2	344.5000	—	—	—	0.0055
1992	156	—	—	2.6	60.0000	—	—	—	0.0038
1993	1,078	—	—	8.2	131.4634	—	—	—	0.0526
1994	102	—	—	13	7.8462	—	—	—	0.0121
1995	899	—	4.4	3.2	280.9375	—	—	—	0.0314
1996	127	—	33.9	11.1	11.4414	—	—	—	0.0123
1997	303	—	19.3	4	75.7500	—	—	—	0.0315
1998	420	—	7.7	3.3	127.2727	—	—	—	0.0109
1999	864	—	39.7	11.9	72.6050	—	—	—	0.0283
2000	756	—	23.8	8	94.5000	—	—	—	0.0093
2001	603	—	11.3	3.5	172.2857	—	—	—	0.0046
2002	139	—	8	4.7	29.5745	—	—	—	0.0078
2003	210	80.6	13.1	1.6	131.2500	0.5799	0.1625	0.0199	0.0115
2004	74	97.3	8.2	2.9	25.5172	0.4633	0.0843	0.0298	0.0138
2005	26	51.2	15.4	0.3	86.6667	0.6919	0.3008	0.0059	0.0041
2006	41	18.2	9.9	0.4	102.5000	0.7000	0.5440	0.0220	0.0154
2007	28	32.5	1	0.4	70.0000	0.7927	0.0308	0.0123	0.0098
2008	23	24.1	2.9	0.6	38.3333	0.8607	0.1203	0.0249	0.0214
2009	17	44.6	2.3	0.3	56.6667	1.9391	0.0516	0.0067	0.0130
2010	29	27.4	3.8	0.8	36.2500	1.6118	0.1387	0.0292	0.0471
2011	343	20	8	2.2	155.9091	0.6897	0.4000	0.1100	0.0759
2012	42	147.3	11.1	0.9	46.6667	0.4294	0.0754	0.0061	0.0026

The U.S. Fish and Wildlife Service's Biological Opinion for delta smelt has criteria pertaining to delta smelt protection based on SKT survey results. Those survey results, provided in near-real time, are used by state and federal resource managers to assess the risk of entrainment of delta smelt at the Central Valley and State Water projects.

The 20-millimeter (mm) survey samples post-larval delta smelt. For convenience we are providing here the general description of the 20-mm survey sampling available at: <http://www.dfg.ca.gov/delta/projects.asp?ProjectID=20mm>. We also include a map (fig. 8-2) of the sampling sites. The text has been edited from the original to be consistent with format and usage in this report. Values of the 20-mm delta smelt abundance index are provided in table 8-1.

This study monitors postlarval-juvenile delta smelt distribution and relative abundance throughout their historical spring range in the Sacramento-San Joaquin Delta and San Francisco estuary. Delta smelt in the central and south Delta areas can be entrained into the pumps of the State Water Project (SWP) and the Central Valley Project (CVP). This survey gets its name from the size (20-mm) at which delta smelt are retained and readily identifiable at the fish facilities associated with the state and federal pumps. The 2004 Biological Opinion requires this survey to provide "recent time" (within 72 hours) information on the distribution and relative abundance of delta smelt throughout the Delta and the upper

estuary. These data can be found under Delta Smelt Distribution and Delta Smelt Length Frequency. Based upon the data, recommendations are made to protect delta smelt.

Methods: There are eight to ten fortnightly sampling surveys that cover stations throughout the delta and downstream to the eastern portion of San Pablo Bay and Napa River. Samples are collected by using an egg and larval, rigid-opening net constructed of 1,600 micrometer (μm) mesh. Three 10-minute stepped-oblique (bottom to top) tows are completed at each station. Samples are preserved in neutral buffered formalin and then all fish larvae are sorted out and identified in a lab. The vast numbers of species (about 50) and amounts of detritus in the samples make this a labor-intensive process.

The summer townet survey (TNS) samples juvenile delta smelt. For convenience, we reprint here the general description of the summer townet survey, which is available at <http://www.dfg.ca.gov/delta/projects.asp?ProjectID=TOWNET>. The text has been edited from the original to be consistent with format and usage in this report. We also include a map (fig. 8-3) of the sampling sites. Values of the TNS delta smelt abundance index are provided in table 8-1.

The TNS was initiated in 1959 to determine the relative distribution and abundance of young of the year (age-0) striped bass (*Morone saxatilis*) in the Delta. To predict fishery recruitment, the survey calculates an index to measure age-0 striped bass year-class strength. This index is based

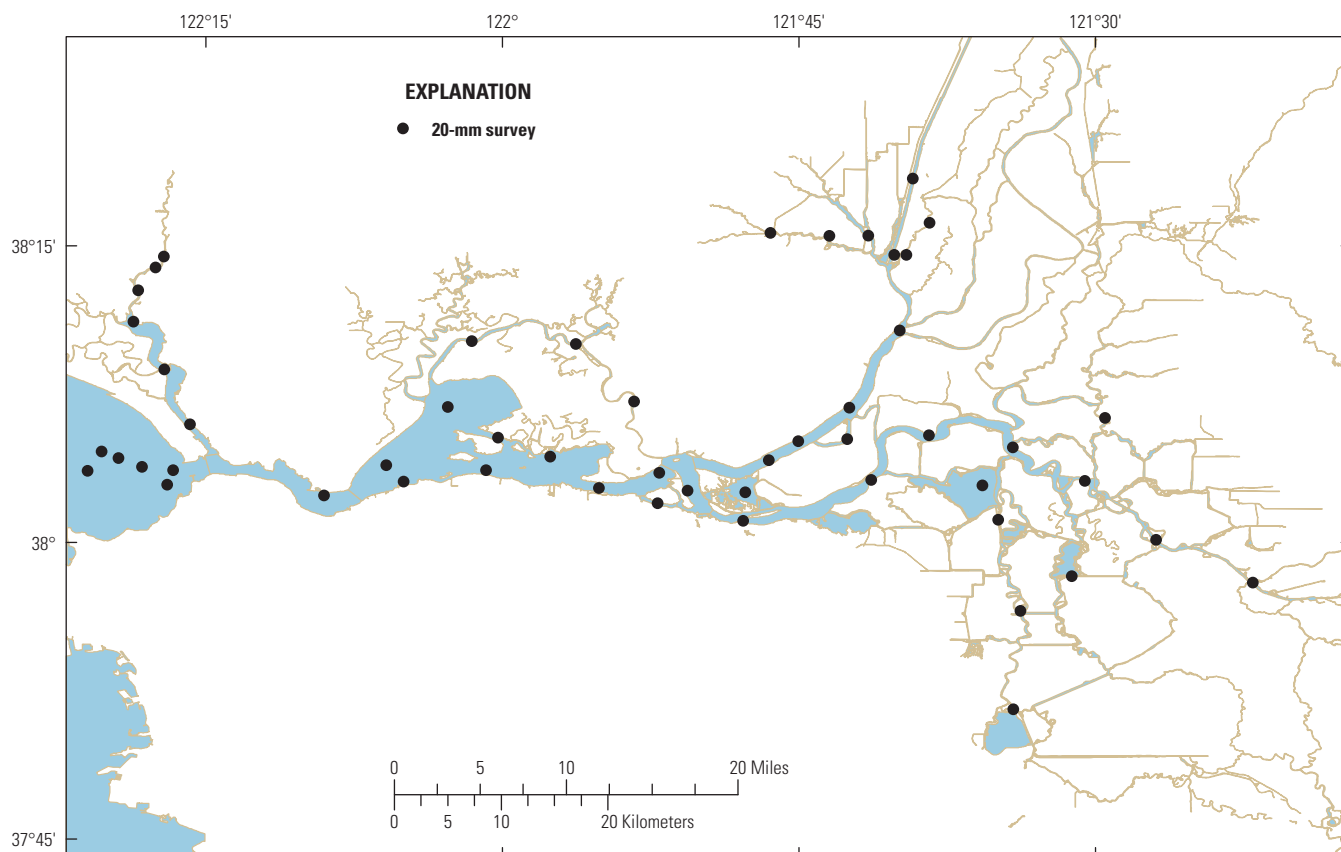


Figure 8-2. Sites sampled by the California Department of Fish and Wildlife 20-millimeter (mm) survey.

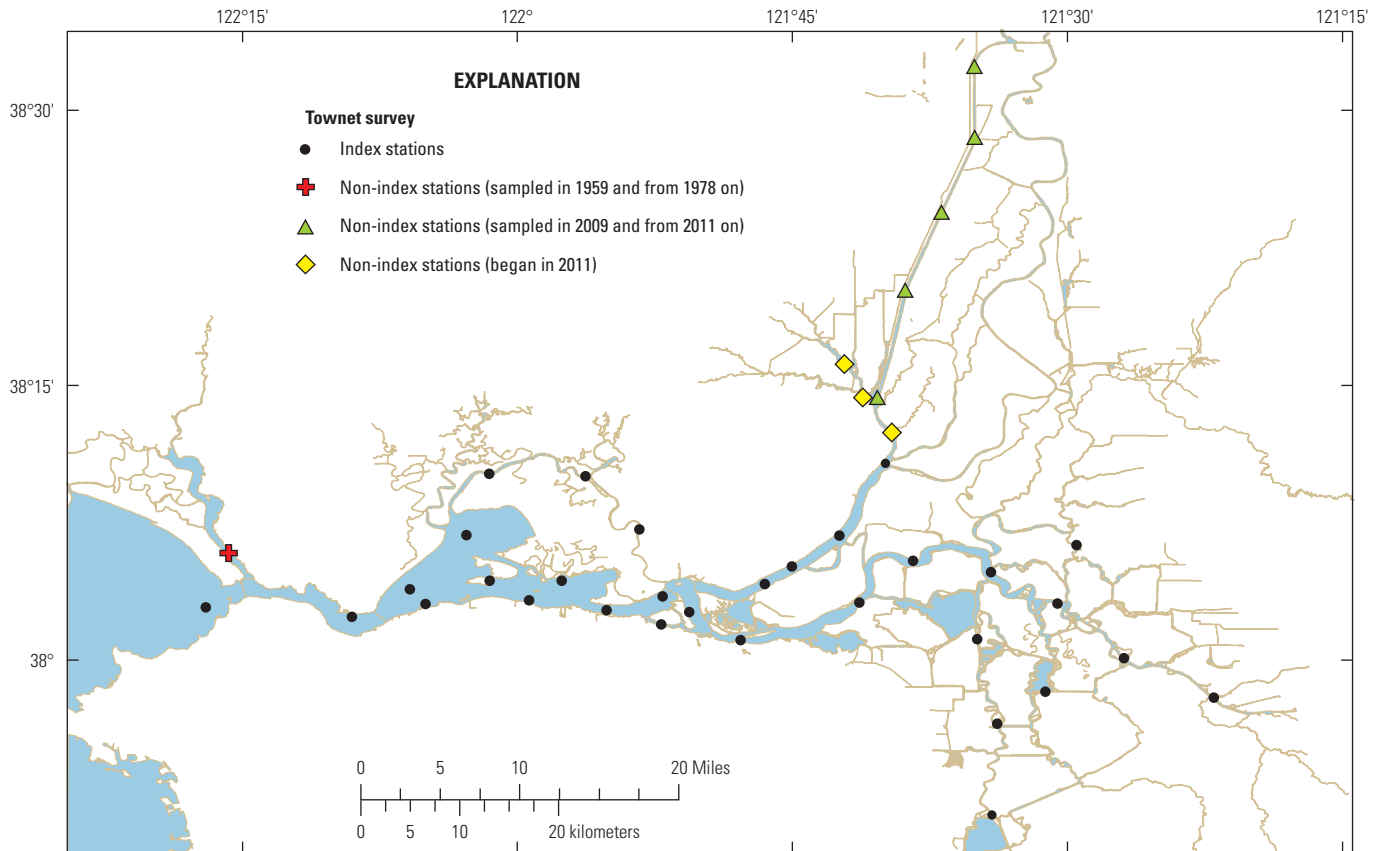


Figure 8-3. Sites sampled by the California Department of Fish and Wildlife summer townet survey.

on abundance when age-0 striped bass attain a mean length of 38.1 mm. In contrast, the delta smelt (*Hypomesus transpacificus*) index is the average of the first two survey indices. The delta smelt index was developed about 1990 in response to declining delta smelt abundance. It has proven valuable in gauging the health of the estuary; delta smelt abundance trend data were used as supporting evidence for their listing as threatened in 1992 under the Federal and State Endangered Species Acts.

TNS samples 32 historic stations, of which, 31 contribute to the indices, ranging from one in eastern San Pablo Bay to Rio Vista on the Sacramento River and to Stockton on the San Joaquin River. In 2011, to better describe delta smelt distribution, as well as that of other fishes, TNS added eight supplemental, non-index, stations in Cache Slough (three stations) and the Sacramento Deep Water Ship Channel (five stations). Historically, the TNS began sampling in mid to late June, when larva sampling near Antioch indicated young-of-the-year striped bass had achieved a mean size of 25 mm. Annually, two to five surveys were completed, depending on how quickly striped bass achieved a mean length of 38.1 mm. Beginning in 2003, CDFW standardized sampling to six surveys annually, starting in early June and continuing on alternate weeks through August.

The townet has two sections; the first is made of one-half inch stretch, knotted, nylon mesh, 6-foot (ft) long, tapering to an additional two ft “fyke.” This “fyke” fits entirely

within the second section, a 9-ft section of woven mesh with approximately eight holes per inch. The entire net measures approximately 15-ft, in total, and is lashed directly to a fixed metal “D” frame. The “D” frame is, in turn, mounted on a 22-pound sled. Since 2005, a modified Clarke-Bumpus net and housing have been attached to the top of the “D” frame to sample mesozooplankton prey availability during one of the fish tows at each station. Two 10-minute stepped oblique tows are performed at each station. At historic stations, a third tow is performed if any fish are captured during the first two tows. TNS enumerates all fishes and several invertebrate species. Fork length is measured to the nearest millimeter for all striped bass, all delta smelt, and the first 50 fish per tow for all other species.

TNS is mandated by the Delta Smelt Biological Opinion. Historically, TNS began in response to the development of Central Valley Project pumping plants exporting water from the south Delta. These exports created a need for information regarding distribution of young striped bass relative to the south Delta diversions. Alongside the collection of other data, TNS continues to monitor striped bass and delta smelt distribution in relation to water diversions for the coordinated operation of the Central Valley Project and the State Water Project.

In addition to the delta smelt abundance indices, we utilized several ratios of these values as indicators of survival and recruitment. These ratios are included in table 8-1.

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