State of California
The Resources Agency
Department of Water Resources
Division of Environmental Services

Water Quality Conditions in the Sacramento-San Joaquin Delta During 1997-2000

Report to the State Water Resources Control Board in Accordance with Water Right Decision 1641.

May 2004

Arnold Schwarzenegger Governor State of California	Mike Chrisman Secretary for Resources The Resources Agency	Lester A. Snow Director Department of Water Resources

Foreword

The California State Water Project (SWP) and the federal Central Valley Project (CVP) are multipurpose projects which supply water, provide flood control, generate power, and provide recreation opportunities. Water quality needs and environmental impacts are important considerations for operators of both projects.

As a condition for operating the SWP and the CVP, the State Water Resources Control Board (SWRCB) has issued a series of water right decisions to the Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR). These decisions establish water quality objectives and responsibilities for monitoring to protect the beneficial uses of water supplies in the Sacramento-San Joaquin Delta (Delta) and Suisun Marsh. Past decisions have included Water Right Decision 1379 (D-1379) of July 1971 and Water Right Decision 1485 (D-1485) of August 1978. Water Right Decision 1641 (D-1641) superceded D-1485 in December 1999.

Staff from DWR, USBR, US Geological Survey, and Department of Fish and Game monitored water quality from 1997 through 2000 to ensure and document compliance with the standards contained in D-1485 and D-1641. The monitoring program and its associated special studies also provided SWP and CVP operators with information to determine (1) changes in aquatic biota and water quality potentially related to SWP and CVP operations; (2) the effectiveness of project operation decisions in preserving the water quality of the Delta and Suisun Marsh; and (3) alternative operating criteria to better protect the waters of the Delta and Suisun Marsh.

In accordance with requirements of past water right decisions, DWR has prepared summary reports of monitoring results and submitted them to the SWRCB. This report is submitted to satisfy the reporting requirement for calendar years 1997 through 2000. Calendar years 1997 through 1999 are being reported pursuant to the mandate of D-1485, and calendar year 2000 is being reported pursuant to the mandate of D-1641. Finally, the compliance monitoring database is available electronically to serve as a source of additional information for agencies, organizations, and individuals involved in the study of the Bay-Delta system.

Barbara McDonnell, Chief
Division of Environmental Services

Executive Summary

This report summarizes the results of water quality monitoring and special studies conducted by the Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR) within the Sacramento-San Joaquin Delta and Suisun and San Pablo bays (the upper San Francisco Estuary) from 1997 to 2000. This monitoring is mandated by Water Right Decision 1641(D-1641) of December 1999, and its predecessor, Water Right Decision 1485 (D-1485) of August 1978. This report is submitted to fulfill the reporting requirements of these decisions.

Water years 1997 through 2000[1] represent a continuation of an extended period of relatively high precipitation that began in northern California in the fall of 1994. Water Years 1997, 1998, and 1999 were classified as “Wet”, and Water Year 2000 was classified as “Above Normal” using the Sacramento Valley 40-30-30 Water Year Hydrological Classification Index. Precipitation, runoff, reservoir storage, and snow pack water content were all “above normal” for these four water years.

DWR and USBR monitored water quality using a protocol implemented in 1996. Under this protocol, eleven sampling sites representing eight regions of the upper San Francisco Estuary were monitored for selected physical and chemical water quality parameters. The results for water temperature, Secchi disk depth, dissolved oxygen (DO), specific conductance, dissolved inorganic nitrogen, orthophosphate, and volatile suspended solids were within their historical range, demonstrated seasonal and inter-annual variation, and provided no major discernable long-term trends.

Special studies of algal blooms within in the upper Estuary were conducted in response to the initial findings of mandated monitoring. These studies were needed to: (1) identify the organisms present in these blooms; (2) document the extent and intensity of the blooms; and (3) provide information to operators of the State Water Project (SWP) and the federal Central Valley Project (CVP). SWP and CVP operations may be modified when bloom algae are known to clog filters and produce water taste and odor problems for water users.

Sixteen algal blooms were detected and monitored during the study period, with the organisms identified as belonging to the following genera: *Microcystis, Cryptomonas, Skeletonema,* and *Aulacoseria*. Bloom activity occurred primarily in the spring and fall within the central and southern Delta.

DWR also conducted a series of special studies to monitor DO levels within the Stockton Ship Channel (Channel) during the late summer and early the fall of calendar years 1997 through 2000. The studies were conducted to determine if DO levels dropped below State Water Resources Control Board’s (5.0 mg/L) and Regional Central Valley Water Quality Control Board’s (6.0 mg/L) water quality objectives established for the Channel. Monitoring was typically conducted biweekly from August through November from Prisoner’s Point in the central Delta to the Stockton Turning Basin at the eastern terminus of the Channel. DO levels within the western Channel typically exceeded 7.0 mg/L throughout the study period, while levels within the central Channel dropped to, and occasionally below, 5.0 mg/L. In the eastern Channel immediately west of Rough and Ready Island, DO levels consistently dropped below 5.0 mg/L. By November of each year DO levels throughout the Channel typically improved to 6.0 mg/L or greater due to improved San Joaquin River inflows, cooler water temperatures, and other factors.

To monitor productivity throughout the upper San Francisco Estuary, chlorophyll samples were collected to measure levels of chlorophyll *a* at 11 representative stations. Phytoplankton samples were also collected for identification and enumeration. Chlorophyll *a* concentrations for 1997-2000

[1] Although this report covers calendar years 1997 through 2000, hydrologic conditions within the upper San Francisco Estuary are characterized using water years. A water year begins on October 1 of one calendar year and ends on September 30 of the following calendar year. A water year is numbered using the calendar year in which it ends. For example, water year 1997 began on October 1, 1996, and ended on September 30, 1997.

were below 10 µg/L for most regions. Concentrations commonly ranged between 0.5 µg/L and 15 µg/L throughout the estuary. Diatoms comprised the spring chlorophyll *a* maximum and flagellates comprised the summer maximum in the north Delta, lower Sacramento River, lower San Joaquin River, central Delta, south Delta, and east Delta. In Suisun Bay most of the chlorophyll *a* was due to flagellates, the crytophyte *Cryptomonas ovatas*, and diatoms, *Skeletonema sp.* and *Aulacosira granulate*. In San Pablo Bay, flagellates and various diatoms were dominant.

Benthic monitoring was conducted at 10 representative stations throughout the upper San Francisco Estuary to document substrate composition and the distribution, diversity and abundance of benthic organisms. The benthic community was determined to be a diverse assemblage of worms, crustaceans, insects, and molluscs. The nine phyla represented include: Cnidaria (hydras, sea anemones), Platyhelminthes (flatworms), Nemertea (ribbon worms), Nematoda (roundworms), Annelida (segmented worms), Arthropoda (aquatic insects, amphipods, isopods, shrimp, crabs, mites, etc.), Mollusca (clams, snails), Chordata (tunicates), and Echinodermata (sea stars). Of the nine phyla identified, Annelida, Arthropoda, and Mollusca constituted 99.4% of the organisms collected.

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Chapter 1. Introduction

The State Water Resources Control Board (SWRCB) establishes water quality objectives and monitoring plans to protect a variety of the beneficial uses of water within the upper San Francisco Estuary (SFE). The SWRCB has allocated responsibilities to meet or help meet most of these objectives through a series of water right decisions issued to the Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) as a condition for operating the State Water Project (SWP) and Central Valley Project (CVP), respectively. These decisions require the two water projects to maintain minimum outflows, limit water diversions, and maintain salinity levels below designated levels at specific locations in the Delta. These decisions also mandate that DWR and USBR conduct a comprehensive monitoring program to determine compliance with terms of the decisions, and report the findings to the SWRCB. Water quality objectives in place since August 1978 were issued by Water Right Decision 1485 (D-1485) (SWRCB 1978). These objectives were revised by Water Right Decision 1641 (D-1641) (SWRCB 1999), which was adopted by the SWRCB in December 1999.

Monitoring data collected since the inception of the Environmental Monitoring Program (EMP) has been stored and managed in a variety of data management systems. Data for water quality and the density and composition of phytoplankton and benthic communities at sites throughout the upper San Francisco Estuary were originally uploaded, stored, and made available to users using the STORET data management system managed by the U.S. Environmental Protection Agency. Data from 1975 to 2001 are currently available at the Interagency Ecological Program (IEP) website at www.iep.water.ca.gov/. EMP water quality data can be found on the IEP website in a stand-alone format through files from the IEP relational database. The IEP relational database file provides data collected by a variety of public sector agencies in a combined format. Additional information concerning the availability of compliance monitoring data can be obtained by contacting DWR directly[1].

This report, titled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays from 1997 Through 2000*, summarizes the findings of the EMP from calendar year 1997 through calendar year 2000, and is submitted to the SWRCB to fulfill the reporting requirements of D-1485 and D-1641. The water quality, benthic, phytoplankton, zooplankton, and special study components of the EMP are discussed in separate chapters. The major patterns and trends demonstrated by the water quality and biological data within and between years are displayed in summary plots and tables and briefly described in the supporting text of each chapter.

Because the hydrology of the upper San Francisco Estuary is strongly influenced by seasonal precipitation and inflows, changes in hydrologic conditions have historically been described using water years. A water year extends from October 1 of one calendar year through September 30 of the following calendar year. A water year is numbered using the calendar year in which the water year ends. For example, the period from October 1, 1999 through September 30, 2000, is identified as water year 2000.

In this report, water years are used to describe conditions within the upper San Francisco Estuary when appropriate. The 1997 through 2000 calendar year reporting period covers most (January through September) of water year 1997; all of water years 1998,1999, and 2000; and the first quarter (October through December) of water year 2001. Figure 1-1 shows a map of all of the Bay-Delta Section monitoring sites.

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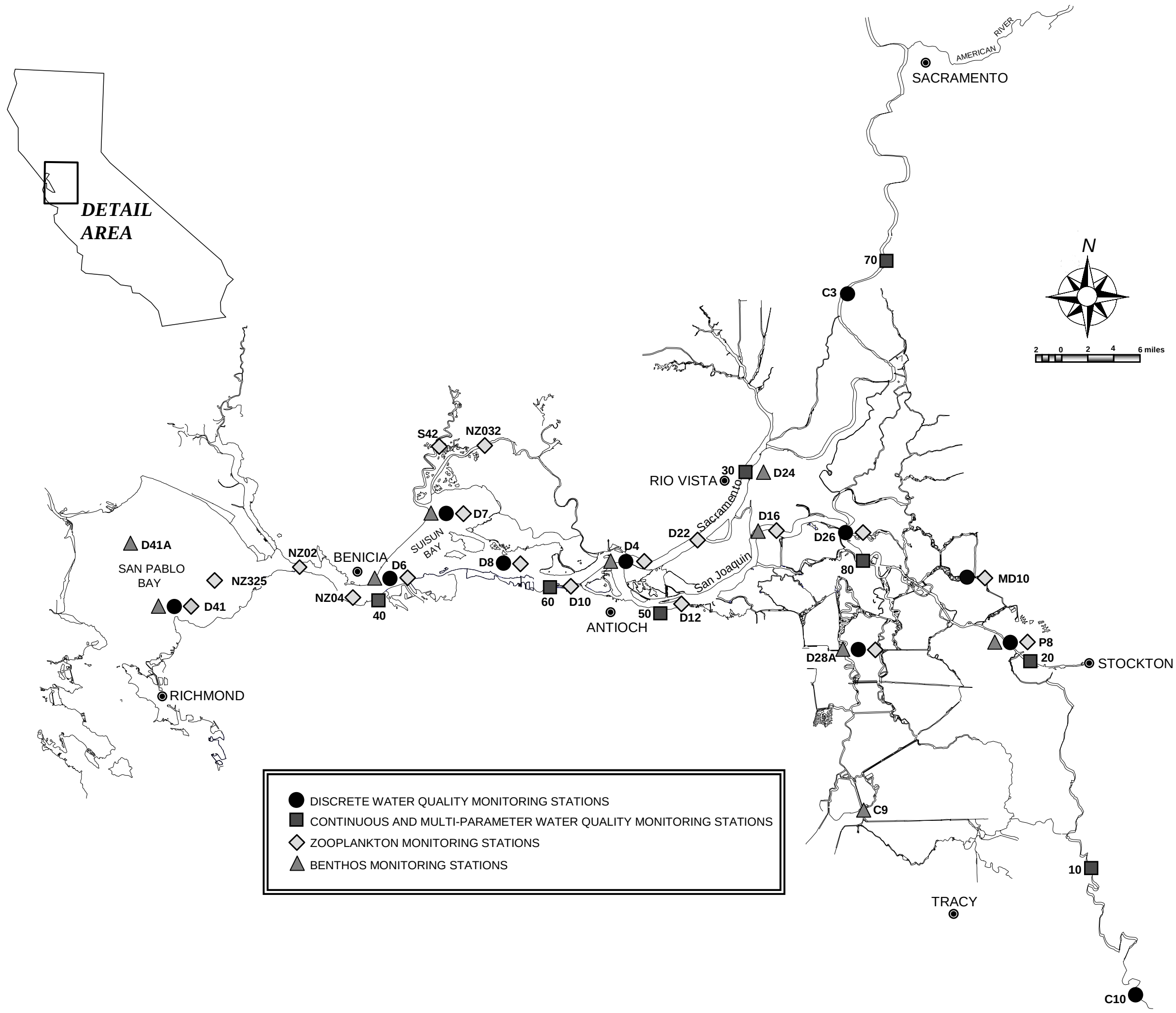


Figure 1-1 Map of all Bay-Delta Section monitoring sites

Chapter 2. Hydrologic Conditions

The January 1997 through December 2000 period covered by this report includes the last nine months (January through September) of water year 1997; all of water years 1998, 1999, and 2000; and the first three months (October through December) of water year 2001. Because hydrologic conditions are typically discussed using water years, this chapter will discuss water years 1997 through 2000 (October 1997 through September 2000) unless otherwise noted.

Water years are classified using the Sacramento Valley 40-30-30 Water Year Hydrological Classification Index[1,2] (the Sacramento Valley Index) and the San Joaquin Valley 60-20-20 Water Year Hydrological Classification Index[3, 4] (the San Joaquin Valley Index) (SWRCB 1999). The Sacramento Valley Index is used to characterize water years statewide because the predominance of precipitation falls within the northern half of the state and much of that precipitation flows down the Sacramento River through the upper San Francisco Estuary. The index is also used because the Sacramento River watershed provides the majority of water to the State Water Project and to the Central Valley Project (SWRCB 1999). Using this index[5], water years 1997 through 1999 were classified as wet and water year 2000 was classified as above normal. Although the San Joaquin Valley Index is used predominantly for regional applications, it provides supporting information concerning water conditions within the San Joaquin Valley. Using the San Joaquin Valley Index[6], water years 1997 and 1998 were classified as wet and water years 1999 and 2000 were classified as above normal. Figure 2-1 summarizes these findings.

Precipitation, runoff, reservoir storage, and snowpack water content were all above normal for all four water years. Statewide figures for May 1 are summarized in Table 2-1.

Due to the above-normal precipitation, runoff, reservoir storage and snowpack water content, unimpaired runoff for all water years was high (CDEC 2002). Table 2-2 summarizes these conditions and Figure 2-2 demonstrates this relatively high-flow period compared with the low-flow period of 1987-1994.

[1] The Sacramento Valley 40-30-30 Water Year Hydrological Classification Index is equal to 0.4 x current April to July unimpaired runoff + 0.3 x current October to March unimpaired runoff + 0.3 x previous year's index (if the previous year's index exceeds 10.0, then 10.0 is used).

[2] Sacramento River unimpaired runoff is the sum of Sacramento River flow at Bend bridge, Feather River flow to Lake Oroville, Yuba River flow at Smartville, and American River flow to Folsom Lake (SWRCB, 1999).

[3] The San Joaquin Valley 60-20-20 Water Year Hydrological Classification Index is equal to 0.6 x current April to July unimpaired runoff +0.2 x current October to March unimpaired runoff + 0.2 x previous year's index (if the previous year's index exceeds 4.5, then 4.5 is used).

[4] San Joaquin River unimpaired runoff is the sum of Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

[5] Using the Sacramento Valley Index, water years are defined as follows: (1) a "Wet" year occurs when the Index is equal to or greater than 9.2; (2) an "Above Normal" year occurs when the Index greater than 7.8 but less than 9.2; (3) a "Below Normal" year occurs when the Index is greater than 6.5 but equal to or less than 7.8; (4) a "Dry" year occurs when the Index is greater than 5.4 but equal to or less than 6.5; and, (5) a "Critical" year occurs when the Index is equal to or less than 5.0 (SWRCB, 1999)

[6] Using the San Joaquin Valley Index, water years are defined as follows: (1) a "Wet" year occurs when the Index is equal to or greater than 3.8; (2) an "Above Normal" year occurs when the Index greater than 3.1 but less than 3.8; (3) a "Below Normal" year occurs when the Index is greater than 2.5 but equal to or less than 3.1; (4) a "Dry" year occurs when the Index is greater than 2.1 but equal to or less than 2.5; and, (5) a "Critical" year occurs when the Index is equal to or less than 2.1 (SWRCB, 1999)

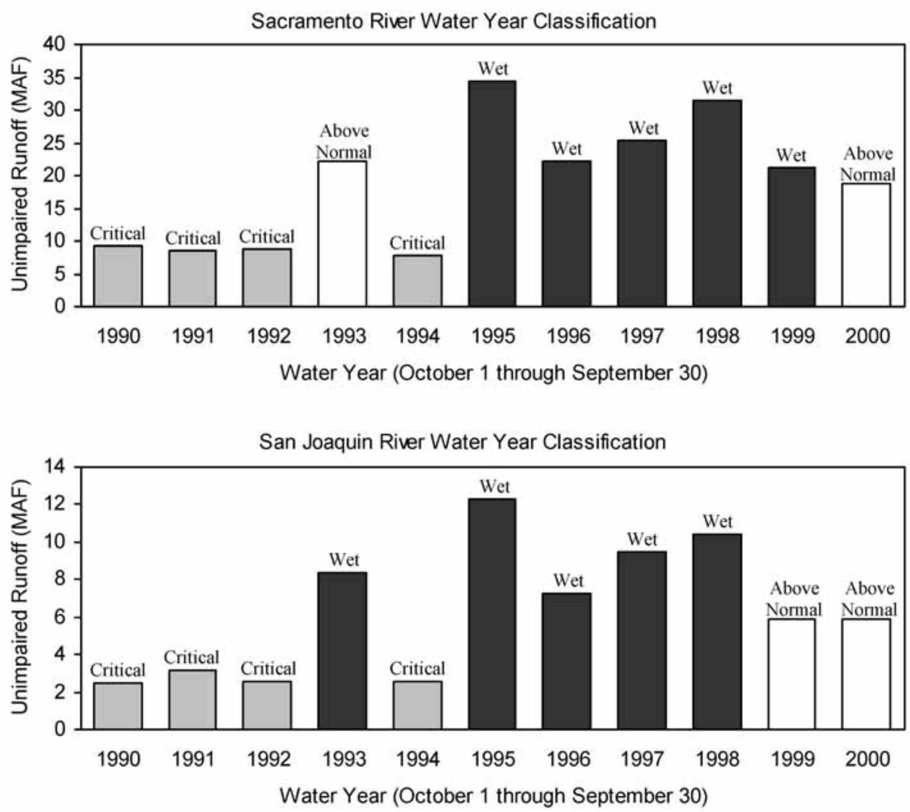


Figure 2-1 Sacramento River Hydrologic Region 40-30-30 and the San Joaquin River Hydrologic Region 60-20-20 Indices from 1990 through 2000.

Table 2-1 Summary of the major hydrologic characteristics of water years 1997 through 2000

Water Year	Precipitation (% of normal)	Seasonal Runoff (% of normal)	Reservoir Storage (% of normal)	Snow Water Content (% of normal)
1997	120	175	110	55
1998	160	155	115	190
1999	100	115	115	120
2000	95	100	115	75

Table 2-2 Average runoff for water years 1997, 1998, 1999, and 2000.

Sacramento River			
	Oct 1st-	Apr 1st-	Whole
Year	Mar 30th (MAF)	Jul 30th (MAF)	Year (MAF)
1997	20.23	4.39	25.42
1998	17.65	12.54	31.39
1999	12.97	7.26	21.19
2000	12.01	5.99	18.88

San Joaquin River			
	Oct 1st-	Apr 1st-	Whole
Year	Mar 30th (MAF)	Jul 30th (MAF)	Year (MAF)
1997	5.75	3.59	9.51
1998	2.83	7.11	10.43
1999	1.9	3.85	5.91
2000	1.98	3.78	5.9

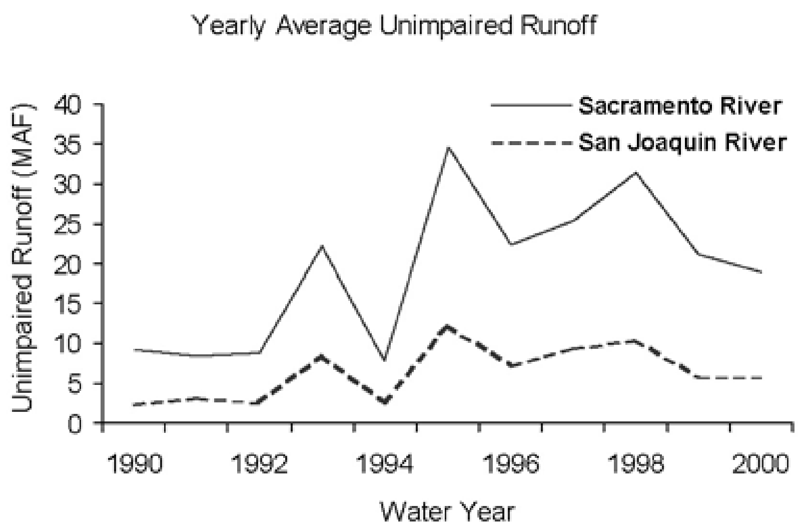


Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin Rivers for water years 1990 through 2000.

Water year 1998 had the highest unimpaired runoff of the study period, with a value exceeding 31 million-acre feet in the Sacramento Valley River Basin and 10 million-acre feet in the San Joaquin Valley River Basin.

The Net Delta Outflow Index[7] (Figure 2-3) is used to determine the freshwater outflow from the estuary. Much of the water that flows through the estuary does so during the late winter and early spring months. Water year 1997 had the widest range of flows during the study period, with maximum Delta outflow indices exceeding 17 million acre-feet in January and minimum outflow indices approaching 200,000 acre-feet in September.

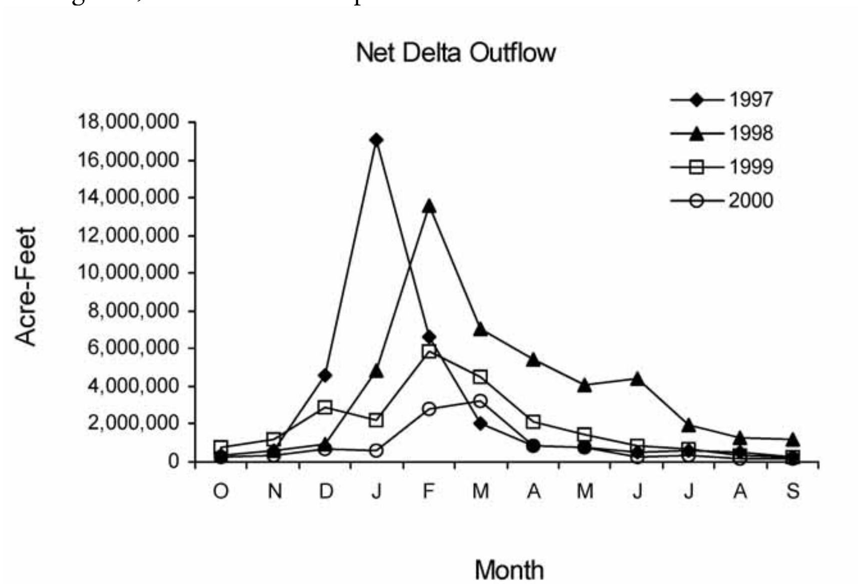


Figure 2-3 Net Delta Outflow Indices 1997 through 2000.

[7] The Net Delta Outflow Index is a calculation of freshwater outflow from the Delta past Chipps Island. The NDOI includes a factor dependent upon inflows of the Yolo Bypass System, the eastside stream system (the Mokelumne, Consumnes, and Caleveras Rivers), the San Joaquin River at Vernalis, the Sacramento Regional Treatment Plant, and miscellaneous Delta inflows (Bear Creek, Dry Creek, Stockton Diverting Canal, French Camp Slough, Marsh Creek, and Morrison Creek).

Chapter 3. Water Quality Monitoring

Water quality monitoring from 1997 through 2000 continued according to the amended protocol implemented in 1996 (Lehman and others 2001). Discrete samples were taken monthly at 11 representative sites (Figure 3-1). Data were recorded within one hour of high slack tide and the time of each sample was recorded to the nearest five minutes of Pacific Standard Time. A qualitative description of weather conditions was recorded for each cruise. Samples were analyzed for the 14 physical and chemical parameters shown in Table 3-1. This chapter presents the results for seven water quality parameters. The complete database is available online at http://www.bdat/index.html

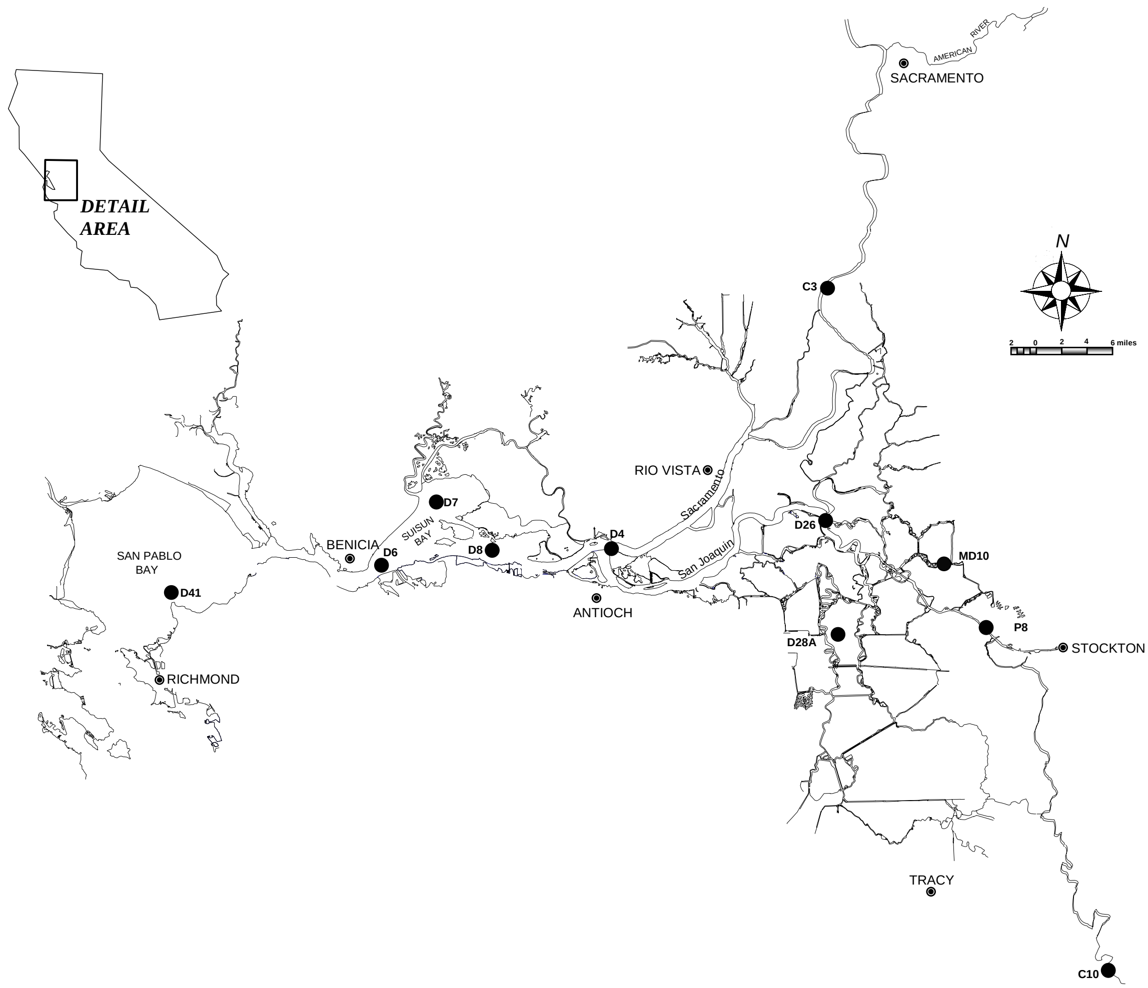


Figure 3-1 Map of sampling sites

Table 3-1 Water quality parameters measured

Water temperature (°C)
Secchi disk depth (m)
Dissolved oxygen (mg/L)
Specific conductance (µS/cm)
Dissolved inorganic nitrogen (mg/L)
Volatile suspended solids (mg/L)
Orthophosphate (mg/L)
Silica (mg/L)
Total dissolved solids (mg/L)
Total suspended solids (mg/L)
Chloride (mg/L)
Kjelahl nitrogen (mg/L)
Total phosphorus (mg/L)
Dissolved organic nitrogen (mg/L)

As shown in Table 3-2, 11 sampling sites are used in this study to represent eight regions of the Bay-Delta system. The results from a single sampling site are used to represent water quality conditions in six of these eight regions. The south Delta and Suisun Bay regions, however, are represented by averaged values of two and three stations, respectively.[1]

Table 3-2 Sampling sites and regions

Region	Sampling Sites
Lower Sacramento River	D4
Lower San Joaquin River	D26
North Delta	C3
Central Delta	D28a
East Delta	MD10
South Delta	C10 & P8
Suisun Bay	D6, D7, & D8
San Pablo Bay	D41

[1] An exception to this protocol exists for Secchi disk depth measurements for the south Delta region. Secchi disk depth measurements for this region are represented by a single sampling at Site P8, as no Secchi disk depth measurements are made at sampling Site C10.

Parameters Measured

Water Temperature

Water temperature was measured in degrees Centigrade (°C) with a YSI thermistor. The thermistor measured the temperature of water collected by pump at a depth of 1 meter.

Recorded temperatures varied seasonally, being significantly lower in winter than in the summer. A temperature minima of 7.1 °C was recorded in the lower San Joaquin River region during January 1999, and a maxima of 26.9 °C was recorded in the central Delta region in July 1998. All regions showed a similar seasonal pattern, with temperature minima occurring in approximately January of each year. Temperature maxima were recorded from July to September. Lowest annual mean temperatures occurred in the Suisun and San Pablo Bay regions (Figure 3-2).

Secchi Disk Depth

Water transparency was measured to the nearest centimeter using a 20-cm diameter Secchi disk attached to a 2.5-m rod marked in cm. Water transparency was recorded as the average of (1) the depth at which the disk could no longer be seen as it was lowered into the water column from the shaded side of the vessel, and (2) the depth at which it was seen as it was raised.

Secchi disk depth ranged from a low of 0.15 m in the lower Sacramento River in February 1998, to a high of 1.88 m in San Pablo Bay in May 1997. Secchi disk depth varied seasonally and inter-annually. Both the lowest seasonal and inter-annual variations were observed in Suisun Bay and the lower Sacramento River regions. These regions also had the lowest mean annual Secchi disk depths. Both the highest annual and inter-annual variations were observed in San Pablo Bay and the north Delta regions. The long-term increase in transparency data noted in previous reports (Lehman 1996) was not discernable in the 1997-2000 data (Figure 3-3).

Dissolved Oxygen

Dissolved oxygen (DO) was measured using the modified Winkler iodometric method described in Standard Methods (APHA 1998). A sample aliquot was collected from a through-hull pump or from a grab sample, at a depth of 1 meter. The samples were collected in 300-ml glass-stoppered bottles and immediately analyzed onboard.

During the period of study, DO concentrations ranged from a minimum of 4.6 mg/L in the south Delta in July 1997, to a maximum of 11.4 mg/L in the lower Sacramento River in January 1999. Strong seasonal trends were evident in all regions, with DO concentrations decreasing during the summer months and rising in the winter months. DO levels between years generally were within a range of about 2 mg/L in most regions, and followed consistent seasonal patterns. The most variable measured DO concentrations were found in the south Delta region. (Figure 3-4).

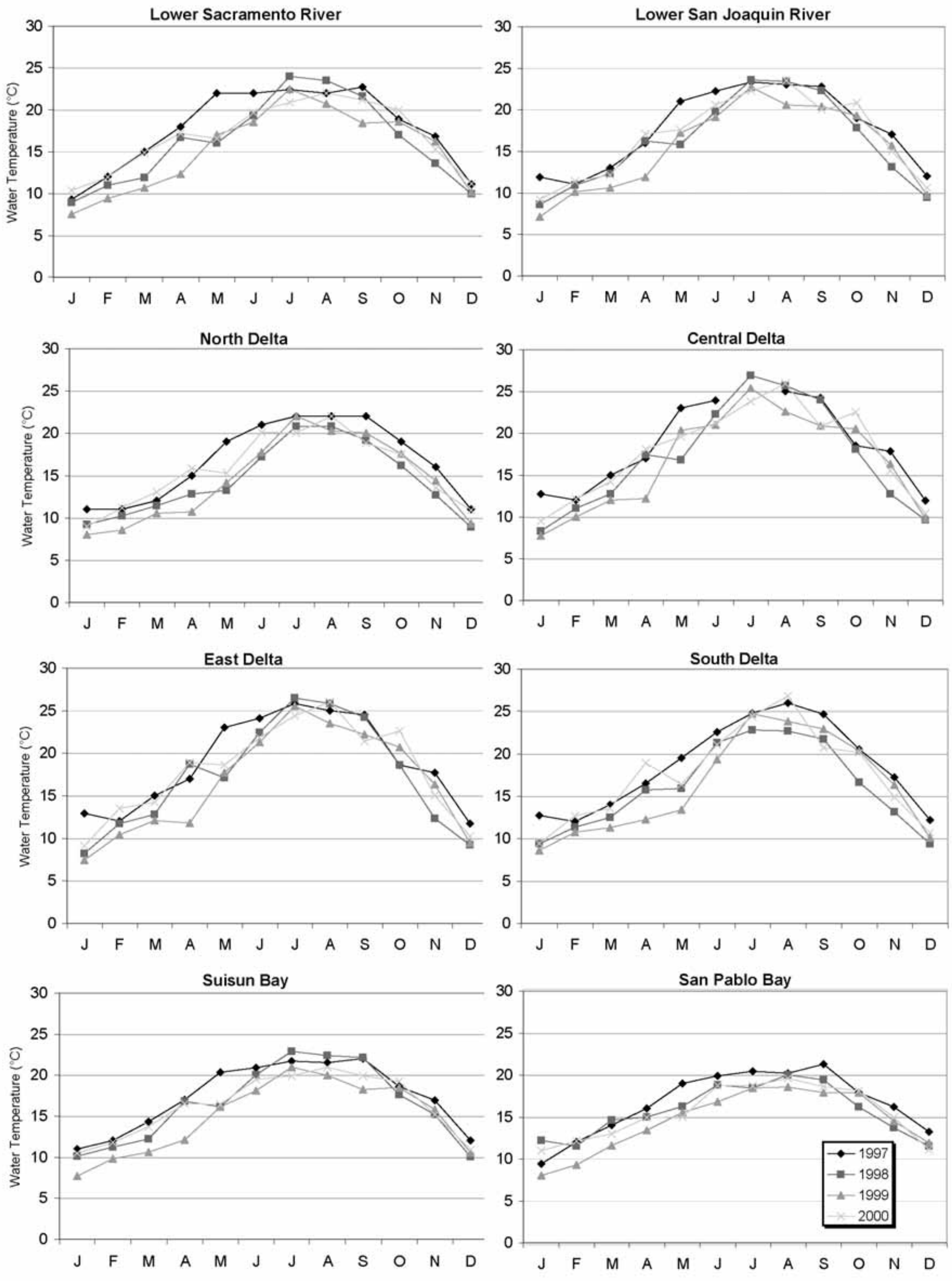


Figure 3-2 Monthly water temperatures (°C) at eight upper San Francisco Estuary regions, 1997-2000

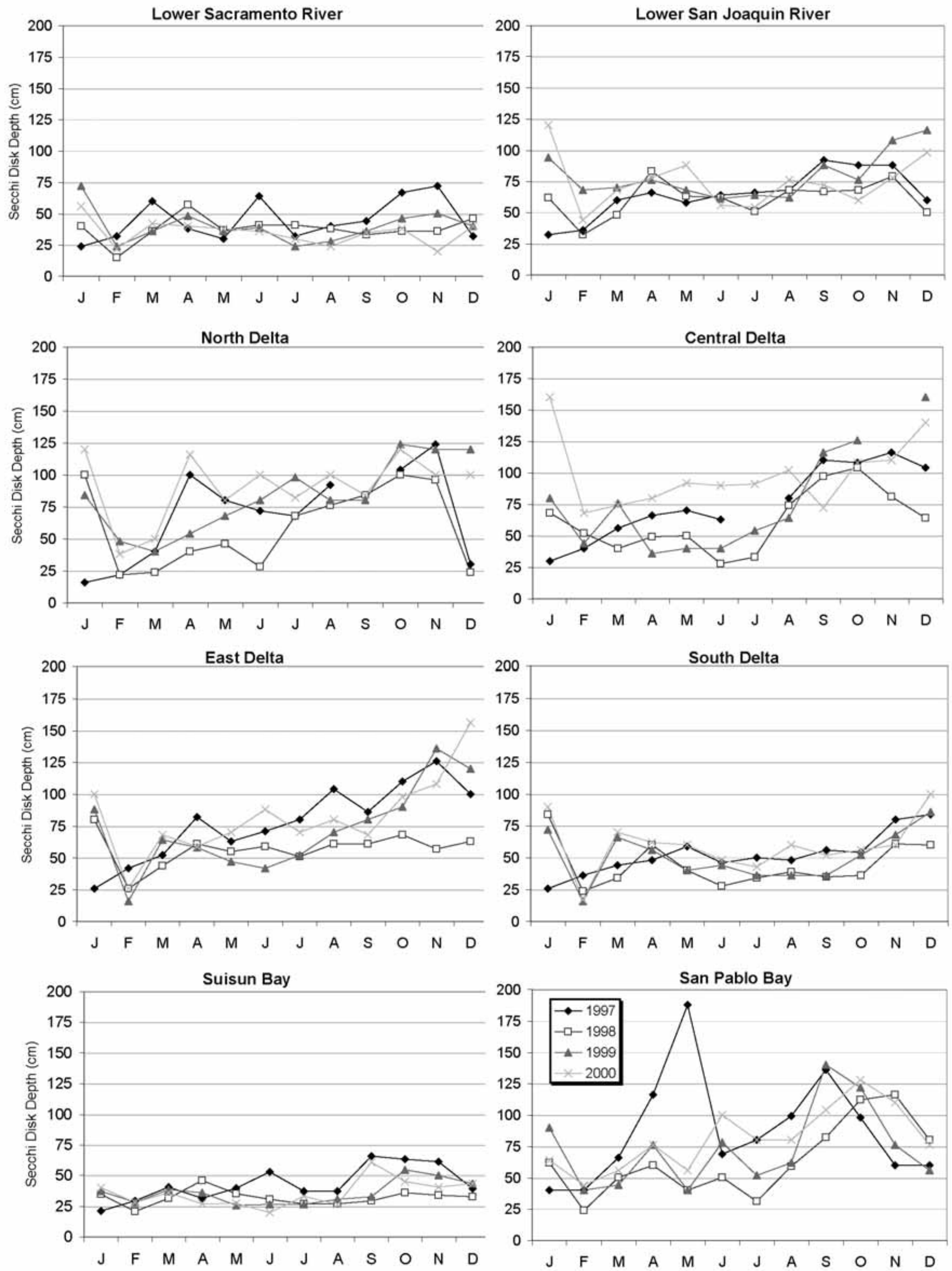


Figure 3-3 Monthly Secchi disk depths (cm) at eight upper San Francisco Estuary regions, 1997-2000

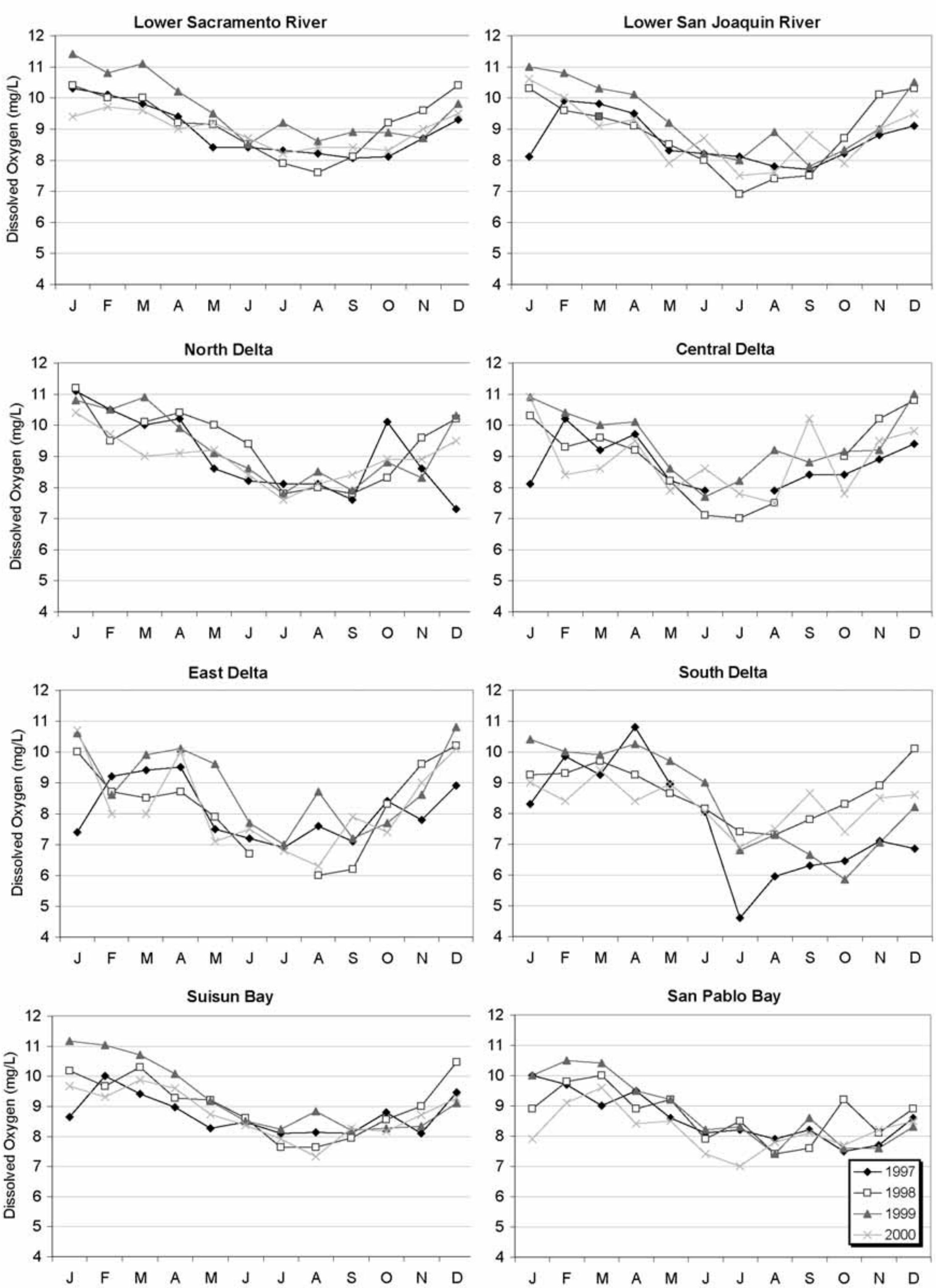


Figure 3-4 Monthly DO levels (mg/L) at eight upper San Francisco Estuary regions, 1997-2000

Specific Conductance

Specific conductance, an indicator of salinity, was determined from samples collected from a through-hull pump at a 1-meter depth. The samples were analyzed for specific conductance using a Beckman RC-20 conductivity bridge equipped with manual temperature compensation. Measured values were temperature compensated to 25 °C.

Specific conductance in the upper San Francisco Estuary ranged from a low of 68 µS/cm in the north Delta in January 1997 to a high of 44,349 µS/cm in San Pablo Bay in November 1999. Specific conductance generally increased from east to west and was affected by inflows and tidal action. Maximum values occurred in the late summer and fall when flows through the Delta were low and marine intrusion was greatest. Relatively high inflows throughout the study period resulted in little seasonal variation in the north and east Delta regions and in the lower San Joaquin River region. Overall, specific conductance showed similar patterns for all years of the study period. (Figure 3-5).

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is a measure of total ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2), the nitrogen forms immediately available for assimilation by phytoplankton. DIN was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed 0.45-micron pore size membrane filter. The filtrate was immediately frozen and later transported to Bryte Laboratory[2] for analysis. The minimum reporting limit[3] for nitrogen was 0.01 mg/L. The methods of analysis used for measuring DIN are listed in Table 3-3.

DIN concentrations ranged from 0.08 mg/L in the east Delta region in August 1997, to 5.2 mg/L in the south Delta region in December 1999. In several regions, particularly the east Delta, concentrations were highest during winter and spring, the period when seasonal runoff is greatest. Concentrations in most regions generally were lowest in August and September, when water temperatures and phytoplankton growth were highest and inflows were lowest. Concentrations in the south Delta showed the greatest degree of variability both seasonally and inter-annually. By contrast, DIN concentrations in the San Pablo and Suisun Bay regions varied little on a seasonal or inter-annual basis (Figure 3-6).

Table 3-3 Nutrient analysis methods

Substance	Method	Ref. Method #
Ammonia	Colormetric, automated phenate method	350.1
Nitrate plus nitrite	Colormetric, automated cadmium reduction	353.2
Orthophosphate	Colormetric, automated ascorbic acid method	365.1

(Environmental Protection Agency 1983)

[2] Bryte Chemical Laboratory, Department of Water Resources, 1450 Riverbank Road, West Sacramento, CA 95605

[3] The reporting limit is a laboratory determined value that is three to ten times the method detection limit.

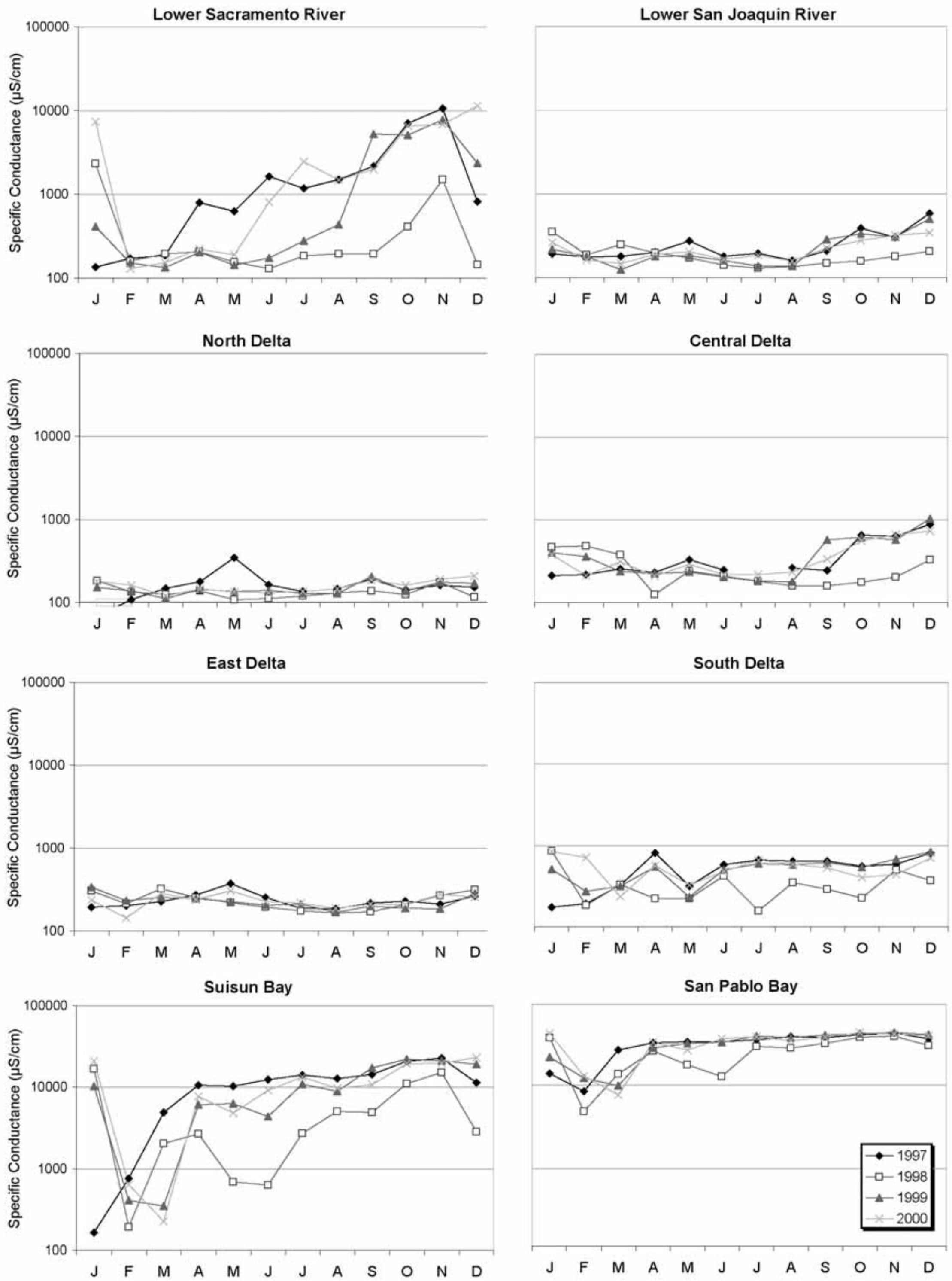


Figure 3-5 Monthly specific conductance measurements (µS/cm) at eight upper San Francisco Estuary regions, 1997-2000

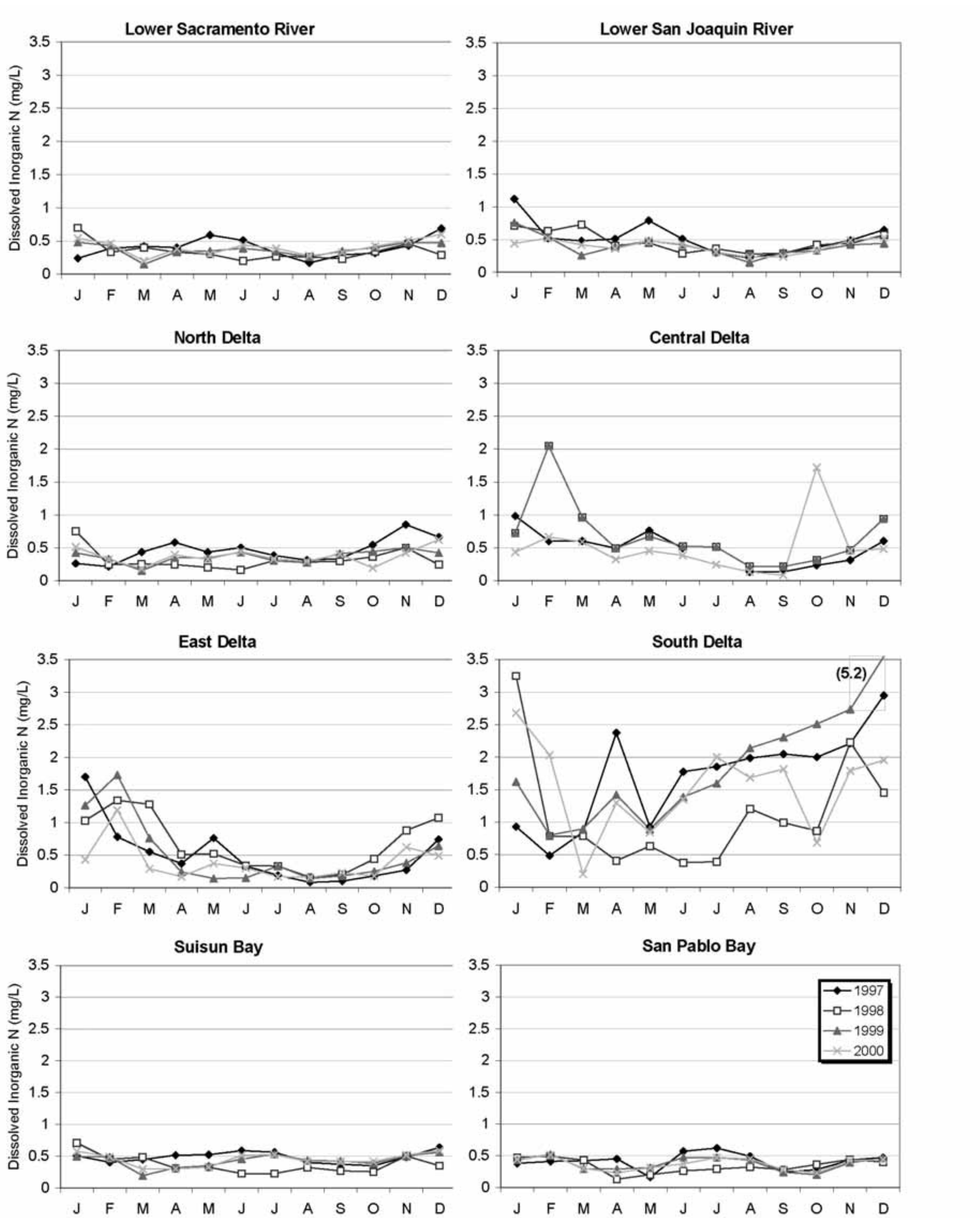


Figure 3-6 Monthly dissolved inorganic nitrogen levels (mg/L) at eight upper San Francisco Estuary regions, 1997-2000

Orthophosphate

Orthophosphate is soluble inorganic phosphate, the phosphorus compound most immediately available for assimilation by phytoplankton. Orthophosphate concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis. The minimum reporting limit for orthophosphate is 0.01 mg /L. The method of analysis for measuring orthophosphate is listed in Table 3-3.

Measured orthophosphate concentrations ranged from a low in several locations of 0.02 mg/L, to a high of 0.36 mg/L in the Delta in February 1999. The north Delta, lower Sacramento River, lower San Joaquin River, east Delta, and Suisun Bay regions all had minimum concentrations of 0.02 mg/L. The central and south Delta regions had slightly higher concentrations at 0.03 mg/L. Since natural levels of orthophosphate in freshwaters usually range from 0.005 to 0.05 mg/L (Dunne and Leopold 1978), these levels likely represent approximate minimum baseline, or natural levels in the regions. The highest regional orthophosphate concentrations occurred during the winter months in the east and south Delta regions. These levels were approximately three times higher than maximum concentrations recorded for the same period in the downstream regions. In the downstream regions of Suisun Bay and San Pablo Bay, orthophosphate concentrations rose in the spring and summer months. Seasonal variation was lowest in the lower Sacramento River and north Delta (Figure 3-7).

Volatile Suspended Solids

The measurement of volatile suspended solids (VSS) provides a relative indicator of the amount of organic matter present in the water sample. Water samples for VSS analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for VSS according to EPA Method 160.4 (EPA 1983). The minimum reporting level for VSS in these analyses was 1.0 mg/L.

VSS levels fell below minimum detection levels (<1 mg/L) in several regions from 1997 through 2000, and reached a high of 35 mg/L in the lower Sacramento River in February 1998. The western bays were generally more variable than the other regions, due possibly to tidal influences or increased resuspension of shallow bottom sediments. VSS levels in the central Delta region were consistently higher than the levels in the other regions (Figure 3-8).

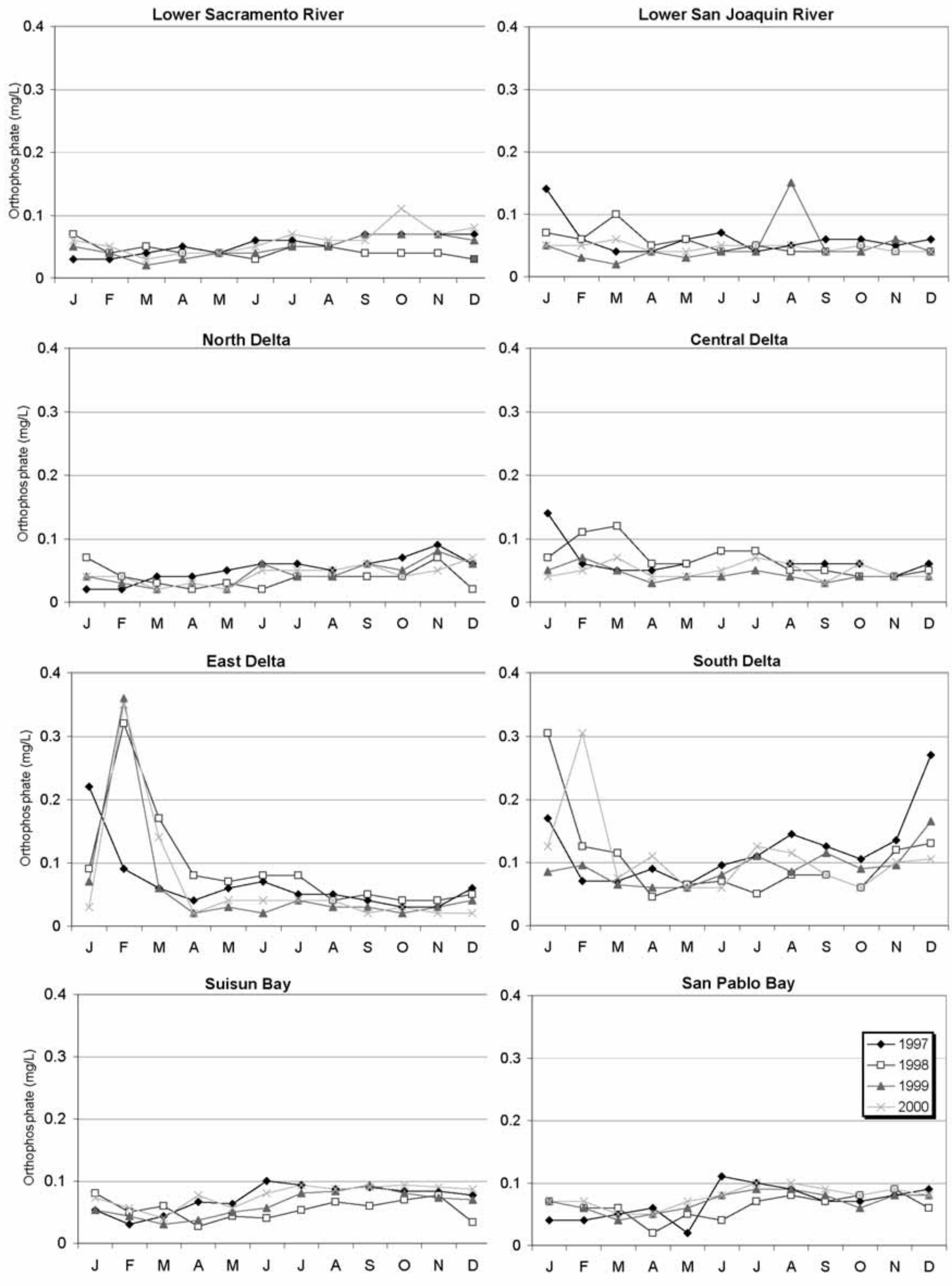


Figure 3-7 Monthly orthophosphate levels (mg/L) at eight upper San Francisco Estuary regions, 1997-2000

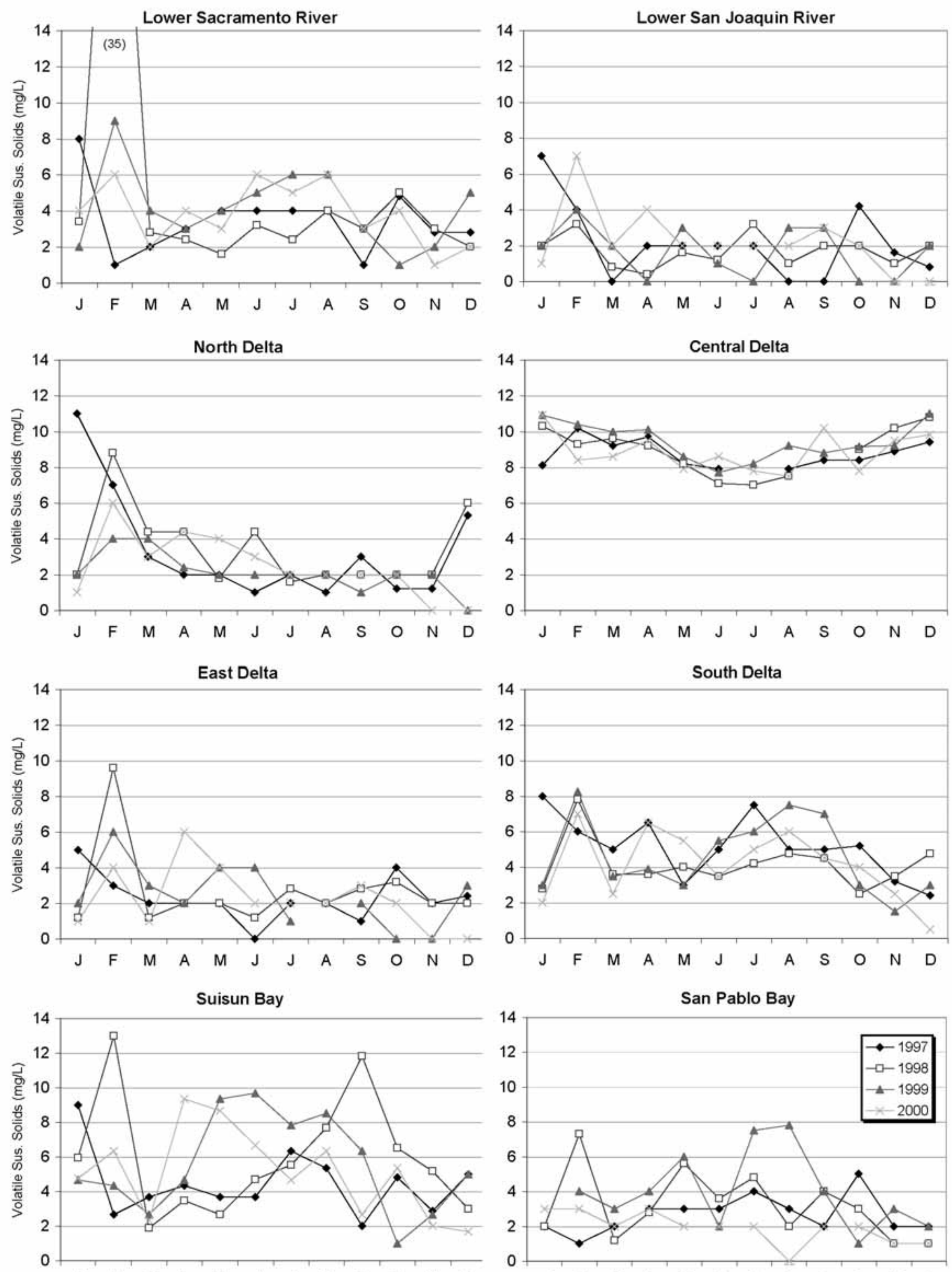


Figure 3-8 Monthly volatile suspended solids levels (mg/L) at eight upper San Francisco Estuary regions, 1997-2000

Chapter 4. Chlorophyll and Phytoplankton Community Composition, 1997-2000

Pursuant to the monitoring mandate of D-1641, the Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) collect phytoplankton and chlorophyll samples throughout the upper San Francisco Estuary (Estuary). This chapter describes the chlorophyll *a* concentration and phytoplankton community composition measurements obtained from calendar years 1997-2000 in the upper Estuary.

Samples for chlorophyll *a* analysis and phytoplankton samples for identification and enumeration were collected at 11 stations (Figure 4-1). For this summary, stations were grouped into regions according to the results of previously published hierarchical cluster analysis of Environmental Monitoring Program (EMP) data (DWR 2001). Chlorophyll *a* was filtered from samples using a fiberglass filter (47-mm diameter, pore size 1.0 µm) at a vacuum pressure of 10 inches of mercury immediately after sampling. Chlorophyll *a* analyses were completed at DWR's Bryte Laboratory according to standard methods (APHA 1998). Phytoplankton identification and enumeration were also performed at Bryte Laboratory using the Utermohl inverted microscope method at a magnification of 700x with a 40x objective and a 10x eyepiece. For more information about the methods for identification and enumeration refer to DWR's report *Water Quality Conditions in the Sacramento-San Joaquin Delta During 1996* (2001).

Figures 4-2 through 4-5 display the results of chlorophyll *a* and pheophytin analysis. Chlorophyll *a* concentrations for 1997-2000 were below 10 µg/L for most regions. Concentrations commonly ranged between 0.5 µg/L and 15 µg/L throughout the estuary. In 1996, chlorophyll levels were below 7 µg/L for all stations with the exception of the southern Delta and San Pablo Bay, which both peaked below 20 µg/L (DWR 2001).

The highest chlorophyll *a* concentrations occurred between March and June in the north Delta, lower Sacramento River, Suisun Bay, and lower San Joaquin River. The highest chlorophyll *a* concentration for the central, west, east, and south Delta regions occurred during July or September. The San Pablo Bay region was unique with a maximum biomass increase during April and July.

Phytoplankton species composition changes seasonally due to the interaction of many factors. Changes in water inflows, turbidity, light penetration, nutrients, water temperature, salinity, and other water quality parameters are all probable factors that contribute to changes in phytoplankton species composition. Diatoms comprised the spring chlorophyll *a* maximum and flagellates comprised the summer maximum in the north Delta, lower Sacramento River, lower San Joaquin River, central Delta, south Delta, and the east Delta. The chlorophyll *a* maximum consisted of miscellaneous flagellates, the crytophyte *Cryptomonas ovatas,* and the diatoms *Skeletonema sp.* and *Aulacosira granulate,* in Suisun Bay, as well as miscellaneous flagellates and various diatoms in San Pablo Bay.

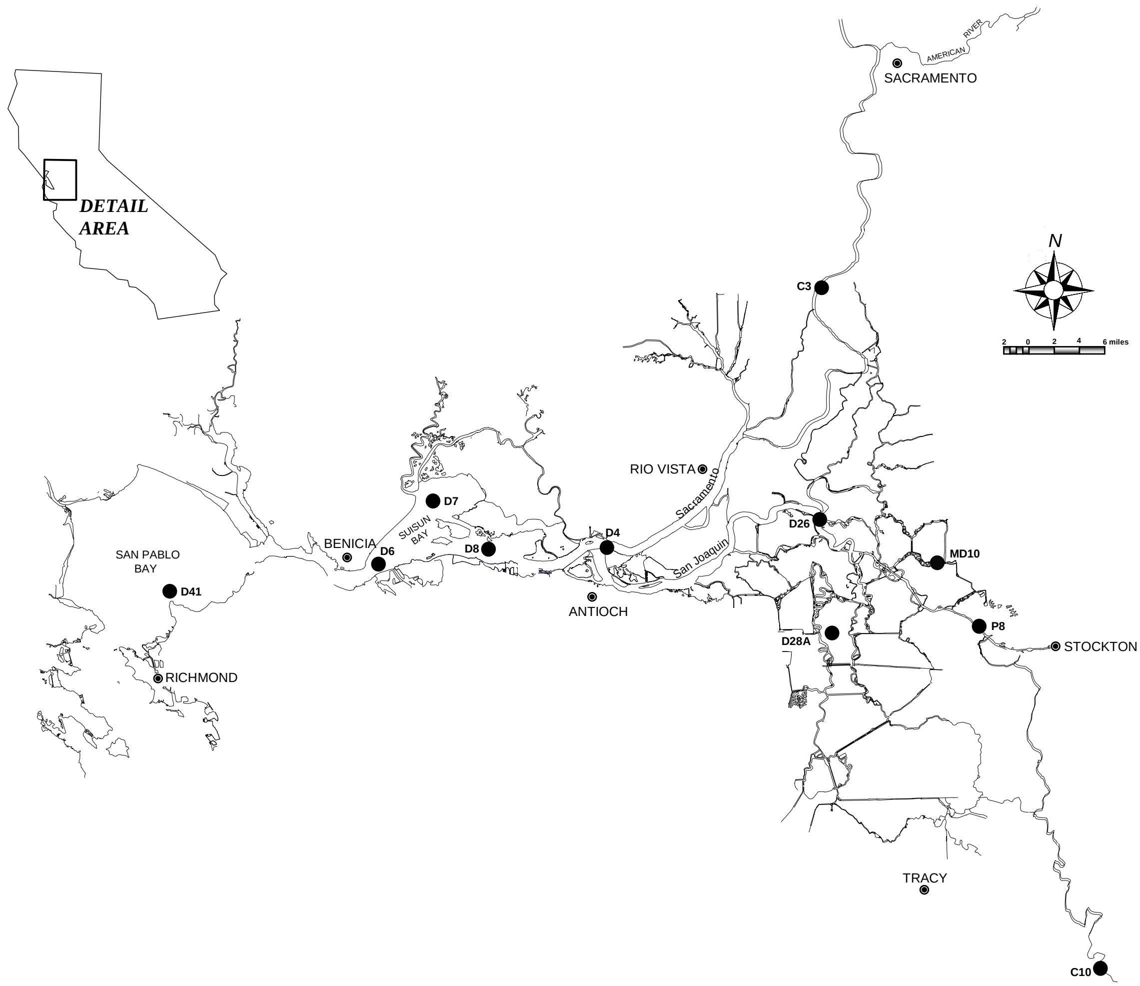


Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

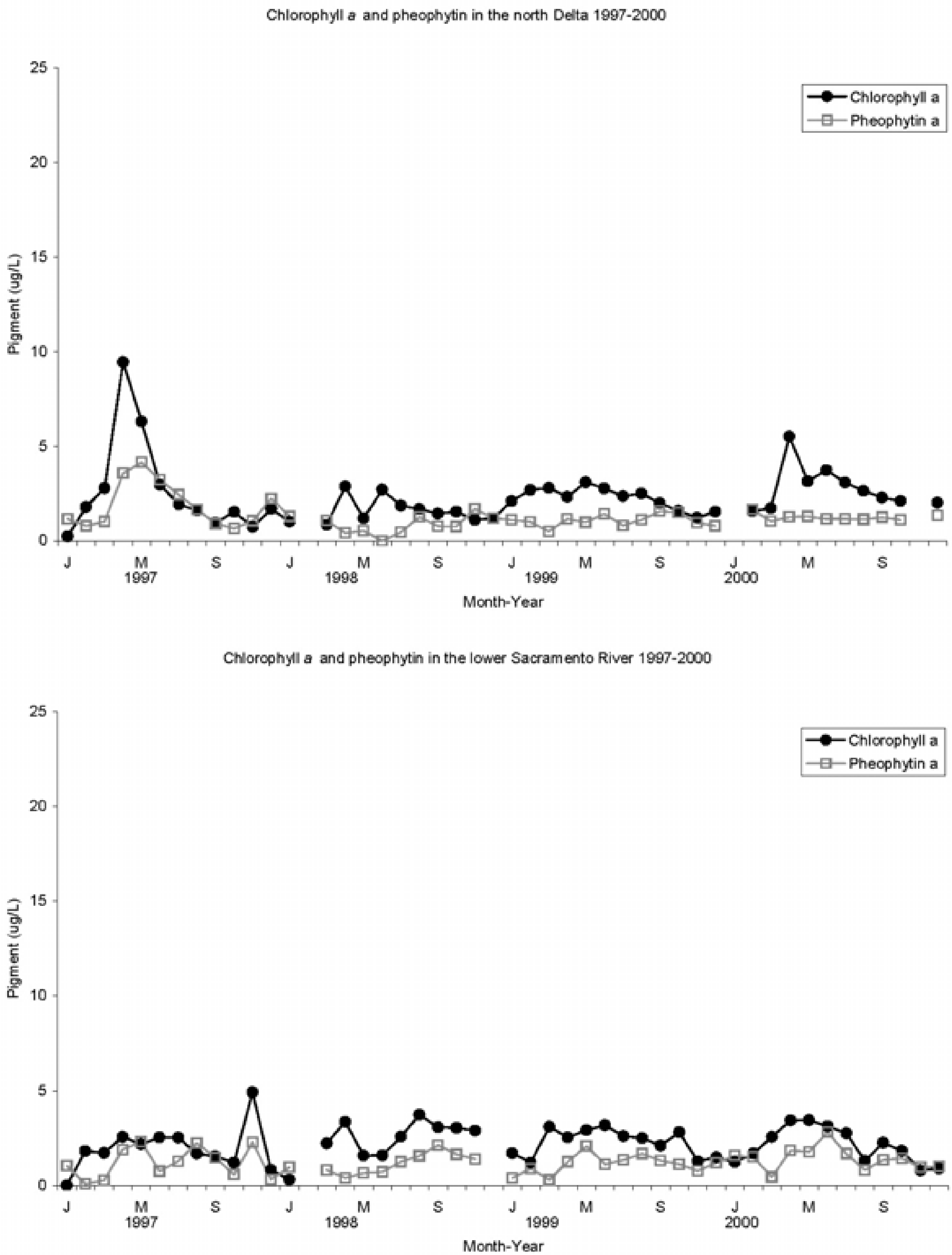


Figure 4-2 Chlorophyll *a* and pheophytin in the north Delta and lower Sacramento River, 1997-2000

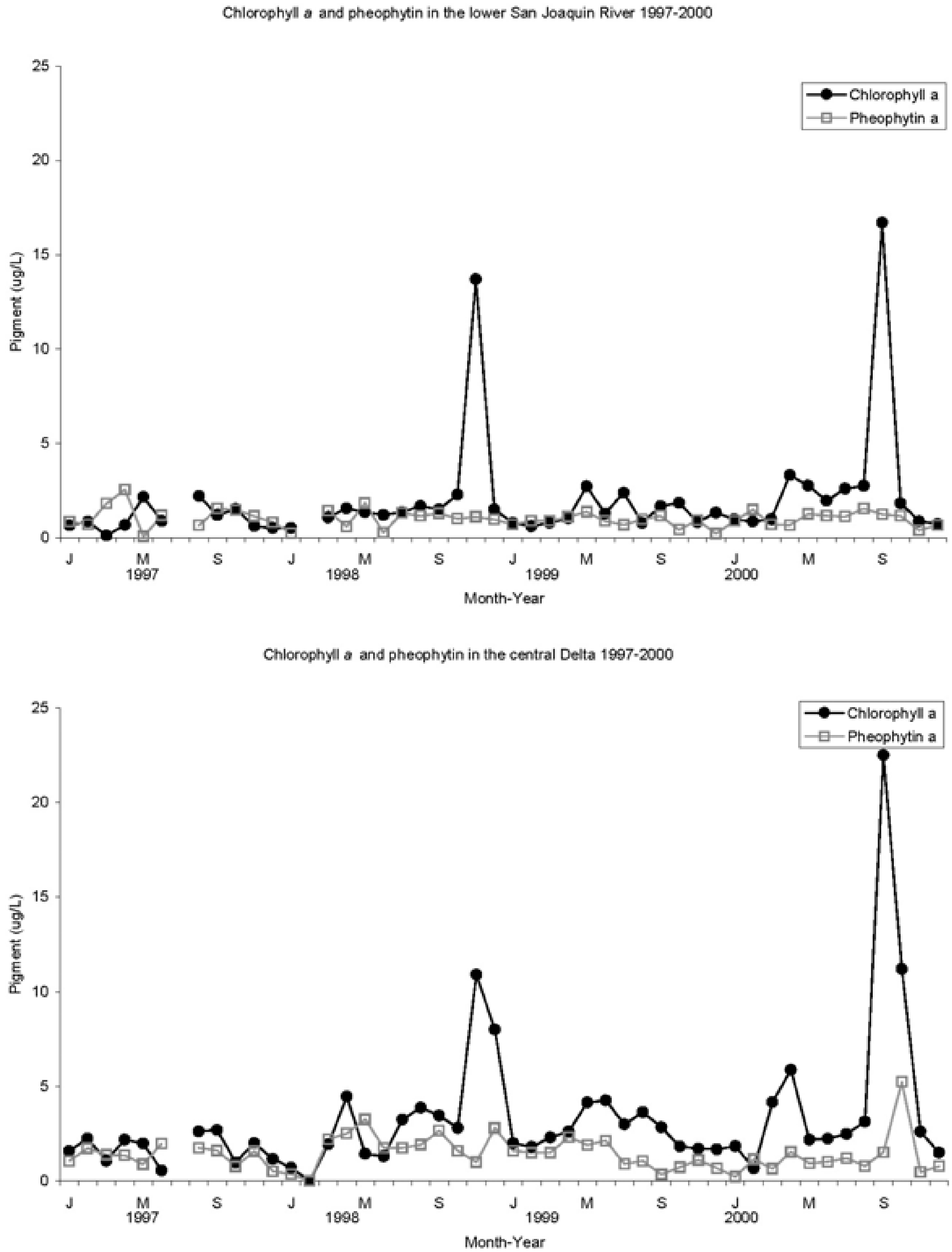


Figure 4-3 Chlorophyll *a* and pheophytin in the lower San Joaquin River and central Delta, 1997-2000

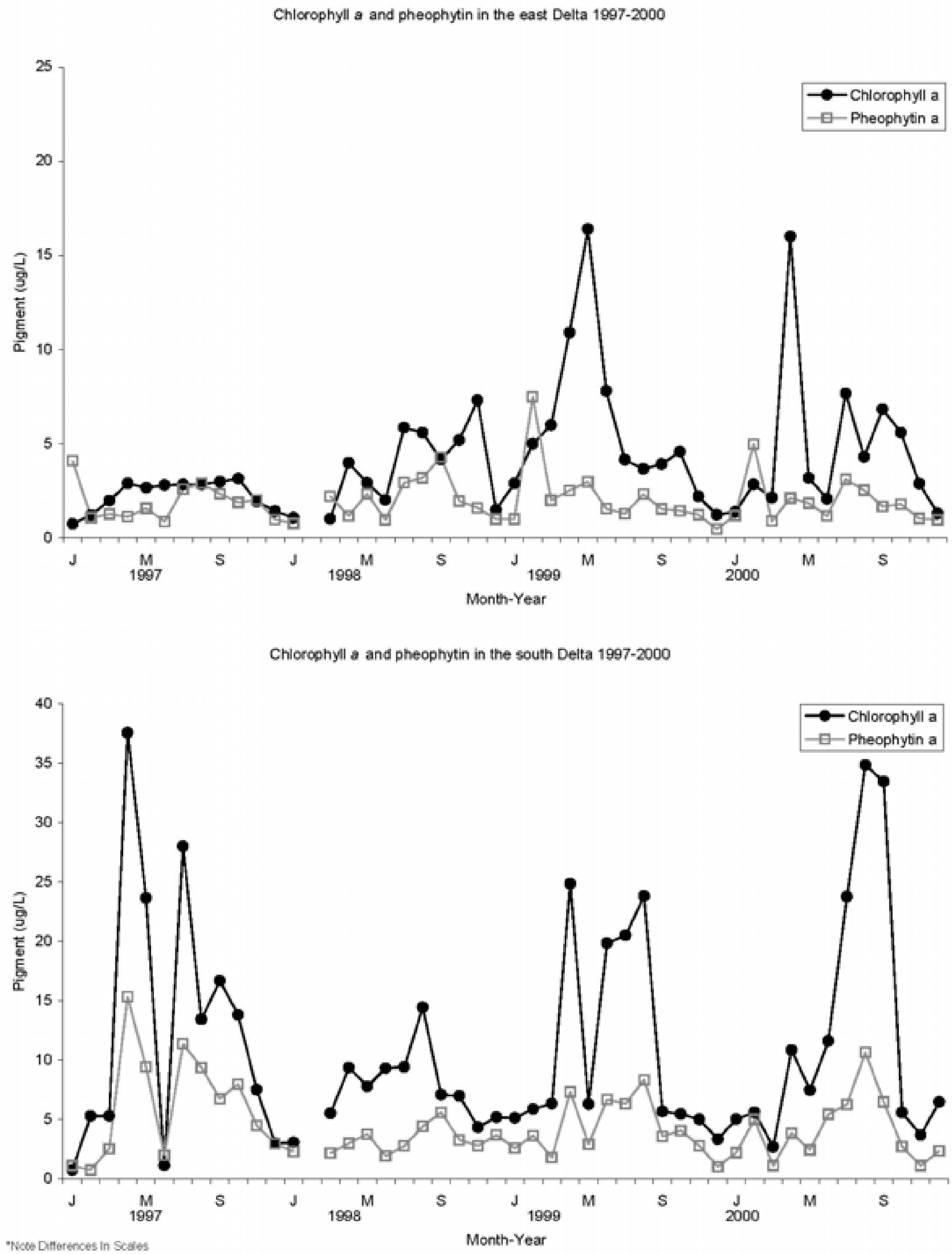


Figure 4-4 Chlorophyll *a* and pheophytin in the east Delta and south Delta, 1997-2000

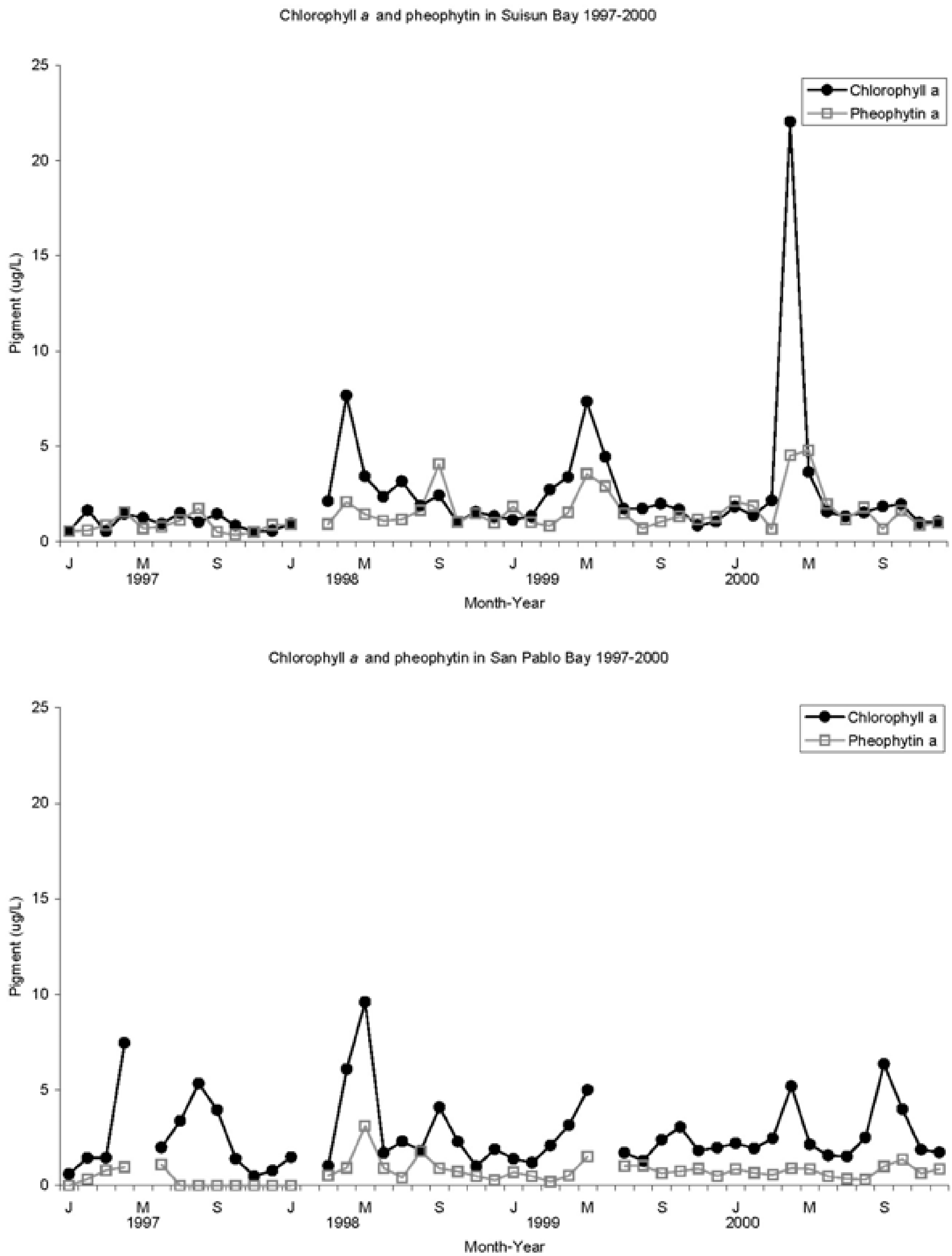


Figure 4-5 Chlorophyll *a* and pheophytin in Suisun and San Pablo bays, 1997-2000

Chapter 5. Zooplankton, 1997-2000

Mysid shrimp and zooplankton are important food sources for larval, juvenile, and small fish, such as delta smelt, juvenile salmon, striped bass, and small splittail. The zooplankton monitoring program seeks to determine the annual population level of *Neomysis mercedis*, and various zooplankton species or genera in order to assess the size of the food resource for fish. This monitoring also seeks to detect the presence of exotic species introduced to the estuary. The zooplankton study began in June 1968 to monitor *Neomysis mercedis*, and expanded in January 1972 to include copepods, cladocera, and rotifers.

Methods

Zooplankton and mysid shrimp were sampled monthly at 15 to 20 stations in the upper San Francisco Estuary (Figure 5-1). Eighteen of these stations were at fixed locations and two stations were considered "floating" stations, which were located where the bottom electrical conductance was 2 and 6 mS/cm, respectively. One station (Station 325) in San Pablo Bay and two stations (Stations 2 and 4) in Carquinez Strait were sampled only when their surface salinity was less than 20 mS/cm. Station D41 in San Pablo Bay was sampled on every survey beginning in March 1998.

At each station, three types of sampling gear were deployed. These included: a large *Neomysis* net (1.48-m long and 29 cm in mouth diameter, mesh size of 0.505 mm) mounted on a towing frame made of steel tubing, with a General Oceanics flow meter at its mouth; a Clarke-Bumpus net for zooplankton (mouth diameter of 12.5 cm and a mesh size of 154 µm) mounted above the *Neomysis* net; and a 15 liter/minute-capacity pump. At each station, the towing frame was lowered to the bottom and retrieved obliquely in several steps over a 10-minute period. Zooplankton small enough to pass through the Clarke-Bumpus net (mostly copepod, nauplii, rotifers, and Oithonids) were sampled with the pump. At each station, the pump intake was lowered to the bottom, raised slowly to the surface, and then lowered and raised a second time. The pumped water was discharged into a 19-liter carboy, the carboy was shaken, and a 1.5 to 1.9 liter sample was then decanted into a jug. All samples were preserved in buffered 10% formalin and returned to the laboratory for identification. Surface temperature and specific conductance were both measured at the beginning of each tow, and surface specific conductance was measured at the end of each tow. Bottom specific conductance was measured using a Seabird (model CTD 911) where the surface specific conductance was >1 mS/cm.

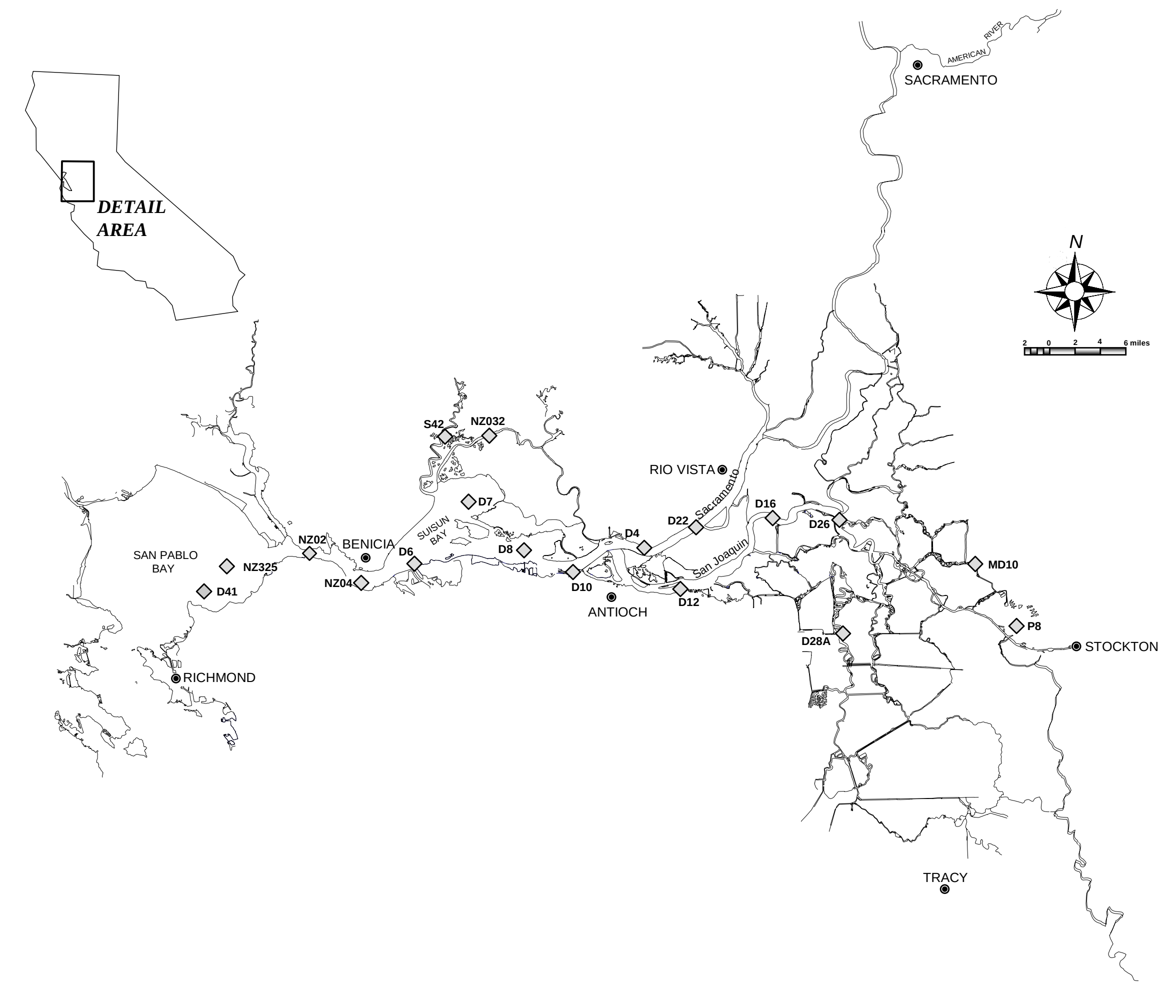


Figure 5-1 Zooplankton monitoring stations

To calculate monthly abundance indices, the sample area was divided into three zones based on bottom specific conductance. These zones were upstream of the entrapment zone (conductance <1.8 mS/cm); the entrapment zone (conductance from 1.8 mS/cm to 6.6 mS/cm); and downstream from the entrapment zone (conductance > 6.6 mS/cm). The density for each taxon was calculated as the number of organisms/m^3. Monthly abundance was calculated as the mean monthly density of each taxon in each zone. The number of stations in each zone varied month to month based on upstream and downstream shifts in the salinity gradient. Although no species was present at all stations in every month, averaging the density by the total number of stations sampled in each zone provided a common and consistent base for comparing taxon densities. Abundance data were log transformed (log_{10}(abundance+1)) before plotting to improve interpretation by reducing month to month variability.

Neomysis mercedis has been identified and counted since 1968 and *Acanthomysis bowmani* since 1994. Identification and counting of the other five species of mysid shrimp caught by the Zooplankton Monitoring Project (*A. aspera, A. hwanhaiensis, A. macropsis*, *Deltamysis holmquistae*, and *N. kadiakensis*) began in 1998.

For brevity, the zooplankton were divided into the following four groups: calanoid copepods, cyclopoid copepods, cladocera, and rotifers. The trends of the three or four most abundant taxa in each group are presented.

Results

The zooplankton and mysid shrimp findings for the 1997 through 2000 study period are summarized in Figures 5-2 through 5-6.

The mean densities of most taxa remained stable or increased throughout the 1997 to 2000 period. Only the calaniod copepod *Pseudodiaptomus forbesi* and the rotifer *Polyarthra* declined during 1997-2000 (Figure 5-3). The mean densities of the calanoid copepods *Acartia* and *Sinocalanus*, the cladocerans *Daphnia* and *Diaphanosoma,* and the cyclopoid copepod *Limnoithona tetraspina* increased slightly.

Mysids

Acanthomysis bowmani was by far the most abundant mysid in all areas in 1997, 1999, and 2000 (Figure 5-2). In 1998, however, *A. bowmani* abundance was low. *A. bowmani* abundance was highest in the entrapment zone and downstream from the entrapment zone. Peak *A. bowmani* abundance occurred from May through October, except in 1998 when abundance peaked in April and May. In 1997 *A. bowmani* abundance outside the entrapment zone declined from 1996 levels, but increased thereafter.

Neomysis mercedis, the second most abundant mysid, was caught primarily in and upstream from the entrapment zone. Peak *N. mercedis* abundance in these areas occurred from April through June (Figure 5-2). Downstream from the entrapment zone, *N. mercedis* was found in small numbers only from February through July.

Identification and counting of *Neomysis kadiakensis* and *Acanthomysis aspera* began in 1998. *Neomysis kadiakensis*, the third most abundant mysid, was found primarily downstream from the entrapment zone, with few found within and upstream of the entrapment zone (Figure 5-2). Downstream from the entrapment zone, peak abundance came in April through May. A second peak was observed in November 2000. *Neomysis kadiakensis* was less abundant in 1999 than in 1998 and 2000.

Acanthomysis aspera, the fourth most abundant mysid, occurred almost exclusively downstream from the entrapment zone and was abundant only in 1998 and 2000 (Figure 5-2). Peak *A. aspera* abundance occurred in May of both years.

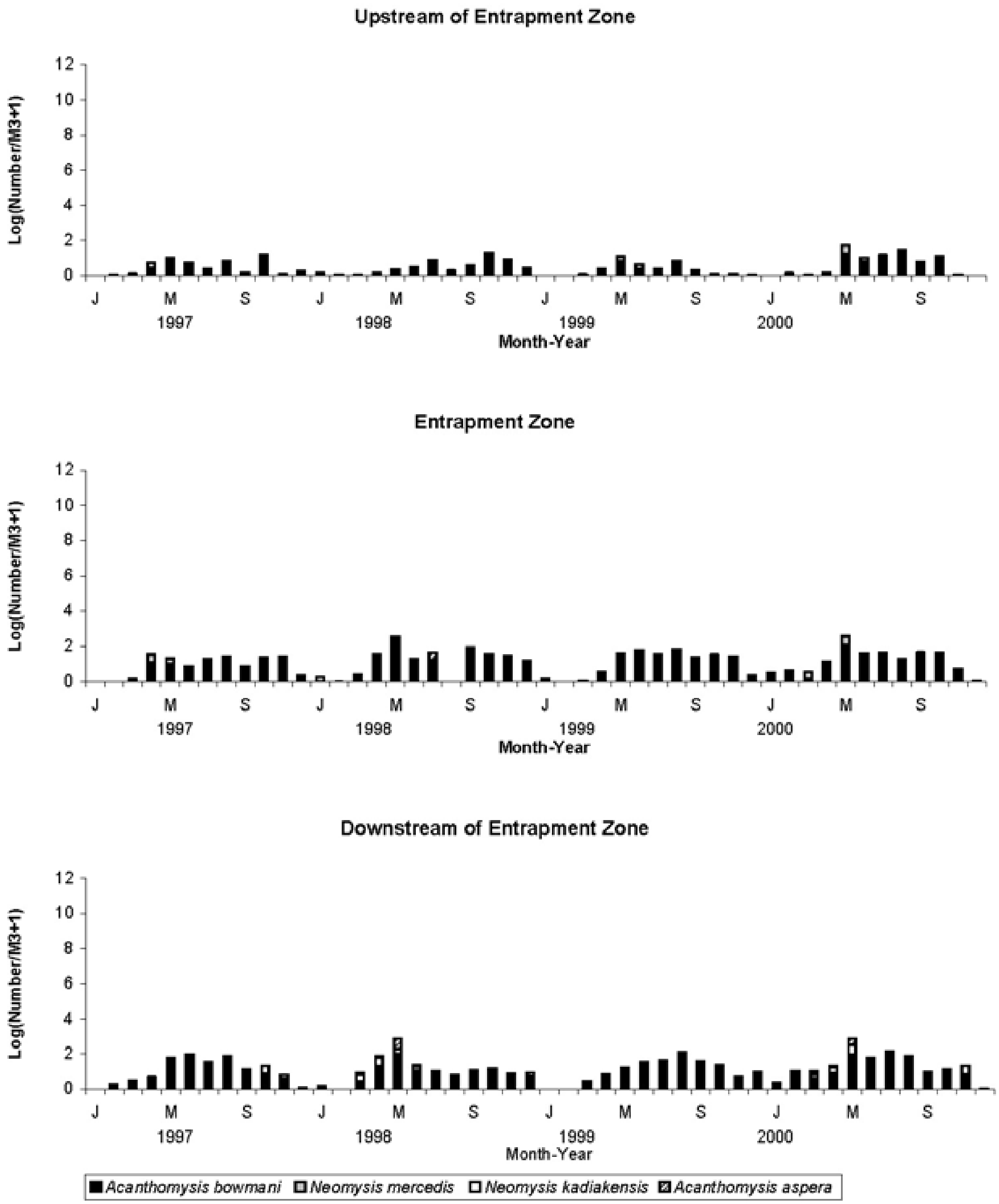


Figure 5-2 Monthly mysid abundance upstream from, in, and downstream from the entrapment zone, 1997-2000

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in all areas in all four years except for downstream from the entrapment zone where *Acartia*, a native calanoid, was occasionally more abundant (Figure 5-3). *Pseudodiaptomus forbesi* abundance was greatest upstream of the entrapment zone and was almost as high in the entrapment zone. Peak *P. forbesi* abundance in all areas was from May through November. In 1999, the spring increase in abundance began in May, one to two months later than in the other years.

Acartia spp. was the second most abundant calanoid copepod and it occurred primarily downstream from the entrapment zone (Figure 5-3). Abundance downstream from the entrapment zone was high from January through June with peak abundance from March through June, minimal populations in September, and occasionally minimal populations as early as June and July. In 1997, *Acartia* abundance downstream from the entrapment zone was particularly low from June through September. *Acartia* spp. was also found sporadically from late fall through spring in the entrapment zone and upstream of the entrapment zone from late fall through spring.

The third most abundant calanoid copepod was the introduced *Sinocalanus doerrii* (Figure 5-3). The highest concentrations of this copepod were found upstream of and in the entrapment zone, although large numbers were also found downstream from the entrapment zone. Upstream of the entrapment zone, *S. doerrii* abundance peaked from April through September. In the entrapment zone, the abundance peaks occurred from March through July. The abundance peak downstream from the entrapment zone was from February through July.

Eurytemora affinis, probably an introduced species (Lee 2000), was the fourth most abundant calanoid copepod (Figure 5-3). Abundance was equally distributed across all three areas. Upstream of the entrapment zone and in the entrapment zone, *E. affinis* densities peaked between March and June. Downstream from the entrapment zone, abundance peaked from March through April, except in 1997 when the peak started in February. Densities were very low in the entrapment zone from August through September in all four years and upstream of the entrapment zone in all years except 2000.

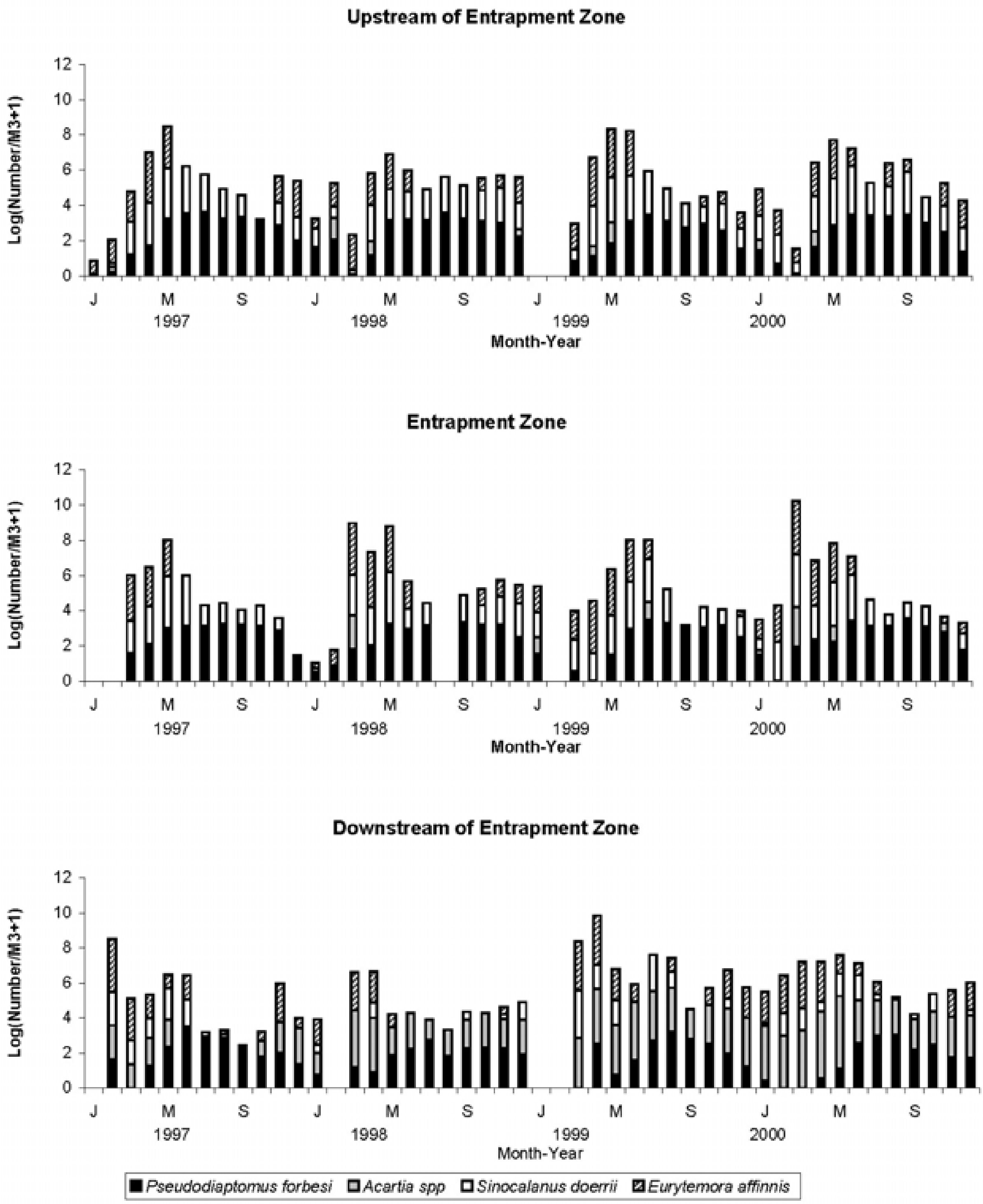


Figure 5-3 Monthly calanoid abundance upstream from, in, and downstream from the entrapment zone, 1997-2000

Cyclopoid Copepods

Limnoithona tetraspina, introduced in 1994, was the most abundant cyclopoid copepod (Figure 5-4). *Limnoithona tetraspina* was abundant in all three areas but less abundant upstream of the entrapment zone than in the other two areas. Upstream of the entrapment zone, *L. tetraspina* had a peak abundance period from July through December. Beginning in 1998, a second period of high abundance occurred from March through May. By 2000, this second peak had become slightly higher than the late summer-fall peak. In the entrapment zone, *L. tetraspina* abundance peaked from April through November. Downstream from the entrapment zone, the abundance was more uniform throughout the year with a nominal April through October peak.

The native *Acanthocyclops vernalis* was the second most abundant cyclopoid copepod, and was abundant throughout the sampling area (Figure 5-4). *Acanthocyclops vernalis* was, however, less abundant downstream from the entrapment zone than in the other two areas. Its abundance peak was from February through July or August with a secondary peak in November, December, or November and December.

The introduced *Oithona davisae* was the third most abundant cyclopoid copepod and occurred primarily downstream from the entrapment zone (Figure 5-4). *Oithona davisae* was also abundant in the entrapment zone, and occurred sporadically upstream of the entrapment zone. Peak abundance occurred from August through February. Downstream from the entrapment zone, *O. davisae* abundance was characterized by a sharp dip in May.

Cladocera

Bosmina longirostris was the most abundant cladoceran found from 1997 through 2000 (Figure 5-5). It was abundant throughout all four years upstream of the entrapment zone with a nominal peak from April through October. *Bosmina longirostris* was absent from the entrapment zone from July through October, but was present from January through June and in November and December in most years with the peak occurring from February through June. Its presence downstream from the entrapment zone was variable, with a nominal peak from February through June.

Daphnia spp., the second most abundant cladoceran, was most abundant upstream of the entrapment zone where its peak abundance occurred from February through September (Figure 5-5). In the entrapment zone and downstream, *Daphnia* spp. peaked from February through July. Its abundance downstream from the entrapment zone was lower and more variable than in the other areas.

Diaphanosoma spp., the least abundant of the identified cladocera, was found almost exclusively upstream of the entrapment zone (Figure 5-5). Peak abundance occurred from June through October.

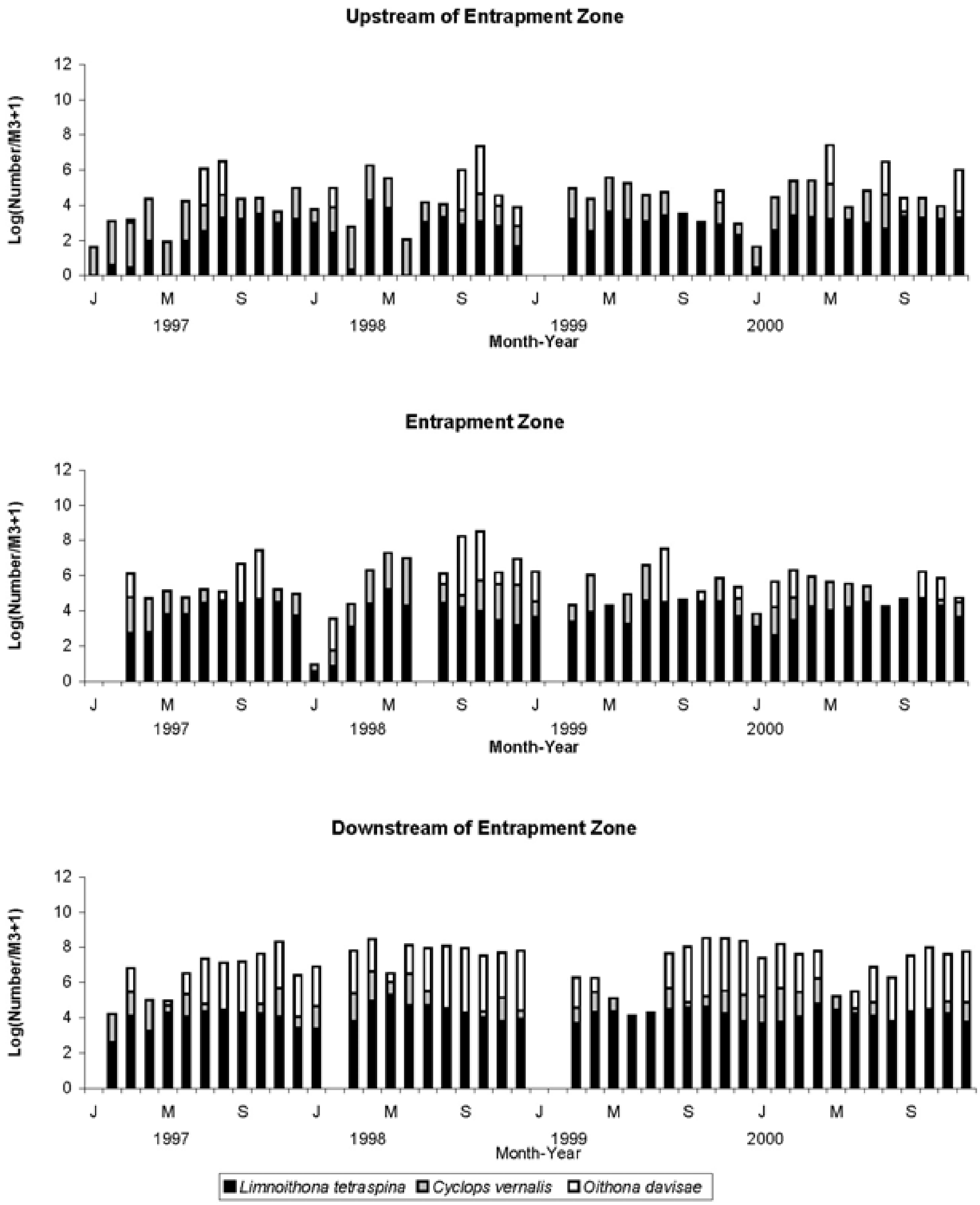


Figure 5-4 Monthly cyclopoids abundance upstream from, in, and downstream from the entrapment zone, 1997-2000

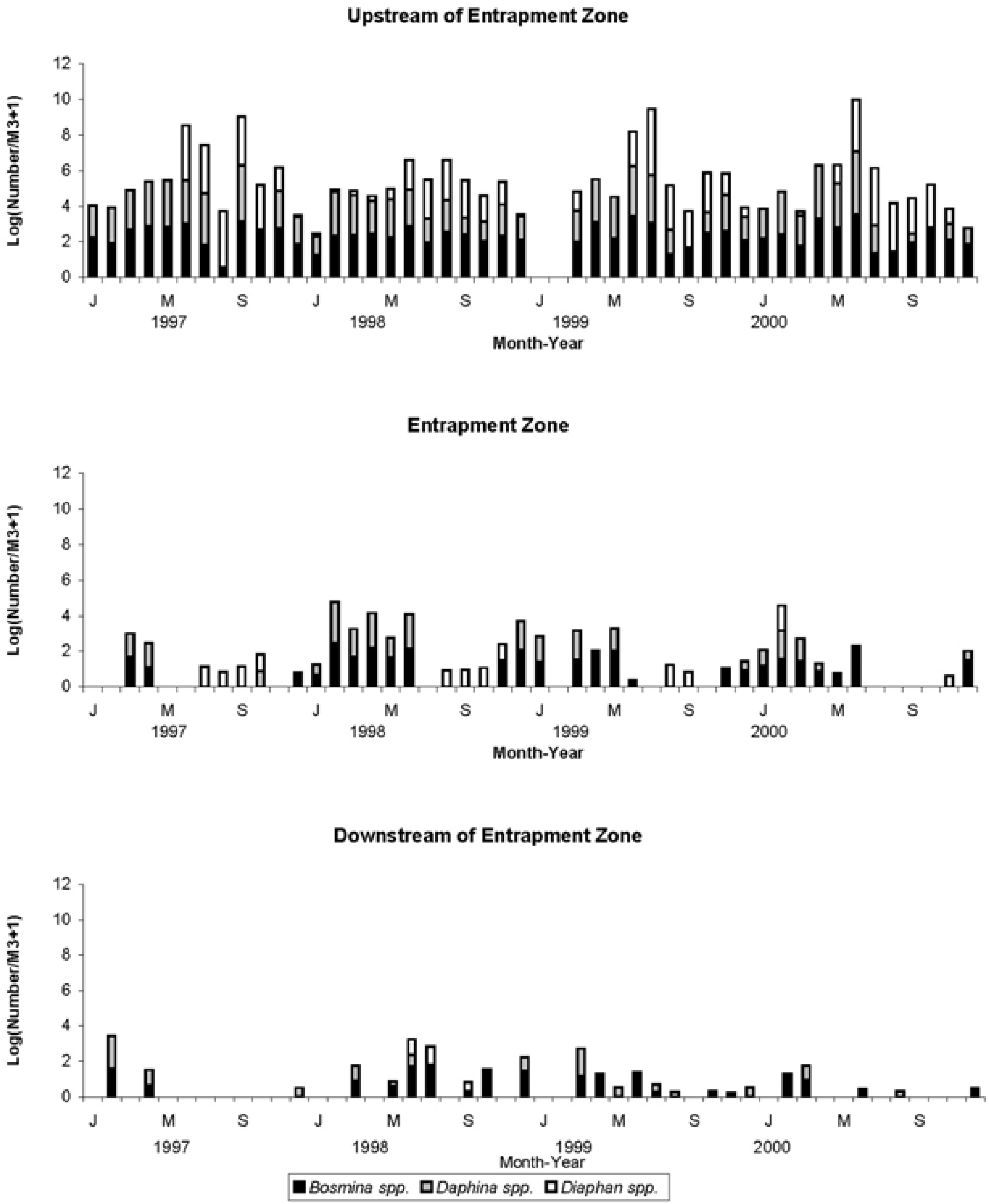


Figure 5-5 Monthly cladocera abundance upstream from, in, and downstream from the entrapment zone, 1997-2000

Rotifers

The genus *Synchaeta* (not including *Synchaeta bicornis*) was the most abundant rotifer taxon (Figure 5-6). Although abundant in all areas, *Synchaeta* spp. was slightly more abundant upstream of the entrapment zone, with an abundance peak that began in October and continued through May of the following year. In the entrapment zone, abundance during the off peak period was lower than in the other areas.

The genus *Polyarthra* was the second most abundant rotifer and, except for sharp declines in June 1997 and 2000, its abundance upstream of the entrapment zone was roughly uniform throughout the year (Figure 5-6). In the entrapment zone, an abundance peak started in December and continued through May or June. Downstream from the entrapment zone, *Polyarthra* abundance was erratic, with a nominal peak from February through May.

The third most abundant rotifer taxon was the genus *Trichocerca* (Figure 5-6). The highest *Trichocerca* spp. abundance occurred downstream from the entrapment zone where there was a spring abundance peak from March through May, and a fall abundance peak from October through December for all four years. Upstream from the entrapment zone, *Trichocerca* abundance tended to be more uniform throughout the year with a nominal peak from January through July. Abundance was lowest in the entrapment zone where the two abundance peaks occurred in March and April and in October through December.

The fourth most abundant rotifer taxon was the genus *Keratella* (Figure 5-6). This genus was most abundant upstream of the entrapment zone and least abundant downstream from the entrapment zone. Except for 2000, *Keratella* abundance upstream of the entrapment zone peaked in April, and then gradually declined to its lowest value in December. In June 2000, there was a sharp drop in abundance with a gradual recovery to normal levels by September. In the entrapment zone, *Keratella* abundance was highest from February through May and October through December, and this rotifer was usually absent from June through August. *Keratella* was not found downstream from the entrapment zone during most of 1997. By October 1997, *Keratella* had returned to normal abundance levels. During the other three years, peak *Keratella* abundance occurred from January through April.

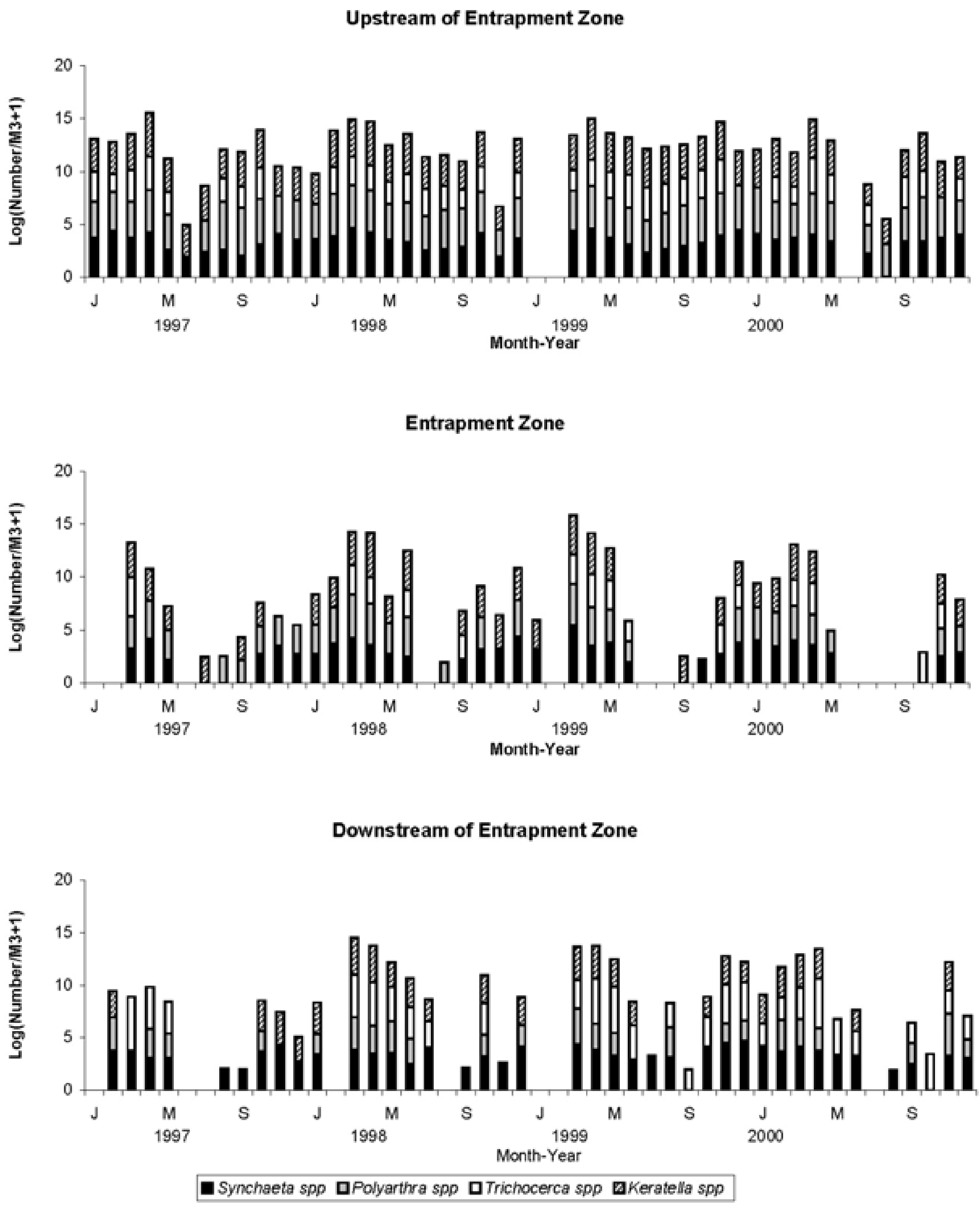


Figure 5-6 Monthly rotifer abundance upstream from, in, and downstream from the entrapment zone, 1997-2000

Chapter 6. Benthic Community Density and Composition

The Benthic Monitoring Program is designed to document the distribution, diversity and abundance of benthic (bottom dwelling) organisms and substrate composition in the Sacramento-San Joaquin Delta and Suisun and San Pablo bays. The benthic community of the Delta and these westerly bays is a diverse assemblage of organisms, which include fungi, ciliates, worms, crustaceans, insects and molluscs. The program focuses on monitoring the benthic macrofauna (organisms larger than 0.5 mm) (DWR 2001). Substrate composition is monitored to evaluate changes in benthic fauna in relation to the substrate. Hydrozoology, a private laboratory under contract with the Department of Water Resources, identified and enumerated organisms in the macrofaunal samples. Particle size analysis and dry weight measurements for each sediment sample are performed at the DWR Soils and Concrete Laboratory. Methods of analysis for each the independent laboratories are explained below.

Methods

We sample benthic macroinvertebrates using the methods described in *Standard Methods for the Examination of Water and Wastewater* (APHA 1998). The formalin preservative used to fix the sample in the field is poured off in the laboratory and the sample is washed on a United States standard #30 mesh screen. Organisms are then placed in 70% ethyl alcohol for identification and enumeration. A stereoscopic dissecting microscope (70-120x) is used to identify most organisms. When taxonomic features are too small for identification under the dissecting scope, the organism is permanently mounted on a slide and examined under a compound microscope. If more than four hours of sorting are required, and a sample contains many organisms but few species, a one-fourth sub-sample is chosen at random. The sub-sample is sorted and the results are multiplied by four to represent the total sample. The remainder of the sample is inspected to make sure no taxa are overlooked. Individual species counts are multiplied by 19 to convert the number of organisms per grab sample to organisms per square meter.

Substrate is analyzed for particle size according to the American Society of Testing and Materials Protocol D422 (ASTM a. 2000). Particles are sorted into the following categories: >2350 µm, >1180 µm, >600 µm, >300 µm, >100 µm and >75 µm. Organic content of the sediment is determined by taking a sub-sample and using the American Society of Testing and Materials Protocol D2974, Method C (ASTM b. 2000). For this method an ash free dry weight of the sample is used to determine the organic content.

The ten EMP benthic monitoring stations in the upper San Francisco Estuary represent diverse salinity and substrate conditions. Figure 6-1 shows the location of each station and Table 6-1 summarizes latitude and longitude, salinity range, substrate composition, and the four most numerically dominant species for each station. Table 6-2 lists the new species found in the upper San Francisco Estuary from 1997-2000.

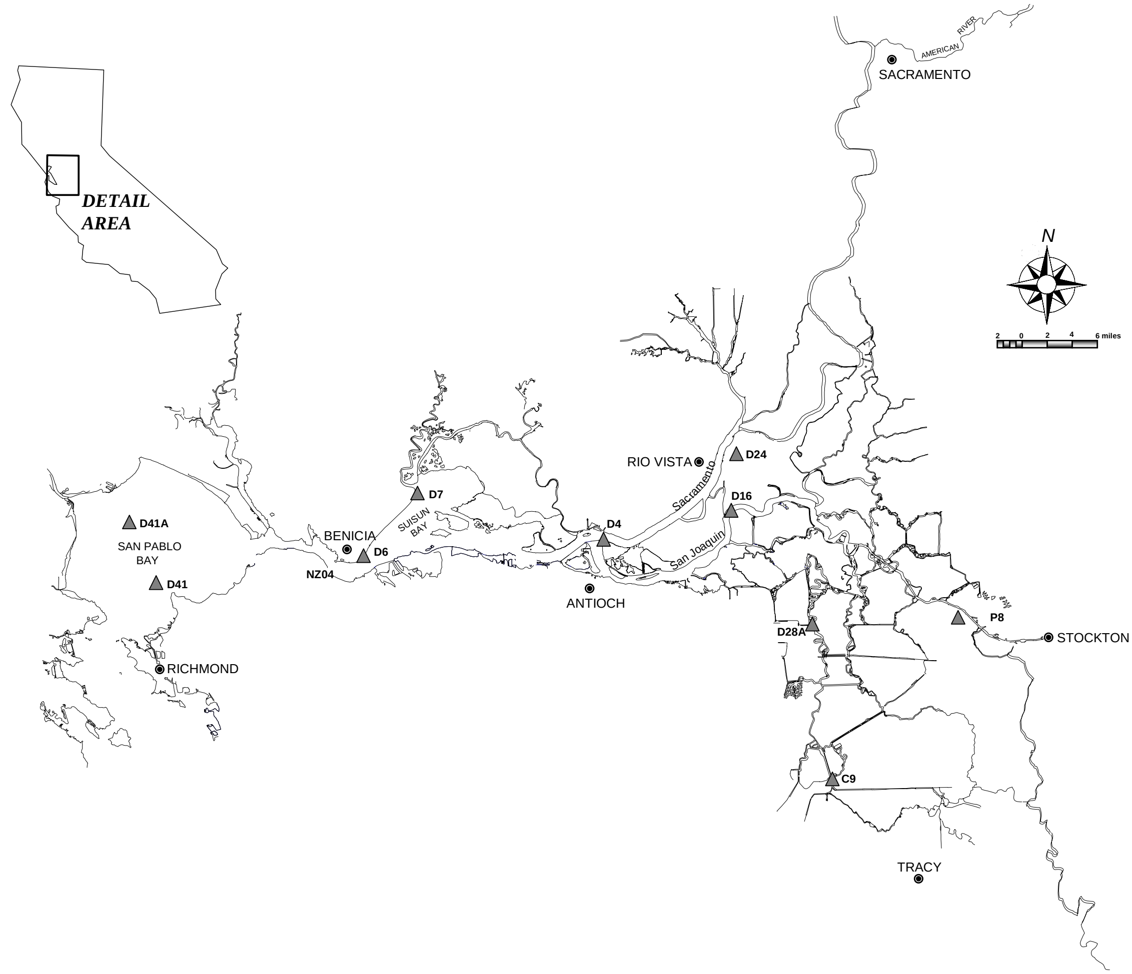


Figure 6-1 Map of benthic monitoring stations

Table 6-1 Macrobenthic monitoring station characteristics

Station Region	Latitude Longitude	Substrate Composition	Approx. Salinity Range 1997-2000 (uS/cm)	Genus Species	Abbreviation Used For Plots
C9 Delta-Old River	37^{o} 49' 50" 121^{o} 33' 09"	Consistent. Over 90% sand.	200-800	*Aulodrilus limnobius* *Limnodrilus hoffmeisteri* *Varichaetadrilus angustipenis* *Corophium stimpsoni*	*A. limnobius* *L. hoffmeisteri* *V. angustipenis* *C. stimpsoni*
P8 Delta San Joaquin River	37^{o} 58' 42" 121^{o} 22' 55"	Consistent. High sand content (60%).	175-750	*Ilyodrilus frantzi capillatus* *Limnodrilus hoffmeisteri* *Varichaetadrilus angustipenis* *Corophium stimpsoni*	*I. frantzi* *L. hoffmeisteri* *V. angustipenis* *C. stimpsoni*
D28A Delta Old River	37^{o} 58' 14" 121^{o} 34' 19"	Mixed composition of sand and fines.	200-350	*Varichaetadrilus angustipenis* *Manayunkia speciosa* *Corophium stimpsoni* *Corbicula fluminea*	*V. angustipenis* *M. speciosa* *C. stimpsoni* *C. fluminea*
D16 Delta San Joaquin River	38^{o} 05' 50" 121^{o} 40' 05"	Consistent. Mostly fines with some organic materials.	130-500	*Varichaetadrilus angustipenis* *Corophium stimpsoni* *Gammarus daiberi* *Corbicula fluminea*	*V. angustipenis* *C. stimpsoni* *G. daiberi* *C. fluminea*
D24 Delta Sacramento River	38^{o} 09' 27" 121^{o} 41' 01"	Consistent. High sand content (80%).	200-1200	*Limnodrilus hoffmeisteri* *Varichaetadrilus angustipenis* *Corophium stimpsoni* *Corbicula fluminea*	*L. hoffmeisteri* *V. angustipenis* *C. stimpsoni* *C. fluminea*
D4 Delta Sacramento River	38^{o} 03' 45" 121^{o} 49' 10"	Mixed composition of sand, fines, and organic materials.	130-8,000	*Varichaetadrilus angustipenis* *Corophium spinicore* *Corophium stimpsoni* *Gammarus daiberi*	*V. angustipenis* *C. spinicore* *C. stimpsoni* *G. daiberi*
D6 Suisun Bay	38^{o} 02' 40" 122^{o} 07' 00"	Fairly equal mixture of sand and fines.	135-30,000	*Marenzelleria virdis* *Balanus improvisus* *Nippoleucon hinumensis* *Potamocorbula amurensis*	*M. virdis* *B. improvisus* *N. hinumensis* *P. amurensis*
D7 Grizzly Bay	38^{o} 07' 02" 122^{o} 02' 19"	Consistent. Mostly fines with some organic materials.	200-20,000	*Marenzelleria virdis* *Corophium alienense* *Corophium stimpsoni* *Potamocorbula amurensis*	*M. virdis* *C. alienense* *C. stimpsoni* *P. amurensis*
D4 San Pablo Bay	38^{o} 01' 50" 122^{o} 22' 15"	Consistent. High content of fine material (87%).	20,000-45,000	*Nippoleucon hinumensis* *Ampelisca abdita* *Corophium acherusicum* *Potamocorbula amurensis*	*N. hinumensis* *A. abdita* *C. acherusicum* *P. amurensis*
D41A San Pablo Bay	38^{o} 03' 75" 122^{o} 24' 40"	Consistent. High content of fine material (90%).	30,000-44,000	*Heteromastus filiformis* *Nippoleucon hinumensis* *Ampelisca abdita* *Potamocorbula amurensis*	*H. filiformis* *N. hinumensis* *A. abdita* *P. amurensis*

Table 6-2 New species, 1997-2000

Station Found	Date	Phylum	Genus and/or Species
C9	April 2002	Annelida	*Pristinella jenkinae*
C9	June 1998	Annelida	*Potamothrix sp.A*
C9	March 1997	Annelida	*Uncinais uncinata*
C9	May 1998	Annelida	*Specaria josinae*
D24	April 1999	Arthropoda	*Bezzia sp. A*
D24	December 1998	Arthropoda	*Gymnometriocnemus sp. A*
D24	February 1999	Arthropoda	*Microcylloepus sp. A*
D24	February 2000	Arthropoda	*Dubiraphia sp. A*
D24	February 2000	Arthropoda	*Tanytarsus sp. B*
D24	March 1997	Annelida	*Dervo nivea*
D24	March 1997	Arthropoda	*Polypedilum sp.B*
D24	March 1997	Arthropoda	*Chironominid pupa sp. A*
D24	March 2000	Arthropoda	*Psectrocladius sp. B*
D28A	April 1999	Annelida	*Kincaidiana freidris*
D4	January 1999	Arthropoda	*Caecidotea racovitzai*
D4	May 1997	Arthropoda	*Cricotopus sp. B*
D4	September 1998	Arthropoda	*Eriocheir sinensis*
D41	April 1997	Mollusca	*UNID Tellinid Sp. A*
D41	December 1998	Arthropoda	*Cancer productus*
D41	December 1999	Mollusca	*Clinocardium nuttallii*
D41	February 1997	Annelida	*Mediomastus californiesis*
D41	February 1998	Mollusca	*Musculium sp. A*
D41	February 2000	Nematoda	*Monochulus sp. A*
D41	July 1997	Annelida	*Anaitides groenlandica*
D41	July 2000	Platyhelminthes	*UNID Planariid sp. A*
D41	March 1997	Arthropoda	*Eudorella pacifica*
D41	March 1997	Arthropoda	*Ampelisca lobata*
D41	March 1997	Mollusca	*Siliqua lucida*
D41	March 2000	Nematoda	*UNID Nematode sp. A*
D41	May 1997	Mollusca	*Moldiolus rectus*
D41	May 2002	Annelida	*Scolepis sp. A*
D41	November 1999	Arthropoda	*Pygodelphys sp.A*
D41	November 1999	Annelida	*Polydora socialis*
D41	November 1999	Mollusca	*Facelinidae sp. A*
D41	October 1997	Annelida	*Tubificoides motei*
D41	October 1997	Annelida	*Armandia brevis*
D41	October 1997	Annelida	*Typosyllis sp. A*
D41	October 1999	Annelida	*Amaeana occidentalis*
D41	October 1999	Arthropoda	*Stenothoe valida*
D41	September 1999	Arthropoda	*Achelia nudiuscula*
D41	October 1999	Arthropoda	*Caprella sp. B*
D41A	February 1997	Arthropoda	*Holmsimysis macropsis*
D41A	May 1997	Cnidaria	*UNID Actinarian sp. A*
D41A	May 1997	Arthropoda	*Acanthomysis aspera*
D6	April 1997	Arthropoda	*Acanthomysis bowmani*
P8	April 1997	Arthropoda	*Sphaeromias sp. A*

Figures 6-3 through 6-7 exhibit the abundance of the four most dominant species at each station and Figures 6-8 through 6-12 present the corresponding sediment characteristics. Typically the four species represent 90 to 95% of the total organisms collected at each station. Data from all stations within a region were averaged to estimate regional abundance.

Results

All animals collected during 1997-2000 belonged to one of the following nine phyla:

- Cnidaria (hydras, sea anemones)
- Platyhelminthes (flatworms)
- Nemertea (ribbon worms)
- Nematoda (roundworms)
- Annelida (segmented worms)
- Arthropoda (aquatic insects, amphipods, isopods, shrimp, crabs, mites, etc.)
- Mollusca (clams, snails)
- Chordata (tunicates)
- Echinodermata (seastars)

Of the nine phyla identified, Annelida, Arthropoda and Mollusca constituted 99.4% of the organisms collected (Figure 6-2).

The Environmental Monitoring Program (EMP) maintains a database of 284 benthic organisms identified within the upper San Francisco Estuary. The benthic database is dynamic and is constantly undergoing peer review and being updated. When a new organism is found at any of the sampling stations, the organism is identified to the species taxonomic level when possible and added to the database. During the study period, 46 new organisms were added to the benthic species list. Table 6-2 provides a list of new species and the locations from which they were collected.

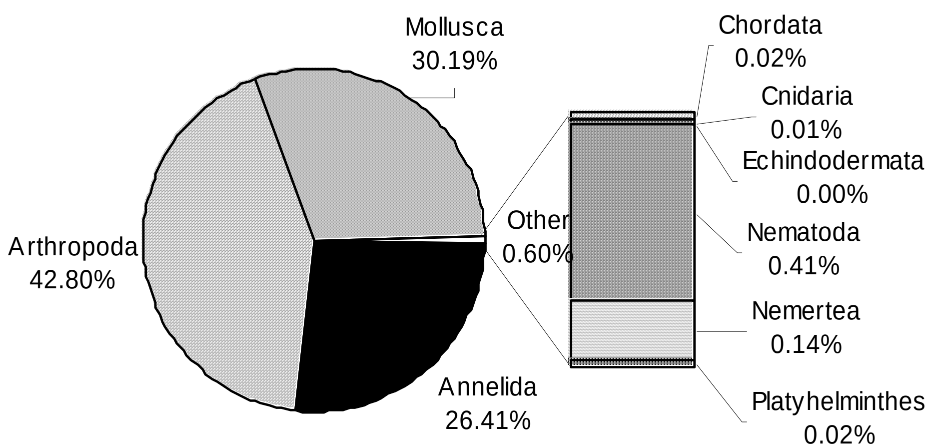
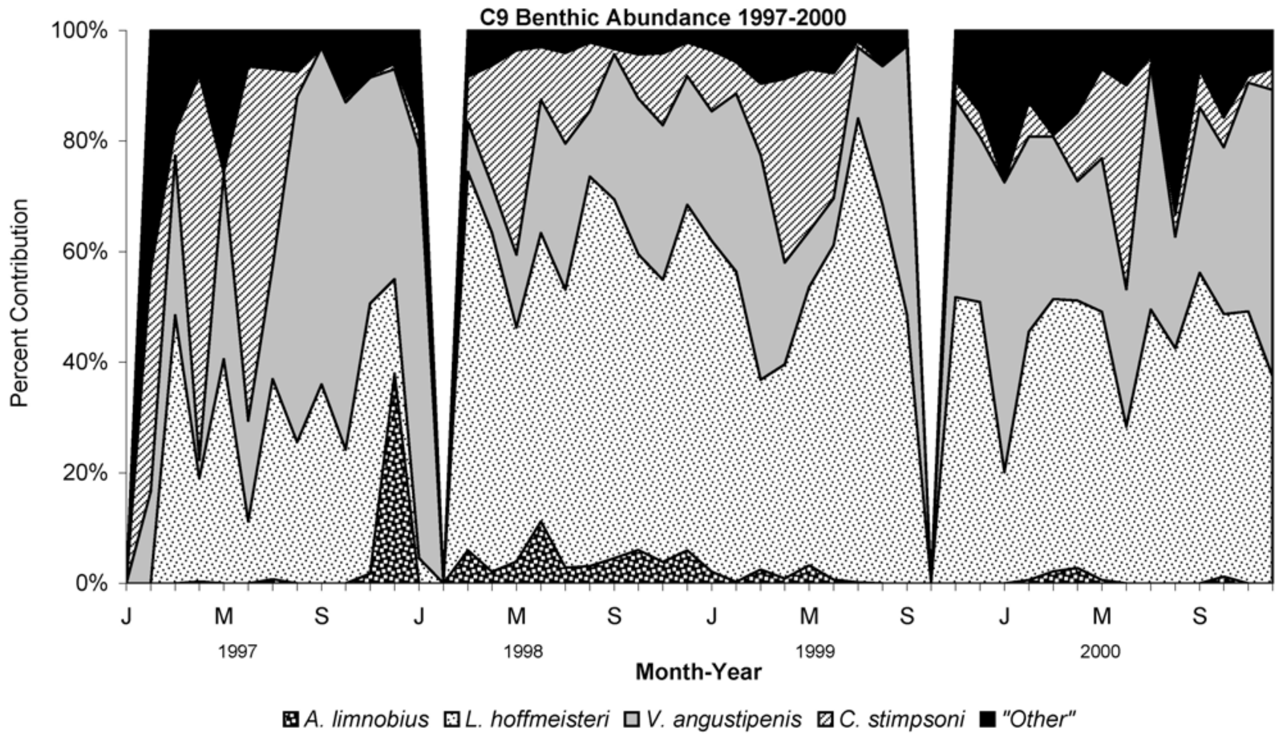


Figure 6-2 Total estuary contribution by phyla from 1997 through 2000



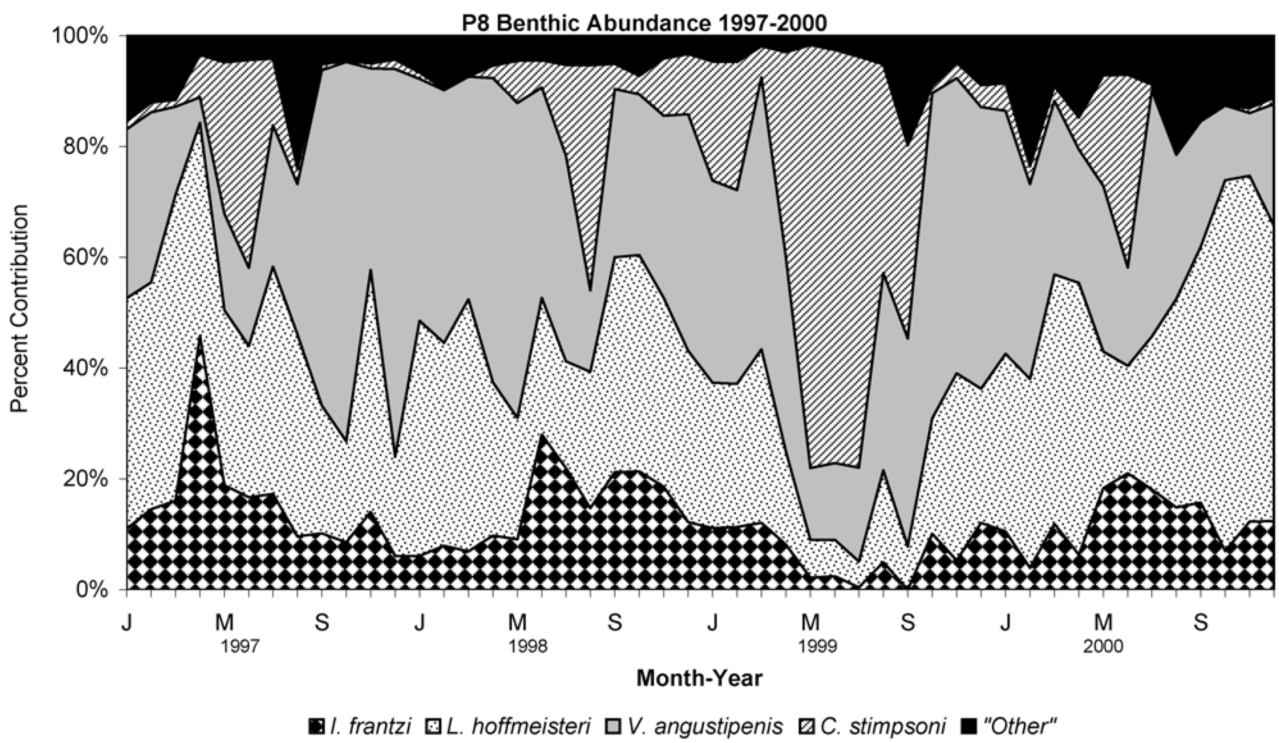
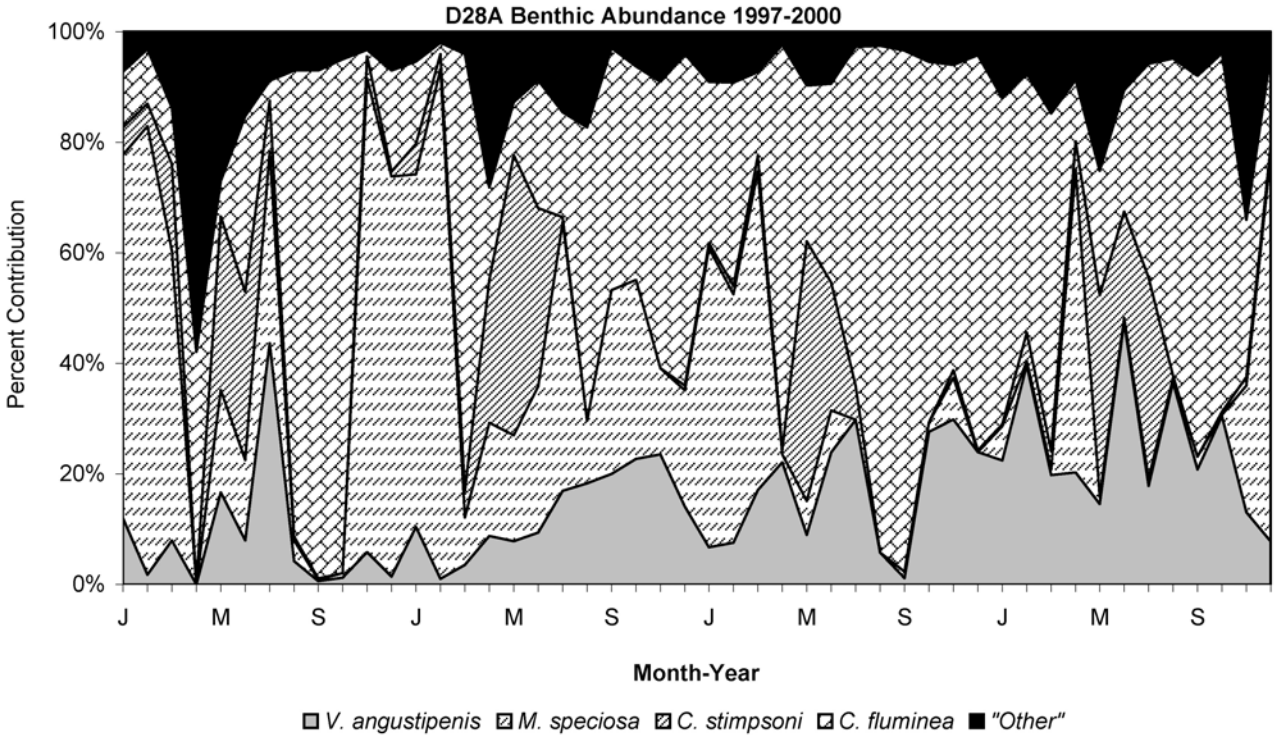


Figure 6-3 Percent abundance of macrobenthos at Stations C9 and P8, 1997-2000



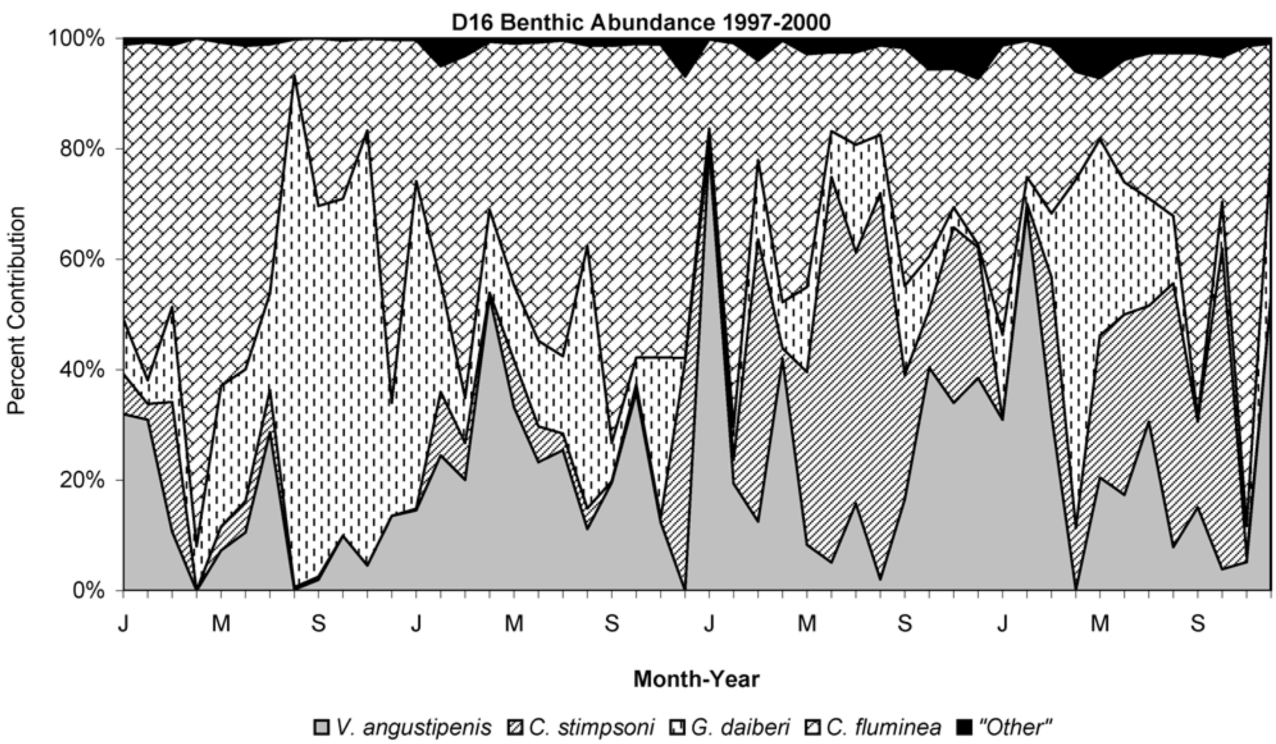
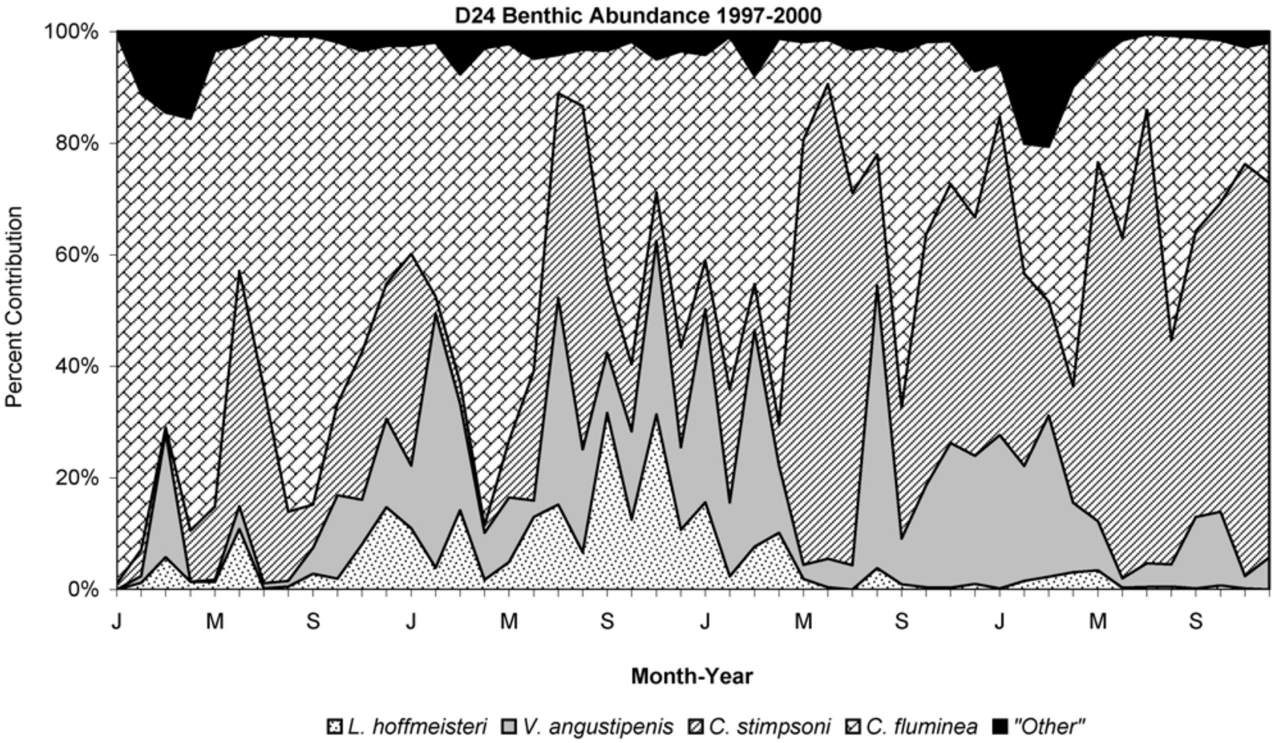


Figure 6-4 Percent abundance of macrobenthos at Stations D28A and D16, 1997-2000



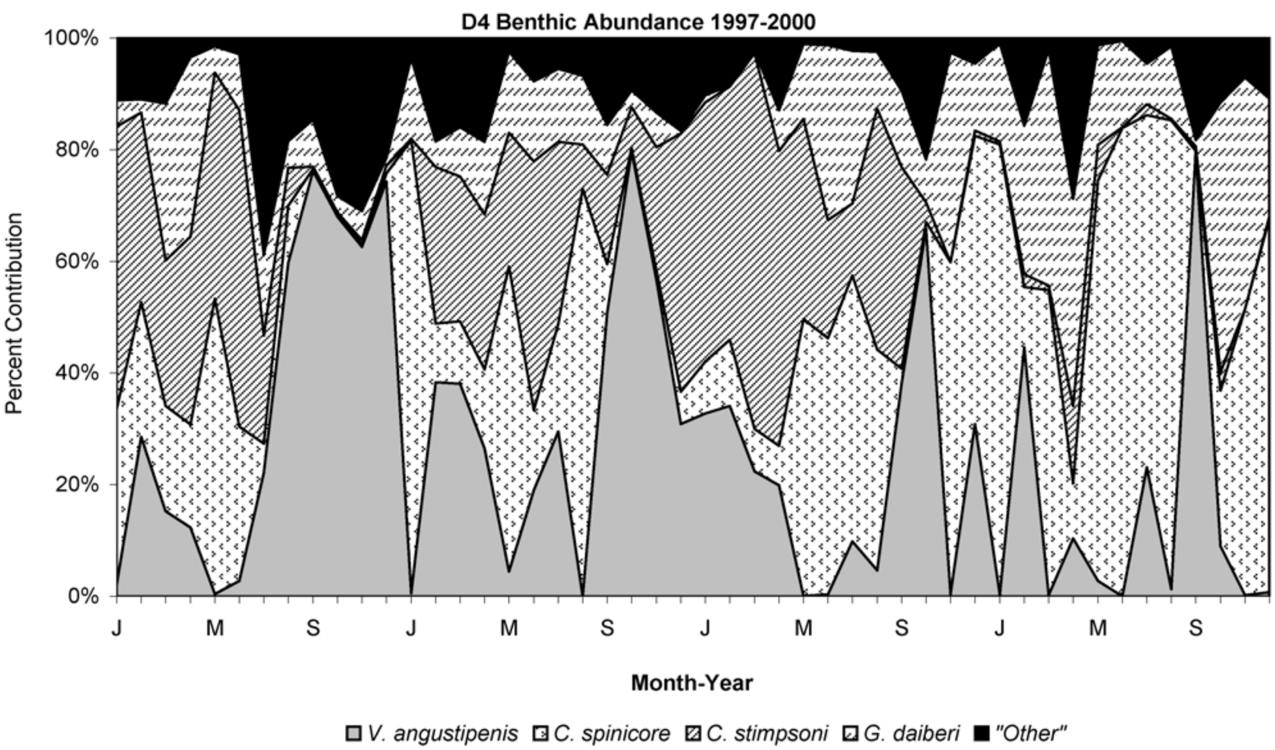
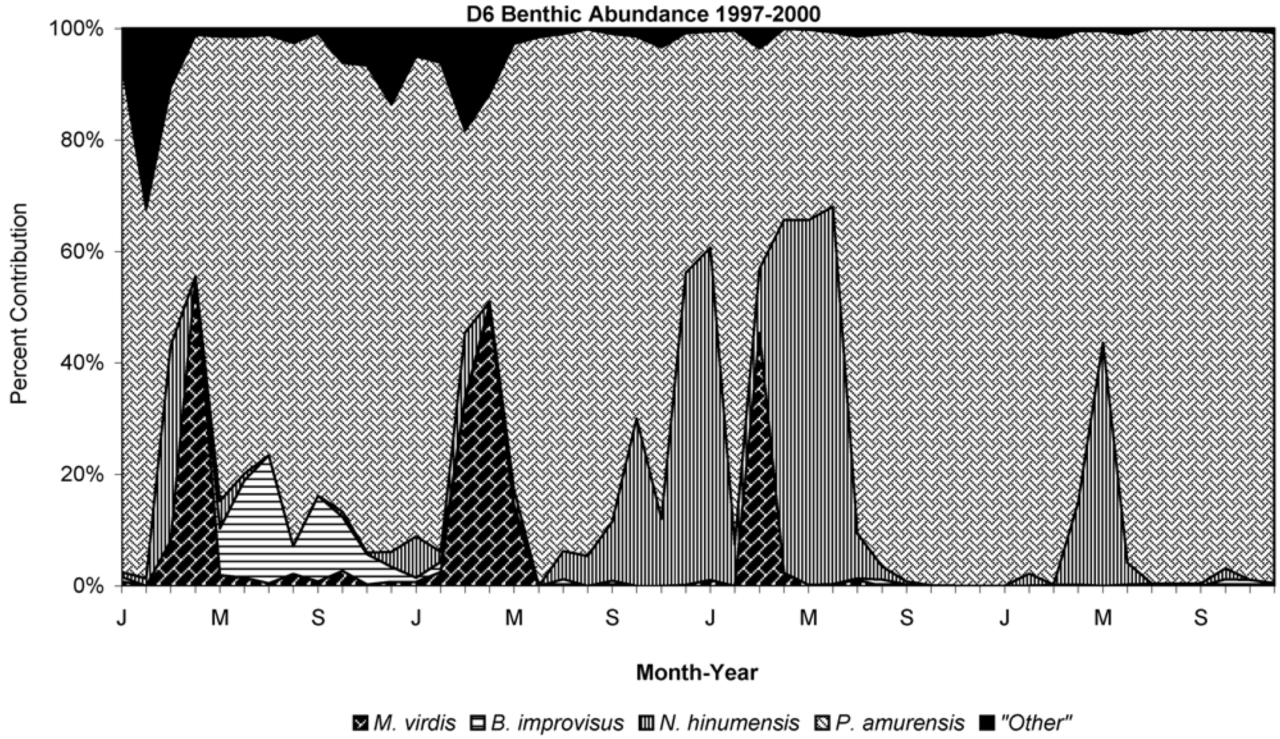


Figure 6-5 Percent abundance of macrobenthos at Stations D24 and D4, 1997-2000



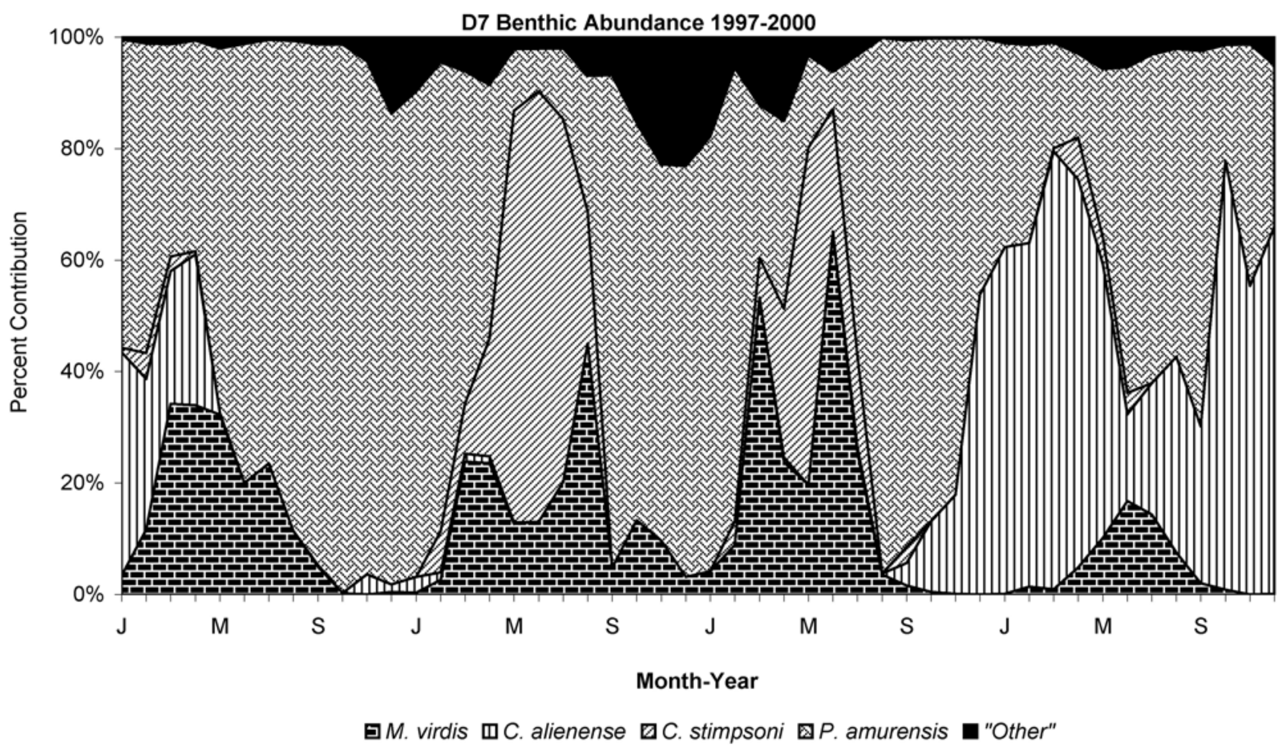
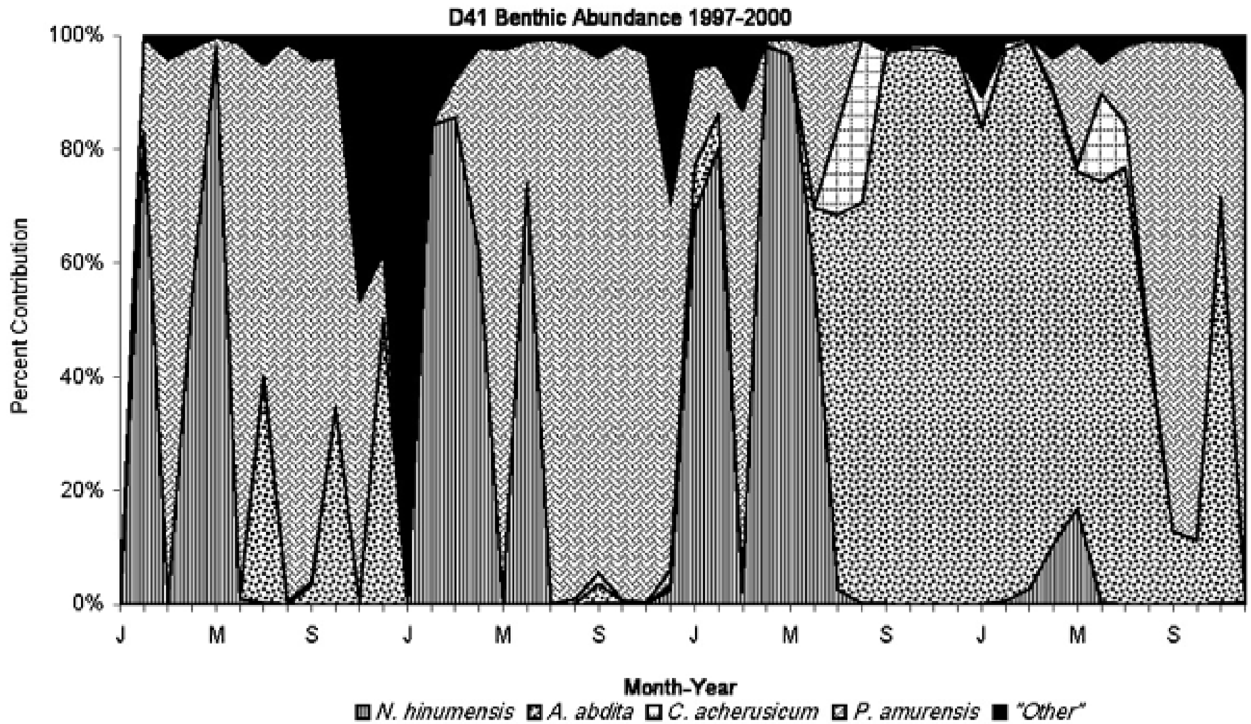


Figure 6-6 Percent abundance of macrobenthos at Stations D6 and D7, 1997-2000



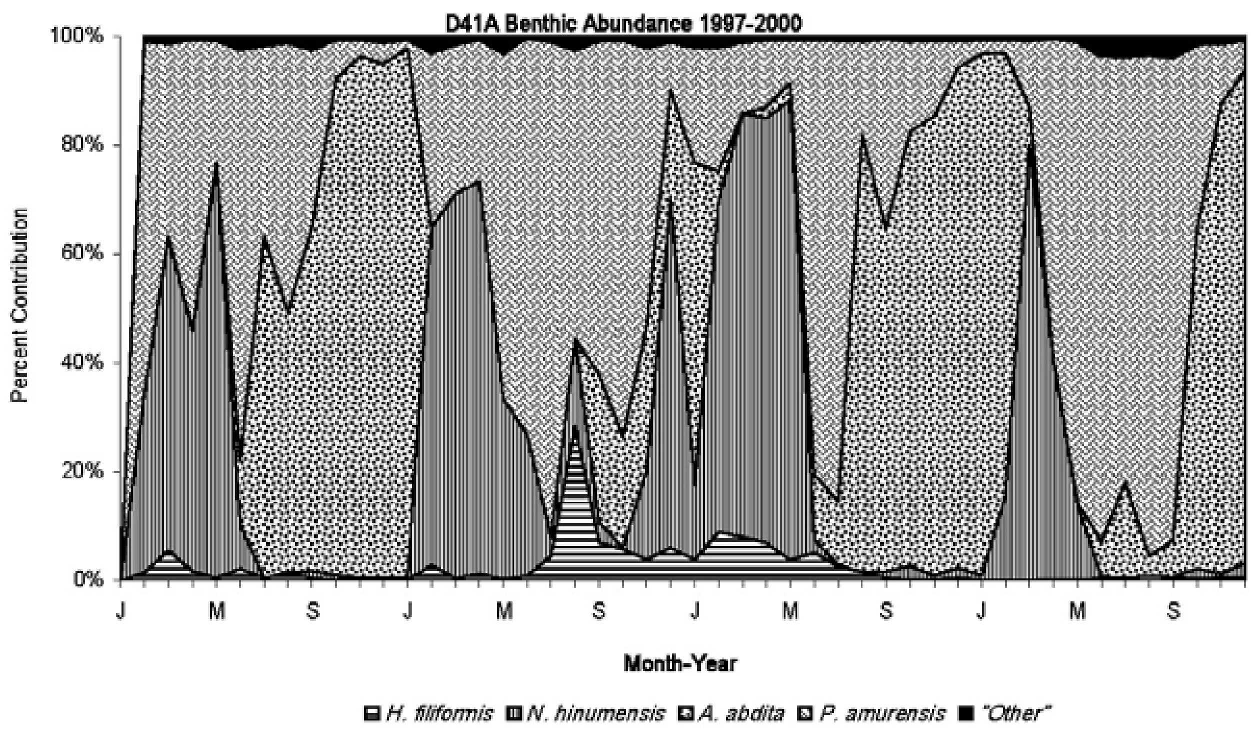


Figure 6-7 Percent abundance of macrobenthos at Stations D41 and D41A, 1997-2000

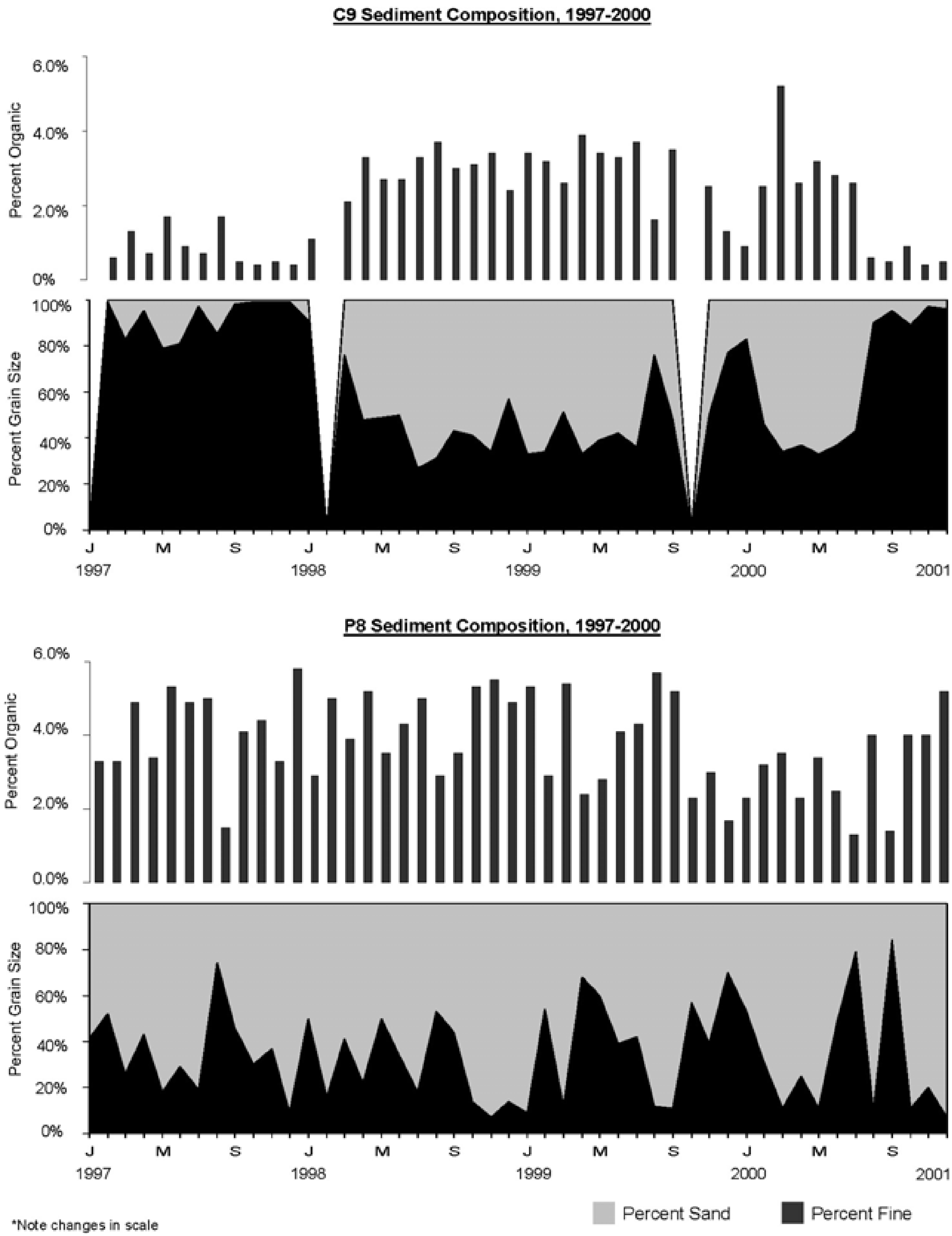


Figure 6-8 Sediment composition at sampling Stations C9 and P8, 1997-2000

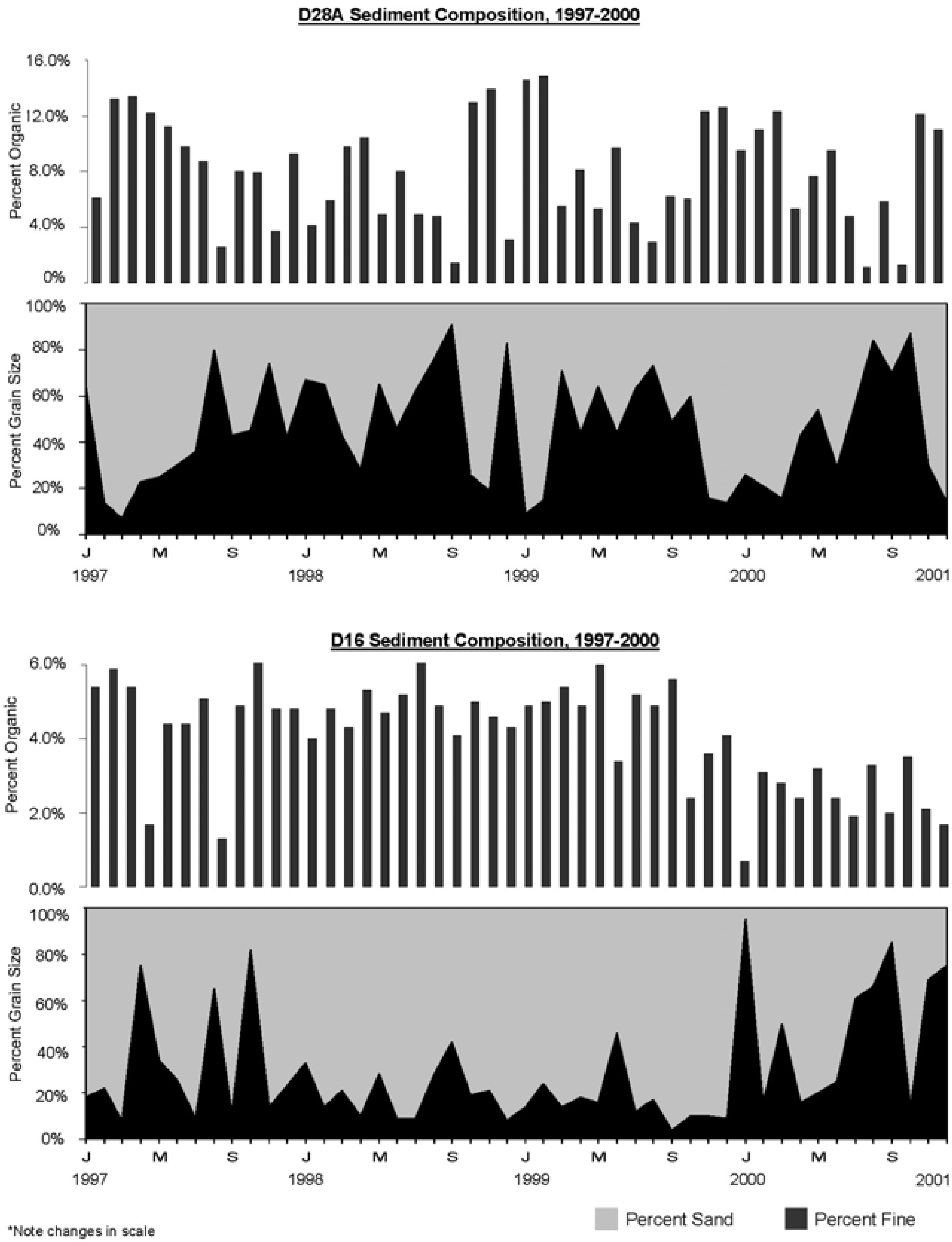


Figure 6-9 Sediment composition at sampling Stations D28A and D16, 1997-2000

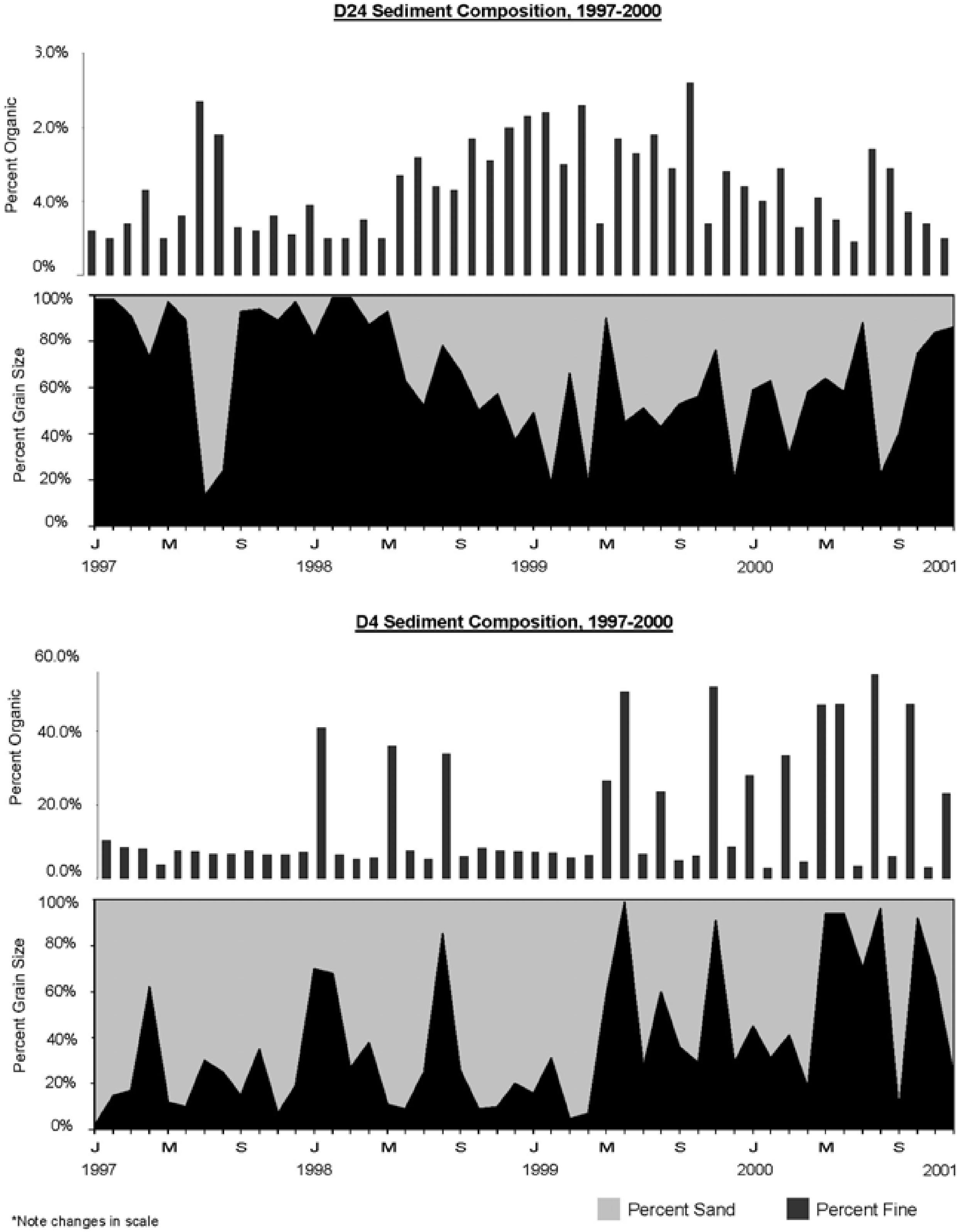


Figure 6-10 Sediment composition at sampling Stations D24 and D4, 1997-2000

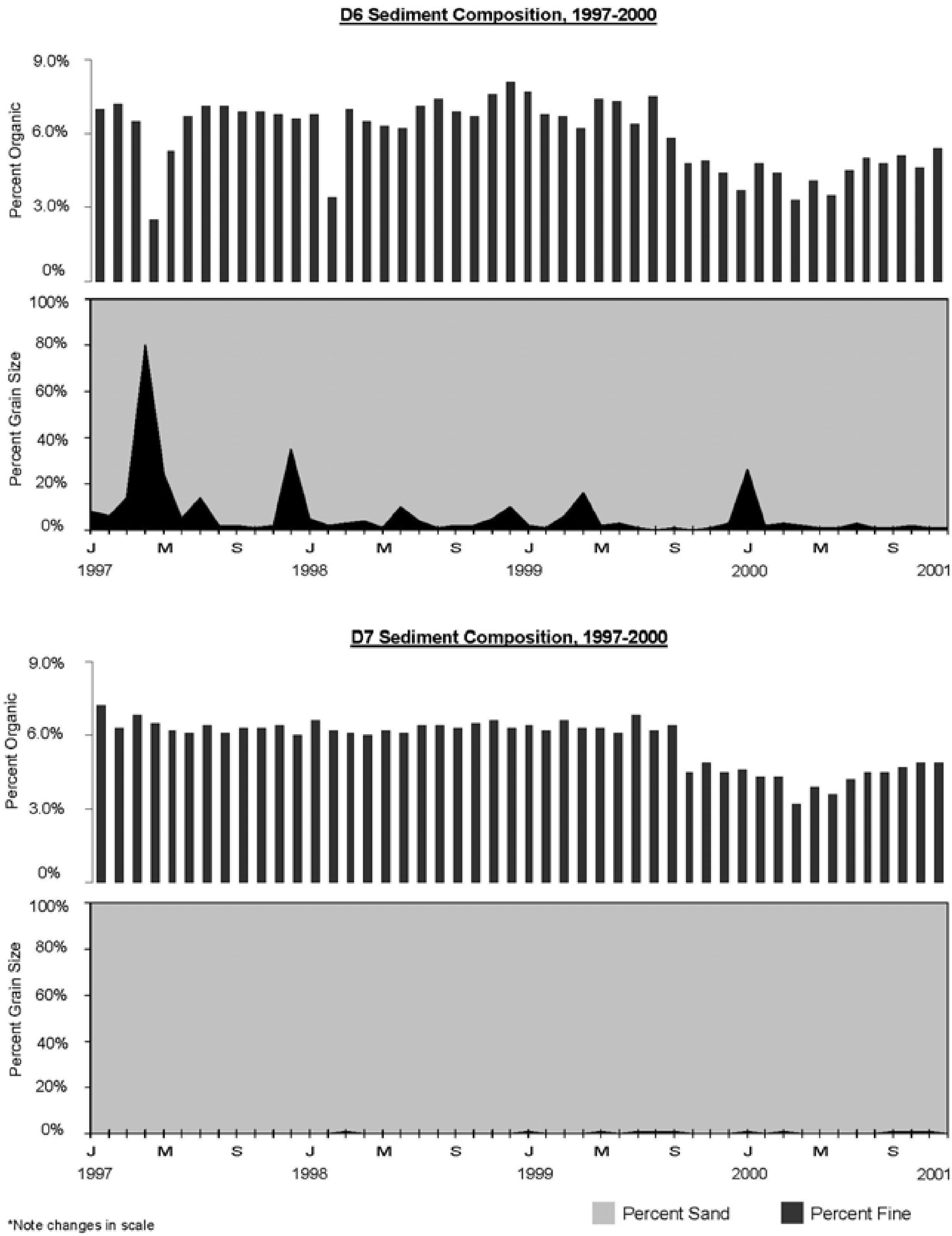


Figure 6-11 Sediment composition at sampling Stations D6 and D7, 1997-2000

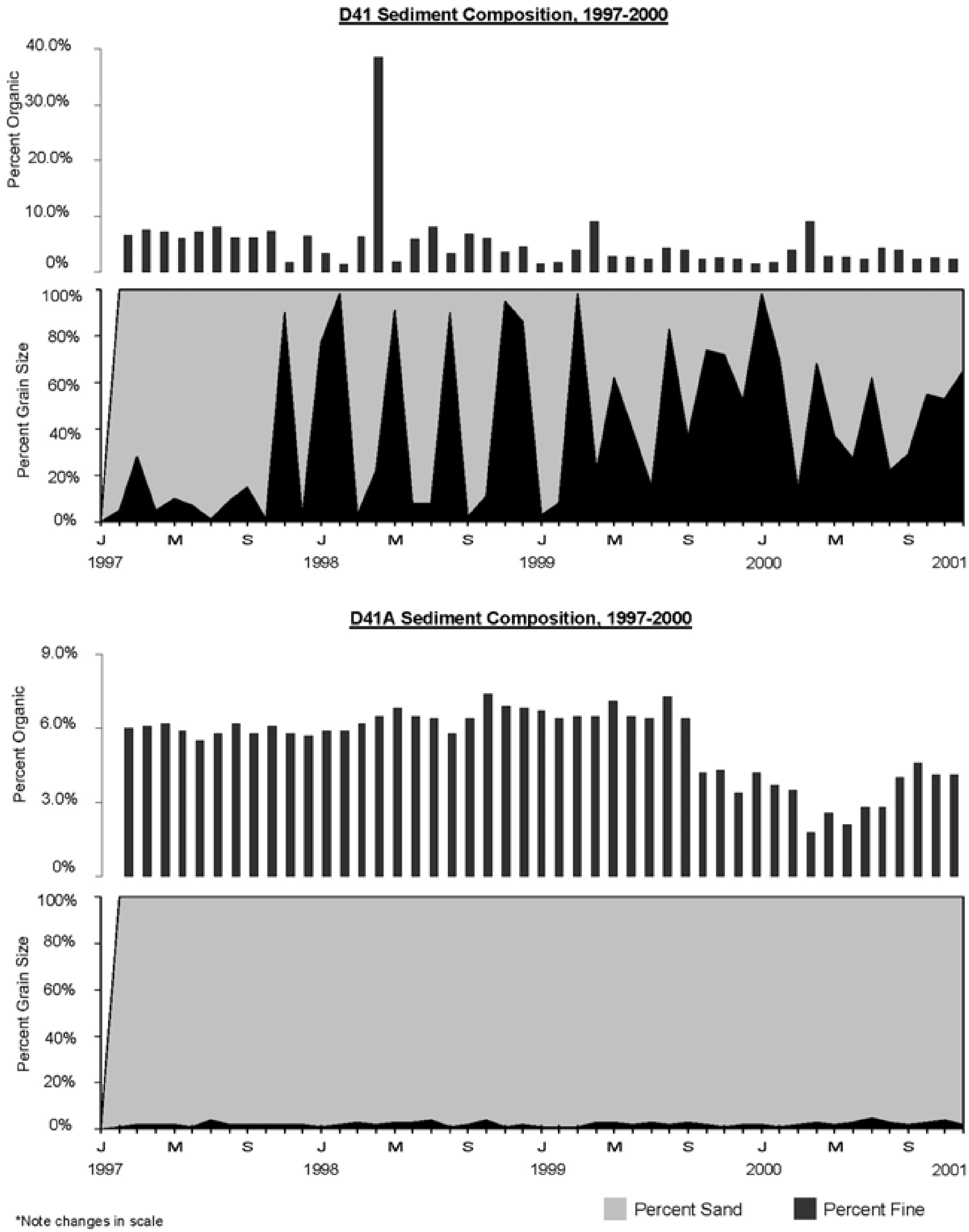


Figure 6-12 Sediment composition at sampling Stations D41 and D41A, 1997-2000

Chapter 7. Special Studies

Dissolved Oxygen Monitoring in the Stockton Ship Channel

As part of a series of special studies authorized under the Environmental Monitoring Program, dissolved oxygen (DO) levels were monitored in the Stockton Ship Channel (Channel) from Prisoner's Point in the central Delta to the Stockton Turning Basin (Basin). This study was initiated to gain more information about periodic drops in DO levels that occur in the central and eastern portions of this Channel during the late summer and early fall. Dissolved oxygen levels reported within these regions from 1997 to 2000 were characterized by frequent occurrences of DO levels of ≤ 5.0 mg/L, which, in the context of this study, is defined as DO sag[1] (DO sag). Several factors are assumed to contribute to DO sags within the Channel. These factors include: low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River past Stockton.

Because low DO levels can adversely impact fisheries and other beneficial uses of the waters within the upper San Francisco Estuary (Estuary), the State Water Resources Control Board (SWRCB) has established specific water quality objectives to protect these uses. Within the Channel, two separate DO objectives are mandated. From September through November, a DO objective of 6.0 mg/L has been established specifically for the eastern Channel (in the lower San Joaquin River between Stockton and Turner Cut) to protect fall-run Chinook salmon (SWRCB 1995). From December through August within the eastern Channel, and year round for the remainder of the Delta region, a DO objective of 5.0 mg/L has been established in the Basin Plan of the Central Valley Regional Water Quality Control Board (RWQCB 1998).

To alleviate the occurrence of low DO levels in the Channel, a rock barrier can be installed at the head of the Old River (Barrier) when warranted by the Department of Water Resources (DWR). This Barrier is designed to increase net flows in San Joaquin River past Stockton and minimize the occurrence of low DO levels in the channel. The Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2000 cfs or less. The Barrier was not installed in 1997, 1998, or 1999. In 2000, however, the Barrier was installed on October 7 because fall flows past Vernalis were projected to be lower than 2,000 cfs.

Methods

DO levels in the Channel were monitored by vessel during the late summer and early fall. During each of the monitoring runs, 14 sites were sampled biweekly from Prisoner's Point (Station 1) in the central Delta to the Stockton Turning Basin (Station 14) at the terminus of the Channel (Figure 7-1). Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each site at ebb slack tide. These samples were analyzed for DO concentrations and temperature. Top DO samples were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were measured using either a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ datalogger, or with a YSI 6600 sonde equipped with a Model No. 6562 DO sensor. Water temperatures for top and bottom were measured using either a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe, or a Seabird SBE3 temperature probe.

[1] For the purpose of this study, a "DO depression" is defined as the occurrence of DO levels ≥ 5.0 mg/L and ≤ 6.0 mg/L, and a "DO sag" is defined as DO levels of ≤ 5.0 mg/L.

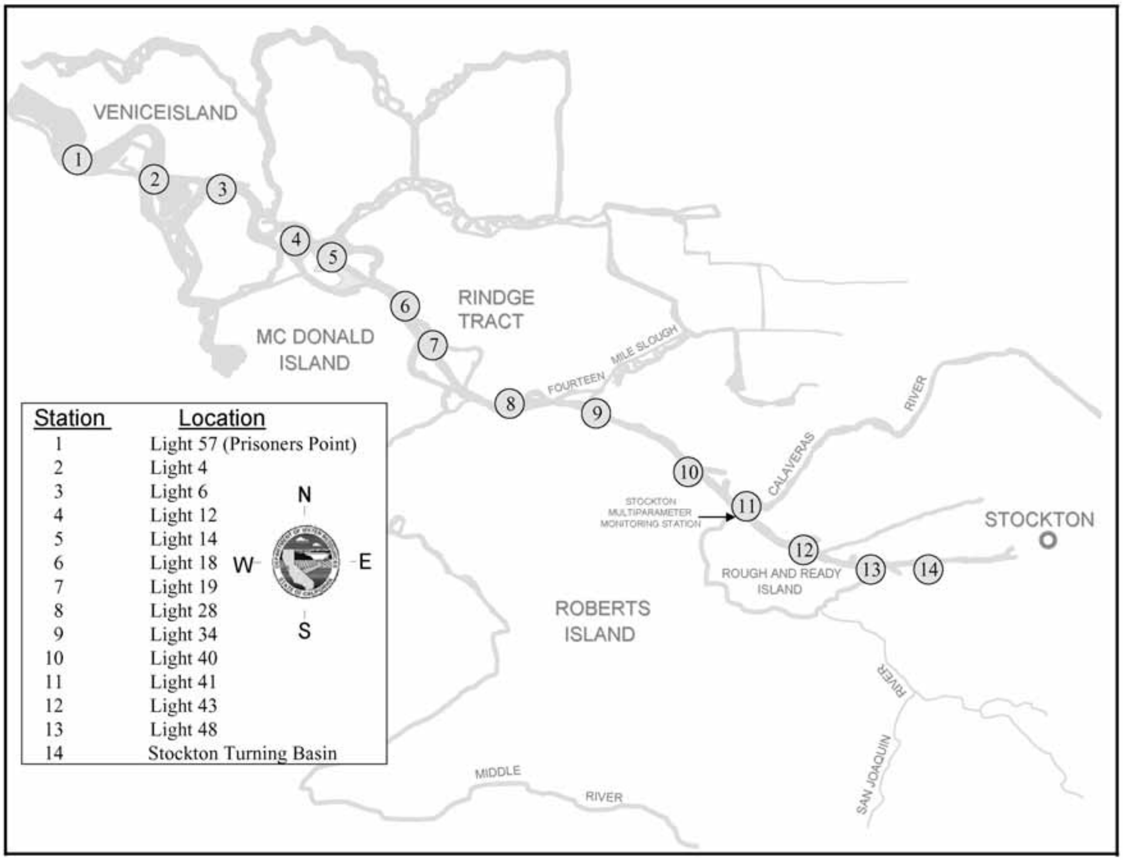


Figure 7-1 Map of dissolved oxygen monitoring stations

Flow data for the San Joaquin River at Vernalis and Stockton were obtained from continuous monitoring stations compiled by DWR's Division of Operations and Maintenance[2] and by USGS[3]. Flows past Vernalis were down-channel throughout the year and are reported as an average daily flow rate. Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter[4] to yield net daily flow. Because of low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes be reversed, or up-channel, in which case the average daily flow rate is reported as a negative value.

Results and Discussion

Measured flows in the San Joaquin River at Vernalis and Stockton are summarized by year in Table 7-1, along with measured water temperature conditions and minimum observed DO levels for the critical August through October period. Based on late summer and early fall DO findings and projected fall flows, DWR decides whether to have the Old River Barrier constructed. When deemed necessary the Barrier is usually constructed in September.

[2] Division of Operations and Maintenance, Department of Water Resources, 1416 Ninth Street, Room 620, Sacramento, CA 95814.

[3] Station information: Station SJR at Vernalis, RSAN112

[4] USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15-minute flow data, that occur on less than a 30 hour period. The resulting 15-minute time-series is then averaged to provide a single daily value which represents net river flow exclusive of tidal cycles.

Table 7-1 Summary of flow and water quality conditions in the San Joaquin River during the late summer and fall, 1997-2000

Year	Vernalis Avg. Daily Flow Aug.-Nov. (cfs)	Stockton Range of Flows Aug.-Nov. (cfs)	Reverse Flow at Stockton?	Water Temp. Aug.-Sept. (°C)	Water Temp. Oct.-Nov. (°C)[1]	Minimum DO Aug.-Nov. (mg/L)	Barrier at Old River?
1997	2,089	–466 to +188	Present	22.0 – 27.8	15.6 – 24.3	2.6	No
1998	5,042	1,070 to 2,011	Not Present	21.9 – 28.0	16.3–18.8*	5.0	No
1999	2,139	-392 to +352	Present	21.0 – 26.5	13.4 – 21.9	3.2	Yes
2000	2,413	–401 to +626	Present	21.8 – 27.1	12.7 – 19.4	4.5	No

[1] By late fall, water temperatures within the Stockton Ship Channel had dropped considerably from the late summer measurements. By the end of monitoring (usually in November) the temperatures within the Channel were 15 °C or less. Monitoring in 1998 ended on October 20.

During the 1997 through 2000 calendar study period[5], water years 1997 and 1998 were classified as "Wet", and water years 1999 and 2000 were classified as "Above Average", according to the San Joaquin Valley 60-20-20-Water Year Hydrological Classification Index[6]. Although the fall San Joaquin River flows past Vernalis were relatively high for all years, the DO conditions within the Channel differed considerably between years. The late summer and early fall DO conditions for each year are described in the remainder of this text.

Calendar Year 1997

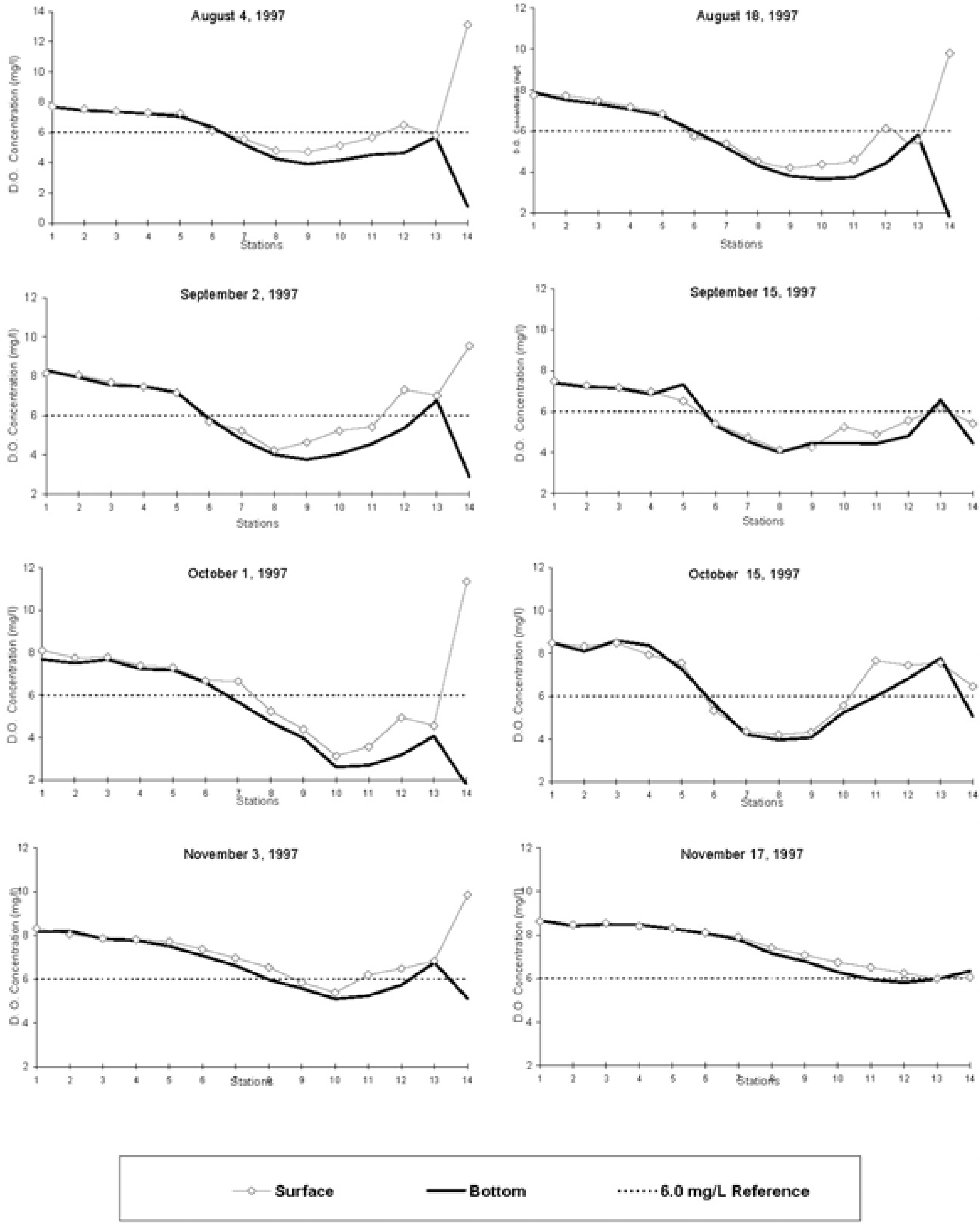
Calendar year1997 was a wet year with moderate San Joaquin River fall flows past Vernalis averaging 2,089 cfs (Table 7-1). The average daily flows in the San Joaquin River past Vernalis approached 2,000 cfs in August and September and exceeded 2,000 cfs in October and November. Because of these relatively high average daily flows and the potential for overtopping, bank erosion, and October reservoir drawdown releases, the Old River Barrier was not installed in the fall of 1997. In spite of the relatively high flows in the San Joaquin River past Vernalis, average daily flows past Stockton ranged from -466 cfs to +198 cfs from August through September (Table 7-1). Reverse flows past Stockton continued until early October when flood-control related reservoir releases within the drainage basin of the San Joaquin River were initiated.

A DO sag developed in the eastern Channel immediately west of the Rough and Ready Island area (Stations 8 through 13) in August, and persisted through early October (Figure 7-2). This DO sag was coincident with a period of warm water temperatures (22-27 °C), and reverse flow conditions past Stockton.

Improved flow conditions in the San Joaquin River ended reverse flow conditions at Stockton on October 10. By October 15 the DO sag had lessened and had moved downstream. By mid-November the DO sag was eliminated.

[5] Because a water year ends on September 30, which is midway through the typical August through November study period, the findings of the fall DO special studies are discussed primarily using calendar years to eliminate the need to use two water years to describe one fall study period. However, hydrologic conditions within the drainage basin of the San Joaquin River influence inflows to the Stockton Ship Channel, and water years will be used when discussing these conditions.

[6] The San Joaquin Valley 60-20-20-Water Year Hydrological Classification Index is used because inflows to the Stockton Ship Channel occur predominantly through the San Joaquin River.



*Note changes in scale

Figure 7-2 Dissolved oxygen concentrations in the Stockton Ship Channel in 1997

Calendar Year 1998

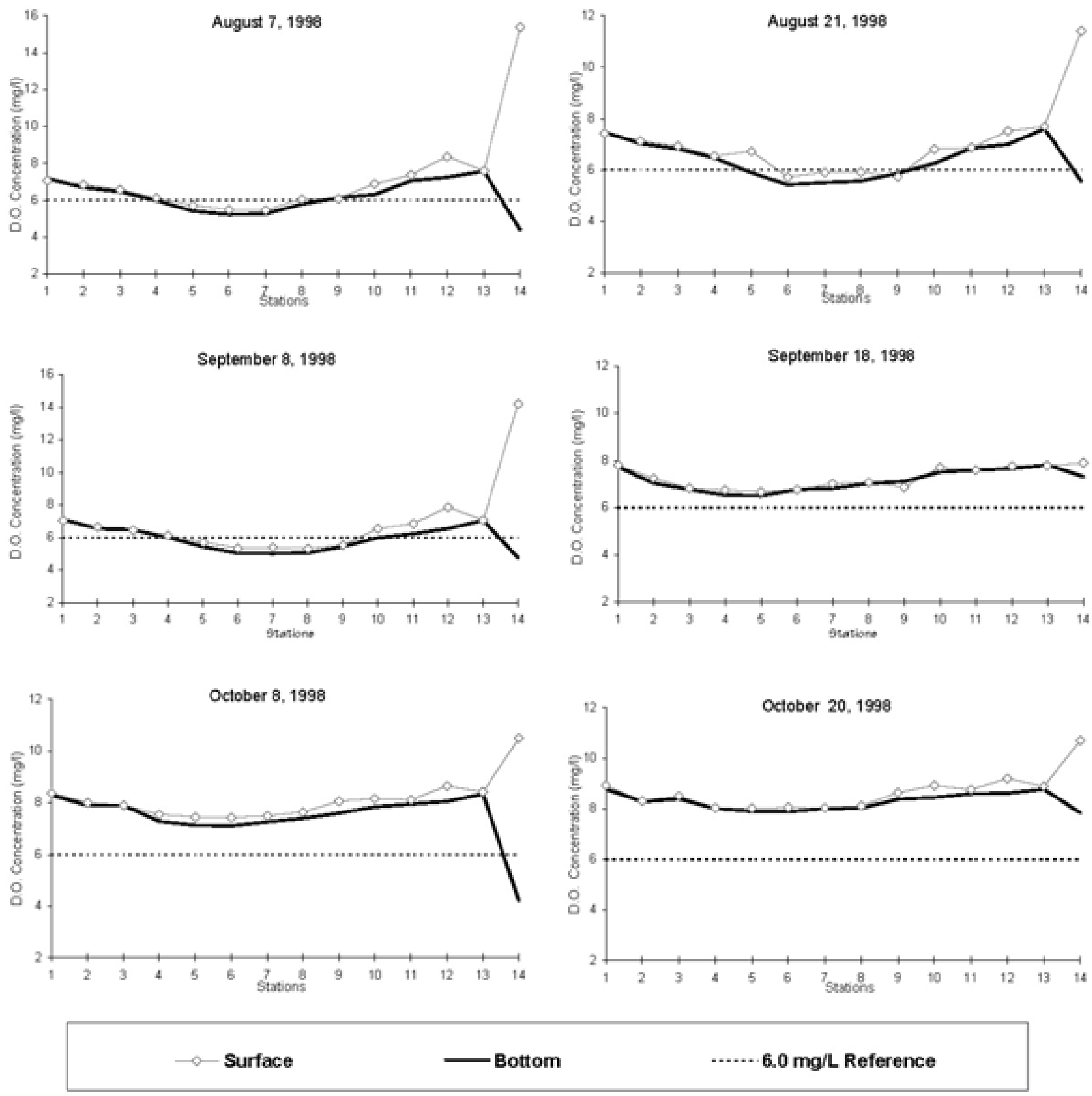
Calendar year 1998 was a wet year with high San Joaquin River fall flows past Vernalis averaging 5042 cfs (Table 7-1). Average daily flows past Stockton ranged from 1,020 to 2,011 cfs. No reverse flows were recorded during the year. Because of the exceptionally high flows at Vernalis and the absence of reverse flow conditions at Stockton, the Barrier at Old River was not constructed.

In spite of the exceptionally high San Joaquin River inflows into the eastern Channel, a DO depression, an area in the channel where DO levels are greater than or equal to 5.0 mg/L and less than or equal to 6.0 mg/L, occurred in the central Channel from Columbia Cut (Station 5) to Fourteen Mile Slough (Station 9) in August and early September (Figure 7-3). This area of depression was considerably west of the Rough and Ready Island area in the eastern Channel where the sag area has historically occurred. By October 20, 1998, DO levels throughout the Channel recovered to levels > 8.0 mg/L due, in part, to cooler water temperatures (15-18 °C in October) and sustained high San Joaquin River inflows to the Channel.

Calendar Year 1999

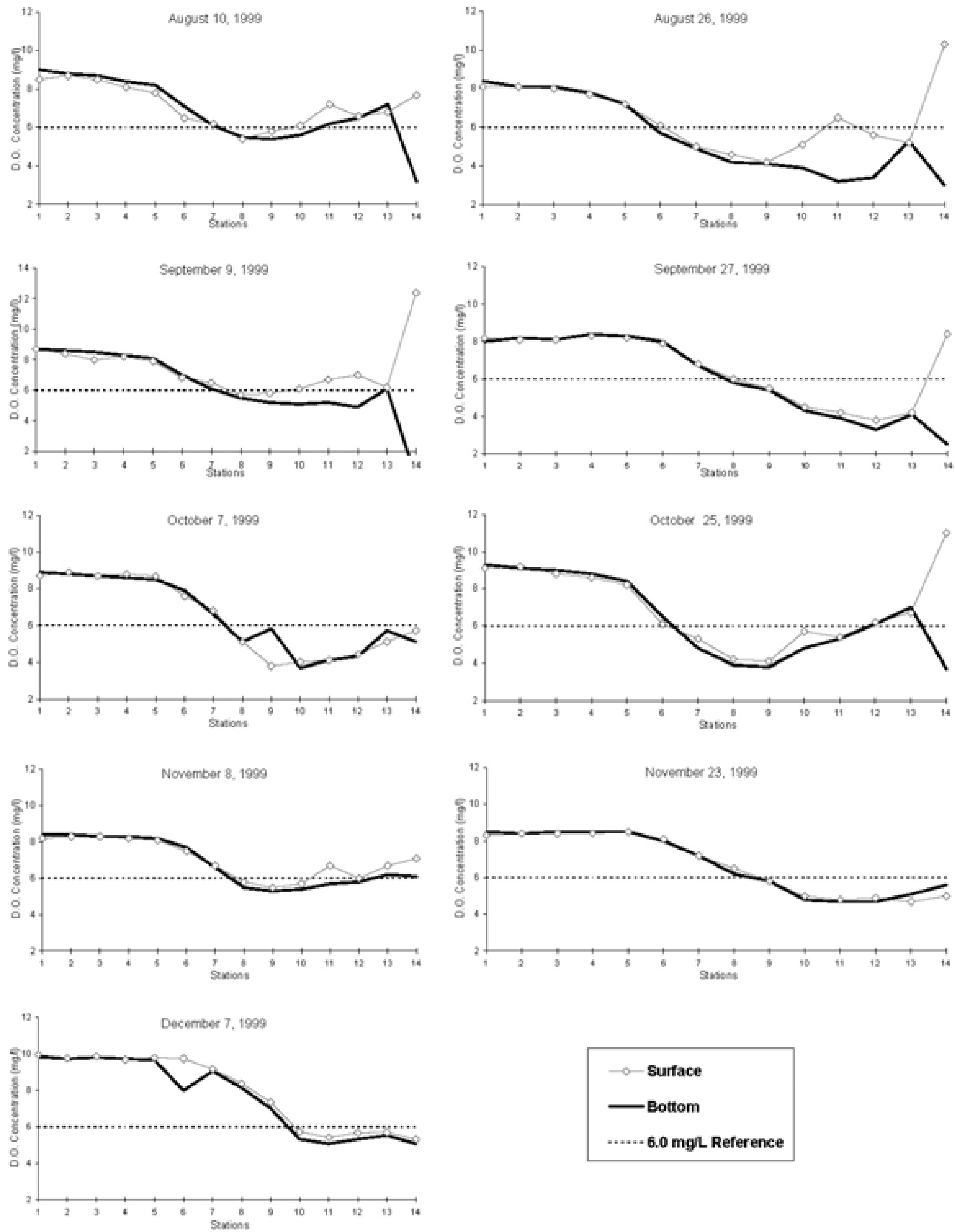
Calendar year 1999 was an above average water year with moderate San Joaquin River fall flows. The average daily flows in the San Joaquin River past Vernalis were 2,139 cfs (Table 7-1). Because of the relatively high average daily flows, and concern over possible bank erosion and overtopping, the Old River Barrier was not installed. In spite of the high average daily flows in the San Joaquin River past Vernalis, average daily flows past Stockton ranged from -392 cfs to +352 cfs from August through November. These reverse flows continued until early December when reservoir releases within the drainage basin of the San Joaquin River were initiated.

In November and December of 1999, field crews observed extensive dredging in the central and eastern Channel. In addition, aerators maintained by the Army Corps of Engineers near the eastern end of Rough and Ready Island (Station 13) were not operating during the dredging operations, as required. The lack of aeration and potential increase in BOD may have contributed to the persistence of DO levels of ≤ 5.0 mg/L measured within the central and eastern Channel in 1999 through late fall (Figure 7-4). The 1999 DO sag was the longest lasting of the four-year monitoring period. Unlike previous years, DO concentrations did not recover to levels greater than 6.0 mg/L in the central and eastern Channel in the late fall, despite slightly higher inflow and markedly cooler water temperatures (10 -17 °C in November and December).



*Note changes in scale

Figure 7-3 Dissolved oxygen concentrations in the Stockton Ship Channel in 1998



*Note changes in scale

Figure 7-4 Dissolved oxygen concentrations in the Stockton Ship Channel in 1999

Calendar Year 2000

Calendar year 2000 was an above average water year, with moderate late summer San Joaquin River flows past Vernalis averaging 2,415 cfs (Figure 7-5). Because late summer San Joaquin River flows past Vernalis were relatively low, and fall flows were not projected to be sufficient to alleviate DO concerns within the eastern Channel, DWR installed the Old River Barrier on October 7. Although average daily flows in the San Joaquin River past Vernalis increased in October, the installation of the Barrier was not sufficient to eliminate reverse flow conditions in the San Joaquin River past Stockton. Average daily flows past Stockton ranged from -401 cfs to +626 cfs from August through October (Figure 7-5).

A DO sag was detected in the central portion of the Channel on August 14, a period when water temperatures were warmest and San Joaquin inflows were lowest (Figure 7-5). Although DO levels improved to 6.0 mg/L or greater in late August and early September, a DO depression developed within the Channel by September 26. This depression also coincided with warm water temperatures (21-27 °C) and sustained reverse flow conditions past Stockton. Dissolved oxygen conditions improved in early October, and were ≥ 8.0 mg/L throughout the Channel by October 26. These high levels were sustained in November, and the Old River Barrier was removed on December 8.

Turning Basin

Exceptionally high surface and low bottom DO levels were periodically measured in the Stockton Turning Basin in the fall during all four years of the study. Surface DO levels ranged from 7.7 to 17.0 mg/L, and bottom DO levels ranged from 0.3 to 5.6 mg/L (Figures 7-2 through 7-5).

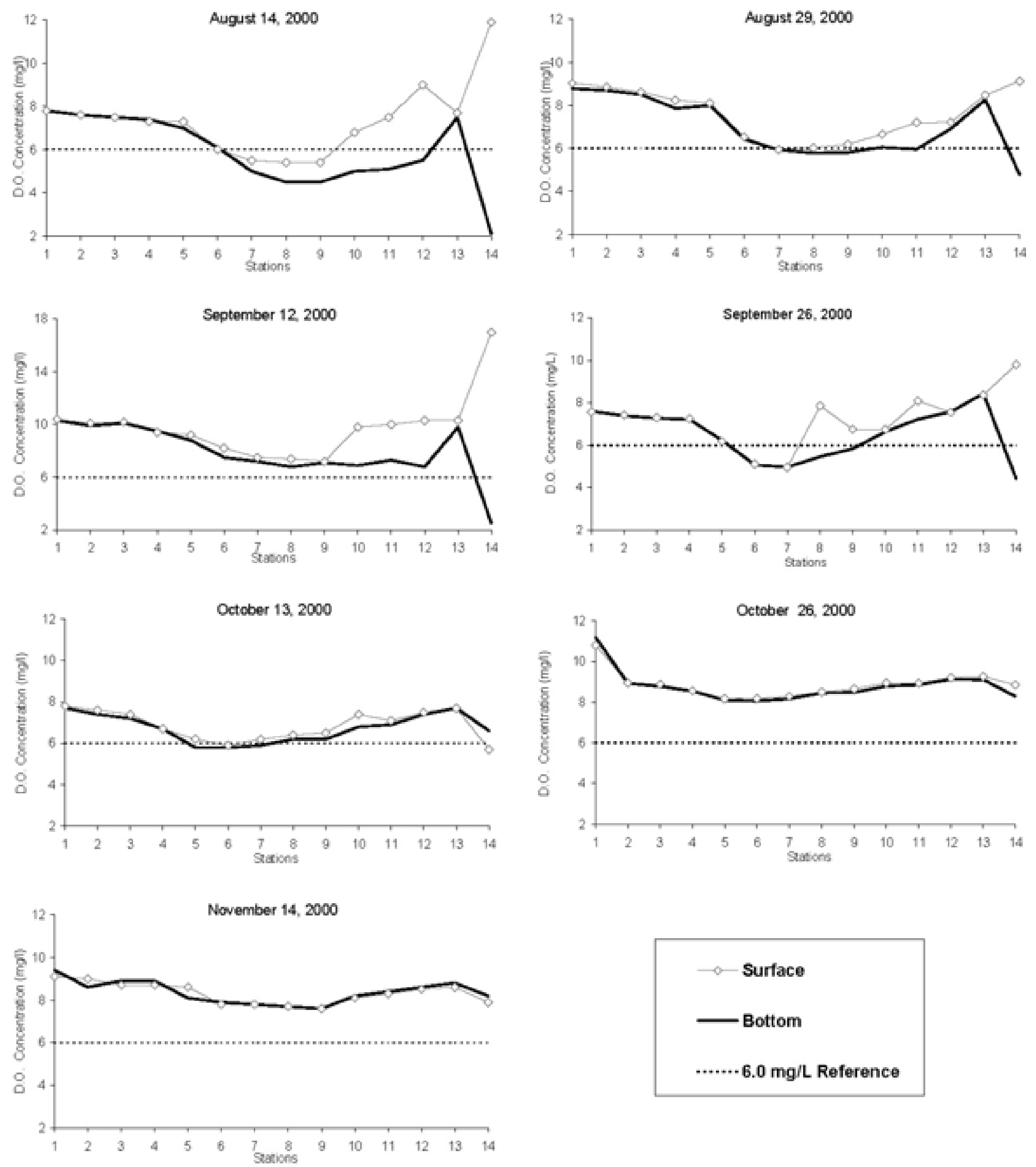
The highly stratified DO conditions periodically detected appear to be the result of localized biological and water quality conditions occurring within the Basin. The Basin is at the eastern dead-end terminus of the Ship Channel. The Basin has lower tidal activity and water circulation, and increased residence times, as compared with the downstream Channel. As a result, water quality and biological conditions within the Basin historically differ from those within the main downstream Channel.

The Basin also has periodic extensive late summer and fall algal blooms and die-offs. These algal blooms are composed primarily of cryptomonads, diatoms, flagellates, blue green algae, and green algae. When conditions are right, these blooms can result in highly vertically stratified DO levels. At the surface, high algal production produces supersaturated DO levels. At the bottom, dead or dying algae contribute to high oxygen demand and can deplete DO levels to near zero. Water quality conditions in the Basin are further influenced by BOD loadings in the area from regulated discharges into the San Joaquin River, and from recreational activities adjacent to the Basin.

Summary

Monitoring of DO conditions in the Stockton Channel from 1997 to 2000 showed that DO levels regularly dropped below the State established water quality objectives. Although this special study was not designed to determine the specific cause of these DO sags, it appears that specific hydrologic conditions, combined with changes in biochemical oxygen demand, algal production, and water temperature, affect DO levels within the channel.

Because hydrologic measurements are available for use with this study, it is possible to make preliminary observations between recorded DO levels and Channel hydrology. In particular, DO levels dropped below 5 mg/L in the Channel primarily when reverse flows occurred (Table 7-1). In addition, low DO levels appeared to be associated with low flow conditions (Table 7-1).



*Note changes in scale

Figure 7-5 Dissolved oxygen concentrations in the Stockton Ship Channel in 2000

Algal Bloom Surveys

Introduction

Algal blooms are a natural and regularly occurring phenomenon within the upper San Francisco Estuary. The Compliance Monitoring Program has conducted special studies over the years to identify the causative bloom organisms and to document the extent and intensity of those blooms. These studies were conducted in response to mandated Compliance Monitoring and in response to the bloom's potential impact to the State Water Project (SWP) operations and the upper San Francisco Estuary. This chapter briefly describes algal bloom surveys conducted during the 1997 through 2000 calendar year period.

The Upper San Francisco Estuary contains more than 600 species of phytoplankton, many of which can cause water-discoloring blooms when rapid growth of a phytoplankton species is triggered by suitable conditions. A number of environmental factors influence the growth of phytoplankton, including nutrient levels, photoperiod, light intensity, water temperature, pH, salinity, turbidity, flow rates, and predation. Generally, algal blooms occur in the Estuary when nutrient availability is sufficient, predation is low, and factors essential for phytoplankton growth such as light and water temperature are within the appropriate ranges. Blooms generally occur in the late winter and spring when nutrient levels are at, or near, their maximum; water temperature and light levels have increased to suitable levels for algal growth; and inflows have dropped sufficiently to permit water residence times within the Estuary sufficient for rapid algal growth.

Blooms in most estuaries can be identified visually by the appearance of free-floating algae or the distinct coloration of surface water due to the presence of algae. A bloom can also be defined by the presence of highly elevated surface chlorophyll *a* concentrations. Within the upper San Francisco Estuary, the blooms detected typically showed both characteristics. Figure 7-6 shows the location of the major blooms detected within the estuary during the study period.

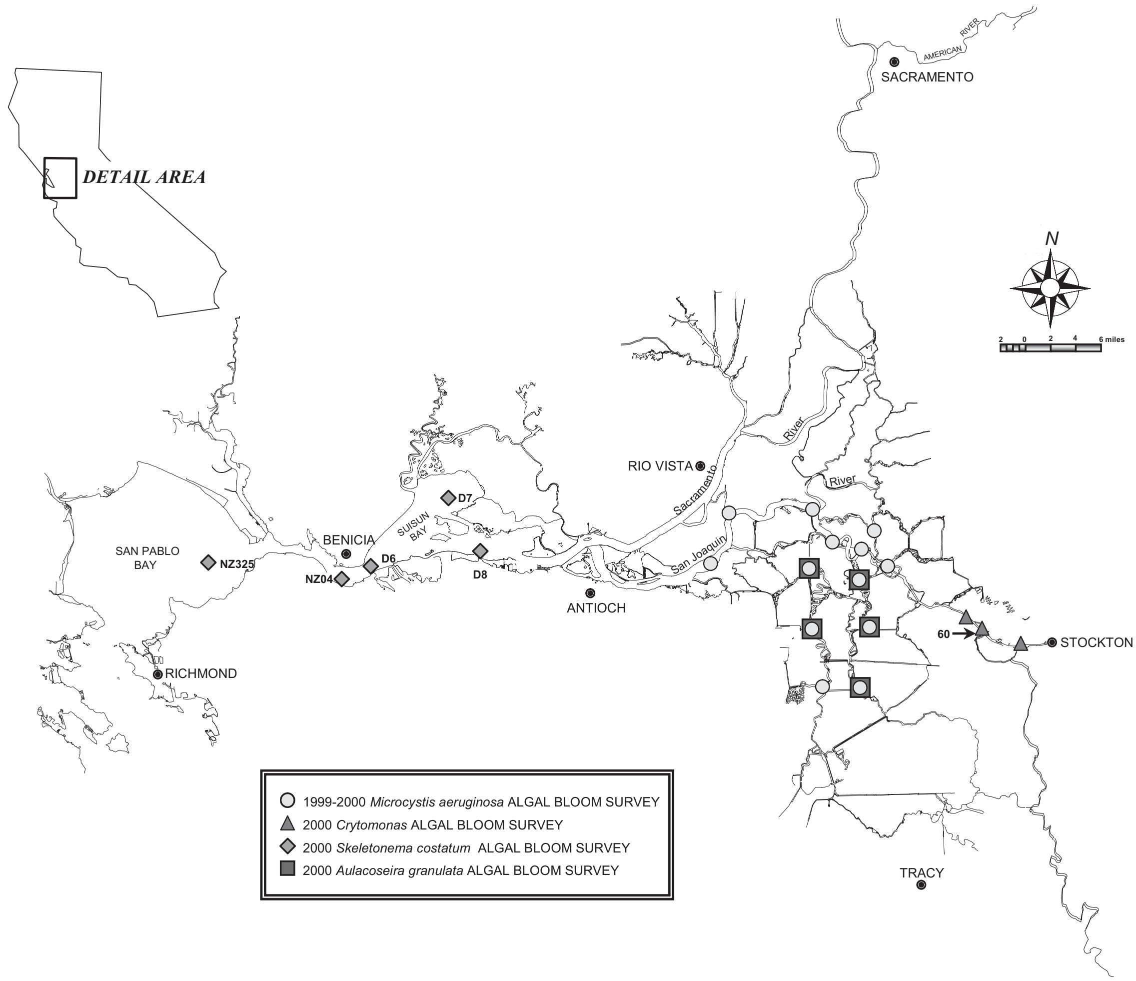


Figure 7-6 Map of algal blooms surveyed during 1997-2000

Methods

Monitoring for algal blooms is incorporated within the protocols for regular monthly mandated monitoring aboard the research vessel *San Carlos*. The presence of blooms is monitored visually or by continuous fluorometric readings while the vessel is moving or at fixed predetermined sampling stations. Water samples are pumped from a 1-meter depth through an onboard continuous monitoring instrument (Sea Bird Electronics/31 unit), which records values for water temperature, DO, and specific conductance. A flow-through Turner Designs Model 10-AU digital field fluorometer and nephelometer measure chlorophyll fluorescence and nephelometric turbidity values, respectively. When a bloom is observed, discrete samples are collected for measurement of extracted chlorophyll *a* and phytoplankton identification by Bryte Laboratory.

Emergency follow-up studies are conducted when a bloom organism may cause taste and odor problems and clog filters for municipal water supplies. These studies sample at 15 stations throughout the central and southern Delta (the area leading to Clifton Court Forebay and the Harvey O. Banks Pumping Plant). In addition, DWR's Delta Field Division and the Contra Costa Water District are notified so that staff can alter project operations or adjust water treatment procedures as necessary to accommodate for the presence of the organism within the Estuary.

Results

Approximately four algal blooms were observed and monitored during the period of this study. The causative organisms were identified as belonging to one of four primary species in the following genera: *Microcystis, Cryptomonas, Skeletonema,* and *Aulacoseria.*

During the late winter and early spring of 2000 (March and April), a bloom of the filamentous diatom, *Skeletonema costatum,* was detected. Historically, most of the blooms in San Pablo and Suisun bays have been *S. costatum* (Cloern and Cheng 1981). This bloom was initially detected in a localized area in mid-March near Station NZ325 (Light 11-San Pablo Bay) (Figure 7-6). During subsequent follow-up surveys in mid-April, the bloom had expanded easterly to include Suisun Bay near Station D8. Growth rates for this diatom are governed primarily by light availability, salinity, and temperature (Cloern 1979; Cloern and Cheng 1981).

In early September 2000, the bloom-forming diatom with filter clogging potential, *Aulacoseira* (formerly *Melosira*) *granulata*, was detected. The bloom formed a thick filamentous mat that fouled the plankton net used in sample collection. *A. granulata* was identified in five phytoplankton samples collected at stations in the central and southern Delta. This species commonly occurs in the southern Delta during summer when salinity is high from discharge of agricultural return water and when longer residence times have increased water temperature (Lehman 1996).

In the eastern Delta, a brief and moderately intense phytoplankton bloom occurred in the Stockton Ship Channel in late May 2000. The bloom was near the multi-parameter recording station (Station 70) in the San Joaquin River at Burns Cutoff, near the Rough and Ready Island. Algal production rates in this area, in the late spring and early summer, are typically influenced by increased light intensity, warmer water temperatures and lower San Joaquin River inflows (Lehman 1996). The high productivity characteristic of the Stockton Turning Basin and Yacht Harbor may have also contributed to the establishment of the bloom in the San Joaquin River. At the end of May 2000, the bloom extended from the San Joaquin River at Buckley Cove to the Stockton Yacht Harbor at the extreme eastern end of the Stockton Ship Channel. The bloom consisted of mixed phytoplankton species, with *Cryptomonas* being the most dominant alga. Other algae present included *Thalassiosira eccentrica*, *Aphanizomenon flos-aquae*, *Cosinodiscus*, and flagellated green algae. Cryptophytes and flagellate groups are most abundant in dry water-years and tolerate higher water temperatures (Lehman 1996), which was characteristic of climatic conditions during this bloom formation.

The central and southern Delta taken as a whole is a region where significant bloom activities occurred during the study period. Water quality in this area is typically influenced by low summer and fall stream inflow. The southern Delta, in particular, has longer residence times than regions adjoining the Sacramento and San Joaquin rivers, and is characterized by high phytoplankton biomass levels (Lehman 1996). Historically, most of the blooms that occurred in this area were primarily composed of diatoms, but the percentage of diatoms relative to other algal groups in this area has decreased during the last two decades. This decrease was accompanied by an increase in the percentage density of green algae, blue-green algae, and flagellates, as well as an increase in total algal bio-volume (Lehman 1996, 2000). Although the magnitude of the blooms varied in this portion of the Estuary, the blue-green alga, *Microsystis aeruginosa,* was persistent from September through mid-November 1999, and during July, August, and September 2000.

Microsystis aeruginosa, notorious for causing taste and odor problems, was observed as green, irregularly shaped flakes approximately one-quarter to three inches in diameter floating on or near the water surface. Since *M. aeruginosa* is also known to produce toxins, called microcystins, that may adversely affect water supply and water treatment facilities, special studies were conducted in 1999 and 2000 to determine the extent and intensity of this bloom. Phytoplankton samples and field observations conducted during these algal surveys confirmed the presence *M. aeruginosa* at 15 stations in the central and southern Upper Estuary. Blue-green alga blooms in freshwater lakes, in stock ponds, and in lagoons have been associated with low flows, warm water temperatures, increased water clarity, and high nutrient inputs. The duplication of these conditions during the exceptionally warm and dry fall of 1999 and 2000 may have stimulated these blooms.

Summary

The results of the algal bloom special study program have provided important information to supplement the long-term mandated program to monitor water quality conditions in the upper San Francisco Estuary. The special study program showed that periodic algal bloom activity is located primarily in the central and southern Delta, and that Delta-wide blooms were dominated by *Microcystis, Cryptomonas, Skeletonema, and Aulacoseria.*

Water Right Decision 1641 has modified the mandated monitoring program to emphasize monthly rather than bi-weekly water quality monitoring. Because algal monitoring is not continuous, blooms may not be readily detected unless they occur during a monthly water quality monitoring run. Algal blooms of short duration or blooms that occur outside of regular monitoring areas may not also be detected either. To address this issue, dedicated algal surveys that are timed and located based on plankton biology are being developed to further clarify the biological, chemical, and physical processes leading to the initiation and development of algal blooms in the upper San Francisco Estuary.

Chapter 8. Continuous Monitoring, 1997-2000

The continuous monitoring program supplements the monthly D-1641 Compliance Monitoring Program by providing real-time water quality data from seven shore-based automated sampling stations in the upper San Francisco Estuary (Figure 8-1). These stations provide data used by operators of the State Water Project and the Central Valley Project to assess the impacts of the project operations and to adjust project operations to comply with water quality standards.

Water temperature, pH, dissolved oxygen (DO), and specific conductance are measured at all continuous monitoring stations with the additional parameters of chlorophyll fluorescence, air temperature, wind speed, wind direction, solar radiation intensity, and river stage measured at selected stations. Table 8-1 summarizes the measurements for each continuous monitoring station. The water quality data are collected at 1 meter below the water surface using a float-mounted pump and distributed to the water quality sensors. A data acquisition system scans the output from the sensors once per second and stores the average of approximately 3,600 readings on the hour.

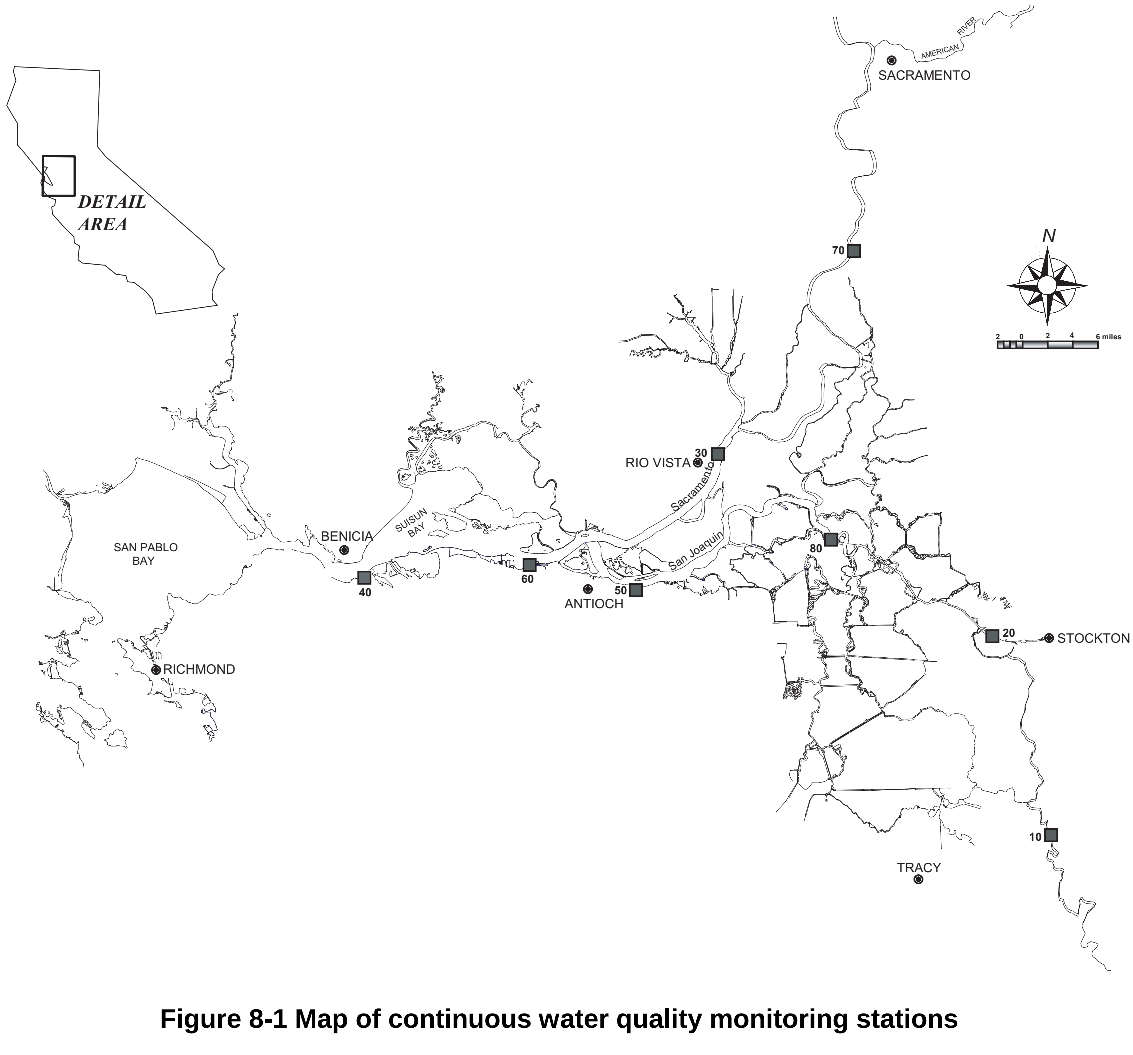


Figure 8-1 Map of continuous water quality monitoring stations

Table 8-1 Station characteristics for the Continuous Monitoring Program

Station Name	Mossdale	Stockton	Hood	Rio Vista	Antioch	Mallard	Martinez
Parameters Measured	All [1] + Chlorophyll Fluorescence	All	All	All	All + Bottom EC[2]	All + Bottom EC & Stage[3]	All + Bottom EC & Stage
Sampling Interval	Hourly	Hourly	Quarter Hour	Hourly	Hourly	Hourly	Hourly
ID Number	10	20	70	30	50	60	40
River Kilometer Index #[4]	RSAN087	RSAN058	RSAC142	RSAC101	RSAN007	RSAC075	RSAC054
Latitude	37° 47' 11"	37° 57' 46"	38° 22'05"	38° 08' 42"	38° 01' 04"	38° 02' 37"	38° 01' 41"
Longitude	121° 18' 22"	121° 21'54"	121°31' 10"	121° 41' 30"	121° 48'06"	121° 55'07"	121° 08' 17"
Surface data (Start of Record)	January 24, 1984	May 11, 1983	December 21, 1998	May 17, 1983	May 25,1983	January 24, 1984	May 19, 1983
Bottom EC Data (Start of Record)	N/A	N/A	N/A	N/A	April 4, 1995	August 4, 1992	December 5, 1990

[1] "All" includes specific conductance (µS), DO (mg/l), pH, water temperature (°C), and air temperature (°C). Other captured parameters vary by site, but include chlorophyll fluorescence, solar radiation intensity (cal/cm²/min), wind direction (°), and wind speed (KPH). Real-time data is telemetered at all Stations except Mossdale.

[2] Bottom EC data collected at 1.5 meters from bottom and is sampled each quarter-hour. All other data collected at one meter below surface.

[3] River stage data is in feet at Mean Sea Level (NGVD 1929)

[4] The River Kilometer Index Number is necessary to access the IEP database values.

In the early 1990s, additional instrumentation was installed at the continuous monitoring stations at Antioch, Mallard Island and Martinez to monitor bottom of channel specific conductance and tidal stage. These measurements were needed to determine compliance with the 2 parts per thousand (ppt) salinity standard (also known as X2) mandated by Water Right Decision 1641. The bottom specific conductance is measured at one and one-half meters off the channel bottom.

Selected water quality data from the continuous monitoring stations are available on the Interagency Ecological Program (IEP) HEC-DSS database (http://www.iep.water.ca.gov/dss/all/). Complete hourly or quarter hourly data for water temperature, pH, DO, specific conductance, air temperature, bottom specific conductance, and river stage are available unless otherwise noted. Data for all other measured parameters are available by contacting the chief of the Real-Time Monitoring and Support Section, Division of Environmental Services, Office of Water Quality, Environmental Water Quality and Estuarine Studies Branch.

Figures 8-3 through 8-9 show the monthly average values for water temperature, pH, DO, specific conductance, bottom specific conductance, and air temperature for calendar years 1997 through 2000. Gaps in data result from periods when monitoring equipment was inoperable or unavailable. A brief summary for each constituent follows:

Water Temperature – Monthly average water temperatures in the upper San Francisco Estuary ranged from 7 °C to 25 °C with lower average water temperatures in the Sacramento River and higher average water temperatures in the San Joaquin River. Monthly average water temperatures in 1997 were higher than those from 1998 through 2000 and ranged from 10.5 °C in the winter or spring on the Sacramento River to a high of 26.5 °C in August 1997 on the San Joaquin River.

Air Temperature – Monthly average air temperatures in the upper San Francisco Estuary ranged from 4.7 °C to 24.4 °C with the air temperature extremes noted at the most inland monitoring stations. The spring and early summer of 1998 were generally cooler than the same time period in 1997, 1999, and 2000.

Dissolved Oxygen – DO values in the upper San Francisco Estuary ranged from 7.5 mg/L to 11.0 mg/L with the lower values occurring during summer and fall. All compliance monitoring stations were above the standard of 5.0 mg/L set by the Central Valley Water Resources Control Board in the Basin Plan (CVWRCB 1998) with the exception of the Stockton station where values were highly variable, and ranged from 4.3 mg/L to 10.3 mg/L.

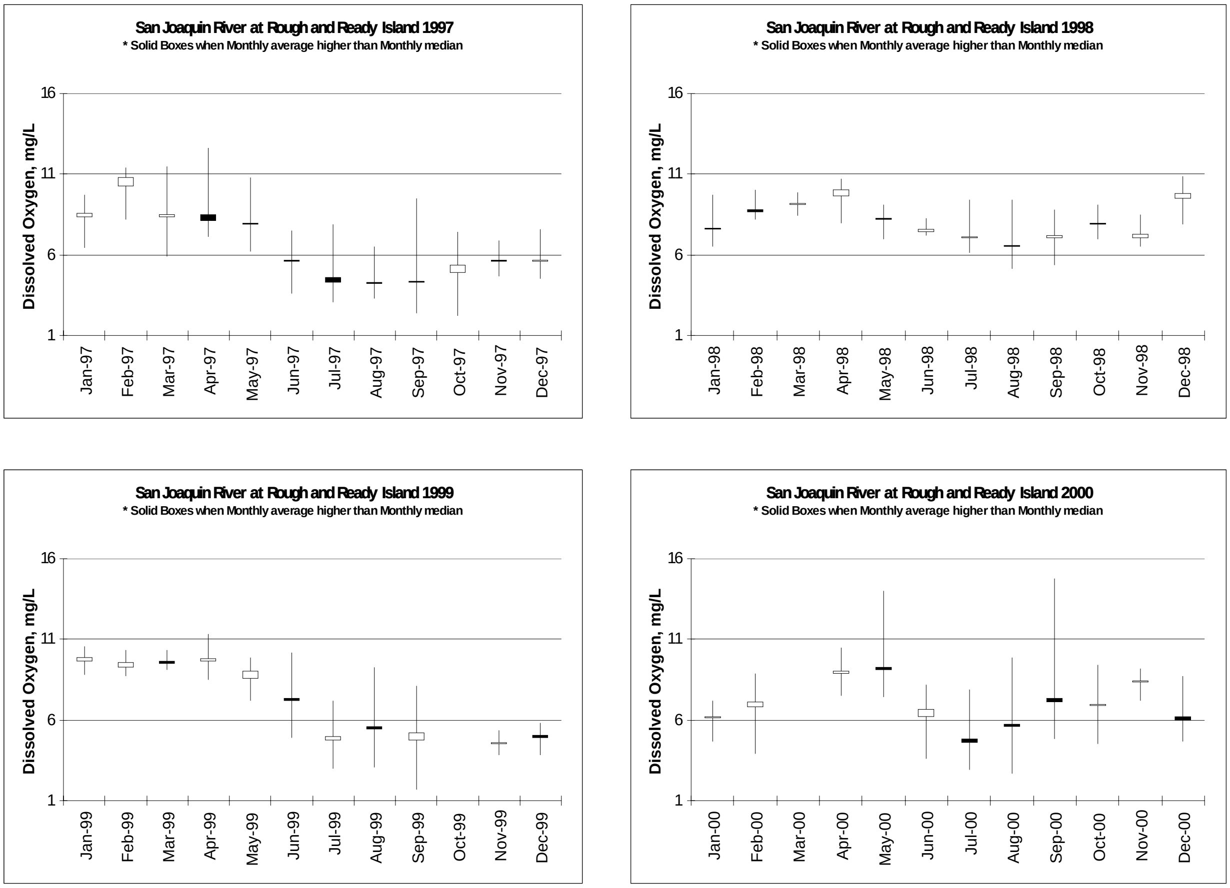
San Joaquin River Dissolved Oxygen Compliance

Monthly DO values at the Stockton station located on the Stockton Ship Channel remained above the 6.0 mg/L standard for the compliance period of September through November for 1998 and 2000 and were below the 6.0 mg/L standard in 1997 and 1999 (SWRCB Bay-Delta Plan 1995)[12]. Figure 8-2 shows that DO values during the compliance period in 1997 ranged from a low of 2.4 mg/L in to a high of 9.5 mg/L. The values in 1999 ranged from 1.7 mg/L to 9.3 mg/L. The monthly average DO values at Stockton were also below 6.0 mg/L in June, July, and August 2000, but recovered by September 2000 to levels greater than 6.0 mg/L. Finally, monthly average DO values at the Mossdale station for 2000 were exceptionally high for the months of June, July, and August, and ranged from 10 mg/L to 11.2 mg/L with the daily extremes ranging from 7.4 mg/L to 15 mg/L.

Specific Conductance – Monthly average specific conductance for the upper San Francisco Estuary ranged from 120 µS/cm to 27,000 µS/cm with the lower values in the Sacramento River and the higher values at the more tidally influenced Martinez continuous monitoring station. Bottom specific conductance measured at the Antioch, Mallard Island and Martinez stations exhibited seasonal patterns and ranges similar to the surface specific conductance measurements. Finally, bottom specific conductance values in 1998 were lower than 1997, 1999, and 2000, and ranged from 127 µS/cm at Mallard Island to 18,900 µS/cm at Martinez.

pH – Monthly pH levels at all stations were stable and ranged from 7 to 8 pH units, except at Mossdale where pH values in July, August, and September 2000 ranged from 8.0 to 8.5 pH units.

[1] State Water Resources Control Board. 1995. *Water quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Estuary*. Adopted May 22, 1995, pursuant to Water Right Order 95-1. Sacramento, CA. 44pp.



*** No power to station caused missing data for October 1999 and March 2000**

Figure 8-2 Range of monthly DO values on the San Joaquin River at Rough and Ready Island, 1997-2000

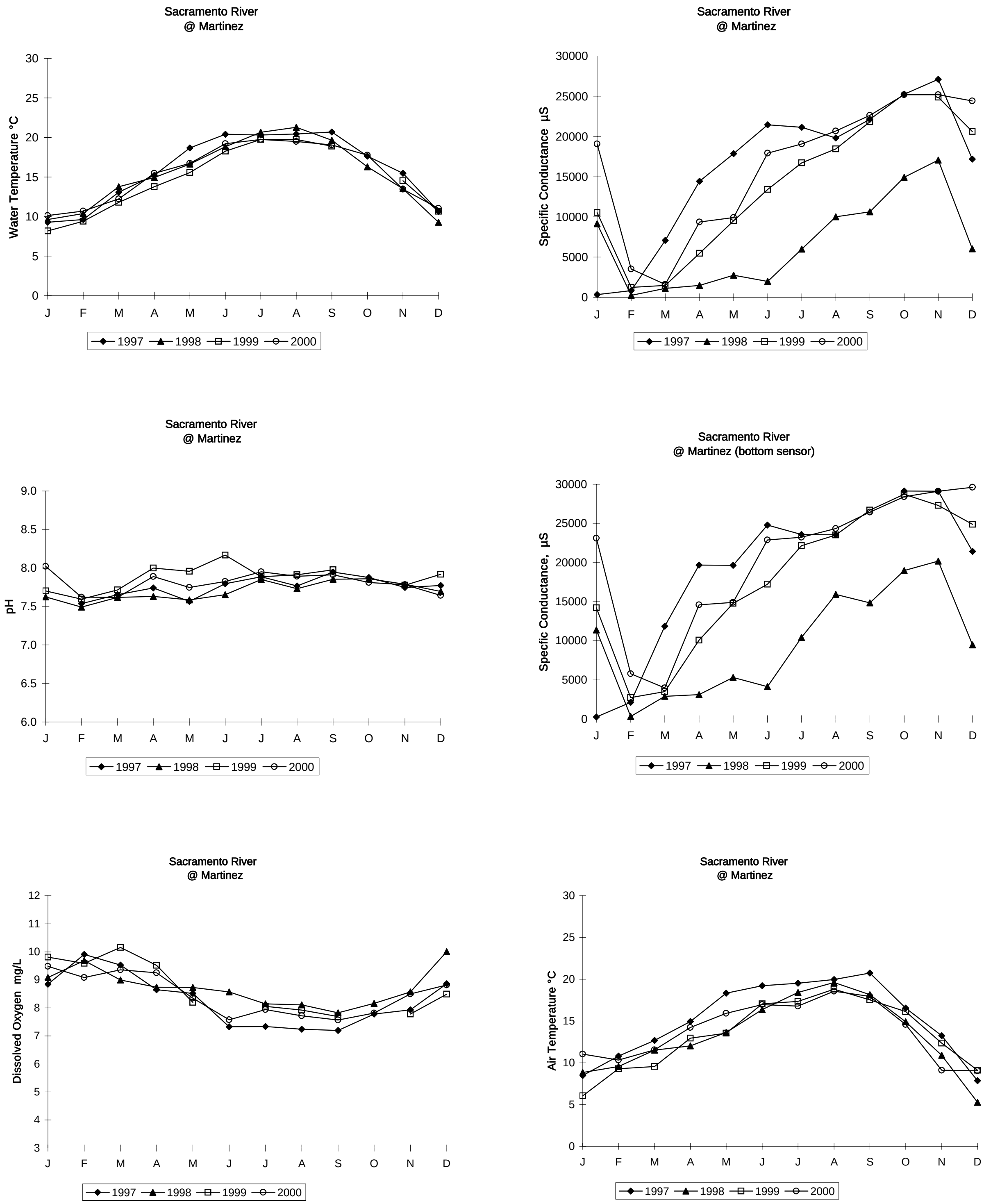


Figure 8-3 Monthly averages of water quality parameters measured at Martinez for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

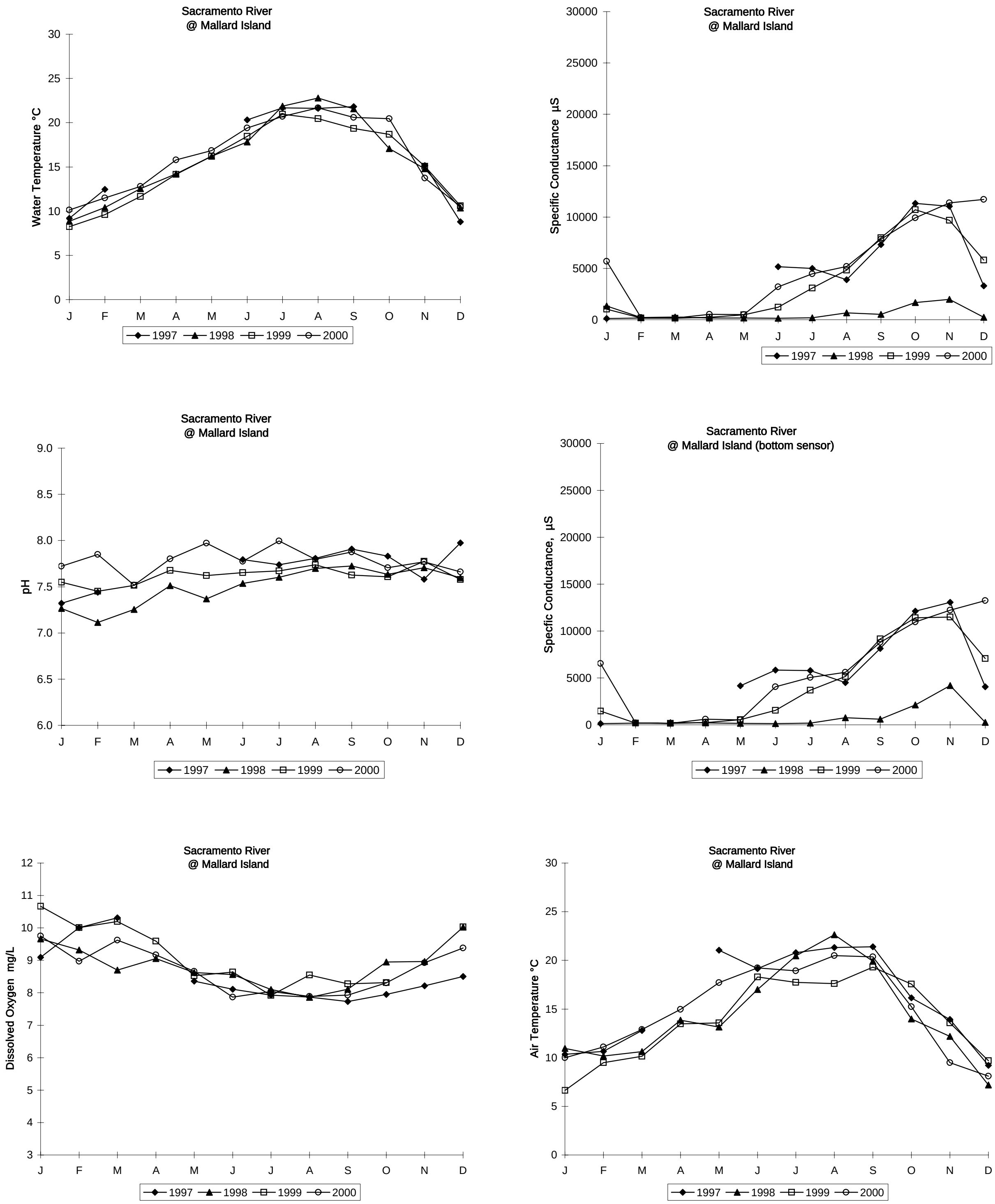


Figure 8-4 Monthly averages of water quality parameters measured at Mallard for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

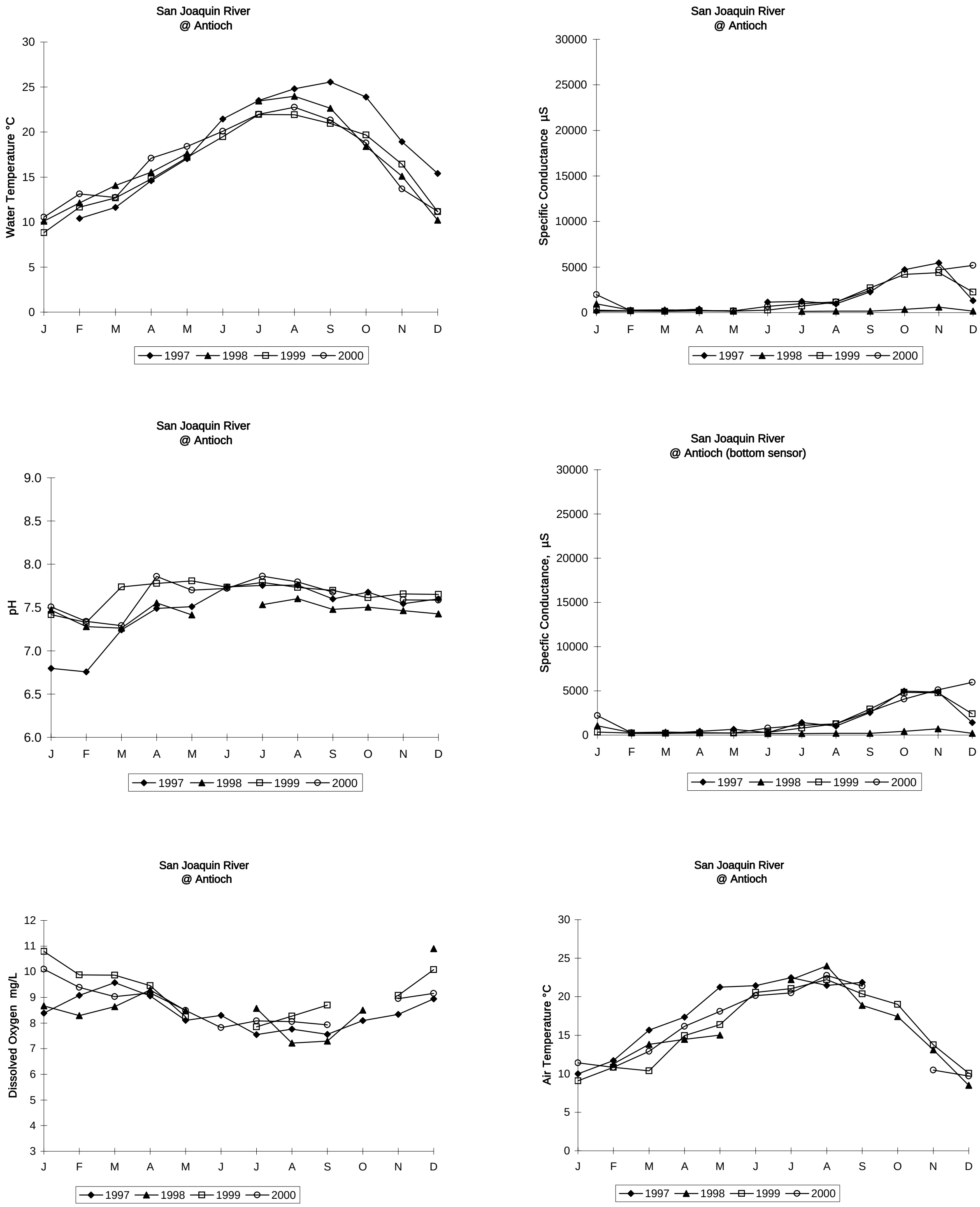


Figure 8-5 Monthly averages of water quality parameters measured at Antioch for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

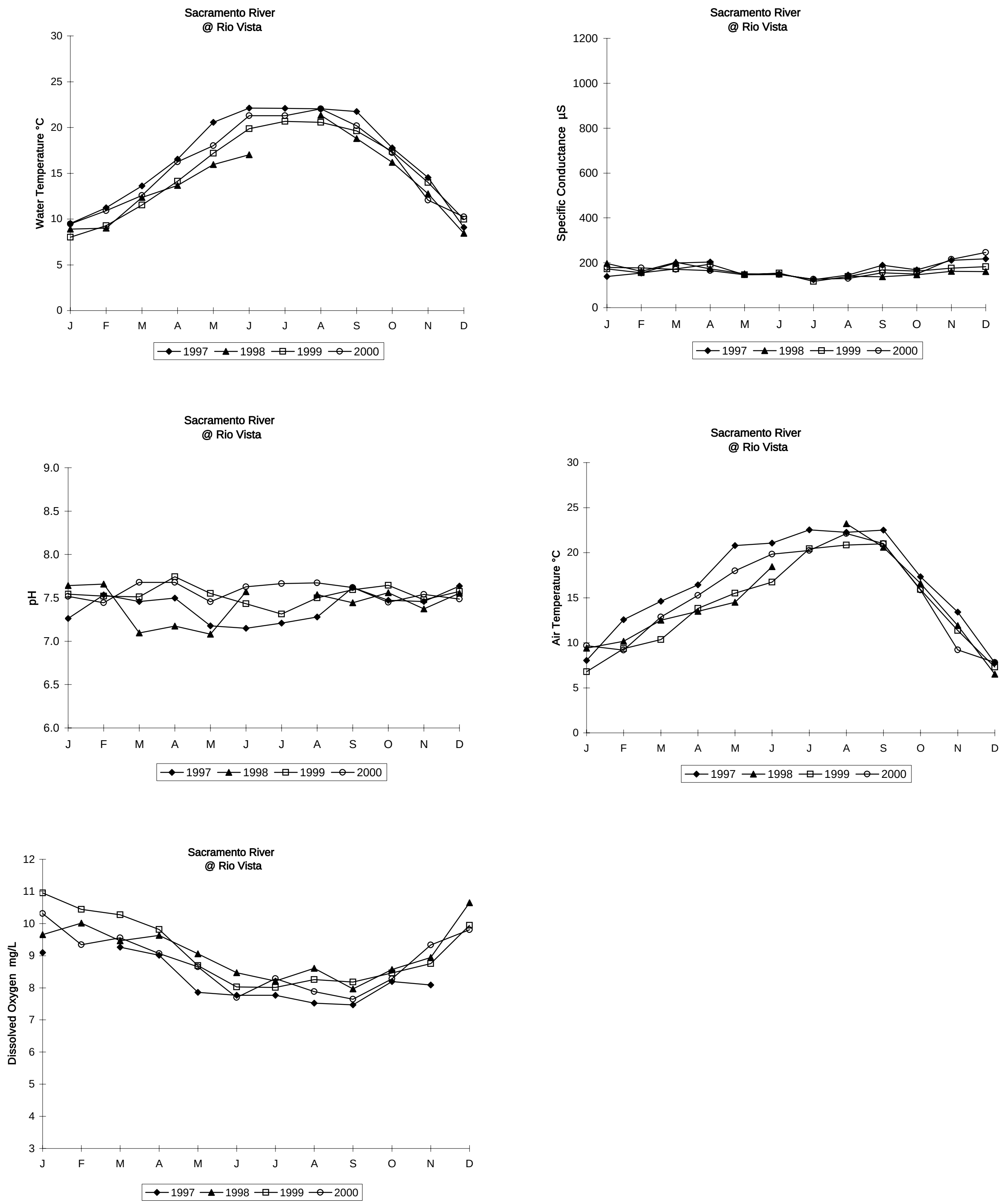


Figure 8-6 Monthly averages of water quality parameters measured at Rio Vista for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

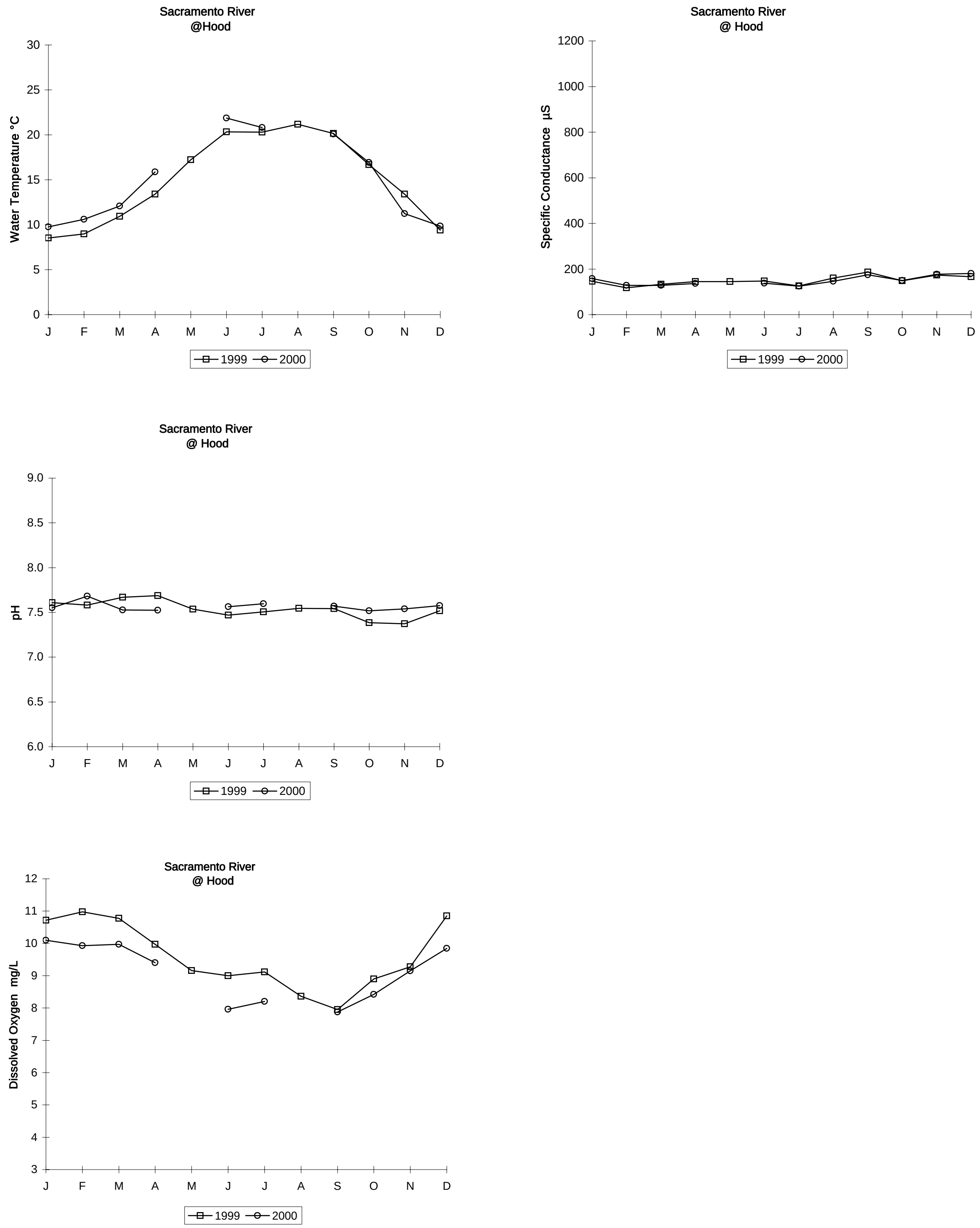


Figure 8-7 Monthly averages of water quality parameters measured at Hood for calendar years 1999-2000 (The Hood station came online 12/22/98)

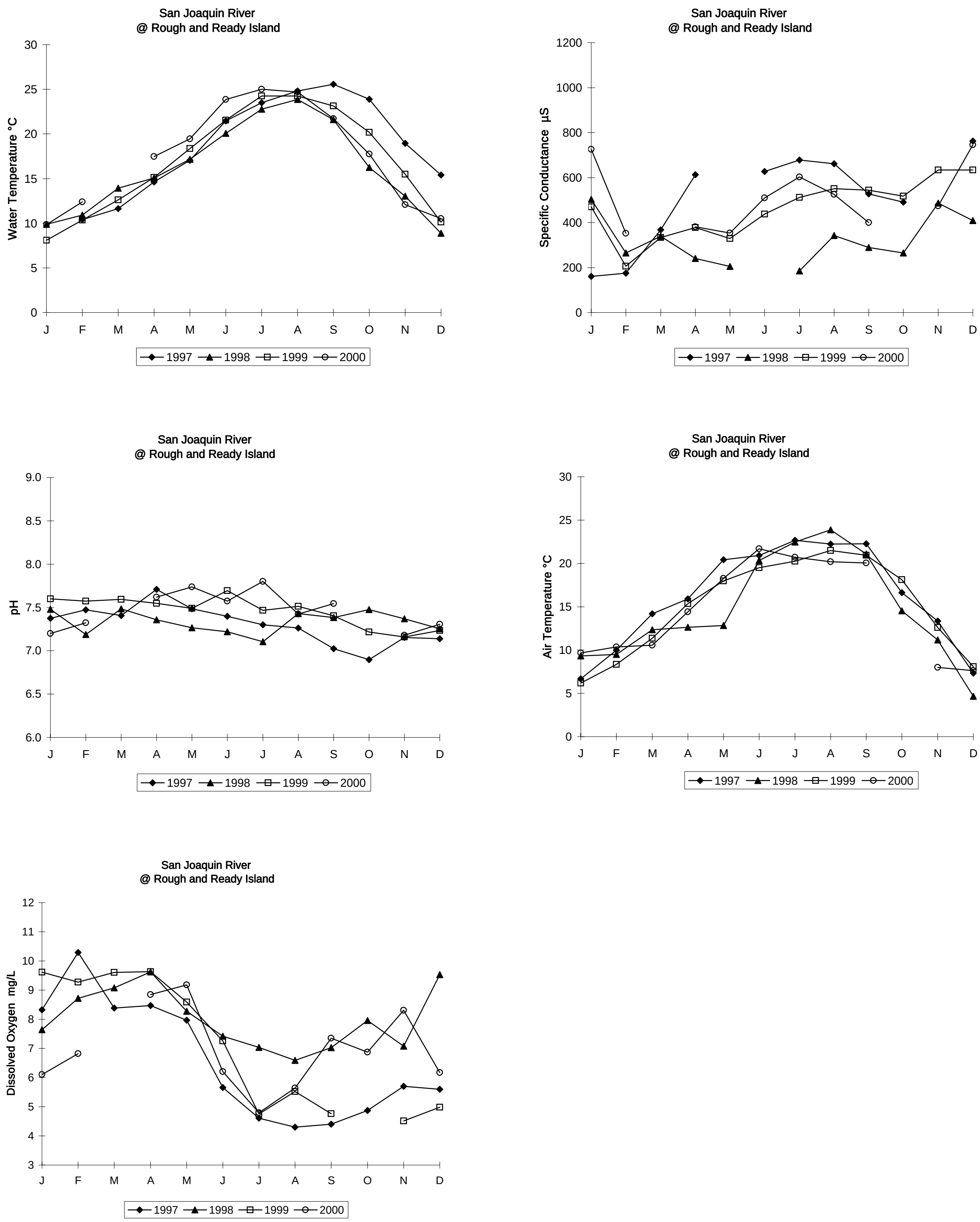


Figure 8-8 Monthly averages of water quality parameters measured at Stockton for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

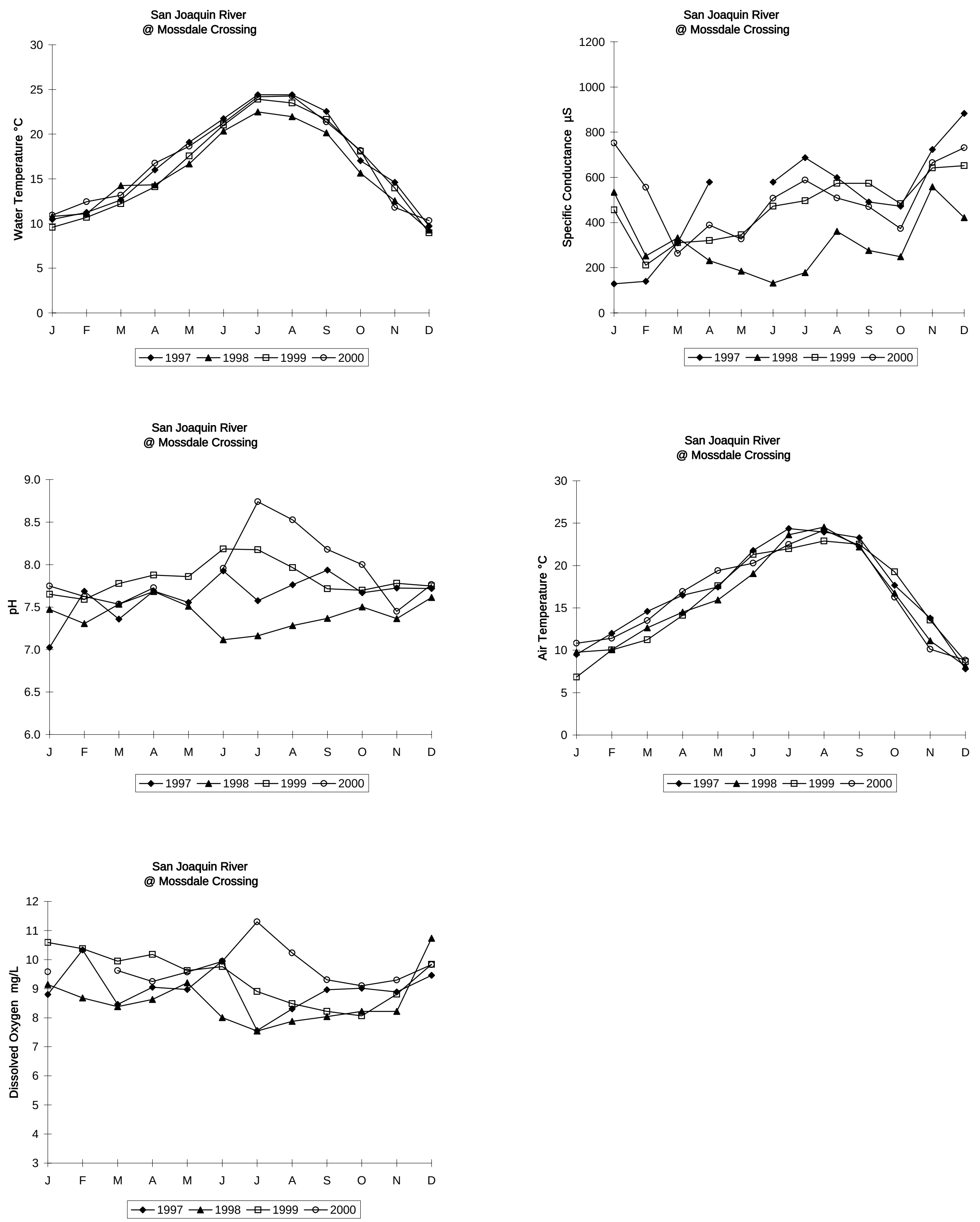


Figure 8-9 Monthly averages of water quality parameters measured at Mossdale for calendar years 1997-2000 (Data for May 1997 are currently stored on discontinued media. Conversion to new media is in process. Data are available upon request.)

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