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

Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2003

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

October 2006

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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) during calendar year 2003. This monitoring is mandated by Water Right Decision 1641 (D-1641) of December 1999. This report is being submitted to fulfill the reporting requirements of this decision.

DWR and USBR monitored water quality using a protocol implemented in 1996. Under this monitoring protocol, eleven sampling sites representing eight regions of the upper San Francisco Estuary (Estuary) are monitored for a variety of physical and chemical water quality parameters. The results gathered from the sampling of these 14 parameters are described in this report. In 2003, parameters—such as water temperature, Secchi disk depth, dissolved oxygen concentration, specific conductance, dissolved inorganic nitrogen, orthophosphate, and volatile suspended solids—were within their historical range. Measured parameters exhibited seasonal variation, as well as changes in response to significant rainfall events and changes in flow rates.

In addition to monitoring physical and chemical water quality parameters, biological sampling was conducted to monitor the productivity and community composition of phytoplankton, zooplankton, and benthic communities. Samples for chlorophyll *a* and pheophytin *a* were taken at 11 sampling sites in the Estuary. Chlorophyll *a* and pheophytin *a* concentrations for 2003 showed typical seasonal patterns and were generally below 15 µg/L for most regions. Chlorophyll *a* concentrations ranged between 0.36 µg/L and 64.5 µg/L throughout the Estuary. Pheophytin *a* concentrations ranged between 0.23 µg/L and 11.6 µg/L throughout the Estuary. Changes in the relative abundance of zooplankton species (most notably the mysids) in the Estuary were observed. *Acanthomysis bowmani* and *Neomysis kadiakensis* remained the dominant mysids in the upper Estuary but a native high salinity mysid, *Alienacanthomysis macropsis*, replaced *Neomysis mercedis* as the third most abundant species. The introduced *Acanthomysis hwanhaiensis*, fourth most abundant mysid in 2001 and 2002, declined to fifth most abundant. Nearly all of the meso and micro-zooplankton retained their respective abundance ranks from 2001 and 2002. Benthic monitoring was conducted at 10 representative stations throughout the Estuary to document substrate composition and the distribution, diversity and abundance of benthic organisms within the Estuary. The benthic community was determined to be a diverse assemblage of organisms including annelids (worms), crustaceans, aquatic insects and molluscs (clams and snails). Of the eight phyla identified, Annelida, Arthropoda and Mollusca constituted 99.4% of the organisms collected during 2003.

DWR also conducted a series of special studies to monitor dissolved oxygen (DO) levels within the Stockton Ship Channel (Channel) during the late summer and early the fall of 2003. The studies were conducted to determine if DO levels dropped below State (5.0 mg/L) and regional (6.0 mg/L) water quality objectives established for the Channel. Monitoring was typically conducted biweekly, from August 11 to December 10 from Prisoner's Point

in the central Delta to the Stockton Turning Basin at the eastern terminus of the Channel. Monitoring results showed DO concentrations in the Channel ranged from 3.0 mg/L to 10.7 mg/L and consistently fell below both the 5.0 mg/L and 6.0 mg/L objectives in 2003 probably due, in part, to relatively low net flows in the San Joaquin River past Stockton and warm water temperatures.

Dr. Dean Messer, Chief
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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. The SWRCB ensures that these objectives are met in part by the inclusion of water quality monitoring requirements into water right decisions issued to the Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) as conditions for operating the State Water Project (SWP) and Central Valley Project (CVP) respectively. These requirements include minimum outflows, limits to water exportation by the SWP and CVP, and maximum allowable salinity levels. In addition, DWR and USBR are required to conduct a comprehensive monitoring program to determine compliance with the water quality objectives, and report the findings to the SWRCB. Water quality objectives were issued in December 1999 by Water Right Decision 1641 (D-1641) (SWRCB 1999).

Data collected since 1975 by the Environmental Monitoring Program (EMP) are stored and managed by DWR and the Department of Fish and Game (DFG). DWR manages phytoplankton data and macro-benthic organism data, as well as environmental water quality data from both discrete and continuous monitoring stations. DFG manages all zooplankton data. Internet access and download of the EMP data is available through the Bay Delta and Tributaries Database (BDAT) at www.baydelta.ca.gov. [1]

This report, entitled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2003*, summarizes the findings of the EMP for calendar year 2003. Separate chapters are devoted to the water quality, benthic, phytoplankton, zooplankton, and special study components of the EMP. Within each chapter, the major patterns and trends demonstrated by the water quality and biological data within and between years are described in the text and displayed in summary plots and tables. This report is submitted to the SWRCB to fulfill the reporting requirements of D-1641.

References

[SWRCB] State Water Resources Control Board. 1999. *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh*. Sacramento, California.

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[1] For specific questions about EMP data on BDAT, contact Mr. Karl Jacobs, Chief, Interagency Information System Services Section, Department of Water Resources, Division of Environmental Studies, 901 P Street, Sacramento, CA. 95814, telephone: (916) 651-9581, or by e-mail at kjacobs@water.ca.gov.

Chapter 2 Hydrologic Conditions

Introduction

Hydrologic conditions are typically discussed using "water years," which begin on October 1 of a calendar year and end on September 30 of the following year. The chronological period covered by this report includes parts of two water years: the last nine months of water year 2003 (January through September 2003) and the first three months of water year 2004 (October through December 2003). To concisely describe hydraulic conditions in the Bay-Delta during this period, this chapter will discuss water year 2003, which runs from October 2002 through September 2003.

Methods

Water years are classified in this report using two indices: the Sacramento Valley 40-30-30 Water Year Hydrologic Classification Index[1,2] (Sacramento Valley Index), and the San Joaquin Valley 60-20-20 Water Year Hydrologic Classification Index[3,4] (San Joaquin Valley Index) (SWRCB 1999). The Sacramento Valley Index is used to characterize water years statewide because most precipitation falls in the northern half of California, and much of that precipitation flows through the San Francisco Estuary (SWRCB 1999). The San Joaquin Valley Index is used predominantly for regional applications; however, this index provides supporting information concerning water conditions within the San Joaquin Valley. According to the Sacramento Valley Index[5], water year 2003 was classified as "Above Normal," while the San Joaquin Valley Index [6]classified water year 2003 as "Below Normal."

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1 The Sacramento Valley 40-30-30 Water Year Hydrologic 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 Hydrologic 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 is 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).

Summary

Water year 2003 conditions contrast with water years 2001 and 2002, which were designated as “Dry” by both indices. Figure 2-1 shows unimpaired runoff and water year designations for Sacramento and San Joaquin rivers for the ten-year period from 1993 to 2003. Although water conditions have improved from the previous two years, conditions remain below what was seen in the second half of the 1990s. Unimpaired runoff in water year 2003 was higher than in the previous two years due to above-normal precipitation, reservoir storage, and snowpack water content (CDEC 2003). Statewide figures for precipitation, runoff, reservoir storage, and snowpack water content in recent years are summarized in Table 2-1.

Water year 2003 had higher unimpaired runoff than in water years 2001 and 2002, with a value of 19.18 million acre-feet in the Sacramento Valley River Basin and 4.88 million acre-feet in the San Joaquin Valley River Basin. Table 2-2 summarizes streamflow conditions in these rivers during water years 2001-2003.

The Net Delta Outflow (NDO) from the estuary for water year 2000 through water year 2003 is shown in Figure 2-2. This NDO is an estimate of average daily outflow at Chipps Island and is calculated as:

$$\mathbf{NDO = Q_{Tot} + Q_{Precp} - Q_{Gcd} - Q_{Misdv}}$$

Where:

$\mathbf{NDO}$ = Net Delta outflow (cfs)

$\mathbf{Q_{Tot}}$ = Total Delta inflow (cfs)

$\mathbf{Q_{Precp}}$ = Total precipitation runoff (cfs)

$\mathbf{Q_{Gcd}}$ = Total consumption in Delta (cfs)

$\mathbf{Q_{Misdv}}$ = Total flooded island and island storage diversions (cfs)

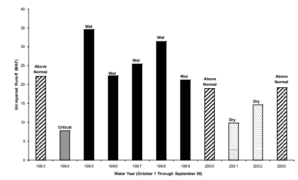

Figure 2-1a&b Unimpaired flow from the Sacramento and San Joaquin rivers from 1993 through 2003

Water year	*Precipitation (% of normal)*	*Seasonal runoff (% of normal)*	*Reservoir storage (% of normal)*	*Snow water content (% of normal)*
2000	95	100	115	75
2001	75	45	100	65
2002	80	80	100	60
2003	110	100	105	105

Table 2-1 Summary of the major hydrologic characteristics of water years 2001-2003

Year	Sacramento River			San Joaquin River		
	Oct 1-Mar 30 (maf)	Apr 1-Jul 30 (maf)	Whole Year (maf)	Oct 1-Mar 30 (maf)	Apr 1-Jul 30 (maf)	Whole Year (maf)
2000	*12.01*	*5.99*	*18.88*	*1.98*	*3.78*	*5.90*
2001	*5.64*	*3.46*	*9.81*	*0.92*	*2.23*	*3.18*
2002	*9.32*	*4.57*	*14.6*	*1.27*	*2.74*	*4.06*
2003	*10.71*	*7.66*	*19.18*	*1.26*	*3.49*	*4.88*

Table 2-2 Average streamflow for the Sacramento and San Joaquin rivers during water years 2001-2003.

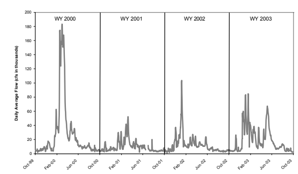

Figure 2-2 Net Delta Outflow and average daily flow from water year 2000 through water year 2003

References

[CDEC] California Data Exchange Center. 2003. Available online at http://cdec.water.ca.gov. Department of Water Resources, California Cooperative Snow Surveys.

[SWRCB] State Water Resources Control Board. 1999. *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh*. Sacramento, California.

Figure 2-1a Unimpaired flow from the Sacramento River from 1993 through 2003, with water year designation. Values given in million acre-feet (maf)

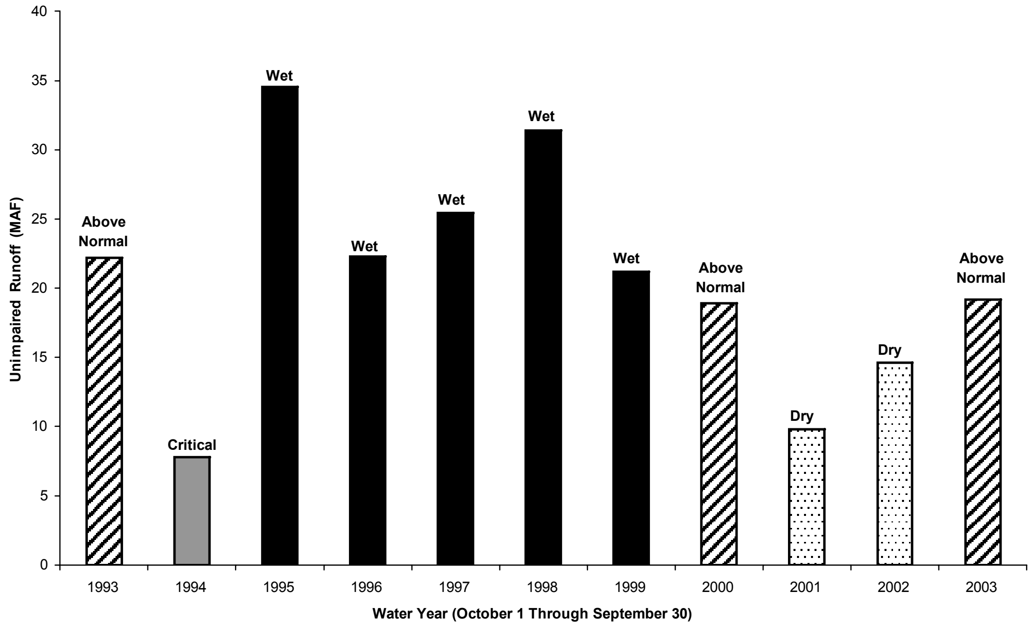

Figure 2-1b Unimpaired flow from the San Joaquin River from 1993 through 2003, with water year designation. Values given in million acre-feet (maf)

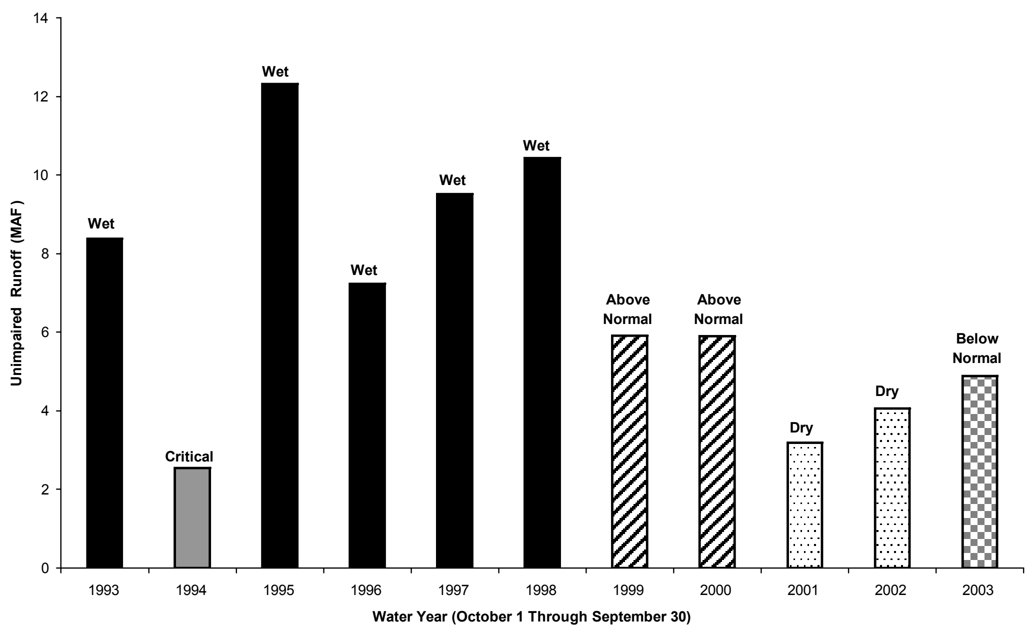

Figure 2-2 Net Delta Outflow and average daily flow from water year 2000 through water year 2003.

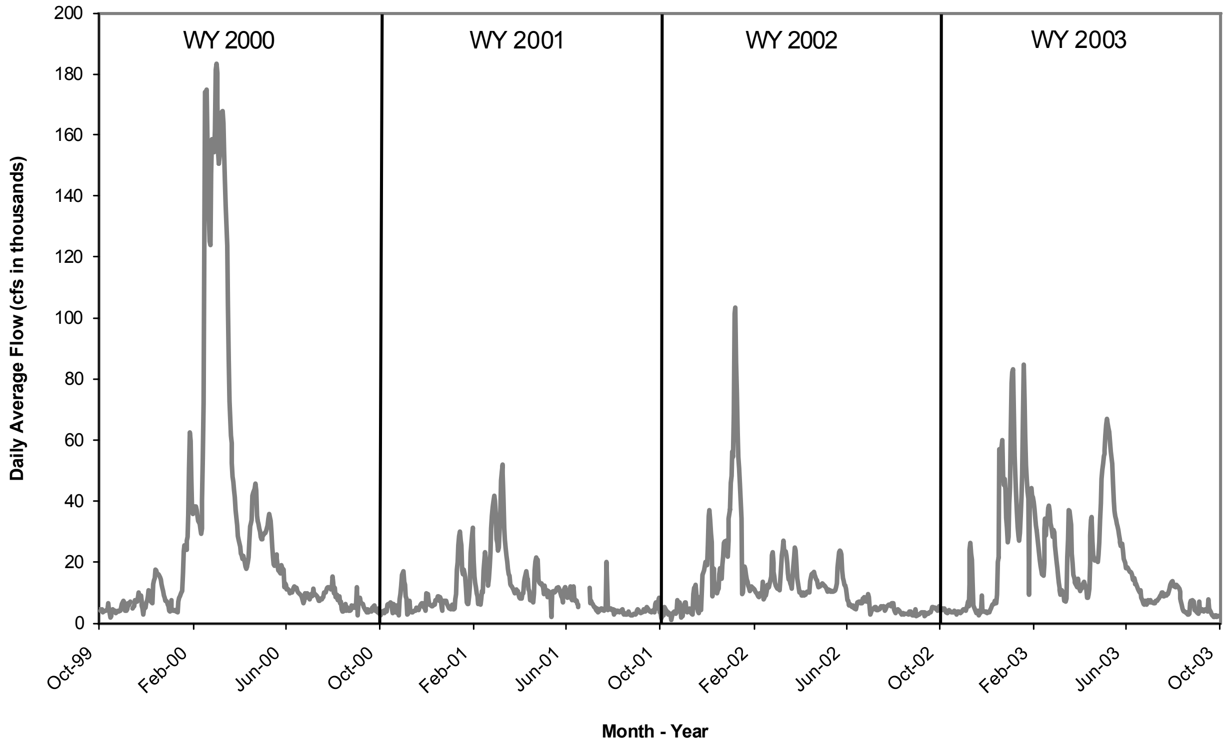

Table 2-1 Summary of the major hydrologic characteristics of water years 2000-2003.

Water year	Precipitation (% of normal)	Seasonal runoff (% of normal)	Reservoir storage (% of normal)	Snow water content (% of normal)
2000	95	100	115	75
2001	75	45	100	65
2002	80	80	100	60
2003	110	100	105	105

Table 2-2 Average streamflow for the Sacramento and San Joaquin rivers during water years 2000-2003. All values in million acre-feet (maf).

Year	Sacramento River			San Joaquin River		
	Oct 1- Mar 30 (maf)	Apr 1- Jul 30 (maf)	Whole Year (maf)	Oct 1- Mar 30 (maf)	Apr 1- Jul 30 (maf)	Whole Year (maf)
2000	12.01	5.99	18.88	1.98	3.78	5.90
2001	5.64	3.46	9.81	0.92	2.23	3.18
2002	9.32	4.57	14.6	1.27	2.74	4.06
2003	10.71	7.66	19.18	1.26	3.49	4.88

Chapter 3 Water Quality Monitoring

Introduction

Water quality monitoring in 2003 continued according to the amended protocol implemented by the Department of Water Resources (DWR) in 1996. As described in the 1996 Water Quality Report (DWR 2001), discrete water quality samples were taken monthly at each of 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 statement of weather conditions (i.e., wind conditions and cloud cover) was recorded for each cruise. Samples were analyzed for 15 physical and chemical parameters shown in Table 3-1. The complete database is available online at http://baydelta.water.ca.gov.

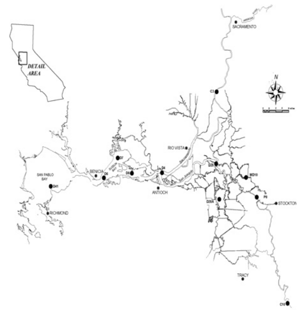

Figure 3-1 Water quality monitoring stations

Parameter	*Units*
Water temperature	*°C*
Dissolved oxygen	*mg/L*
Specific conductance	*µS/cm*
Secchi disk depth	*cm*
Turbidity	*NTU*
Orthophosphate	*mg/L*
Total phosphorus	*mg/L*
Kjeldahl nitrogen	*mg/L*
Dissolved inorganic nitrogen	*mg/L*
Dissolved organic nitrogen	*mg/L*
Total dissolved solids	*mg/L*
Total suspended solids	*mg/L*
Volatile suspended solids	*mg/L*
Silica	*mg/L*
Chloride	*mg/L*

Table 3-1 Water quality parameters measured

Region	*Sampling Sites*
Lower Sacramento River	*D4*
Lower San Joaquin River	*D26*
North Delta	*C3*
Central Delta	*D28A*
East Delta	*MD10*
South Delta	*C10 and P8*

Table 3-2 Water quality sampling sites and regions

As shown in Table 3-2, eleven sampling sites were used in this study to represent eight regions of the Bay-Delta system. Water quality conditions in each of six regions were represented by a single sampling site. The south Delta and Suisun Bay, however, were represented by two and three stations respectively.[1] In previous reports, data from multiple sample sites within each region have been averaged according to the "hierarchical cluster analysis protocol"; however, for clarity, data results in this report are shown for each sample site.

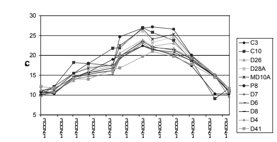

Figure 3-2 Water temperature

Parameters Measured

Except as noted, all discrete water quality samples were obtained with shipboard sampling equipment using the DWR research vessel *San Carlos*. Supplemental discrete samples were taken with mobile laboratory equipment at sites in the south Delta (C10 and C3) which are inaccessible to the vessel *San Carlos*. Secchi disk depth is not taken at site C10 due to restrictions of the sample site, which requires sampling equipment to be deployed from a bridge.

Water Temperature

Water temperature was measured in degrees Centigrade (°C) with a YSI thermistor. For all sites except the south Delta, temperatures were measured from water collected at a depth of one meter. In the south Delta, temperatures were measured by submerging the YSI thermistor to a one meter depth.

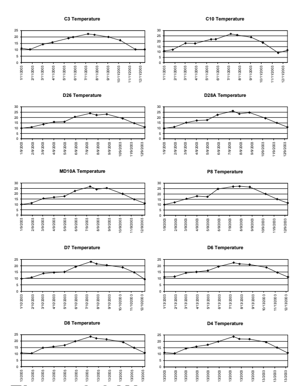

Figure 3-3 Water temperature (°C), 2003

A water temperature minimum of 9.1 °C was recorded in November 2003 at station C10, in the south Delta (Figures 3-2 and 3-3). This minimum temperature represents an increase of 1 °C over the previously recorded minimum for the 2001-2002 period, and a 2 °C increase over the minimum reported for the 1997-2000 period (DWR 2003 and 2004).

[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.

Temperature minima at most sites during 2003 occurred during the months of December and January. The timing of these minima contrasts with results from the 2001-2002 study period, in which most sites' minima occurred in February (DWR 2004).

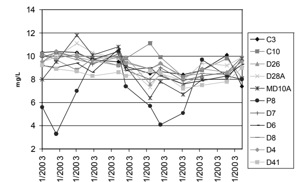

Figure 3-4 Dissolved oxygen

A water temperature maximum of 27.2 °C was recorded at station P8, in the south Delta. This maximum is the same as that recorded for the 2001-2002 study period (DWR 2004). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

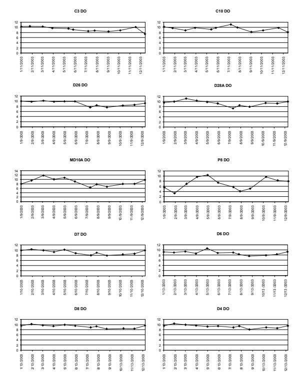

Figure 3-5 Dissolved oxygen (mg/L), 2003

Dissolved Oxygen

Dissolved oxygen (DO) was measured using the modified Winkler iodometric method described in Standard Methods (APHA 1992). A sample aliquot was collected at a depth of one meter. The samples were collected in 300-mL glass-stoppered bottles and immediately analyzed onboard.

During 2003, DO concentrations ranged from 3.3 mg/L at site P8 in the south Delta in February, to 11.8 mg/L at site MD10 in the east Delta in March (Figures 3-4 and 3-5). Strong seasonal trends were evident in most regions, with DO concentrations decreasing during the summer and rising in the winter. Seasonal changes were not as apparent as in previous years; however, sites C3, D26, D28A, D6, D7, and D8 continued to show reduced seasonal DO levels coinciding with warmer summer and fall water temperatures. An exception to this was noted at sites P8 and C10 in the south Delta. Both sites showed poor correlation between temperature and DO levels, and weak seasonal patterns. These sites also showed the greatest degree of variability in DO levels, varying by almost 7.0 mg/L over the year.

In the Suisun Bay, sites D6, D7 and D8 were closely related, and showed a yearly variation of about 2 mg/L, which was consistent with the range observed at most other sites.

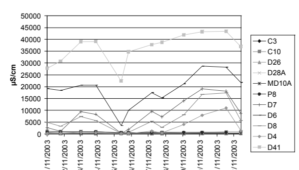

Figure 3-6 Specific conductance

Specific Conductance

Specific conductance, an estimate of salinity, was determined from samples collected at a depth of one meter. The samples were analyzed for specific conductance using a Seabird model CTD 911+ data logger, with temperature compensation to 25 °C.

Specific conductance varied greatly between sites monitored, ranging from 138 µS/cm at site C3 in the north Delta in January to 43,413 µS/cm at site D41 in San Pablo Bay in November (Figures 3-6 and 3-7). This range of specific conductance was less than the 74-45,107 µS/cm range reported for the 2001-2002 study period (DWR 2004).

Specific conductance generally increased from east to west and was well correlated to inflows and tidal action. Maximum values occurred in the late summer and fall when flows through the Delta were low and marine intrusion was most pronounced.

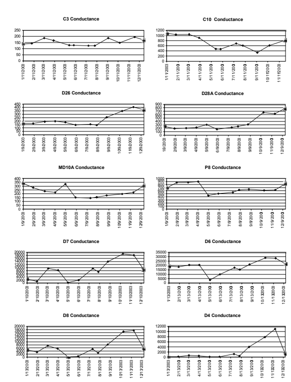

Figure 3-7 Specific conductance (µS/cm), 2003

Sites with high average specific conductivity such as D4, D6, D7, D8 and D41 tended to show stronger seasonal variations, with specific conductance varying from a low in May, to a high in October and November. At sites with lower specific conductance, this seasonal trend was less apparent.

Specific conductance dropped noticeably at most sites in May and December. Downstream sites showed the most variability, especially during winter. Upstream sites with low specific conductance, such as site C3, had the least variation and showed few or no apparent seasonal trends.

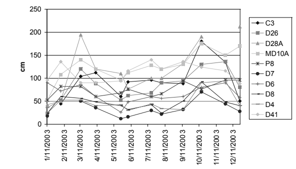

Figure 3-8 Secchi depth

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. Secchi disk transparency was recorded as the average depth in which visual determination of the disk was lost as it was lowered into the water column, and the depth of its visual perception as it was raised.

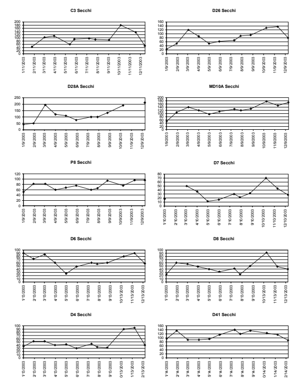

Figure 3-9 Secchi disk depth (cm), 2003

A Secchi depth minima of 12 cm was recorded at sampling site D7, in the Suisun Bay in May (Figures 3-8 and 3-9). A Secchi depth maxima of 212 cm was recorded at sampling site D28A in the central Delta in December. By comparison, Secchi values during 2001-2002 ranged from 16-206 cm (DWR 2004). The long-term increase in transparency values noted in a previous report (DWR 2001) was not discernable in the 2003 data.

Secchi disk depth varied seasonally, with a marked decrease at all sites during December and January, and a gradual decrease during the summer months. Peak Secchi depths occurred in spring (March) and again in fall (October).

Overall, Secchi depths were lowest at sites D6, D7, D8, and D4, while sites C3, D28A, MD10, and D41 had the highest overall average Secchi depths. As noted earlier, Secchi disk depth measurements are not taken at site P8 in the south Delta, due to site restrictions.

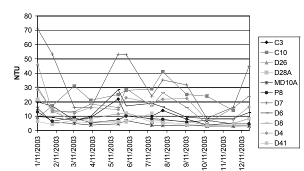

Figure 3-10 Turbidity

Turbidity

Turbidity is a measure of the optical properties of water and substances contained in the water that cause light to be scattered and absorbed rather than transmitted in straight lines (APHA 1992). Turbidity is caused by soluble organic compounds, plankton, and suspended matter such as clay, silt, inorganic substances, and organic matter.

Turbidity was determined from samples collected at a depth of one meter. The samples were pumped through a Turner Model 10 flow-through nephelometer calibrated with a reference sample of formazin suspension at 40 nephelometric turbidity units (NTU) according to Standard Reference protocol 214-A (APHA 1992).

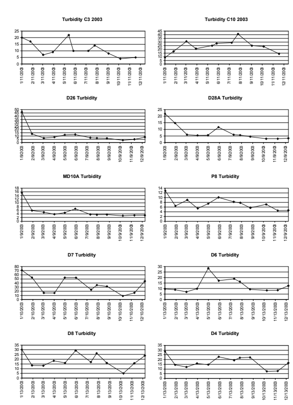

Figure 3-11 Turbidity (NTU), 2003

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 2.9 NTU at site D28A in October, to 71 NTU at site D7 in January. This range of turbidity was slightly less than the 1.3 to 86 NTU range reported for 2001 and 2002.

Turbidity levels at some sites exhibited a seasonal pattern of high turbidity in the early spring, followed by decreasing turbidity in late spring and fall; however, some sites showed no consistent seasonal pattern.

Most sites showed high or highest turbidity levels in January. This is consistent with previous reports of large increases in turbidity observed at most sites in January 2002 (DWR 2004). Exceptions to this occurred at sites C10, D6, and D41, where turbidity levels were low in January and peaked later between May and August. Sites in the Suisun Bay region (D6, D7 and D8) showed summer pulses of turbidity that appear to coincide with marked decreases in specific conductance. This suggests a possible relationship with increases in Delta outflows. Other sites showed similar pulses in turbidity with no apparent correlation with conductance.

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 water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory[2] for analysis according to the EPA (1983) colormetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate was 0.01 mg/L.

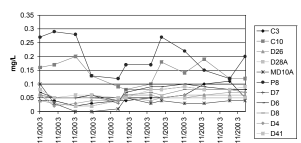

Figure 3-12 Orthophosphate

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest values, recorded in the east Delta at site MD10 in March and April 2003, showed orthophosphate levels below the detectable limit of 0.01 mg/L. The previous 2001-2002 study also showed the lowest values (<0.01 mg/L) of orthophosphate occurring at site MD10 during March and December 2002 (DWR 2004).

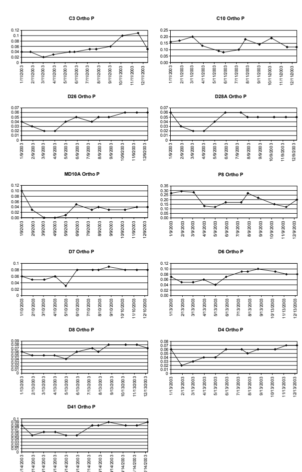

Figure 3-13 Orthophosphate (mg/L), 2003

The highest value of orthophosphate, 0.29 mg/L, was recorded at site P8 in the south Delta in February 2003. In the previous 2001-2002 study, site P8 also showed the highest orthophosphate concentration (0.42 mg/L) in January 2002 (DWR 2004).

Orthophosphate levels were highest in the south Delta region (sites C10 and MD10A) and showed a common seasonal pattern, with high values from January to March, followed by a marked decline from April to July and another peak in later summer and early fall. All other sites had yearly values below 0.10 mg/L.

Total Phosphorus

Total phosphorus is the sum of all phosphorus compounds in the sample. This parameter includes phosphorus compounds that are bioavailable, as well as those that are not. Phosphorus that is unavailable for bioassimilation

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

includes phosphorus compounds that are already incorporated into biological tissue and insoluble mineral particles.

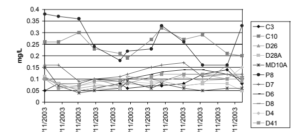

Figure 3-14 Total phosphorus

Total phosphorus concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed 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 according to the EPA (1983) colormetric semi-automated method 365.4. The minimum reporting limit for total phosphorus was 0.01 mg/L.

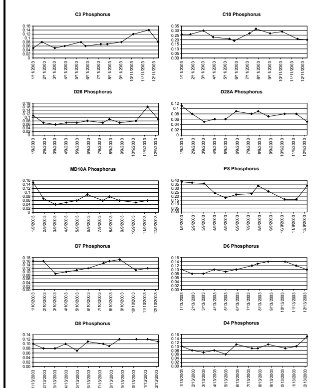

Figure 3-15 Total phosphorus (mg/L), 2003

Values for total phosphorus varied considerably between sites and across seasons (Figures 3-14 and 3-15). Total phosphorus concentrations followed seasonal patterns and regional distributions similar to those reported for orthophosphate. The lowest value of 0.04 mg/L was recorded in the east Delta at site MD10 in March 2002. This value is identical to the minimum value recorded for the 2001-2002 period at the same site in January 2001 (DWR 2004). The highest values for total phosphorus were recorded in the south Delta at sites P8 and C10. A maximum value of 0.38 mg/L was recorded at site P8 in January 2003. This value is lower than the maximum values of 0.5 mg/L recorded between 2001 and 2002 in the south Delta region (DWR 2004).

Except for those in the south Delta region, all sites showed total phosphorus levels at or below 0.11 mg/L during the spring (March through May). Total phosphorus levels at these sites never exceeded 0.17 mg/L.

Kjeldahl Nitrogen

Kjeldahl nitrogen is nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl method (APHA 1992).

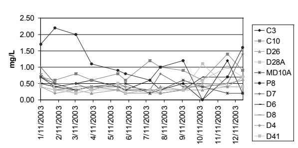

Figure 3-16 Kjeldahl nitrogen

Kjeldahl nitrogen concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed 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 according to the EPA (1983) colormetric semi-automated method 352.1. The minimum reporting limit for Kjeldahl nitrogen is 0.01 mg/L.

Kjeldahl nitrogen concentrations ranged from 2.20 mg/L at station P8 in the south Delta in February, to undetectable levels (<0.01 mg/L) at sites P8 and C3 in October 2003 (Figures 3-16 and 3-17). Kjeldahl nitrogen levels during the 2001-2002 study period also peaked at site P8 with a high of 3.70 mg/L (DWR 2004).

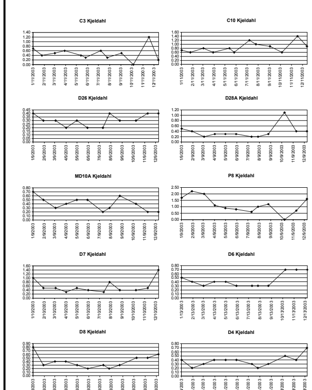

Figure 3-17 Kjeldahl nitrogen (mg/L), 2003

Kjeldahl nitrogen concentrations were generally highest in the south Delta region (Sites P8 and C10). The two south Delta sites also showed the greatest variability. No strong seasonal or interannual trends were apparent among all the sites, although three sites (P8, C10 and C3) showed a sudden one-month marked decline in October 2003.

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 water samples were then passed 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 for total ammonia according to the EPA (1983) colormetric, automated, phenate method 350.1; and for nitrate and nitrite according to the colormetric automated cadmium reduction method 353.2 (EPA 1983). DIN was calculated as the sum of total ammonia plus nitrate and nitrite. The minimum reporting limit for DIN was 0.01 mg/L.

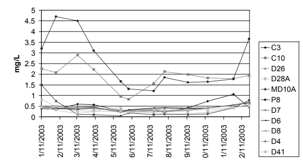

Figure 3-18 Dissolved inorganic nitrogen

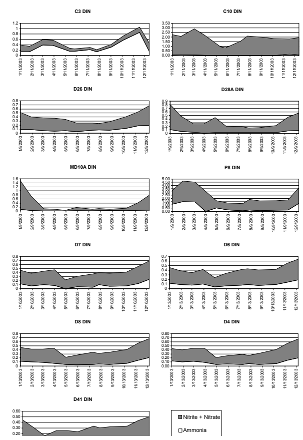

Figure 3-19 Dissolved inorganic nitrogen (mg/L), 2003

DIN concentrations ranged from 4.70 mg/L in the south Delta (site P8) in February to 0.07 mg/L in the east Delta (site MD10) in September (Figures 3-18 and 3-19). These DIN values were similar to results obtained in 2001-2002, which recorded a maximum of 4.8 mg/L at P8 and a minimum value of 0.14 mg/L at station MD10.

DIN values were consistently high in the south Delta stations C10 and P8, as compared to other stations, with almost all values greater than 1.0 mg/L. In contrast all other stations had most DIN values below 1.0 mg/L and a majority of values below 0.05 mg/L. The high values observed in the south Delta may be due to runoff and drainage from agricultural operations on the San Joaquin River.

Concentrations in the south Delta also showed the greatest degree of seasonal variability. By contrast, DIN concentrations in the Suisun Bay (D6, D7, and D8) showed only minor seasonal variations. All regions showed some seasonal variation with DIN values lowest in August and September, when water temperatures and phytoplankton growth were highest and inflows were lowest, followed by increases in late fall and winter.

Dissolved Organic Nitrogen

Organic nitrogen is defined functionally as nitrogen that is bound to carbon-containing compounds in the tri-negative oxidation state (APHA 1992). This form of nitrogen must be mineralized or decomposed before it can be used by aquatic and terrestrial plants. It does not include all organic nitrogen compounds, but does include proteins, peptides, nucleic acids, urea, and numerous synthetic organic compounds (APHA 1992).

Dissolved organic nitrogen (DON) was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed 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 according to the EPA (1983) colormetric, semi-automated method 351.2. The minimum reporting limit for DON was 0.10 mg/L.

DON concentrations ranged from 1.80 mg/L at station P8 in the east Delta in March to concentrations below detectable levels (< 0.10 mg/L) at station D4 in February 2003 (Figures 3-20 and 3-21). Peak DON levels during 2001-2002 were considerably lower, reaching 1.10 mg/L at station MD10 in January 2002 (DWR 2004).

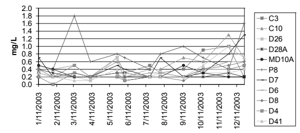

Figure 3-20 Dissolved organic nitrogen

DON concentrations showed no clear seasonal or intra-annual pattern of variation; however, most sites showed increases in DON concentrations during the winter, and most sites had consistently low DON during April 2003.

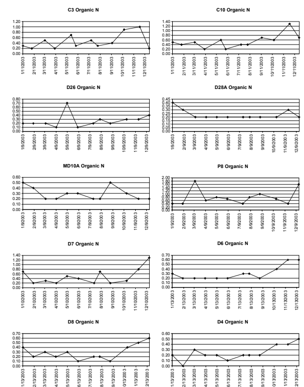

Figure 3-21 Dissolved organic nitrogen (mg/L), 2003

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the solid fraction of a sample able to pass through a filter. The value of dissolved solids gives a general indication of the suitability of the water as a drinking source and for certain agricultural and industrial uses. Waters with high dissolved solids are of inferior palatability and may induce an unfavorable physiological reaction in consumers (APHA 1992).

TDS were 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 membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis, using EPA (1983) method 160.1.

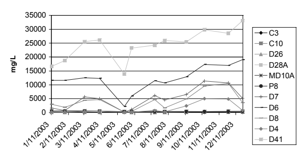

Figure 3-22 Total dissolved solids

TDS in the Bay-Delta varied over a wide range from 33,060 mg/L in the San Pablo Bay (site D41) in December to 76 mg/L in the north Delta (site C3) in August 2003 (Figures 3-22 and 3-23). The values and locations of maxima and minimum TDS were similar to results obtained during 2001-2002. The high values seen in San Pablo Bay are likely due to tidal influences of seawater with high TDS entering the Delta at San Pablo Bay. The lower TDS values seen at site C3 are due to spring flows of low TDS freshwater entering the Delta from the Sacramento Valley basin.

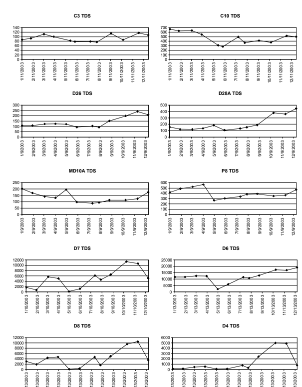

Figure 3-23 Total dissolved solids (mg/L), 2003

All sites subject to significant tidal exchange (that is, sites D41, D6, D7, D8, and D4) showed increasing TDS concentrations the closer they were to the coast. Aside from site D41, these sites also showed high seasonal variability in TDS concentrations. For these sites, low TDS values occurred in May and highest values occurred at year's end.

Total Suspended Solids

Suspended solids are the solids present in a water sample that are retained on a filter after the sample is filtered. Suspended solids include a wide variety of material such as silt, living or decaying organic matter, and anthropogenic matter. High amounts of suspended solids block light penetration into the water column and increase heat absorption.

Total suspended solids (TSS) may increase in surface waters due to increases in flow rate, as higher velocities increase water's capacity to suspend solids. Runoff from heavy rains can simultaneously introduce large amounts of solids into surface waters and provide the capacity for their suspension. Therefore, suspended solids concentrations can vary significantly over relatively short time periods.

Water samples for TSS 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 using EPA (1983) method 160.2.

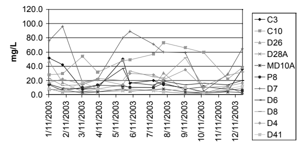

Figure 3-24 Total suspended solids

TSS in the San Francisco Bay-Delta varied over a wide range from 96 mg/L in Suisun Bay in February to 2.0 mg/L at several sites in March and October 2003 (Figures 3-24 and 3-25). These results are in contrast to the previous study period, 2001-2002, where the highest TSS values were recorded in the north Delta (118 mg/L) and the lowest TSS values were below the recording limit of 1 mg/L at several sites (DWR 2004).

TSS values at most sites showed "pulse" increases at various times during the year. These increases did not show any discernable seasonal pattern. Although winter pulse variations may be due to rain or hydrological events, variations in TSS at other times may reflect changing levels of organic matter.

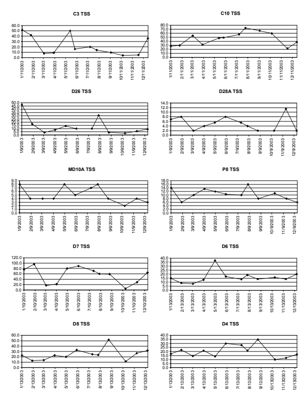

Figure 3-25 Total suspended solids (mg/L), 2003

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.

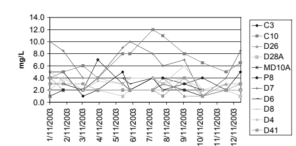

Figure 3-26 Volatile suspended solids

VSS levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions, and reached a high of 12.0 mg/L in the south Delta (site C10) in July (Figures 3-26 and 3-27). These results were similar to those observed in the previous reporting period from 2001-2002 (DWR 2004). Sites C10 in the south Delta and C3 in the north Delta showed the highest degree of variability, with VSS levels ranging from 1.0 to 12.0 mg/L. Other sites showed a narrower range of values; however, no apparent seasonal variation was seen in these data.

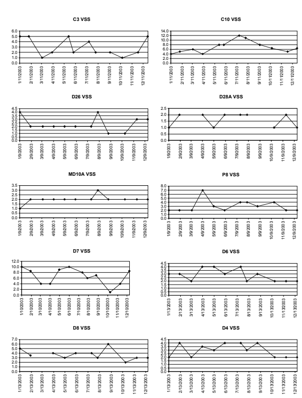

Figure 3-27 Volatile suspended solids (mg/L), 2003

Silica

Water samples for silica 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 silica according to EPA Method 200.7 (EPA 1983). The minimum reporting level for silica in these analyses was 0.1 mg/L.

Silica concentrations ranged from 26 mg/L in Suisun Bay (site D6) in January to 4.8 mg/L in San Pablo Bay (site D41) in March 2003 (Figures 3-28 and 3-29). These values are similar to those observed in the previous 2001-2002 reporting period (DWR 2004). In comparison with the 2001-2002 period, silica values appeared less variable; however, the apparent seasonal trend of declining silica levels in spring months followed by increased silica concentrations in late summer and winter was also observed at the majority of sites.

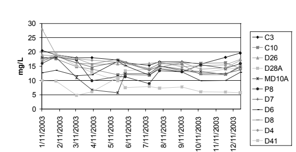

Figure 3-28 Silica

Chloride

Water samples for chloride 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 chloride according to EPA Method 300.0 (EPA 1983).

Chloride concentrations in the Bay-Delta varied over a wide range from 16,500 mg/L in San Pablo Bay (site D41) in November to 3 mg/L in the north Delta (site C3) in August (Figures 3-30 and 3-31). These results are very similar to those observed in the 2001-2002 reporting period, which recorded 17,200 mg/L chloride in the San Pablo Bay in January 2001 and 4 mg/L in the north Delta in July 2002 (DWR 2004). The high values seen in San Pablo Bay are likely due to tidal influences of seawater entering the Delta, while the low values seen at site C3 are likely due to spring flows of fresh water down the Sacramento River. Values of chloride concentrations are closely correlated to values reported for specific conductance and total dissolved solids (TDS) reported earlier in this report.

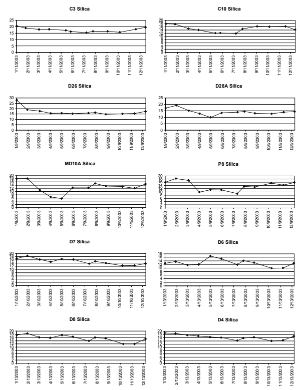

Figure 3-29 Silica (mg/L), 2003

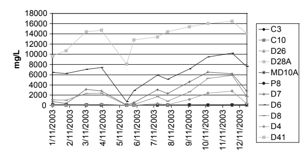

Figure 3-30 Chloride

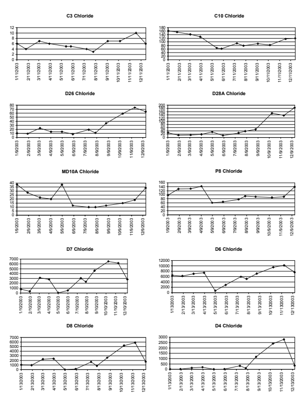

Figure 3-31 Chloride (mg/L), 2003

Summary

The Department's monitoring and reporting of water quality data shown here is mandated in order to ensure compliance with water quality objectives; identify meaningful changes potentially related to the operation of the State Water Project and the Central Valley Project; and to reveal trends in ecological changes potentially related to project operations. Flow rates, influenced by natural forces and project operations, are a primary determinant of water quality dynamics at each site described. However, flow rates are not measured as part of this sampling protocol, and therefore a more analytical treatment of these data in relation to flow rates is not included. These data are presented as a snapshot of the system. They allow a historic comparison of a wide range of water quality parameters and show an overall consistency with recent years.

References

[APHA] American Public Health Association. 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th Edition, Washington DC.

[DWR] California Department of Water Resources. 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1996*.

[DWR] California Department of Water Resources. 2003. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1997- 2000*.

[DWR] California Department of Water Resources. 2004. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2001-2002*.

[EPA] U.S. Environmental Protection Agency. 1983. *Methods for Chemical Analysis of Water and Wastes*. Technical Report EPA-600/4-79-020.

Figure 3-1 Water quality monitoring stations

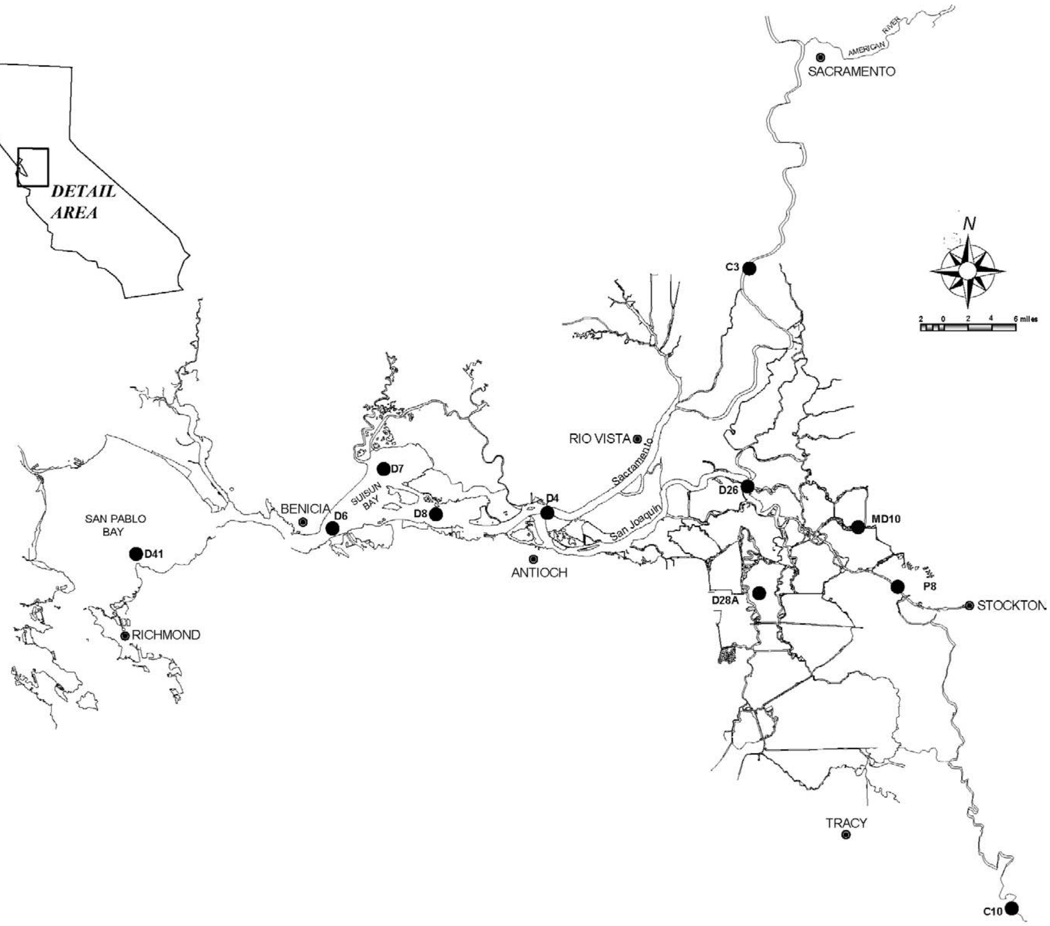

Figure 3-2 Water temperature

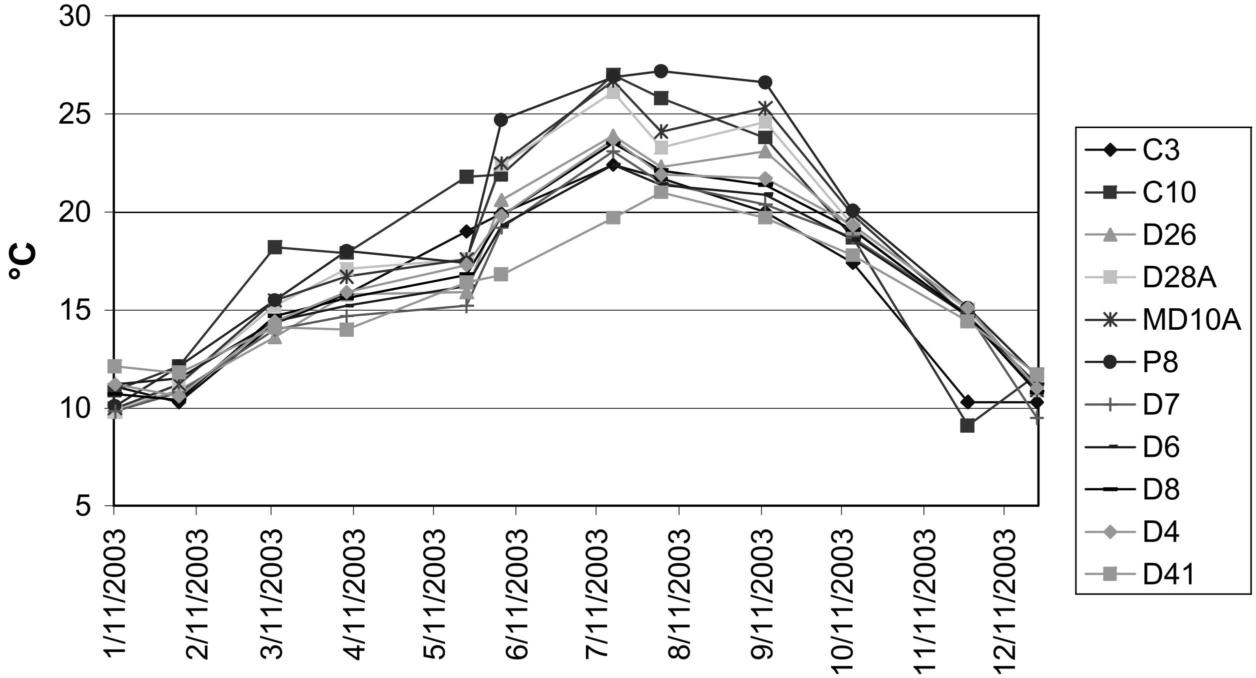

Figure 3-3 Water temperature (°C), 2003

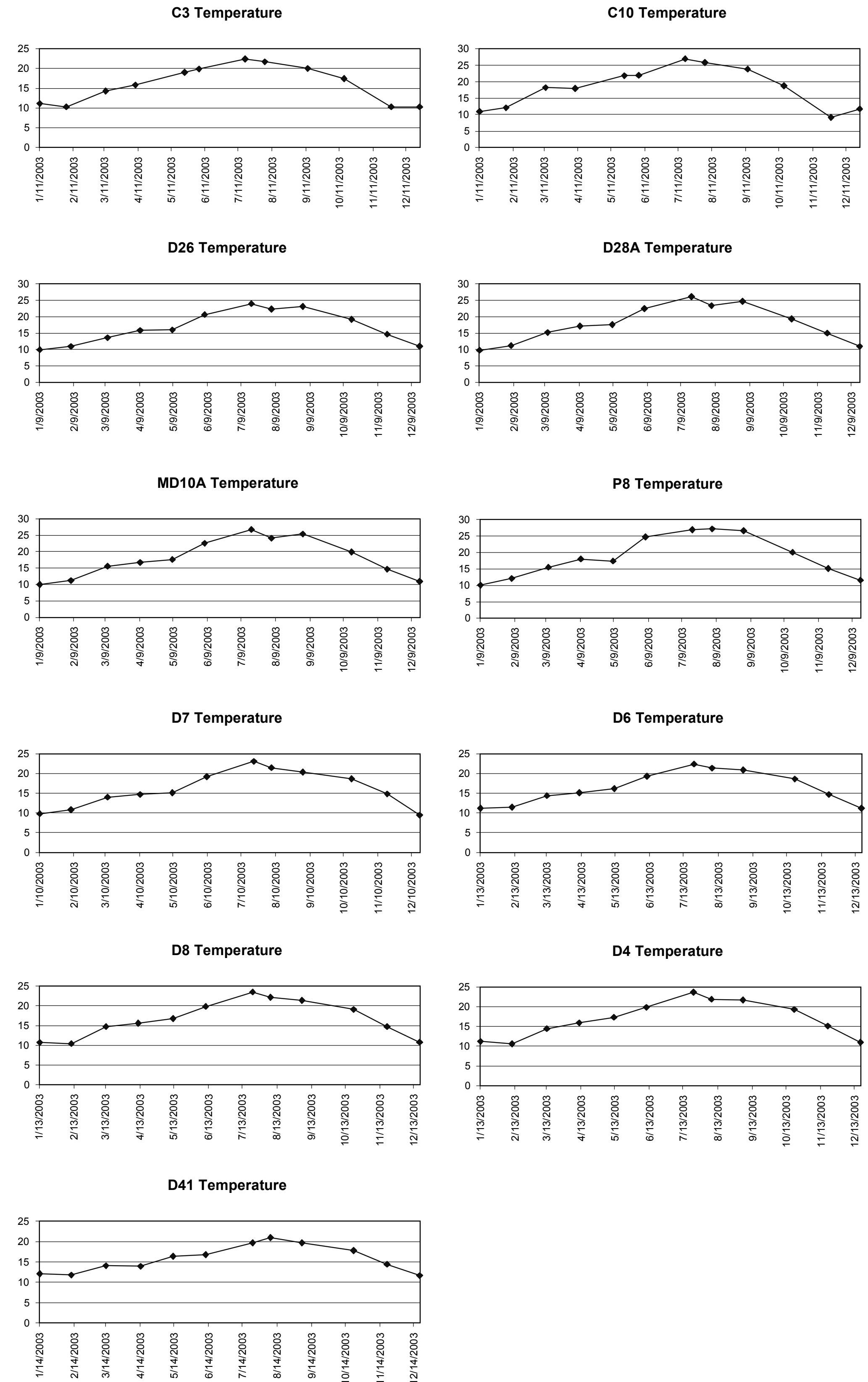

Figure 3-4 Dissolved oxygen

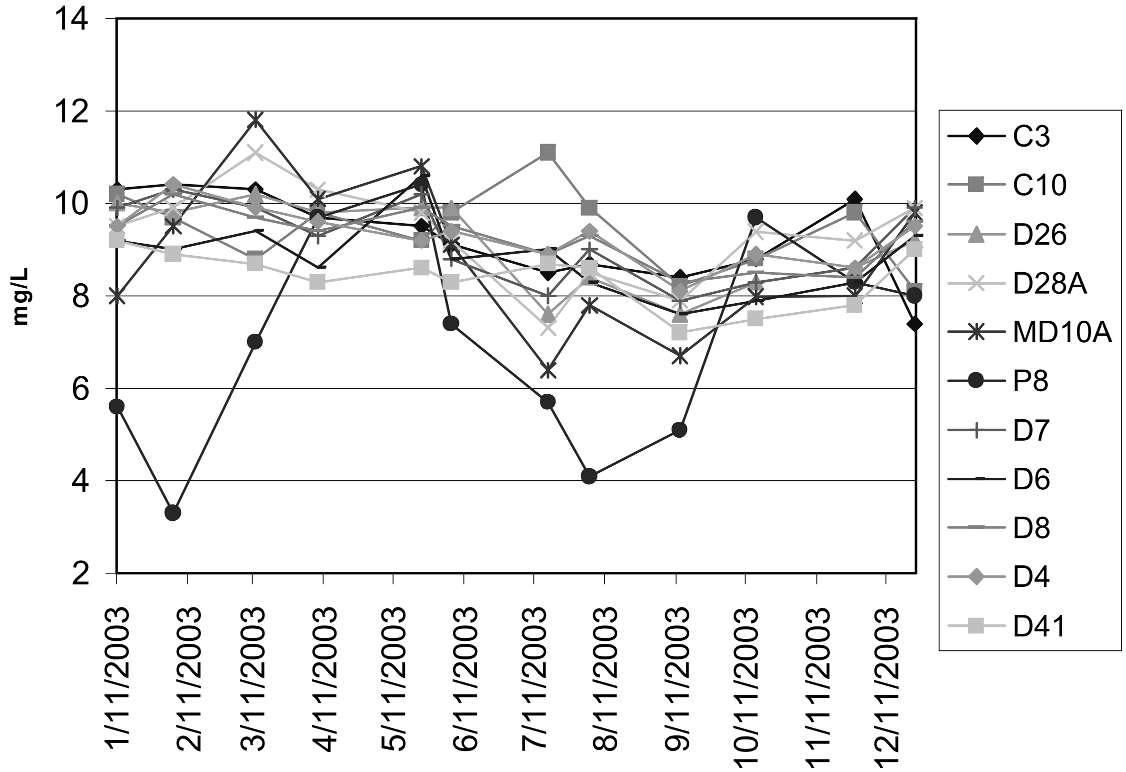

Figure 3-5 Dissolved oxygen (mg/L), 2003

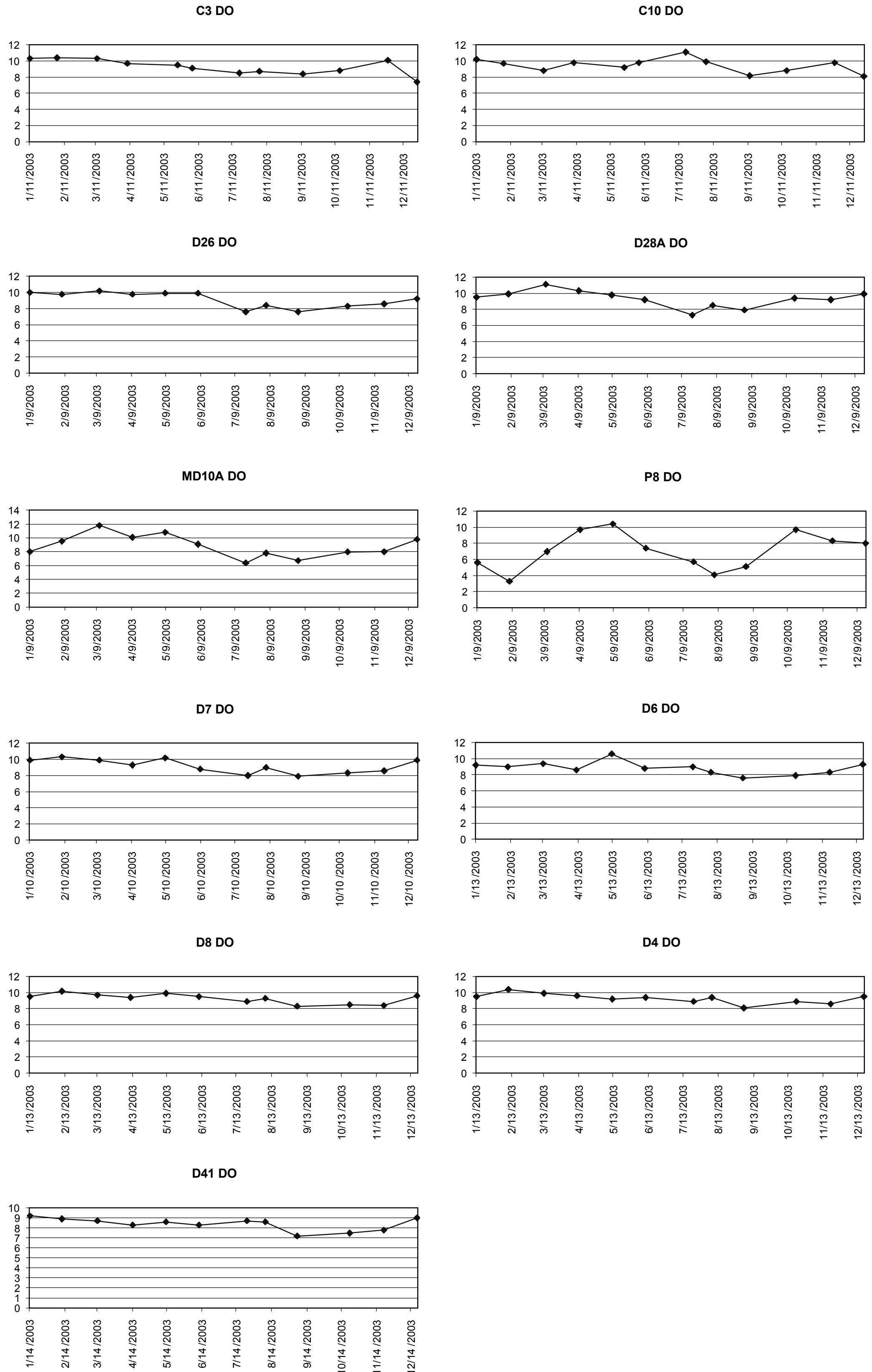

Figure 3-6 Specific conductance

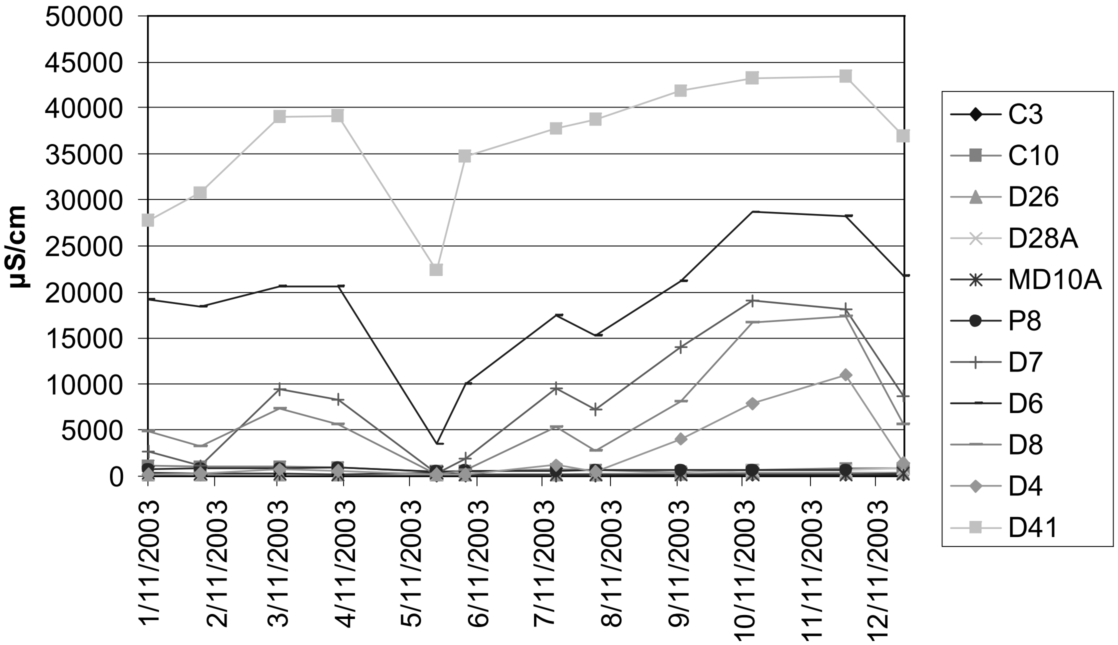

Figure 3-7 Specific conductance (µS/cm), 2003

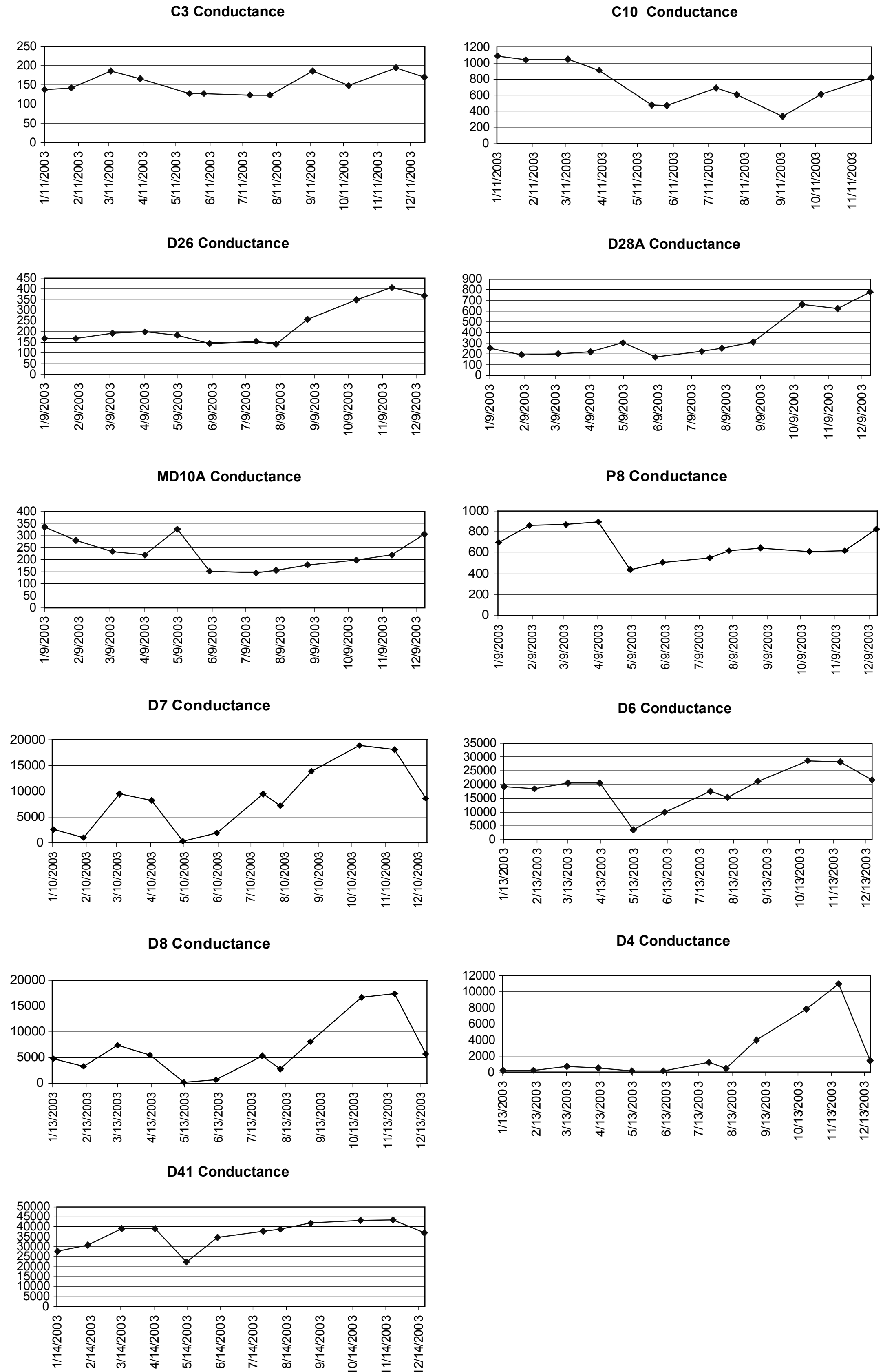

Figure 3-8 Secchi depth

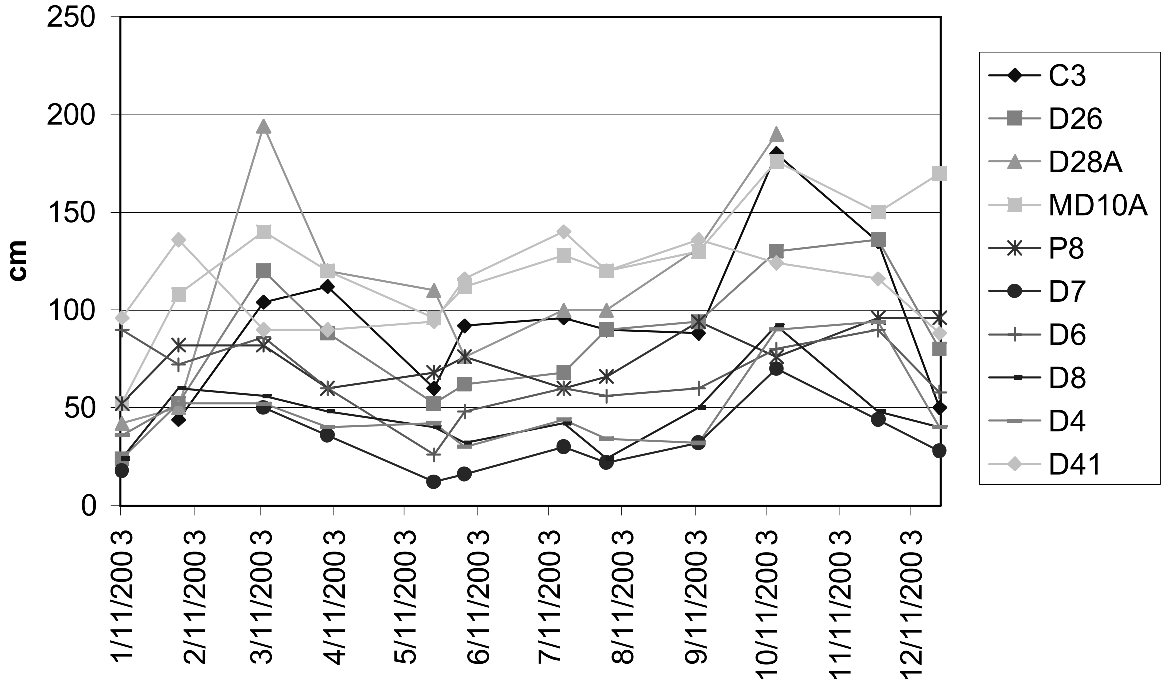

Figure 3-9 Secchi disk depth (cm), 2003

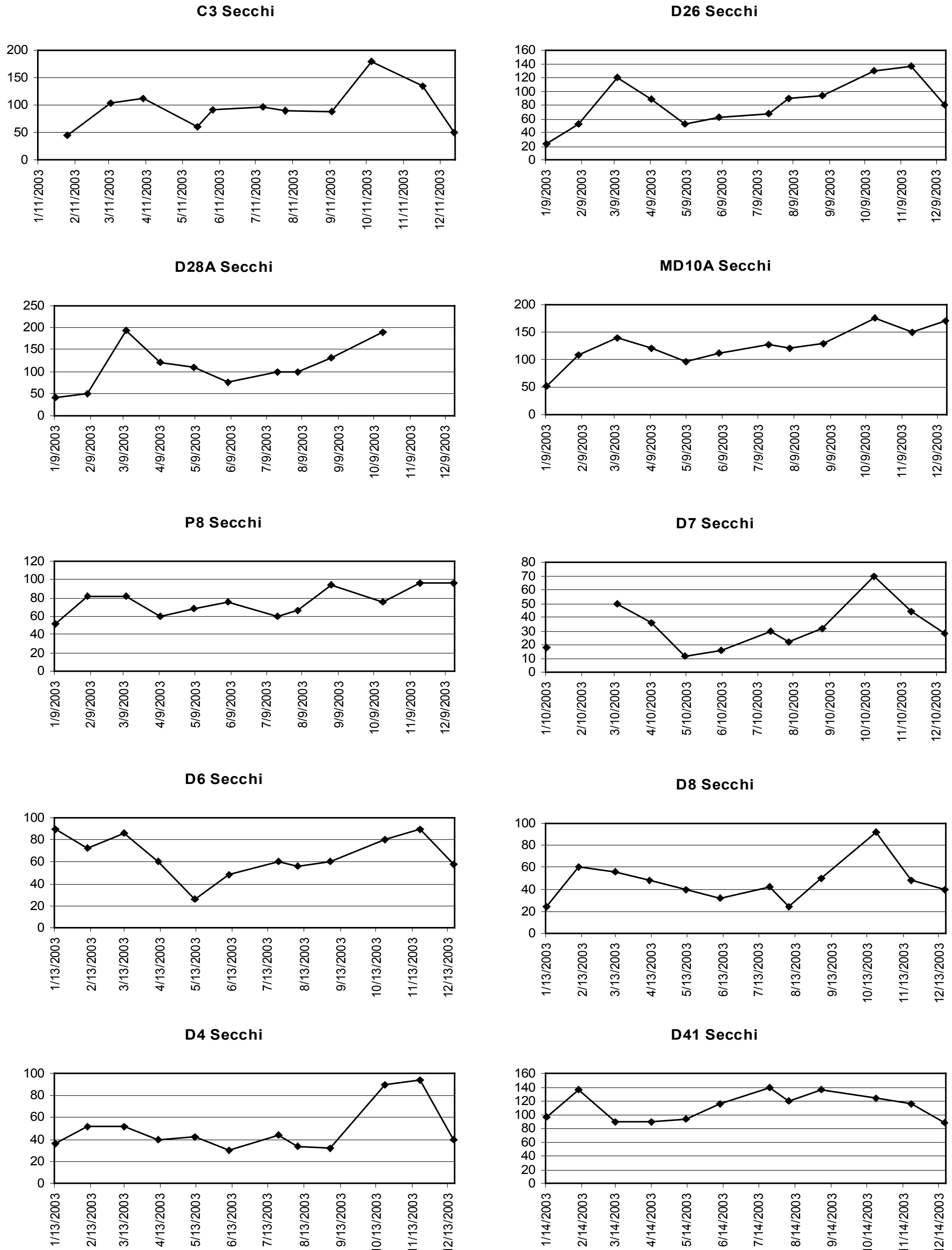

Figure 3-10 Turbidity

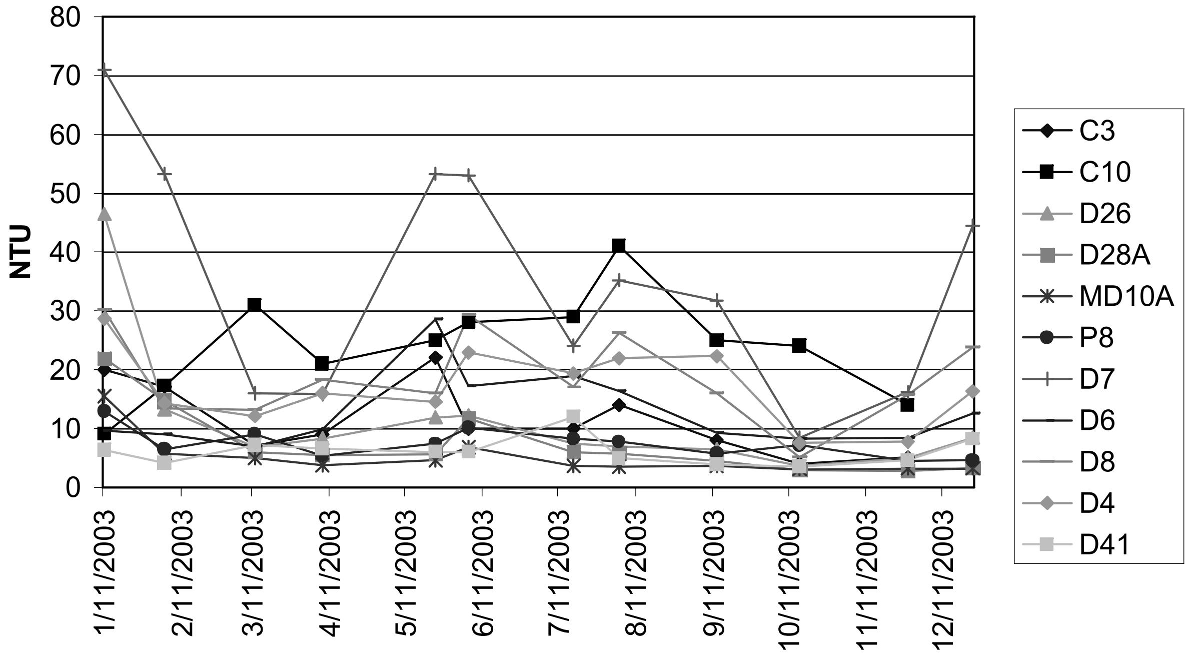

Figure 3-11 Turbidity (NTU), 2003

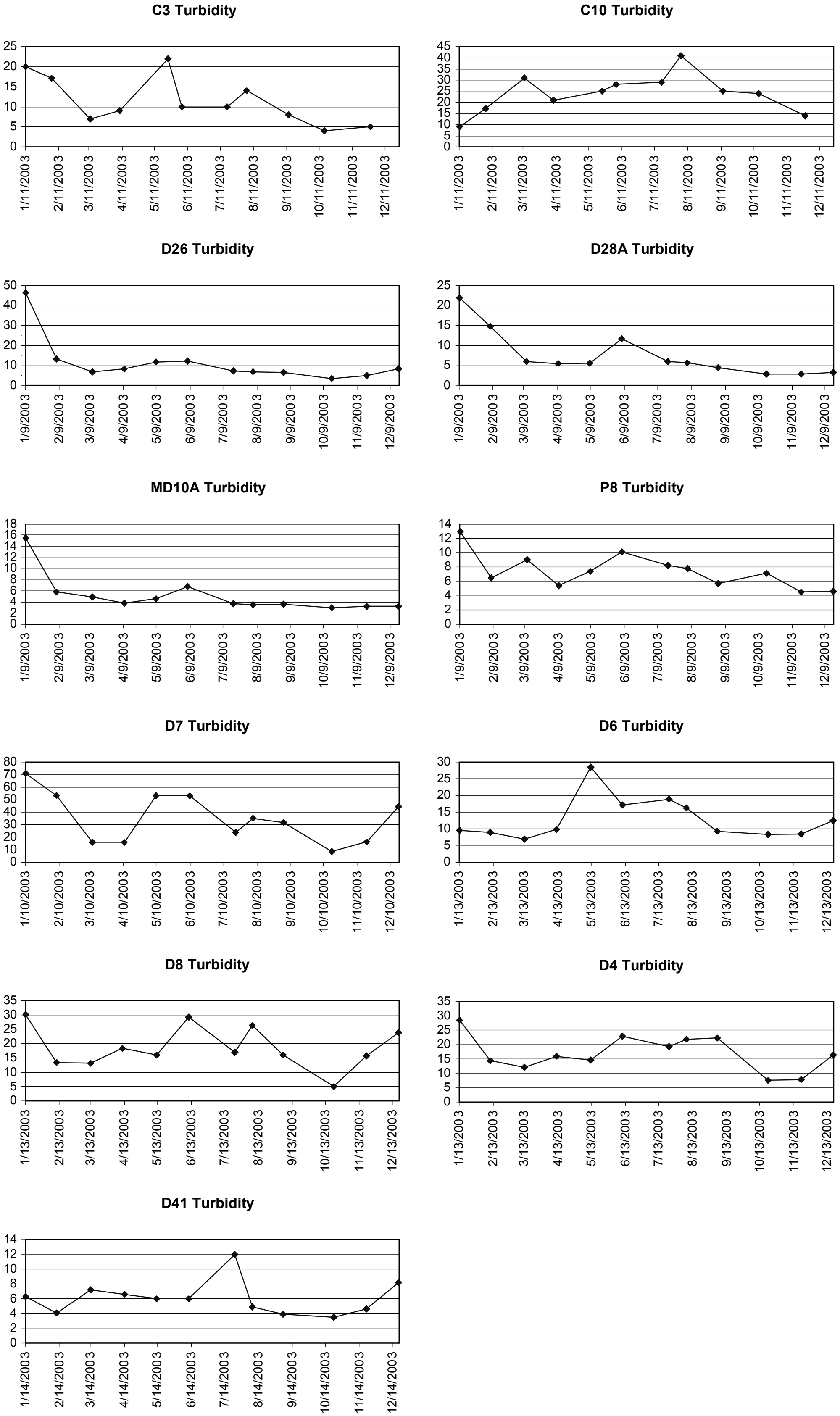

Figure 3-12 Orthophosphate

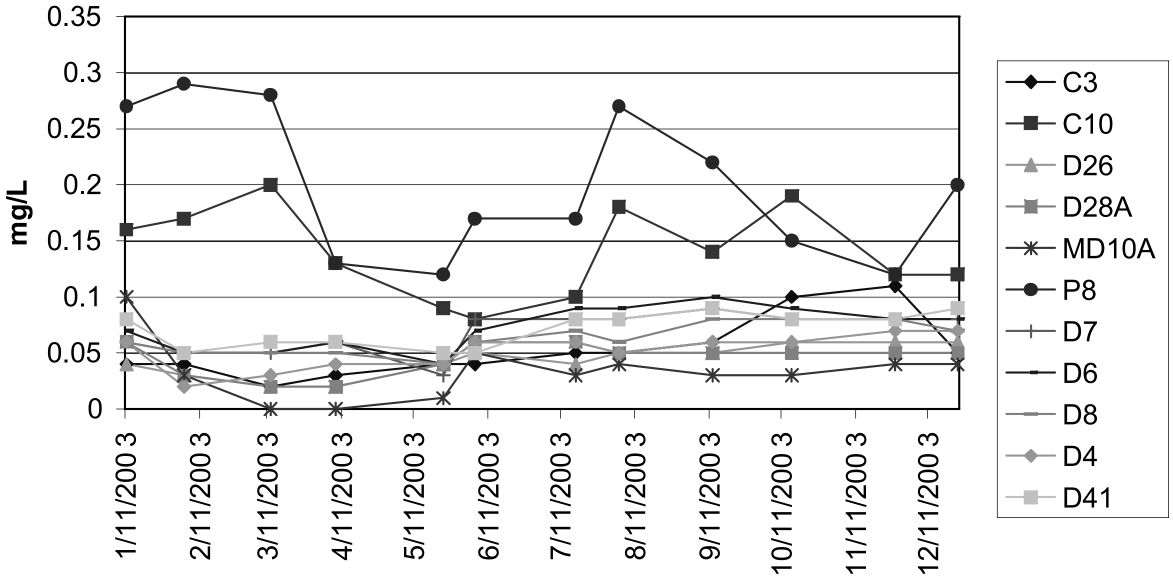

Figure 3-13 Orthophosphate (mg/L), 2003

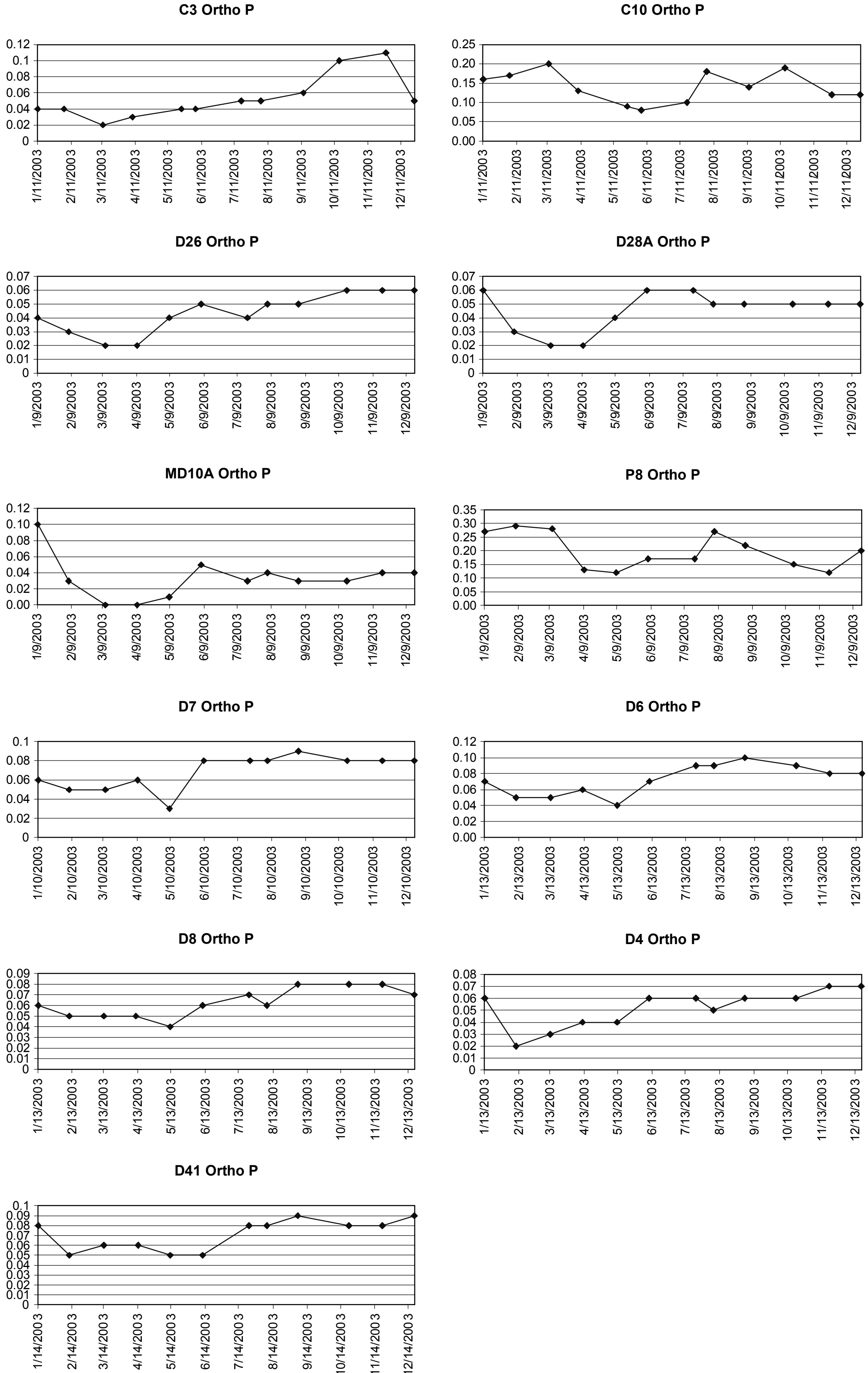

Figure 3-14 Total phosphorus

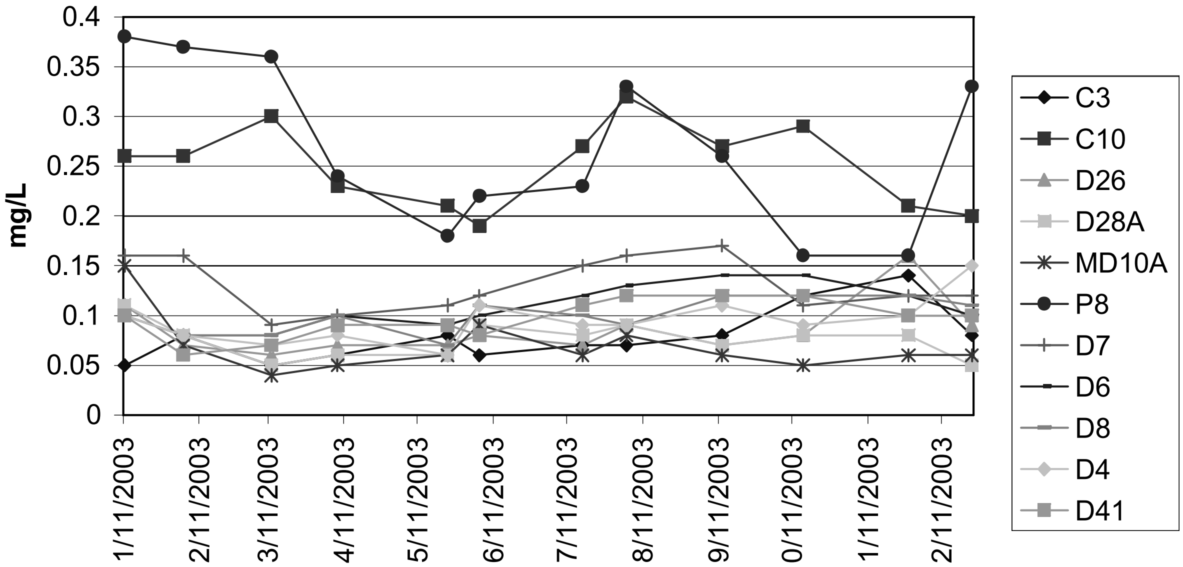

Figure 3-15 Total phosphorus (mg/L), 2003

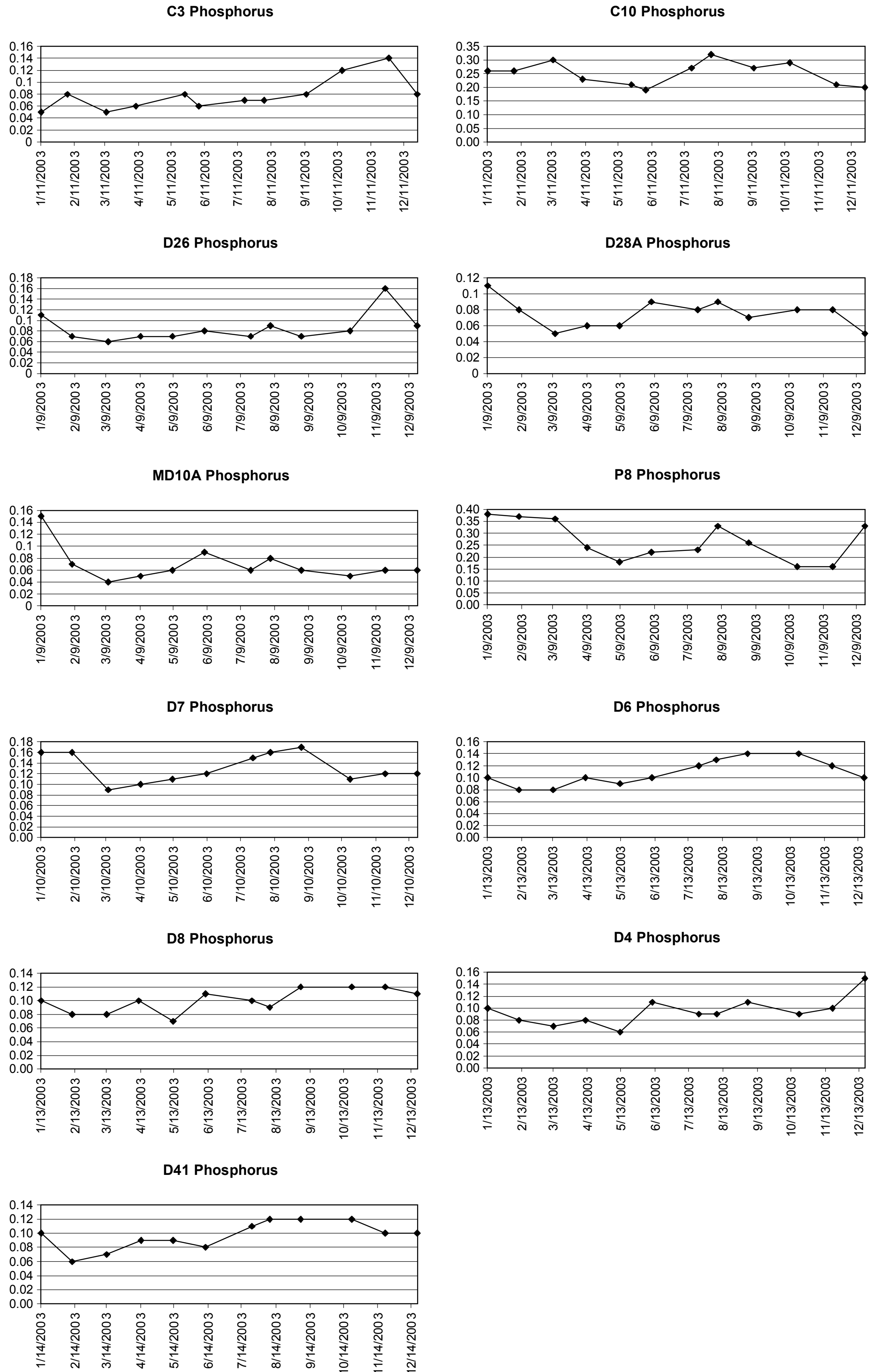

Figure 3-16 Kjeldahl nitrogen

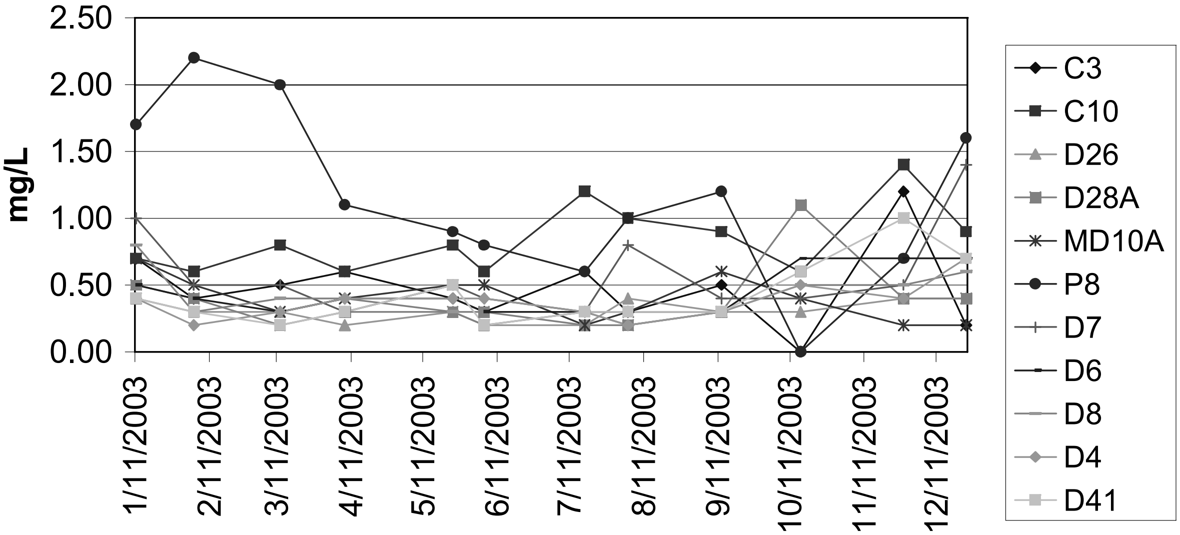

Figure 3-17 Kjeldahl nitrogen (mg/L), 2003

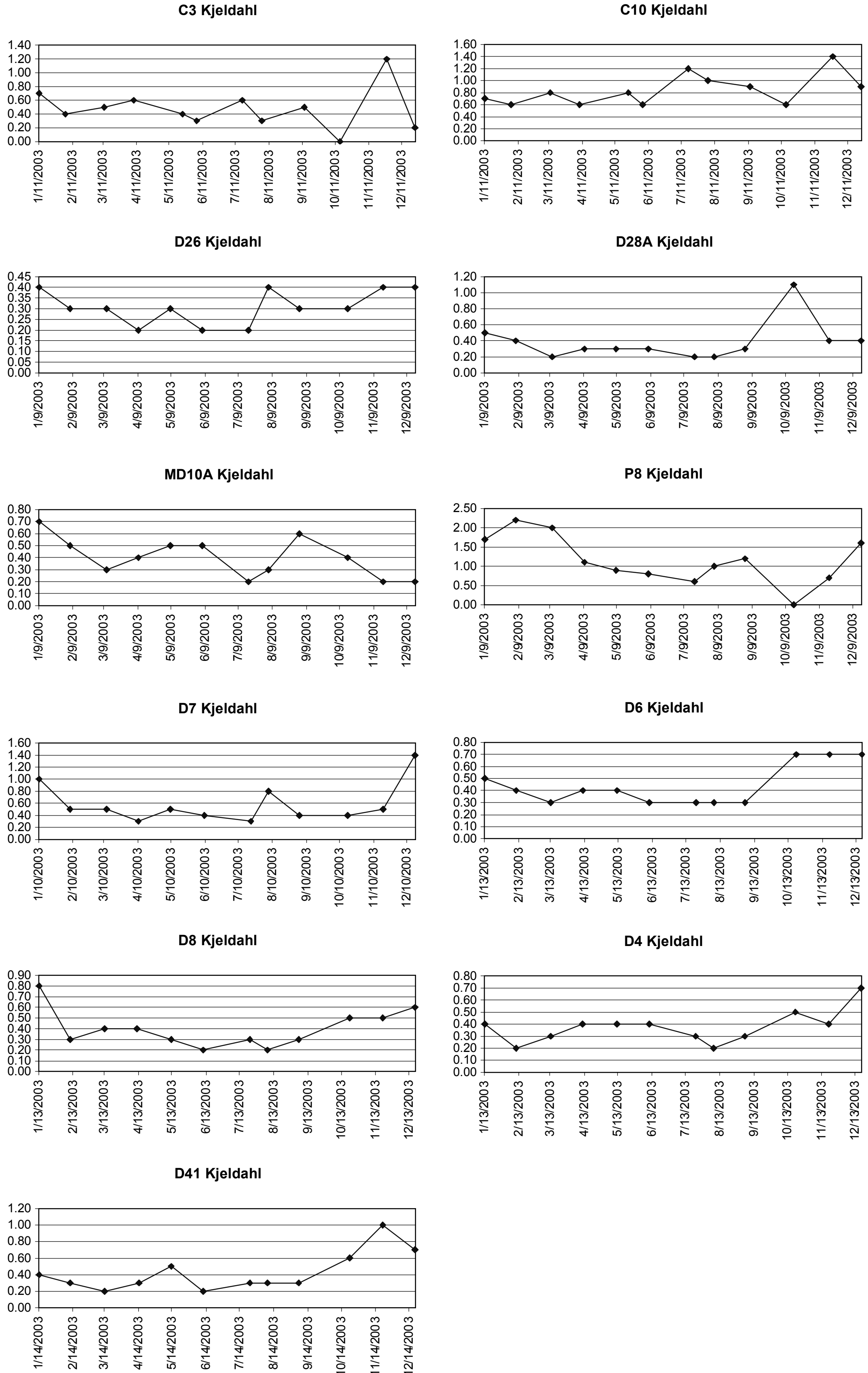

Figure 3-18 Dissolved inorganic nitrogen

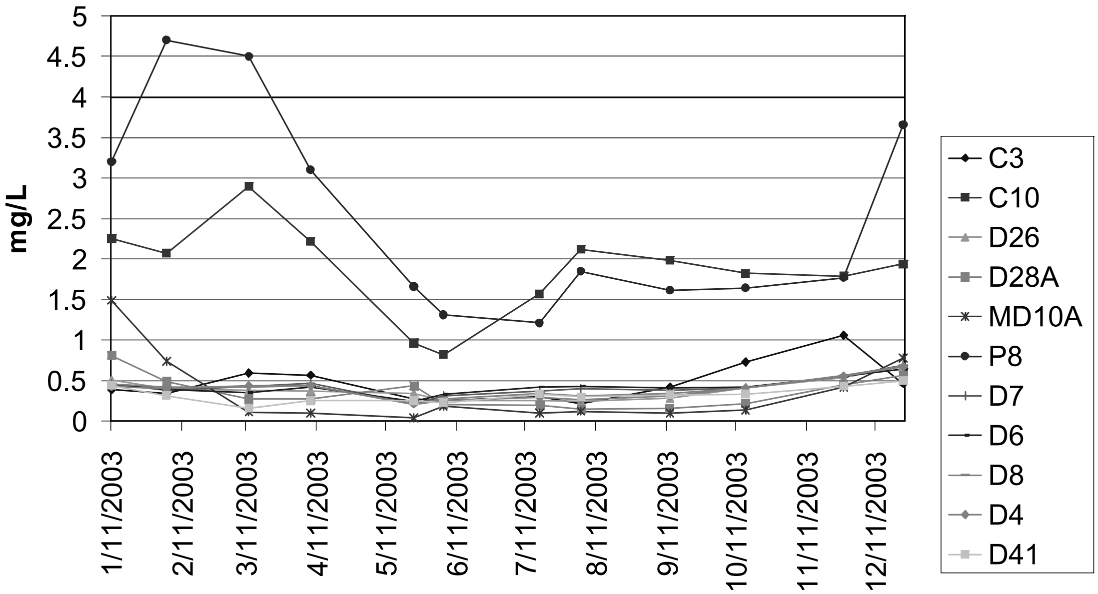

Figure 3-19 Dissolved inorganic nitrogen (mg/L), 2003

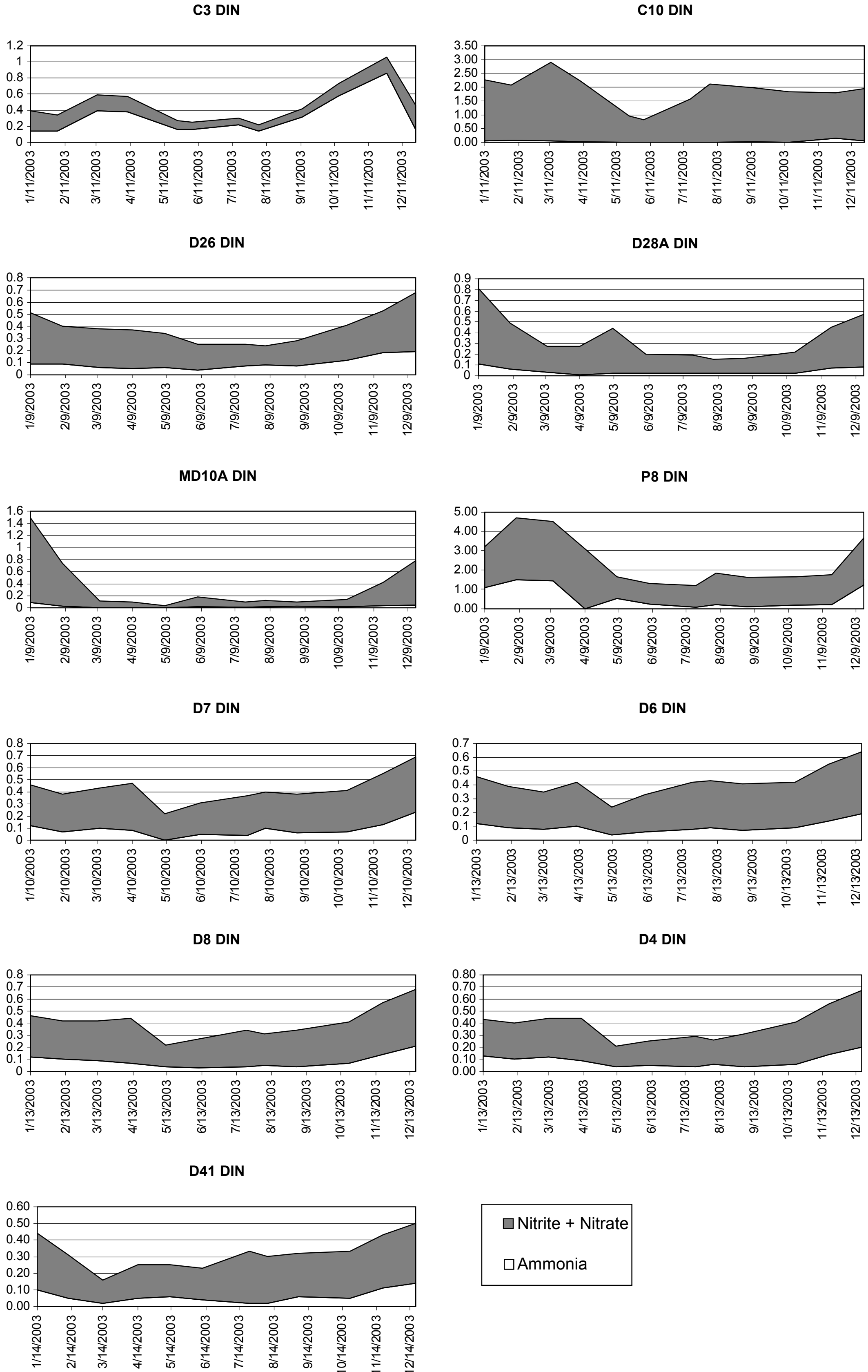

Figure 3-20 Dissolved organic nitrogen

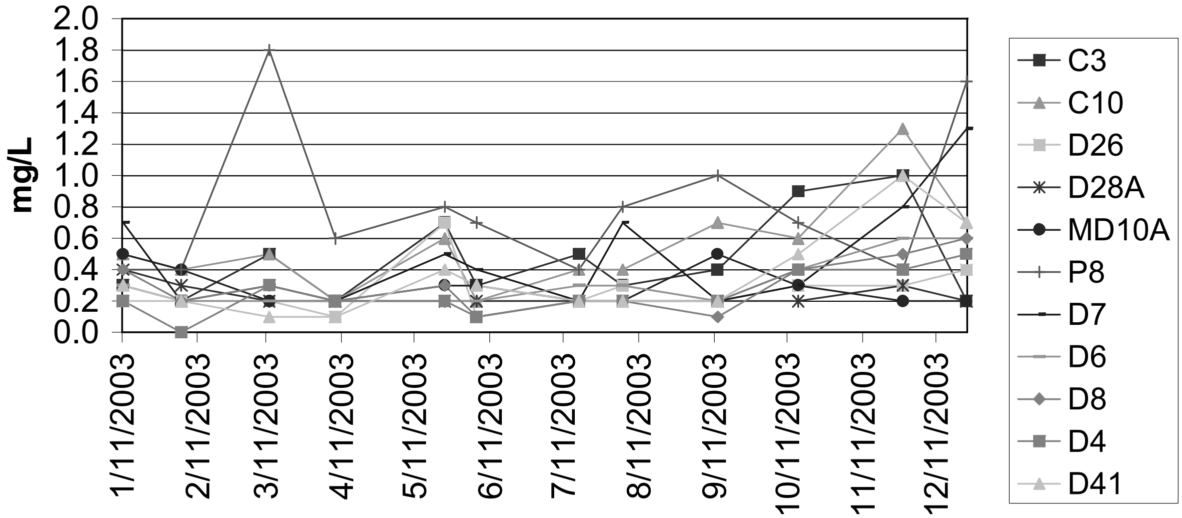

Figure 3-21 Dissolved organic nitrogen (mg/L), 2003

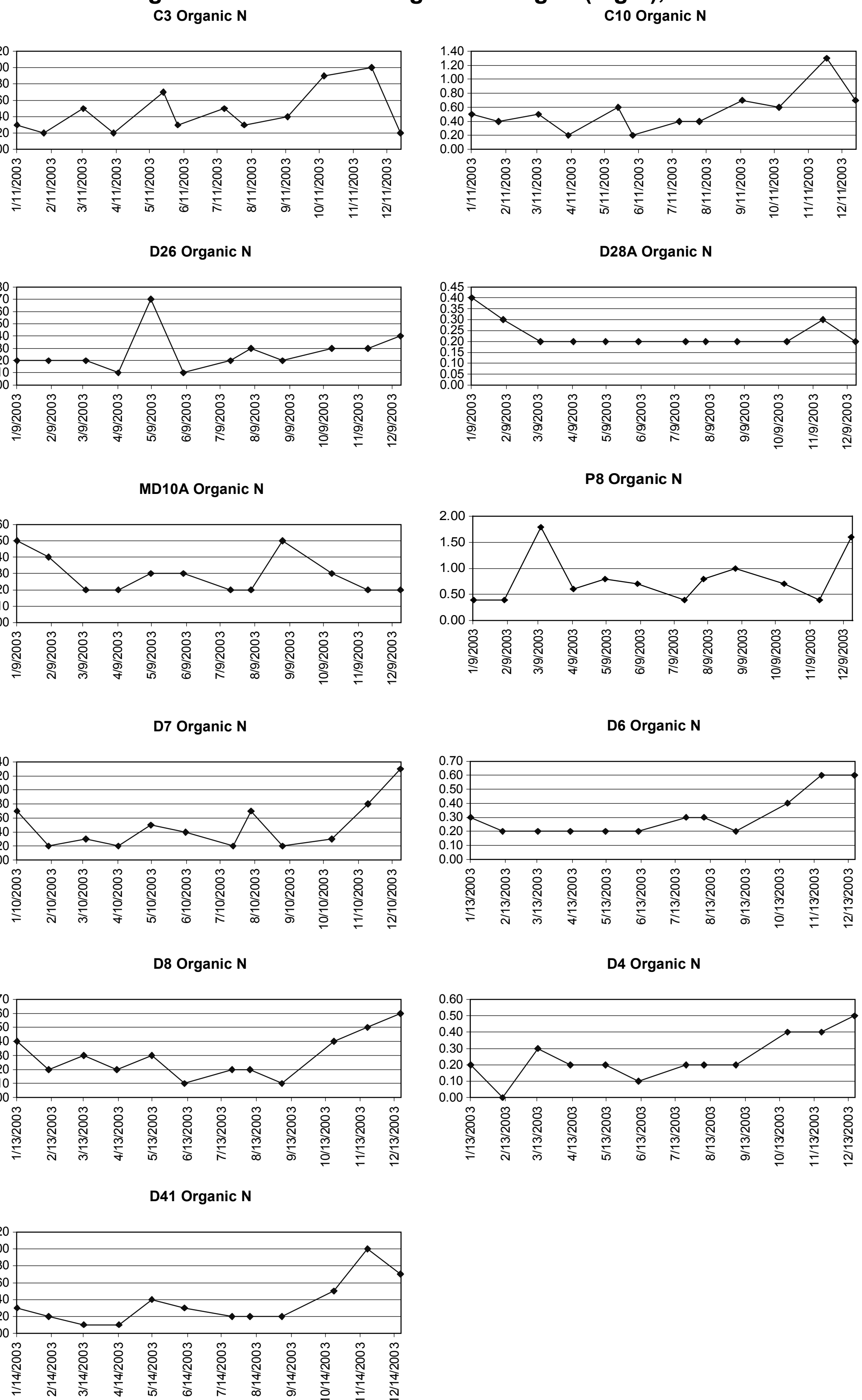

Figure 3-22 Total dissolved solids

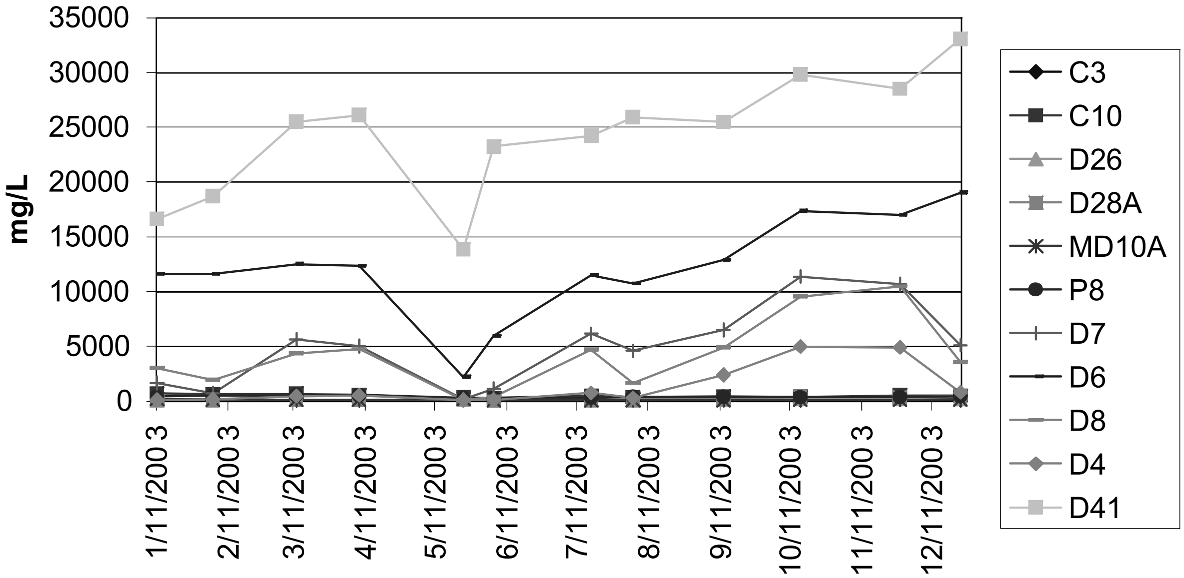

Figure 3-23 Total dissolved solids (mg/L), 2003

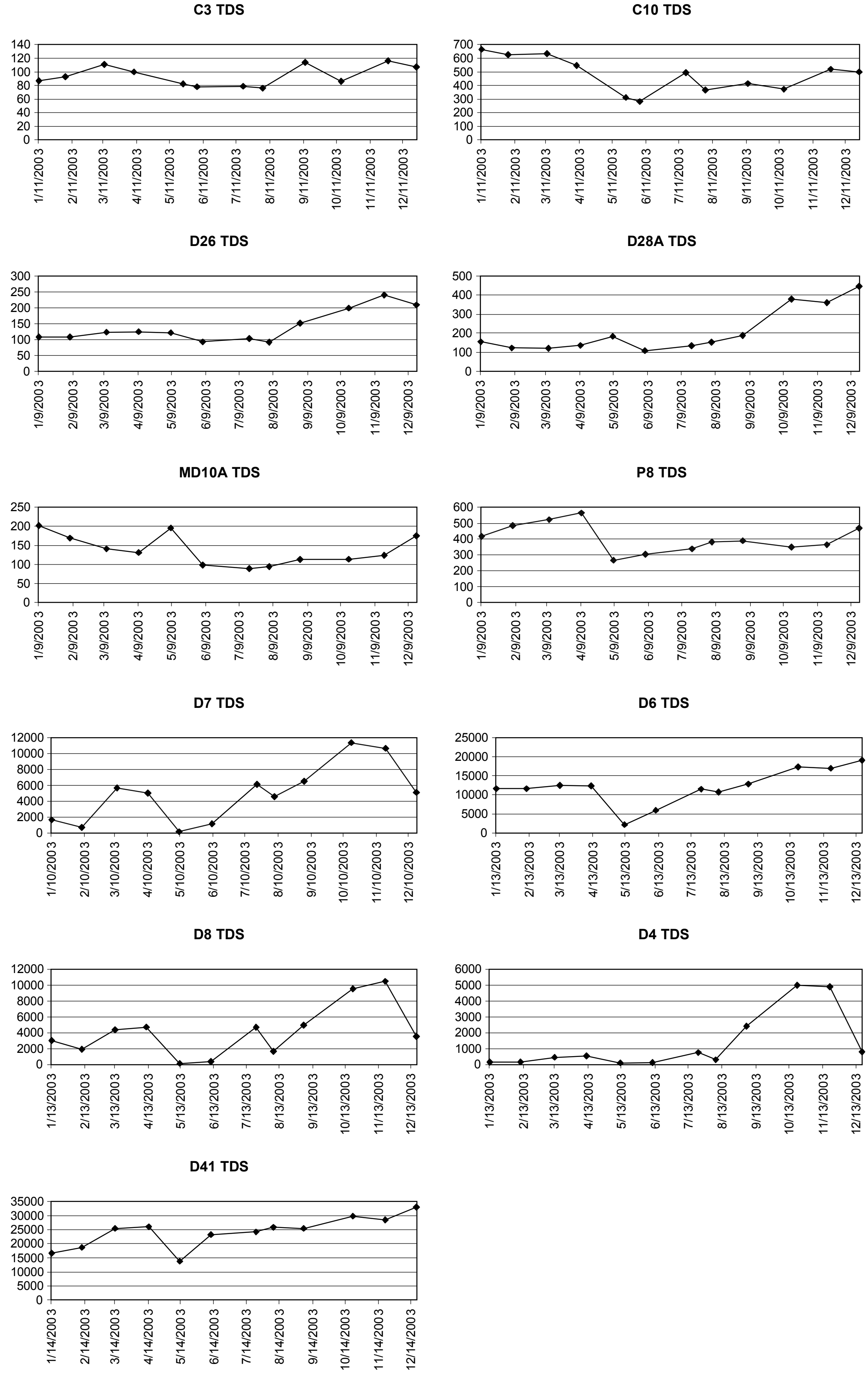

Figure 3-24 Total suspended solids

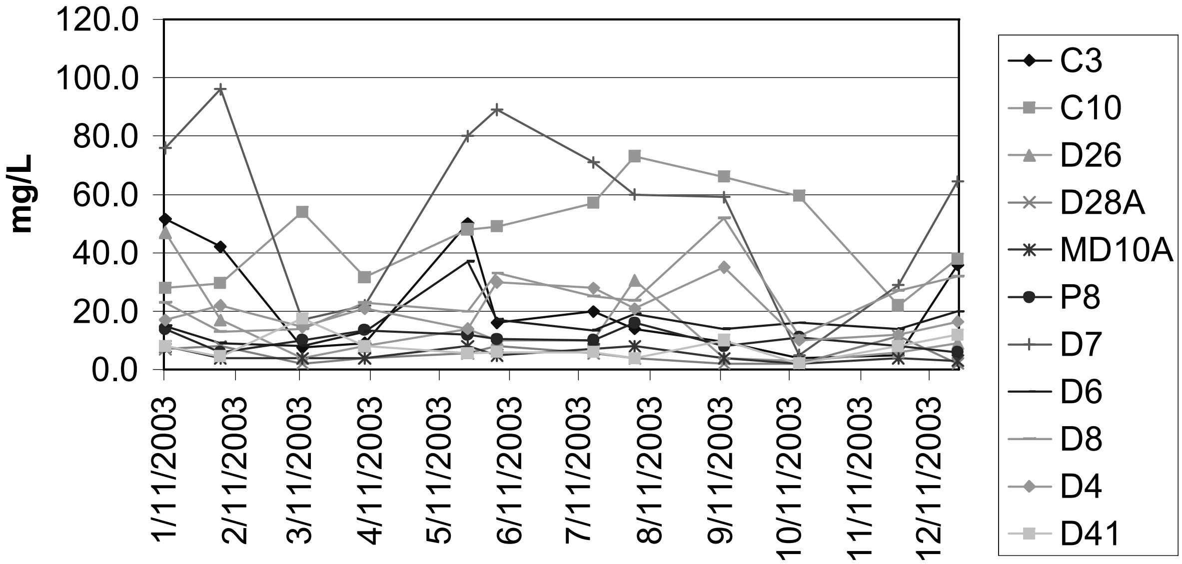

Figure 3-25 Total suspended solids (mg/L), 2003

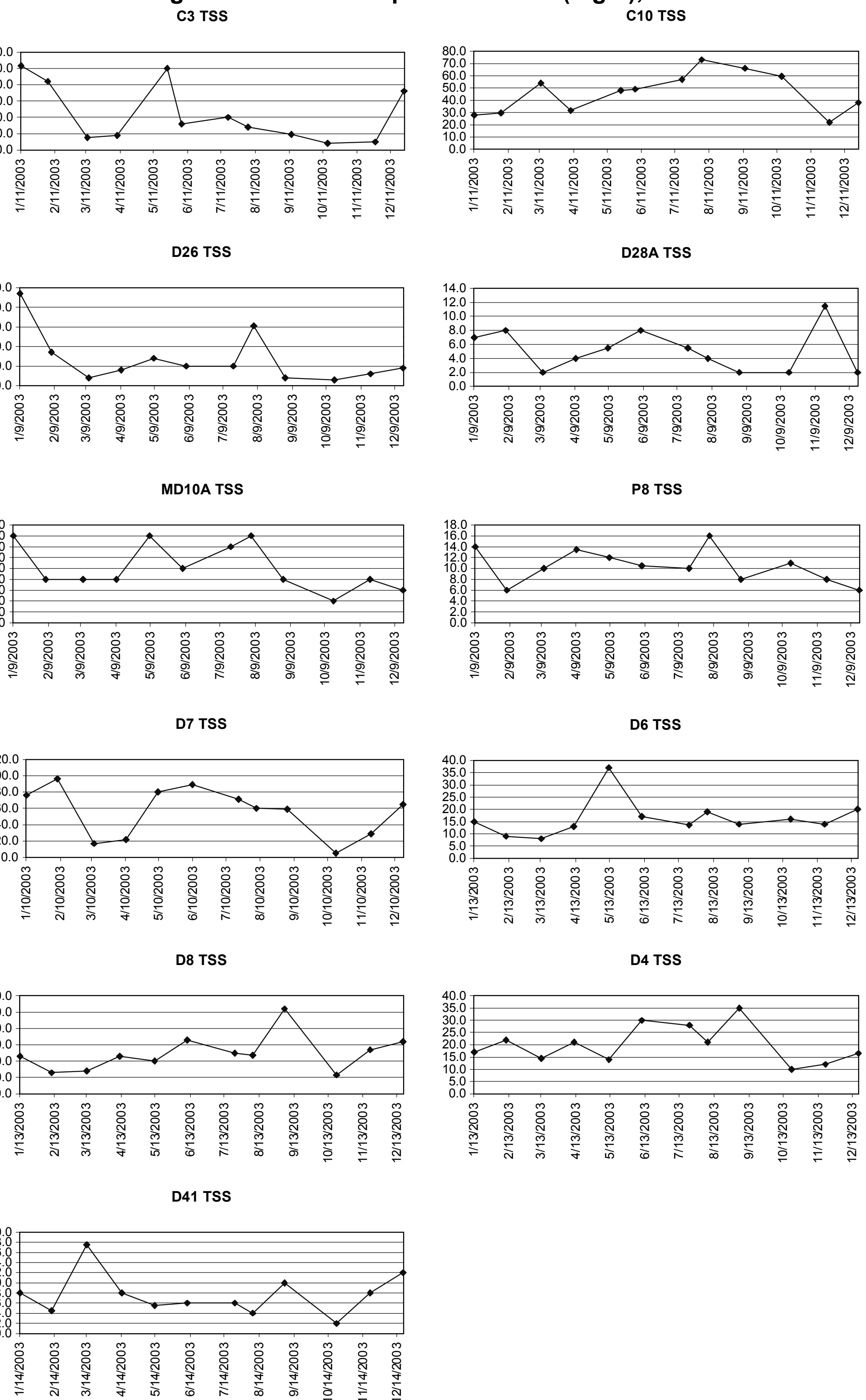

Figure 3-26 Volatile suspended solids

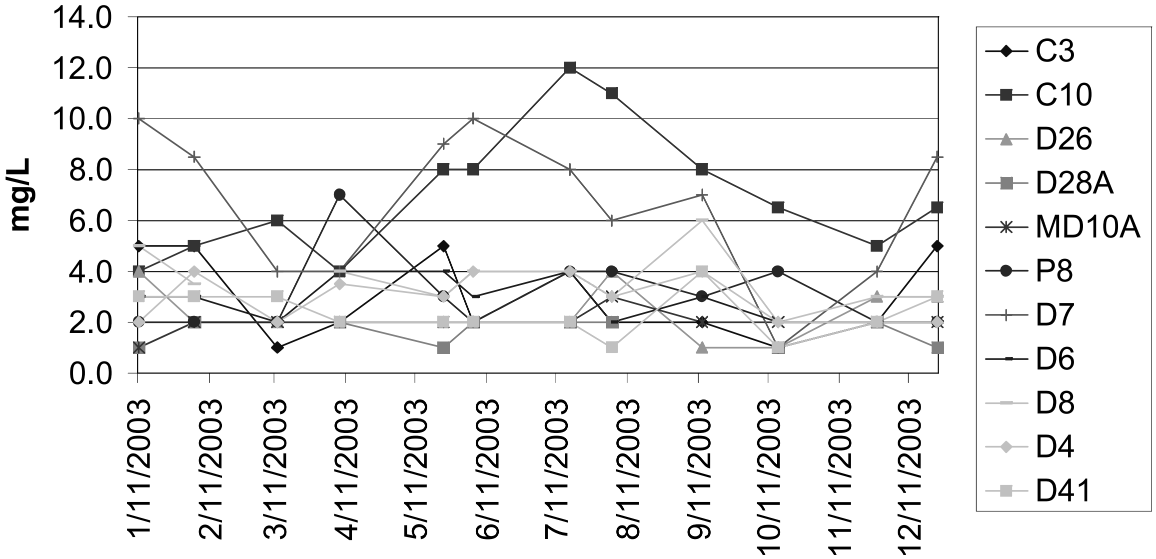

Figure 3-27 Volatile suspended solids (mg/L), 2003

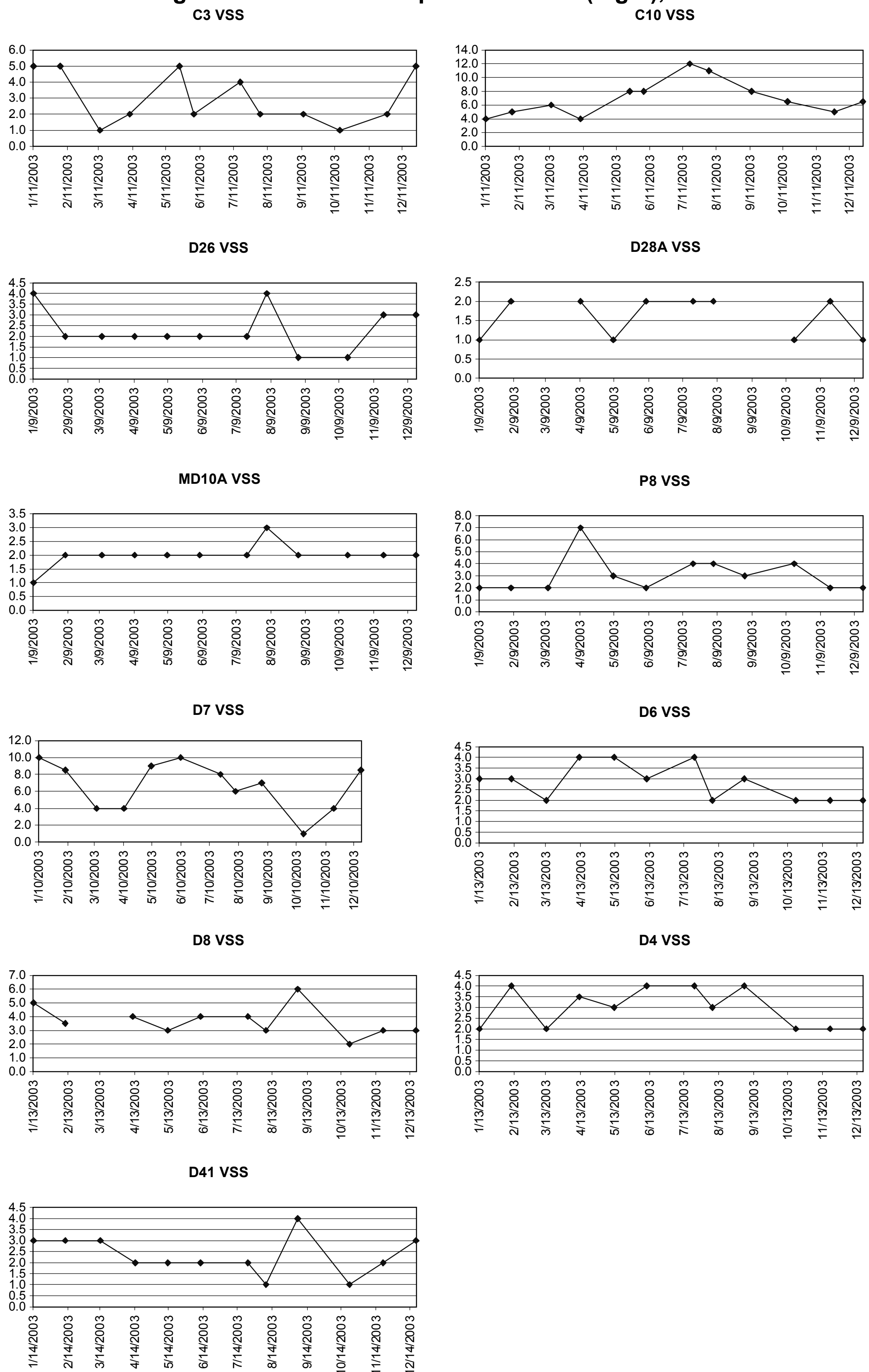

Figure 3-28 Silica

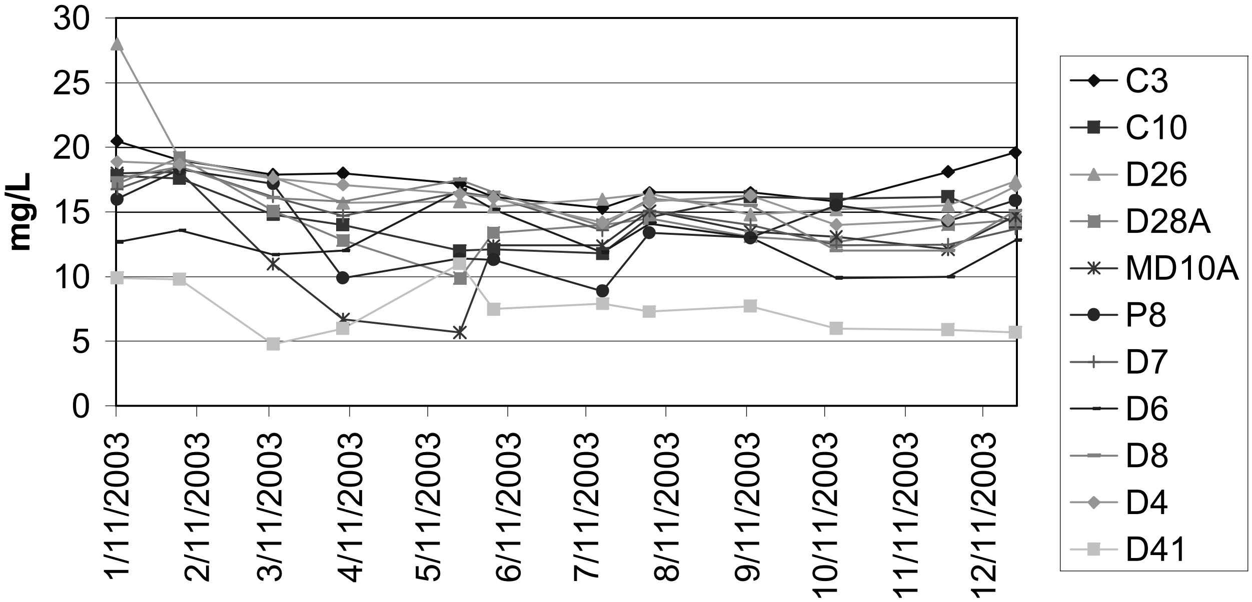

Figure 3-29 Silica (mg/L), 2003

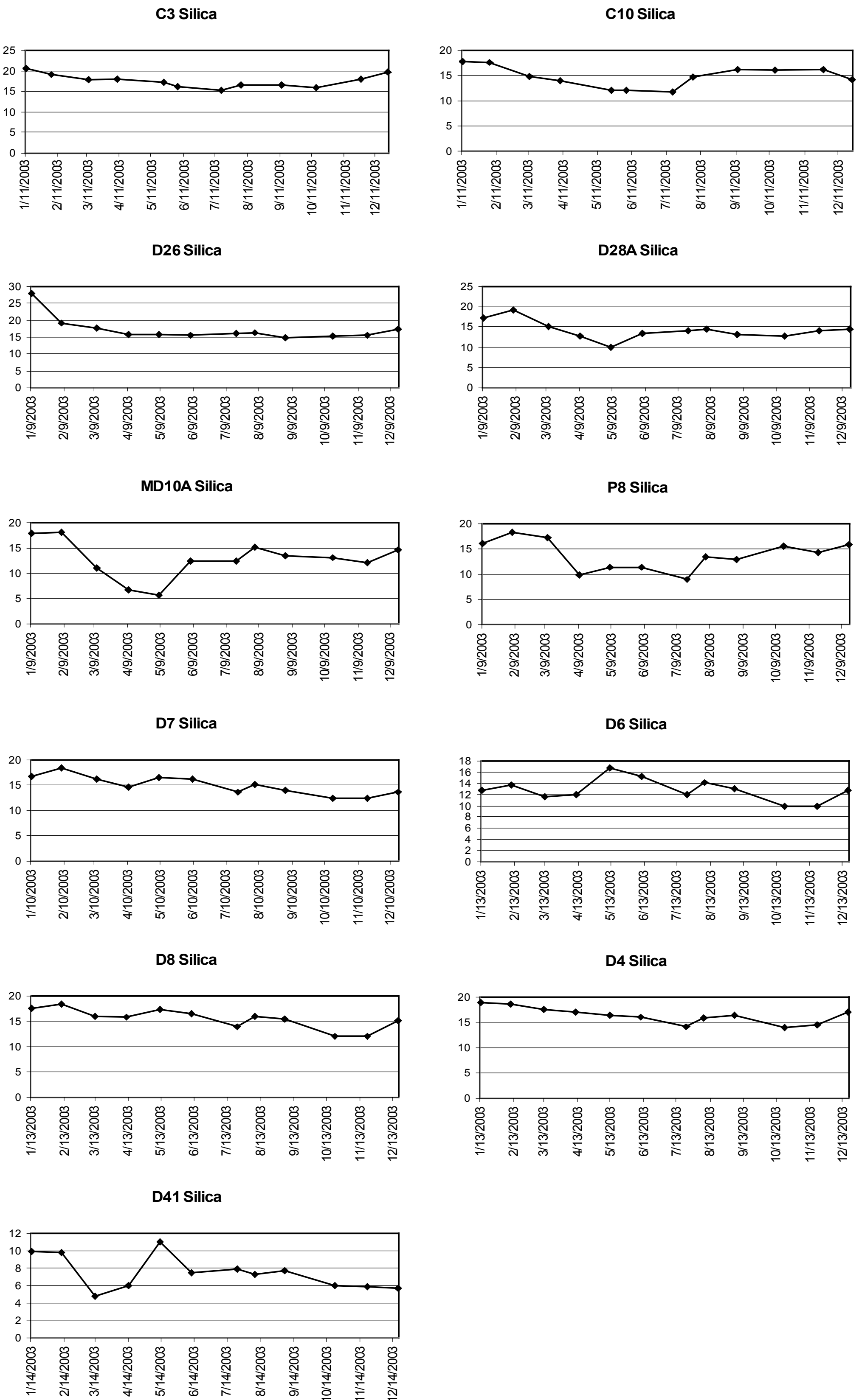

Figure 3-30 Chloride

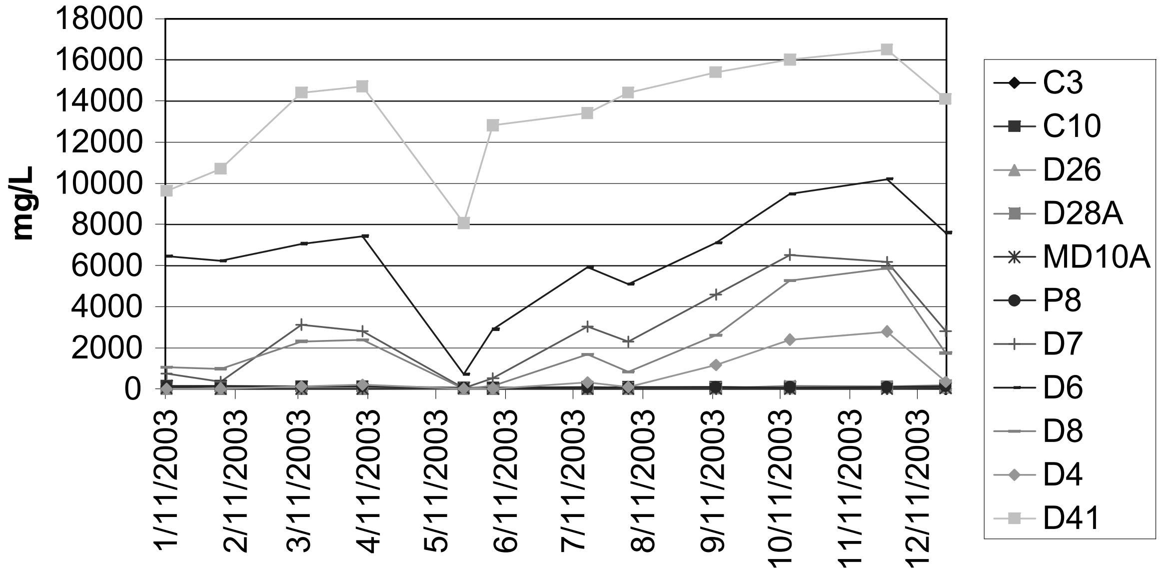

Figure 3-31 Chloride (mg/L), 2003

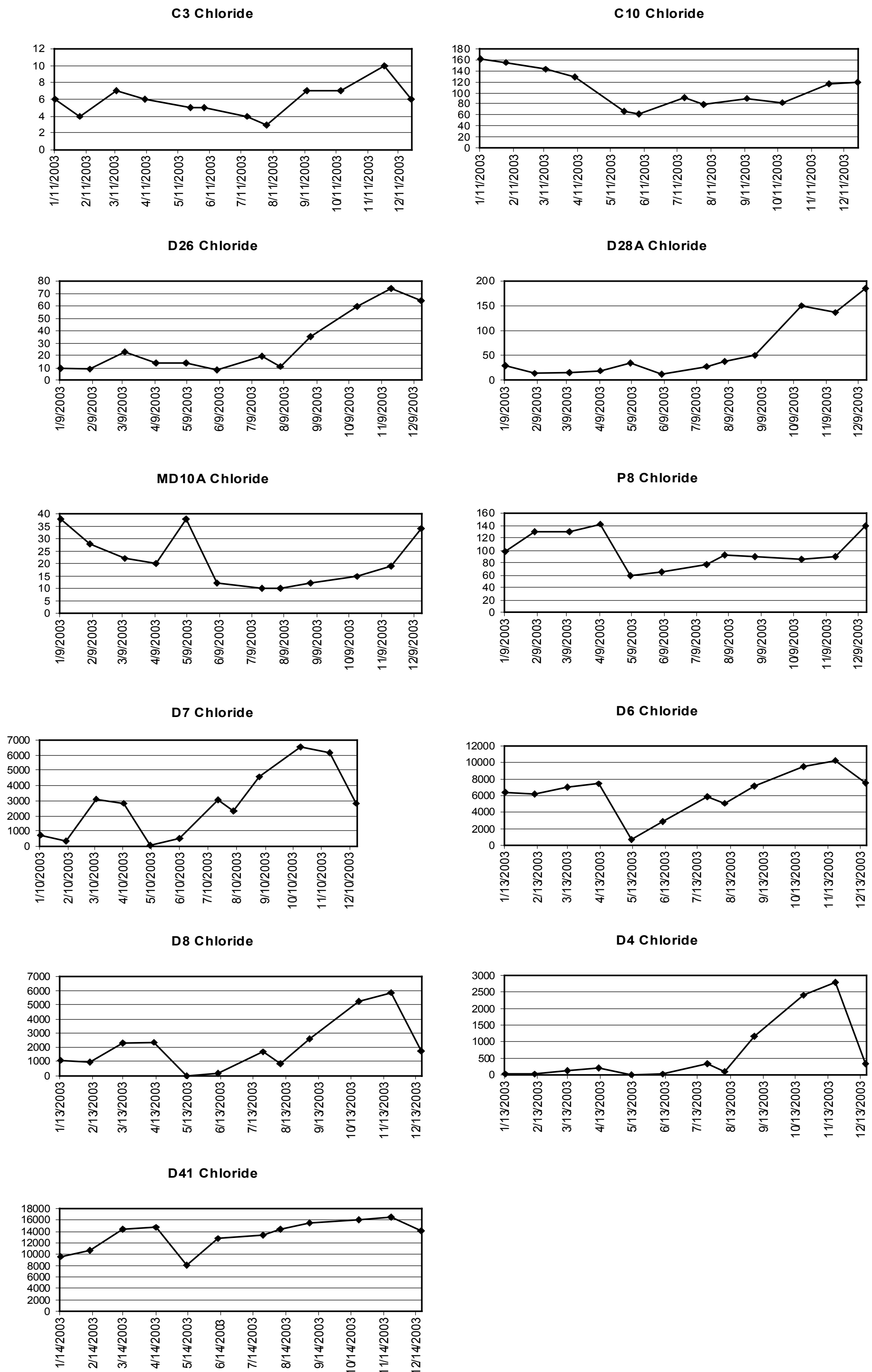

Table 3-1 Water quality parameters measured

Parameter	Units
Water temperature	°C
Dissolved oxygen	mg/L
Specific conductance	µS/cm
Secchi disk depth	cm
Turbidity	NTU
Orthophosphate	mg/L
Total phosphorus	mg/L
Kjeldahl nitrogen	mg/L
Dissolved inorganic nitrogen	mg/L
Dissolved organic nitrogen	mg/L
Total dissolved solids	mg/L
Total suspended solids	mg/L
Volatile suspended solids	mg/L
Silica	mg/L
Chloride	mg/L

Table 3-2 Water quality 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 and P8
Suisun Bay	D6, D7 and D8
San Pablo Bay	D41

Chapter 4 Phytoplankton and Chlorophyll

Introduction

The Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) are required by D-1641 to collect phytoplankton and chlorophyll *a* samples to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (Estuary). The eleven sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays. This chapter describes the results of these monitoring efforts for calendar year 2003.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes that influence water quality in the Estuary. Phytoplankton can affect pH, dissolved oxygen, color, taste and odor, and, under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael 1981). Phytoplankton are small, free-floating organisms that occur as unicellular, colonial, or filamentous forms (Horne and Goldman 1994). In addition to their being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can also be useful in assessing water quality (Gannon and Stemberger 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes, and hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (APHA 1998). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with physiochemical and other biological data (APHA 1998).

Chlorophylls are complex phytopigment molecules found in all photosynthetic organisms, including phytoplankton. There are several types of chlorophyll identified by slight differences in their molecular structure and constituents. These include chlorophyll *a*, *b*, *c*, and *d*. Chlorophyll *a* is the principal photosynthetic pigment and is common to all phytoplankton. Chlorophyll *a* is thus used as a measure of phytoplankton biomass.

In addition to chlorophyll *a*, water samples were analyzed for pheophytin *a*. Pheophytin *a* is a primary degradation product of chlorophyll *a,* and its concentration, relative to chlorophyll *a*, is useful for estimating the general physiological state of phytoplankton populations. When phytoplankton are actively growing, the concentrations of pheophytin *a* are normally expected to be low in relation to chlorophyll *a*.

Phytoplankton biomass and resulting chlorophyll *a* concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, *Corbula amurensis* (Alpine and

Cloern 1992). Well-established benthic populations of *P. amurensis* in the Suisun and San Pablo bays are thought to have contributed to the low chlorophyll *a* concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 11 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed.

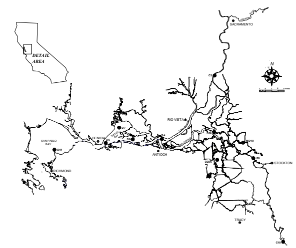

Figure 4-1 Chlorophyll and phytoplankton monitoring stations

Phytoplankton identification and enumeration were performed at the Department's Bryte Laboratory according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 15 hours. The aliquot volume, normally 10 mL, was adjusted according to the algal population density and turbidity of the sample. Phytoplankton were enumerated in 20 randomly chosen fields of a Whipple ocular micrometer grid for each settled aliquot. Sample analysis was conducted at a magnification of 700X using a Wilde M-40 inverted microscope.

Organism counts for each sample can be converted to organisms/mL using the following formula:

$$\text{Organisms} = (C \times Ac) / (V \times Af \times F)$$

where:

Organisms = Number of organisms (#/mL)
C = Count obtained
Ac = Area of cell bottom (mm^2)
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:
Organisms = C / cV

where:

cV = Counted volume (mL)
(Note: cV = Ac /(V x Af x F))

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 11 monitoring sites throughout the upper Estuary (Figure 4-1) using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. Approximately 500 mL of water was passed through a 47 mm diameter glass fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to Standard Method's spectrophotometric procedure (APHA 1998). Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1998). In addition, percent chlorophyll *a* was calculated as the ratio of chlorophyll *a* concentration to chlorophyll *a* plus pheophytin *a* concentrations multiplied by 100.

Results

Phytoplankton Identification

Of the eight families identified, Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Cryptophyceae constituted 96.5% of the organisms collected during 2003. Figure 4-2 shows the total phytoplankton contribution by family for all sites.

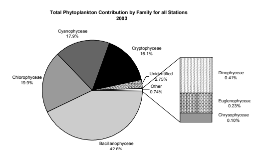

Figure 4-2 Total phytoplankton contribution by family at all stations

All organisms collected during the 2003 fell into these eight families:

- Bacillariophyceae (Diatoms)
- Chlorophyceae (Green algae)
- Chrysophyceae (Yellow-brown algae)
- Cryptophyceae (Cryptomonads)
- Cyanophyceae (Blue-green algae)
- Dinophyceae (Dinoflagellates)
- Euglenophyceae (Euglenoids)
- Unidentified flagellates (Flagellates)

Table 4-1 lists the genera found in each family in the upper Estuary. The 10 most common genera collected in 2003 were:

- *Achnanthes*
- *Rhodomonas*
- *Cyclotella*
- *Selenastrum*
- *Aulacoseira*
- *Synechococcus*
- *Skeletonema*
- *Thalassiosira*
- *Oscillatoria*
- Unidentified flagellates

Family	Genus	Family	Genus
Bacillariophyceae	Achnanthes	Chlorophyceae	Actinastrum
	Amphiprora		Ankistrodesmus
	Amphora		Carteria
	Asterionella		Chlamydomonas
	Bacillaria		Chlorella
	Ceratoneis		Closteriopsis
	Cocconeis		Closterium
	Cosinodiscus		Coelastrum
	Cyclotella		Crucigenia
	Cymbella		Desmidium
	Diatoma		Dictyosphaerium
	Fragilaria		Dimorphococcus
	Gomphonema		Elakatothrix
	Gyrosigma		Eudorina
	Melosira		Micractinium
	Navicula		Oocystis
	Neidium		Pandorina
			Pediastrum
Chrysophyceae	Synura		Pyramimonas
			Scenedesmus
Cryptophyceae	Cryptomonas		Schroederia
	Rhodomonas		Selenastrum
			Sphaerocystis
Cyanophyceae	Agmenellum		Staurastrum
	Anabaena		Tetraedron
	Anabaenopsis		Tetrastrum
	Anacystis		Ulothrix
	Aphanizomenon		Xanthidium
	Gomphosphaeria		
	Oscillatoria		
	Spirulina		
Dinophyceae	Ceratium		
	Glenodinium		
	Gymnodinium		
	Peridinium		
Euglenophyceae	Euglena		
	Trachelomonas		
Unidentified	Unidentified Flagellates		

Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2003

Figures 4-3 through 4-13 show phytoplankton family abundance for each monitoring station in 2003. A list of all phytoplankton genera identified, their shape codes, and the total number counted can be found in the Phytoplankton Dictionary available online at: http://www.iep.ca.gov/emp/Metadata/phytoplankton_metadata.html .

Pigment Concentrations

Chlorophyll *a* concentrations generally showed some seasonal patterns. The highest chlorophyll *a* concentrations occurred during spring and summer for most stations, while the lowest concentrations occurred during late fall and winter.

Monthly chlorophyll *a* concentrations throughout much of the Estuary were relatively low when compared to historical data, with 90% of the 132 samples taken in 2003 having levels below 15 µg/L, and 78% of all samples having levels below 5 µg/L. The mean chlorophyll *a* concentration for all samples in 2003 was 5.73 µg/L and the median value was 2.44 µg/L. In 2001 and 2002 the median chlorophyll *a* concentrations were similar with values of 2.40 µg/L and 2.37 µg/L, respectively. The maximum chlorophyll *a* concentration in 2003 was 64.5 µg/L, recorded in May at the San Joaquin River at Vernalis (C3) monitoring site. This maximum was well below the peaks of 119 µg/L (July 2001) and 118 µg/L (August 2002) recorded in previous years (DWR 2004). Higher peak chlorophyll *a* concentrations in 2001 and 2002 resulted in higher mean values than in 2003. In 2001 and 2002 the mean values were 6.78 µg/L and 7.02 µg/L, respectively. Chlorophyll *a* maxima were recorded in the spring or summer at all stations, except in the San Joaquin River at Buckley Cove (P8) where the maximum was recorded in October. The minimum chlorophyll *a* concentration in 2003 was 0.36 µg/L, recorded in January at the Old River opposite Rancho Del Rio (D28A) monitoring location.

The highest chlorophyll *a* concentrations were measured at Vernalis, Buckley Cove, and Disappointment Slough (stations C10, P8, and MD10), with mean concentrations of 23.8, 12.9, and 8.2 µg/L, respectively. Mean chlorophyll *a* concentrations in these areas were similar in 2002 with values of 36.3, 13.3, and 7.1 µg/L, respectively. Mean yearly chlorophyll *a* concentrations recorded at the other Estuary locations ranged from 1.7 µg/L in the San Joaquin River at Potato Point (D26) to 3.6 µg/L in San Pablo Bay near Pinole Point (D41).

Pheophytin *a* concentrations remained fairly constant and did not show apparent seasonal patterns. Percent chlorophyll *a* concentrations, in relation to pheophytin *a*, ranged from 23% to 94%, with a mean of 70% and a median of 71.6%. In addition, 80% of the samples collected had chlorophyll *a* levels above 60%. This relatively high percentage of chlorophyll *a* is generally associated with healthy, growing populations.

The mean pheophytin *a* concentration for all samples in 2003 was 1.82 µg/L, and the median value was 0.96 µg/L. Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 2.21 µg/L and the median was 1.23 µg/L. In 2002 the mean pheophytin *a* value was 2.09 µg/L and the median was 1.21 µg/L.

Figures 4-14 through 4-28 show the results of chlorophyll *a* and pheophytin *a* analysis. All chlorophyll *a* and pheophytin *a* data can be found at: http://www.iep.ca.gov/emp/data_index.html .

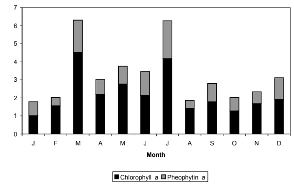

Figure 4-14 Chlorophyll *a* and pheophytin *a* concentrations at station C3, 2003

Site C3: North Delta

Station C3 demonstrated a clear seasonal pattern with its highest chlorophyll *a* concentrations recorded during the spring and summer and its lowest recorded during the fall and winter (Figure 4-14). The maximum chlorophyll *a* concentration during 2003 occurred in March (4.51 µg/L) and was associated with the phytoplankton family Bacillariophyceae (Figure 4-3). The minimum concentration occurred in January (1.01 µg/L) and was associated with Bacillariophyceae and Chlorophyceae. The mean chlorophyll concentration during 2003 at station C3 was 2.20 µg/L. High chlorophyll *a* concentrations recorded in March (outlier) and July skewed the mean higher than the median (1.85 µg/L) (Figure 4-26).

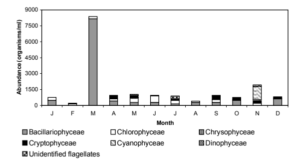

Figure 4-3 Phytoplankton family abundance at station C3, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean chlorophyll *a* value was 3.02 µg/L and the median was 2.78 µg/L. In 2002 the mean chlorophyll *a* value was 2.94 µg/L and the median was 2.61 µg/L.

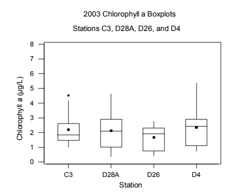

Figure 4-26 Chlorophyll *a* boxplots for stations C3, D28A, D26, and D4, 2003

The maximum pheophytin *a* concentration occurred in July (2.11 µg/L) and was associated with the phytoplankton family Chlorophyceae and unidentified flagellates. The minimum concentration occurred in August (0.43 µg/L) and was associated with the Bacillariophyceae and Chlorophyceae families. In 2003 the mean pheophytin *a* concentration was 1.03 µg/L and the median was 0.91 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 1.61 µg/L and the median was 1.28 µg/L. In 2002 the mean pheophytin *a* value was 1.38 µg/L and the median was 1.29 µg/L.

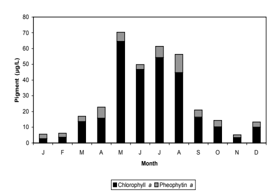

Figure 4-15 Chlorophyll *a* and pheophytin *a* concentrations at station C10, 2003

Site C10: South Delta

Station C10 demonstrated a distinct seasonal pattern with its highest pigment concentrations recorded during the late spring and summer and its lowest recorded during the late fall and winter (Figure 4-15). A maximum chlorophyll *a* concentration of 64.5 µg/L was recorded in May and a minimum of 2.79 µg/L was recorded in January. Bacillariophyceae and Chlorophyceae were the most abundant phytoplankton families in each of these months (Figure 4-4). The mean chlorophyll *a* concentration at station C10 during 2003 was 23.8 µg/L, which was the highest of the eleven monitoring stations. High chlorophyll *a* concentrations recorded in the late spring and summer skewed the mean higher than the median (14.7 µg/L) (Figure 4-28).

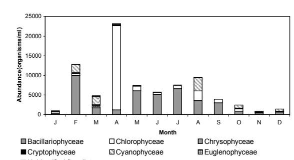

Figure 4-4 Phytoplankton family abundance at station C10, 2003

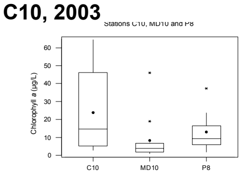

Figure 4-28 Chlorophyll *a* boxplots for stations C10, MD10 and P8, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean chlorophyll *a* value was 32.4 µg/L and the median was 16.4 µg/L. In 2002 the mean chlorophyll *a* value was 36.3 µg/L and the median was 20.9 µg/L.

The maximum pheophytin *a* concentration occurred in August (11.6 µg/L) and was associated with the phytoplankton families Cyanophyceae, Bacillariophyceae, and Chlorophyceae. The minimum concentration was recorded in November (1.84 µg/L) when the most abundant phytoplankton families identified were Bacillariophyceae and Cryptophyceae. In 2003 the mean pheophytin *a* concentration was 4.78 µg/L and the median was 3.77 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 5.87 µg/L and the median was 5.36 µg/L. In 2002 the mean pheophytin *a* value was 7.30 µg/L and the median was 7.15 µg/L.

Site P8: South Delta

The highest chlorophyll *a* concentrations at Station P8 were recorded during the spring and fall, while the lowest were recorded during the winter (Figure 4-16). A maximum chlorophyll *a* concentration of 37.3 µg/L was recorded in October and a minimum of 1.77 µg/L was recorded in January. The mean chlorophyll *a* concentration at station P8 during 2003 was 12.9 µg/L. High chlorophyll *a* concentrations is the spring and fall, including one outlier, skewed the mean higher than the median (9.38 µg/L) (Figure 4-28).

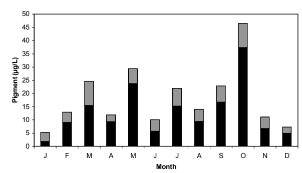

Figure 4-16 Chlorophyll *a* and pheophytin *a* concentrations at station P8, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were higher (median) than in 2003. In 2001 the mean chlorophyll *a* value was 12.6 µg/L and the median was 12.8 µg/L. In 2002 the mean chlorophyll *a* value was 13.3 µg/L and the median was 10.0 µg/L.

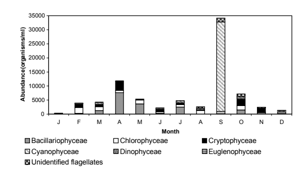

Figure 4-5 Phytoplankton family abundance at station P8, 2003

The maximum pheophytin *a* concentration occurred in October (9.20 µg/L) and was associated with same families as the chlorophyll *a* maximum. The minimum concentration occurred in December (2.33 µg/L) and was associated with the phytoplankton families Chlorophyceae, Cryptophyceae, and Bacillariophyceae. In 2003 the mean pheophytin *a* concentration was 5.21 µg/L and the median was 4.49 µg/L.

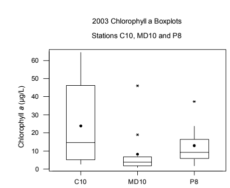

Figure 4-28 Chlorophyll *a* boxplots for stations C10, MD10 and P8, 2003

Pheophytin *a* concentrations recorded in 2001 were higher than in 2003, while concentrations recorded in 2002 were lower than in 2003. In 2001 the mean pheophytin *a* value was 6.71 µg/L and the median was 7.02 µg/L. In 2002 the mean pheophytin *a* value was 4.65 µg/L and the median was 3.77 µg/L.

Site MD10A: East Delta

Station MD10A demonstrated a clear seasonal pattern with its highest chlorophyll *a* concentrations recorded during the spring and its lowest recorded during the winter (Figure 4-17). The maximum chlorophyll *a*

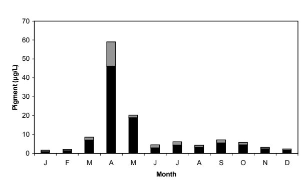

Figure 4-17 Chlorophyll *a* and pheophytin *a* concentrations at station MD10A, 2003

concentration during 2003 occurred in April (46.1 µg/L) and was associated with the phytoplankton families Bacillariophyceae, Chlorophyceae, and Cryptophyceae (Figure 4-6). The minimum concentration occurred in January (0.93 µg/L) and was associated with the families Chlorophyceae and Bacillariophyceae. The mean chlorophyll *a* concentration at station MD10A during 2003 was 8.24 µg/L. High chlorophyll *a* concentrations (outliers) in April and May skewed the mean outside the third quartile or 75th percentile and upper limit (Figure 4-28). Thus the median (3.77 µg/L) was much lower than the mean.

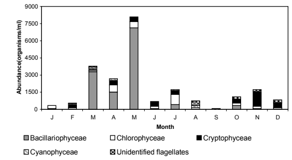

Figure 4-6 Phytoplankton family abundance at station MD10A, 2003

Chlorophyll *a* concentrations recorded in 2001 were higher than in 2003, while concentrations recorded in 2002 were lower than in 2003. In 2001 the mean chlorophyll *a* value was 11.1 µg/L and the median was 4.62 µg/L. In 2002 the mean chlorophyll *a* value was 7.14 µg/L and the median was 3.16 µg/L.

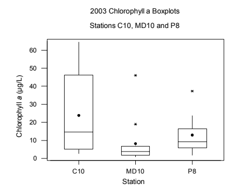

Figure 4-28 Chlorophyll *a* boxplots for stations C10, MD10 and P8, 2003

The maximum pheophytin *a* concentration occurred in April (12.9 µg/L) and was associated with same families as the chlorophyll *a* maximum. The minimum concentration occurred in February (0.68 µg/L) and was associated with the phytoplankton families Cryptophyceae, Chlorophyceae, and Bacillariophyceae. In 2003 the mean pheophytin *a* concentration was 2.21 µg/L and the median was 1.36 µg/L.

Pheophytin *a* concentrations recorded in 2001 were higher than in 2003, while concentrations recorded in 2002 were lower than in 2003. In 2001 the mean pheophytin *a* value was 2.79 µg/L and the median was 1.73 µg/L. In 2002 the mean pheophytin *a* value was 1.40 µg/L and the median was 1.15 µg/L.

Site D26: Lower San Joaquin River

Chlorophyll *a* concentrations during the spring, summer and fall did not vary much, ranging from 1.69 µg/L to 2.74 µg/L (Figure 4-18). In the winter, chlorophyll concentrations were the lowest, ranging from 0.42 µg/L to 0.71 µg/L. The maximum chlorophyll *a* concentration during 2003 occurred in September (2.74 µg/L) and was associated with the phytoplankton family Cryptophyceae and unidentified flagellates (Figure 4-7). The minimum concentration occurred in January (0.42 µg/L). No phytoplankton were identified in the January sample. The mean chlorophyll *a* concentration at station D26 during 2003 was 1.67 µg/L. Low chlorophyll *a* concentrations recorded in the winter skewed the mean lower than the median (1.92 µg/L) (Figure 4-26).

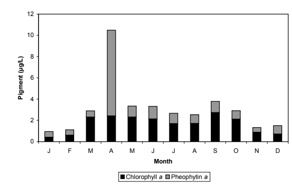

Figure 4-18 Chlorophyll *a* and pheophytin *a* concentrations at station D26, 2003

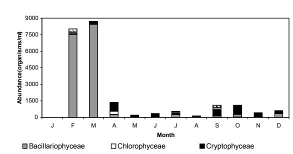

Figure 4-7 Phytoplankton family abundance at station D26, 2003

Chlorophyll *a* concentrations recorded in 2001 were higher than in 2003, while concentrations recorded in 2002 were lower (median) than 2003. In 2001 the mean chlorophyll *a* value was 2.44 µg/L and the median was 2.13 µg/L. In 2002 the mean chlorophyll *a* value was 2.56 µg/L and the median was 1.89 µg/L.

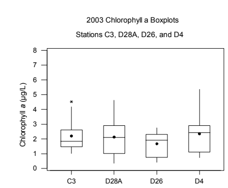

Figure 4-26 Chlorophyll *a* boxplots for stations C3, D28A, D26, and D4, 2003

The maximum pheophytin *a* concentration occurred in April (8.06 µg/L) and was associated with the phytoplankton families Cryptophyceae, Chlorophyceae and Bacillariophyceae. The minimum concentration occurred in November (0.44 µg/L) and was associated with the phytoplankton family Cryptophyceae. In 2003 the mean pheophytin *a* concentration was 1.39 µg/L and the median was 0.80 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher (median) than in 2003. In 2001 the mean pheophytin *a* value was 1.27 µg/L and the median was 1.25 µg/L. In 2002 the mean pheophytin *a* value was 1.03 µg/L and the median was 0.92 µg/L.

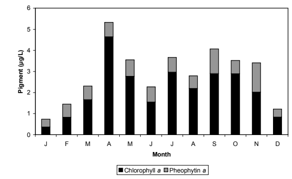

Figure 4-19 Chlorophyll *a* and pheophytin *a* concentrations at station D28A, 2003

Site D28A: Central Delta

Chlorophyll *a* concentrations during the spring, summer, and fall ranged from 1.55 µg/L to 4.64 µg/L (Figure 4-19). In the winter, chlorophyll concentrations were the lowest, ranging from 0.36 µg/L to 0.84 µg/L. The maximum chlorophyll *a* concentration during 2003 occurred in April (4.64 µg/L) and was associated with the phytoplankton families Cryptophyceae and Bacillariophyceae (Figure 4-8). The minimum concentration occurred in January (0.36 µg/L) and was associated with the Chlorophyceae family. The mean chlorophyll *a* concentration at station D28A during 2003 was 2.14 µg/L. The median value (2.11 µg/L) was slightly lower than the mean (Figure 4-26).

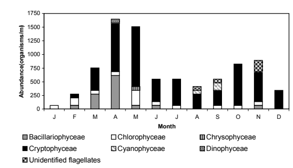

Figure 4-8 Phytoplankton family abundance at station D28A, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean chlorophyll *a* value was 3.05 µg/L and the median was 3.13 µg/L. In 2002 the mean chlorophyll *a* value was 2.35 µg/L and the median was 2.21 µg/L.

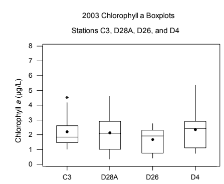

Figure 4-26 Chlorophyll *a* boxplots for stations C3, D28A, D26, and D4, 2003

The maximum pheophytin *a* concentration occurred in November (1.39 µg/L) and was associated with the phytoplankton family Cryptophyceae and unidentified flagellates. The minimum concentration occurred in December (0.38 µg/L) and was associated with the phytoplankton family Cryptophyceae. In 2003 the mean pheophytin *a* concentration was 0.72 µg/L and the median was 0.67 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 1.16 µg/L and the median was 1.02 µg/L. In 2002 the mean pheophytin *a* value was 0.93 µg/L and the median was 0.82 µg/L.

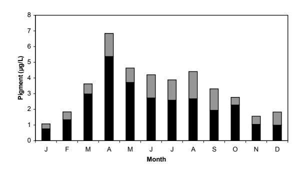

Figure 4-20 Chlorophyll *a* and pheophytin *a* concentrations at station D4, 2003

Site D4: Lower Sacramento River

Station D4 demonstrated a distinct seasonal pattern with its highest pigment concentrations recorded during spring and its lowest recorded during winter (Figure 4-20). The maximum chlorophyll *a* concentration during 2003 occurred in April (5.36 µg/L) and was associated with the phytoplankton families Cryptophyceae and Bacillariophyceae (Figure 4-9). The minimum concentration occurred in January (0.74 µg/L) and was associated with the Cryptophyceae and Chlorophyceae families. The mean chlorophyll *a* concentration at station D4 during 2003 was 2.36 µg/L. The median value (2.58 µg/L) was slightly higher than the mean (Figure 4-26).

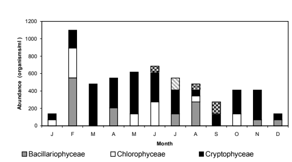

Figure 4-9 Phytoplankton family abundance at station D4, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were lower (median) than in 2003. In 2001 the mean chlorophyll *a* value was 2.22 µg/L and the median was 1.72 µg/L. In 2002 the mean chlorophyll *a* value was 2.61 µg/L and the median was 1.67 µg/L. The mean value was skewed about 1.0 µg/L higher than the median because of a high peak chlorophyll *a* value.

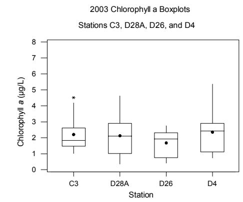

Figure 4-26 Chlorophyll *a* boxplots for stations C3, D28A, D26, and D4, 2003

The maximum pheophytin *a* concentration occurred in August (1.74 µg/L) and was associated with the phytoplankton families Bacillariophyceae, Chlorophyceae, and Cryptophyceae, as well as unidentified flagellates. The minimum concentration occurred in January (0.33 µg/L) and was associated with the same families as the chlorophyll *a* minimum. In 2003 the mean pheophytin *a* concentration was 0.97 µg/L and the median was 0.88 µg/L.

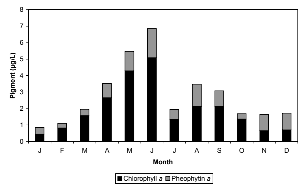

Figure 4-21 Chlorophyll *a* and pheophytin *a* concentrations at station D8, 2003

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 1.33 µg/L and the median was 1.18 µg/L. In 2002 the mean pheophytin *a* value was 1.44 µg/L and the median was 1.42 µg/L.

Site D8: Suisun Bay

Station D8 demonstrated a clear seasonal pattern with its highest chlorophyll *a* concentrations recorded during late spring and early summer and the lowest recorded during late fall and winter (Figure 4-21). The maximum chlorophyll *a* concentration during 2003 occurred in June (5.08 µg/L) and was associated with the phytoplankton families Cryptophyceae and Bacillariophyceae (Figure 4-10). The minimum concentration occurred in January (0.44 µg/L) and was associated with the Chlorophyceae family. The mean chlorophyll *a* concentration at station D8 during 2003 was 1.92 µg/L. High chlorophyll *a* concentrations recorded in the spring and summer skewed the mean higher than the median (1.46 µg/L) (Figure 4-27).

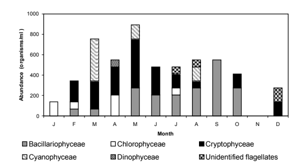

Figure 4-10 Phytoplankton family abundance at station D8, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were higher (median) than in 2003. In 2001 the mean chlorophyll *a* value was 1.65 µg/L and the median was 1.56 µg/L. In 2002 the mean chlorophyll *a* value was 2.17 µg/L and the median was 2.13 µg/L.

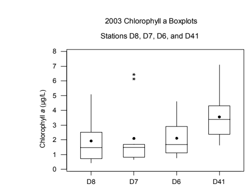

Figure 4-27 Chlorophyll *a* boxplots for stations D8, D7, D6, and D41, 2003

The maximum pheophytin *a* concentration occurred in June (1.77 µg/L) and was associated with the same phytoplankton families as the chlorophyll *a* maximum. The minimum concentration occurred in February (0.29 µg/L) and was associated with the Cryptophyceae, Chlorophyceae, and Bacillariophyceae families. In 2003 the mean pheophytin *a* concentration was 0.85 µg/L and the median was 0.91 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 1.16 µg/L and the median was 1.04 µg/L. In 2002 the mean pheophytin *a* value was 1.26 µg/L and the median was 1.17 µg/L.

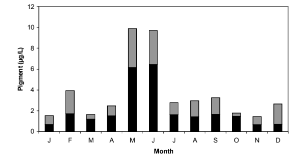

Figure 4-22 Chlorophyll *a* and pheophytin *a* concentrations at station D7, 2003

Site D7: Suisun Bay

Chlorophyll *a* concentrations at station D7 ranged from 0.66 µg/L to 1.7 µg/L, except in May and June (Figure 4-22). Concentrations were higher in May (6.14 µg/L) and June (6.44 µg/L). The maximum chlorophyll *a* concentration during 2003 occurred in June (6.44 µg/L) and was associated with the phytoplankton families Bacillariophyceae, Chlorophyceae, and Cryptophyceae (Figure 4-11). The minimum concentration occurred in November (0.66 µg/L). No phytoplankton were identified in the November and December samples. The mean chlorophyll *a* concentration at station D7 during 2003 was 2.10 µg/L. High chlorophyll *a* concentrations (outliers) in May and June skewed the mean outside the third quartile or 75th percentile and upper limit (Figure 4-27). Thus the median (1.49 µg/L) was much lower than the mean.

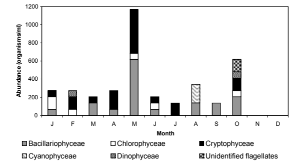

Figure 4-11 Phytoplankton family abundance at station D7, 2003

Chlorophyll *a* concentrations recorded in 2001 were lower than in 2003, while values recorded in 2002 were higher than in 2003. In 2001 the mean chlorophyll *a* value was 1.40 µg/L and the median was 1.30 µg/L. In 2002 the mean chlorophyll *a* value was 2.50 µg/L and the median was 1.68 µg/L.

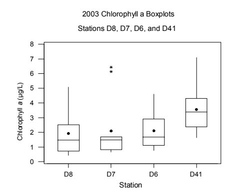

Figure 4-27 Chlorophyll *a* boxplots for stations D8, D7, D6, and D41, 2003

The maximum pheophytin *a* concentration occurred in May (3.76 µg/L) and was associated with the Bacillariophyceae and Cryptophyceae families. The minimum concentration occurred in October (0.31 µg/L) and was associated with the Cryptophyceae and Bacillariophyceae families, as well as unidentified flagellates. In 2003 the mean pheophytin *a* concentration was 1.57 µg/L and the median was 1.35 µg/L.

Pheophytin *a* concentrations recorded in 2001 were lower than in 2003, while concentrations recorded in 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 1.19 µg/L and the median was 1.13 µg/L. In 2002 the mean pheophytin *a* value was 1.88 µg/L and the median was 1.60 µg/L.

Site D6: Suisun Bay

Station D6 demonstrated a distinct seasonal pattern with its highest chlorophyll *a* concentrations recorded in late winter, spring, and mid-fall and its lowest was recorded during summer and midwinter (Figure 4-23). The maximum chlorophyll *a* concentration during 2003 occurred in May (4.59 µg/L) and was associated with the phytoplankton families Cryptophyceae, Chlorophyceae, and Bacillariophyceae (Figure 4-12). The minimum concentration occurred in January (0.77 µg/L) and was associated with the Bacillariophyceae family. The mean chlorophyll *a* concentration at station D6 during 2003 was 2.10 µg/L. High chlorophyll *a* concentrations recorded in the spring skewed the mean higher than the median (1.68 µg/L) (Figure 4-27).

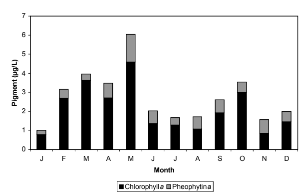

Figure 4-23 Chlorophyll *a* and pheophytin *a* concentrations at station D6, 2003

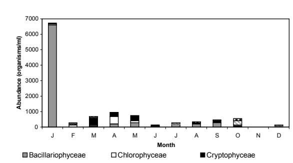

Figure 4-12 Phytoplankton family abundance at station D6, 2003

Chlorophyll *a* concentrations recorded in 2001 were higher (median) than in 2003, while concentrations recorded in 2002 were lower than in 2003. In 2001 the mean chlorophyll *a* value was 1.93 µg/L and the median was 1.86 µg/L. In 2002 the mean chlorophyll *a* value was 1.73 µg/L and the median was 1.61 µg/L.

The maximum pheophytin *a* concentration occurred in May (1.44 µg/L) and was associated with the same families as the chlorophyll *a* maximum. The minimum concentration occurred in January (0.23 µg/L) and was associated with the same families as the chlorophyll *a* minimum. In 2003 the mean pheophytin *a* concentration was 0.63 µg/L and the median was 0.61 µg/L.

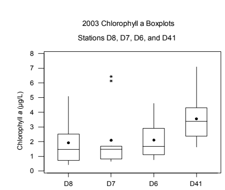

Figure 4-27 Chlorophyll *a* boxplots for stations D8, D7, D6, and D41, 2003

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 0.77 µg/L and the median was 0.70 µg/L. In 2002 the mean pheophytin *a* value was 0.82 µg/L and the median was 0.77 µg/L.

Site D41: San Pablo Bay

Station D41 demonstrated a distinct seasonal pattern with its highest chlorophyll *a* concentrations recorded during spring and summer and its lowest recorded during fall and winter (Figure 4-24). The maximum chlorophyll *a* concentration during 2003 occurred in March (7.10 µg/L) and was associated with the phytoplankton families Dinophyceae and Cryptophyceae, as well as unidentified flagellates (Figure 4-13). The minimum concentration occurred in December (1.63 µg/L) and no phytoplankton were identified. The mean chlorophyll *a* concentration at station D41 during 2003 was 3.55 µg/L. High chlorophyll *a* concentrations recorded in the spring skewed the mean slightly higher than the median (3.39 µg/L) (Figure 4-27).

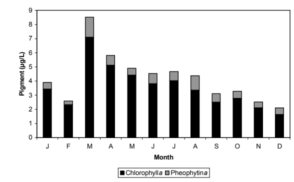

Figure 4-24 Chlorophyll *a* and pheophytin *a* concentrations at station D41, 2003

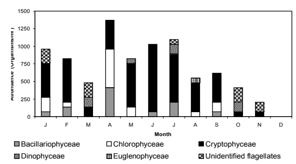

Figure 4-13 Phytoplankton family abundance at station D41, 2003

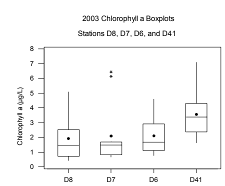

Figure 4-27 Chlorophyll *a* boxplots for stations D8, D7, D6, and D41, 2003

Chlorophyll *a* concentrations recorded in 2001 and 2002 were lower than in 2003. In 2001 the mean chlorophyll *a* value was 3.21 µg/L and the median was 2.48 µg/L. In 2002 the mean chlorophyll *a* value was 2.88 µg/L and the median was 2.40 µg/L.

The maximum pheophytin *a* concentration occurred in March (1.42 µg/L) and was associated with the same families as the chlorophyll *a* maximum. The minimum concentration occurred in February (0.25 µg/L) and was associated with the Cryptophyceae and Bacillariophyceae families. In 2003 the mean pheophytin *a* concentration was 0.64 µg/L and the median was 0.55 µg/L.

Pheophytin *a* concentrations recorded in 2001 and 2002 were higher than in 2003. In 2001 the mean pheophytin *a* value was 0.85 µg/L and the median was 0.86 µg/L. In 2002 the mean pheophytin *a* value was 0.67 µg/L and the median was 0.66 µg/L.

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 11 sites in 2003. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton collected fell into the following eight families: Bacillariophyceae, Chlorophyceae, Chrysophyceae, Cryptophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae, and unidentified flagellates. The ten most common genera were *Achnanthes*, *Rhodomonas*, *Cyclotella*, *Selenastrum*, *Aulacoseira*, *Synechococcus*, *Skeletonema*, *Thalassiosira*, *Oscillatoria*, and unidentified flagellates. Chlorophyll *a* concentrations showed a distinct seasonal pattern; values ranged from 0.36 µg/L to 64.5 µg/L. Pheophytin *a* concentrations did not show a seasonal pattern; values ranged from 0.23 µg/L to 12.9 µg/L. Overall, chlorophyll *a* concentrations were relatively low when compared with the historical data.

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Figure 4-1 Chlorophyll and phytoplankton monitoring stations

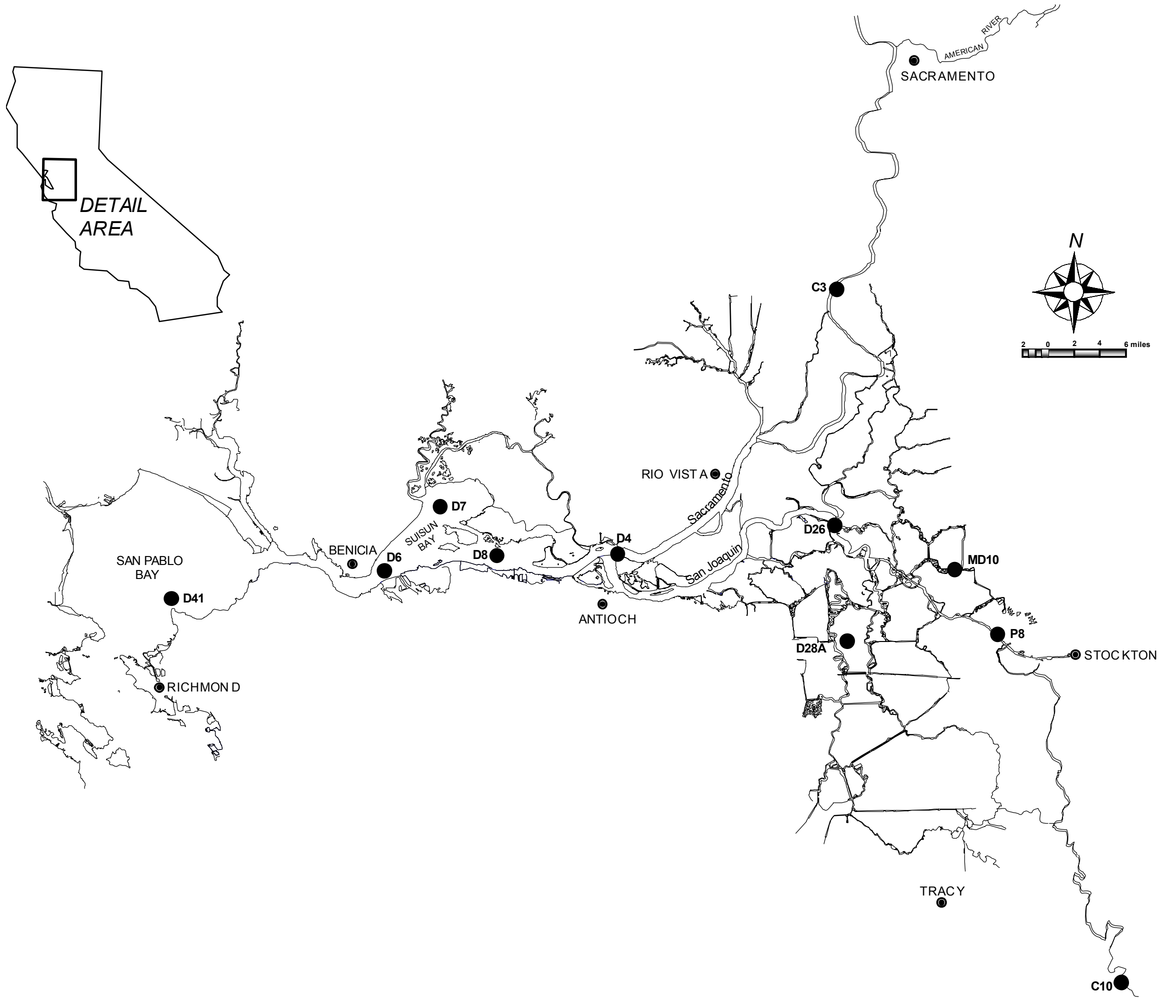


Figure 4-2 Total phytoplankton contribution by family at all stations

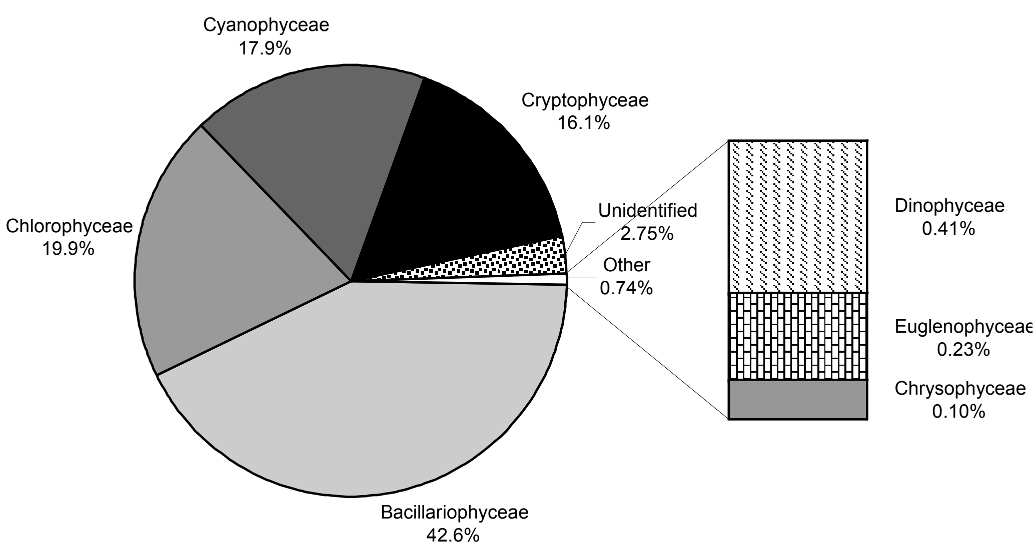


Figure 4-3 Phytoplankton family abundance at station C3, 2003

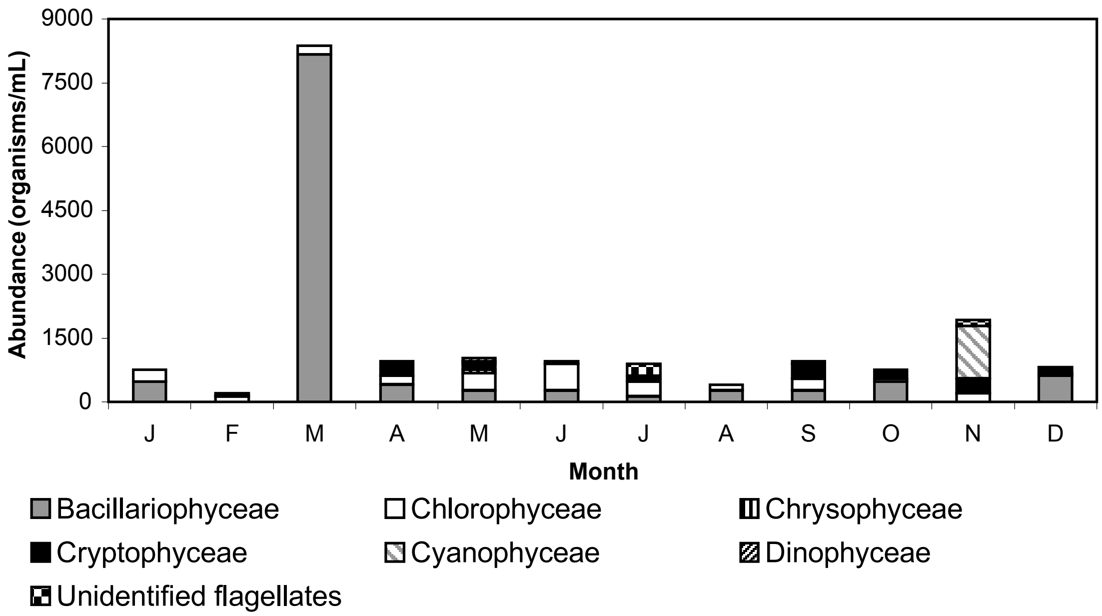


Figure 4-4 Phytoplankton family abundance at station C10, 2003

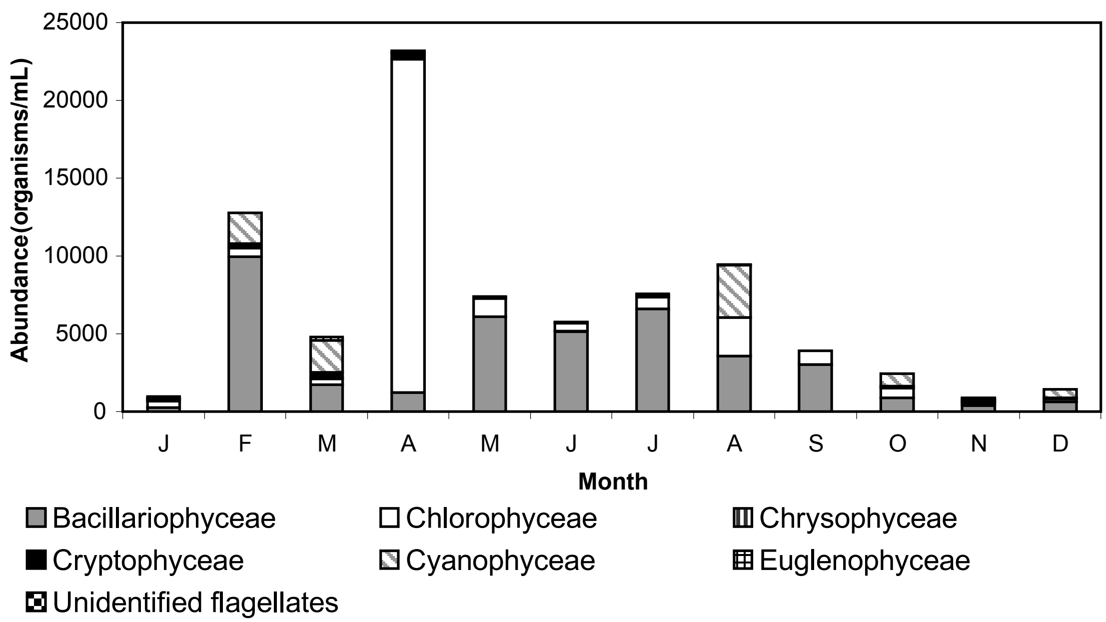


Figure 4-5 Phytoplankton family abundance at station P8, 2003

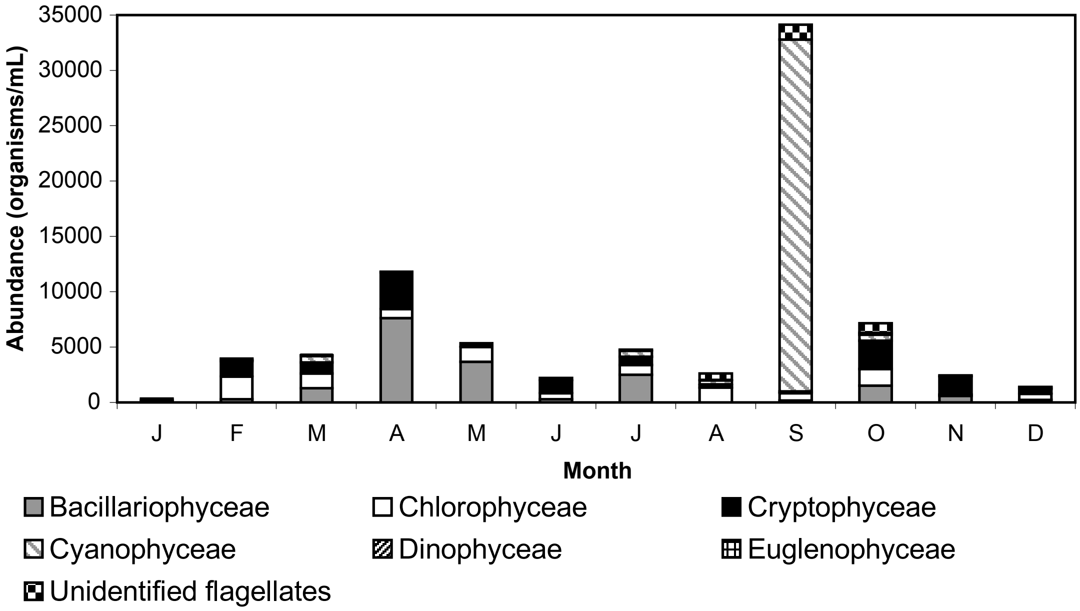


Figure 4-6 Phytoplankton family abundance at station MD10A, 2003

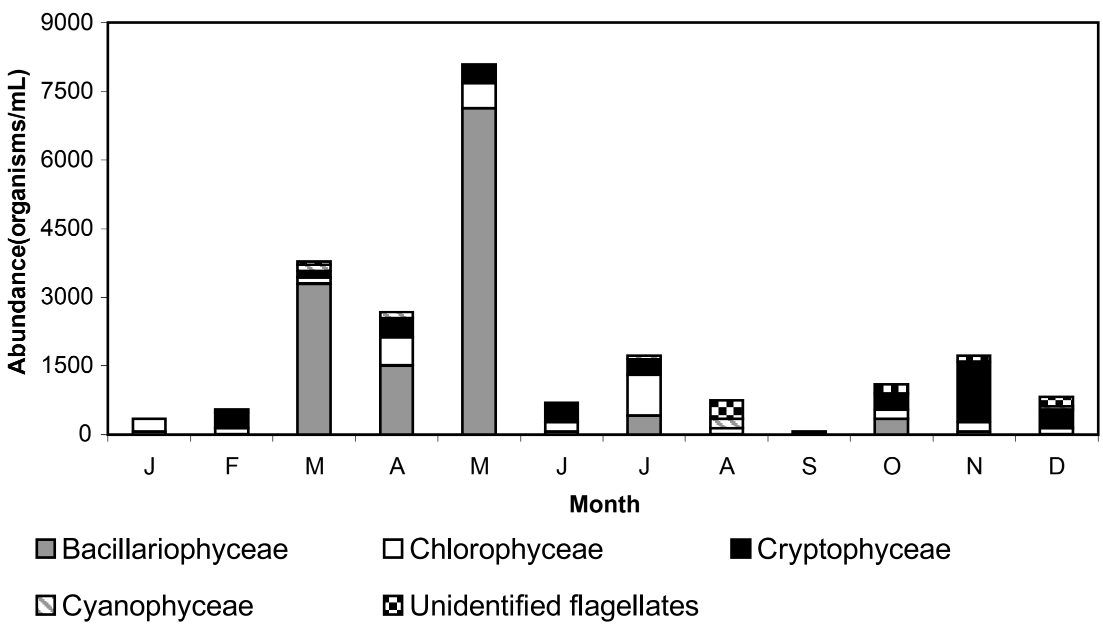


Figure 4-7 Phytoplankton family abundance at station D26, 2003

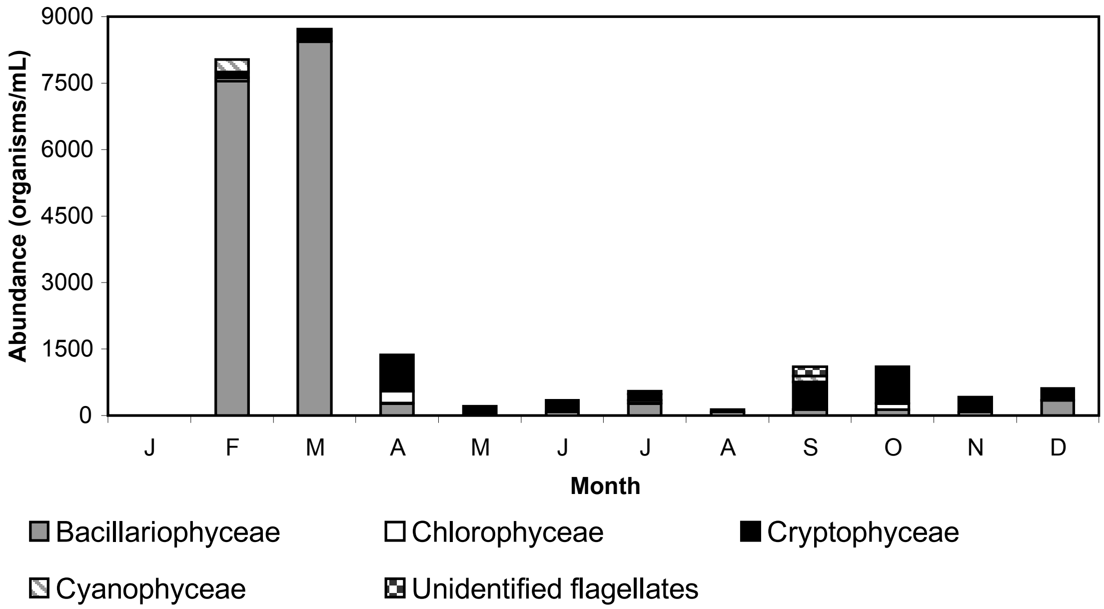


Figure 4-8 Phytoplankton family abundance at station D28A, 2003

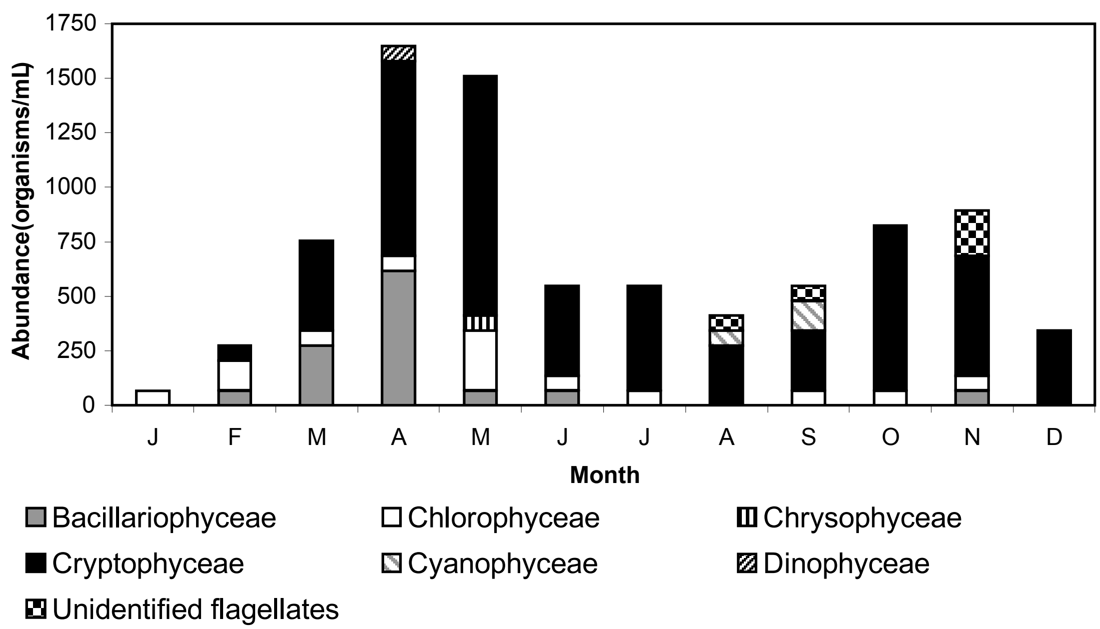


Figure 4-9 Phytoplankton family abundance at station D4, 2003

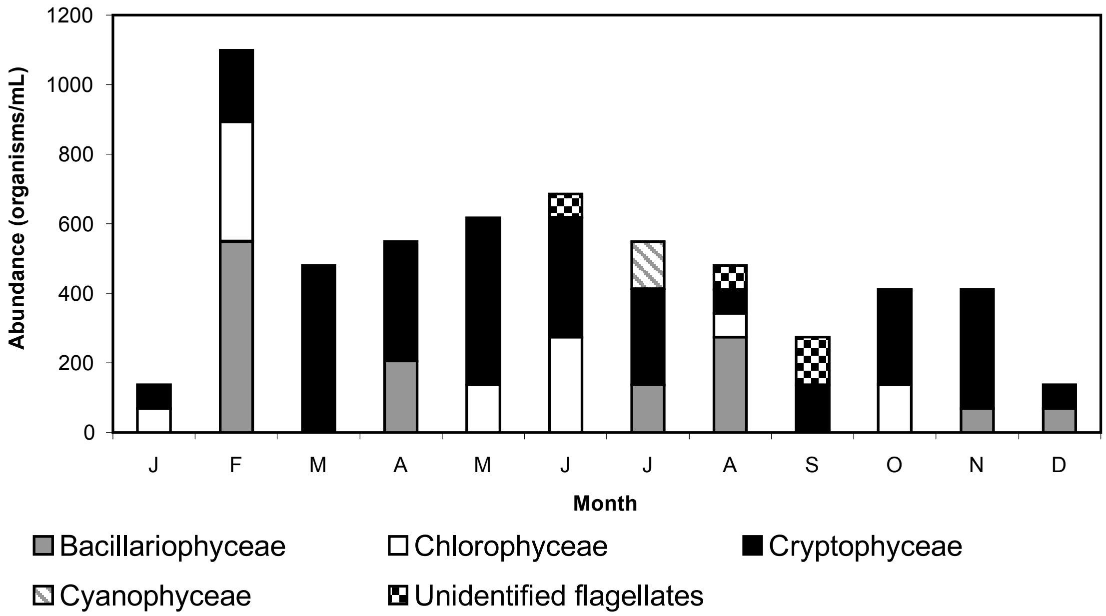


Figure 4-10 Phytoplankton family abundance at station D8, 2003

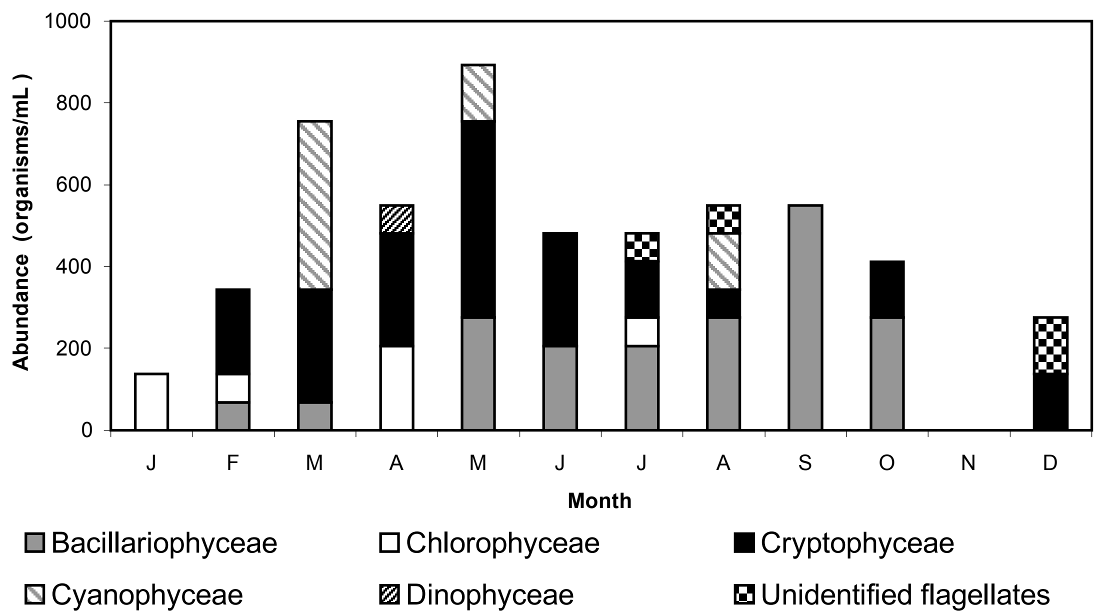


Figure 4-11 Phytoplankton family abundance at station D7, 2003

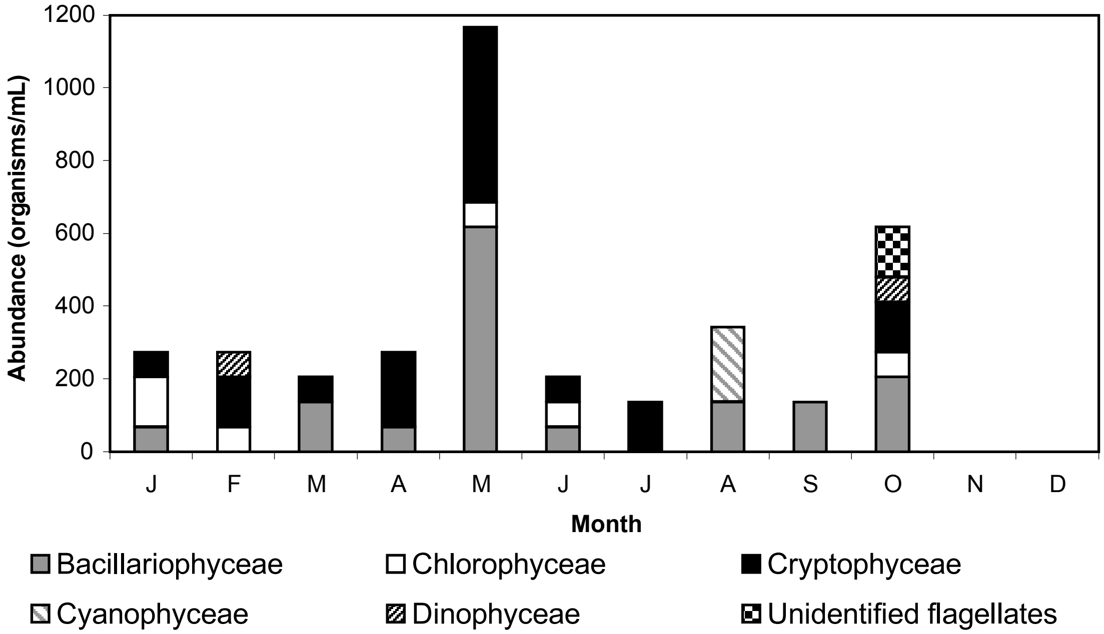


Figure 4-12 Phytoplankton family abundance at station D6, 2003

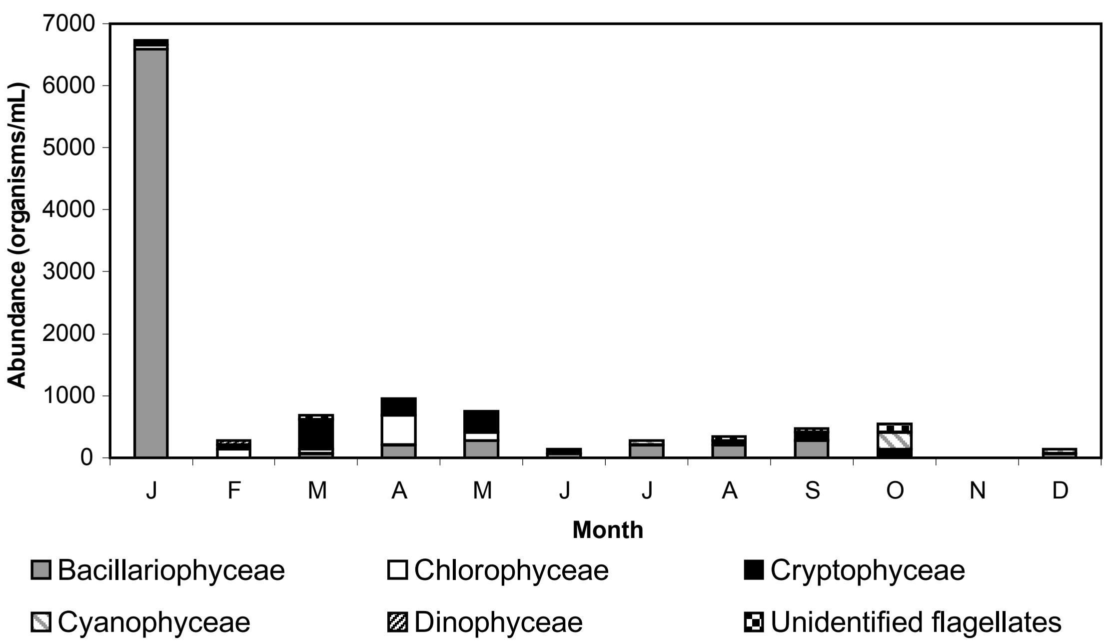


Figure 4-13 Phytoplankton family abundance at station D41, 2003

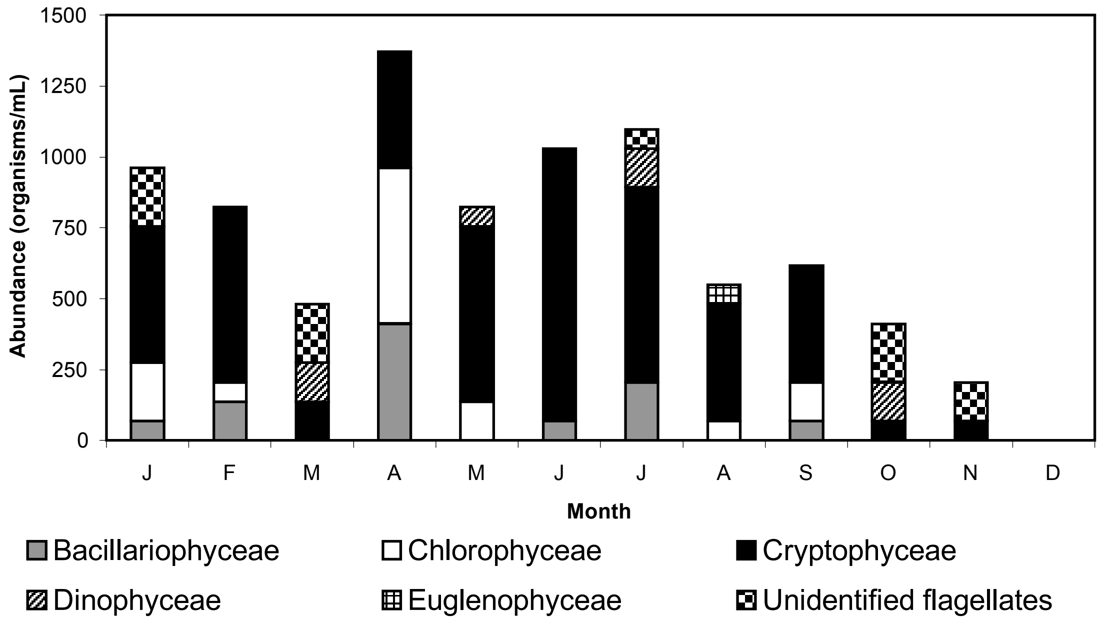


Figure 4-14 Chlorophyll *a* and pheophytin *a* concentrations at station C3, 2003

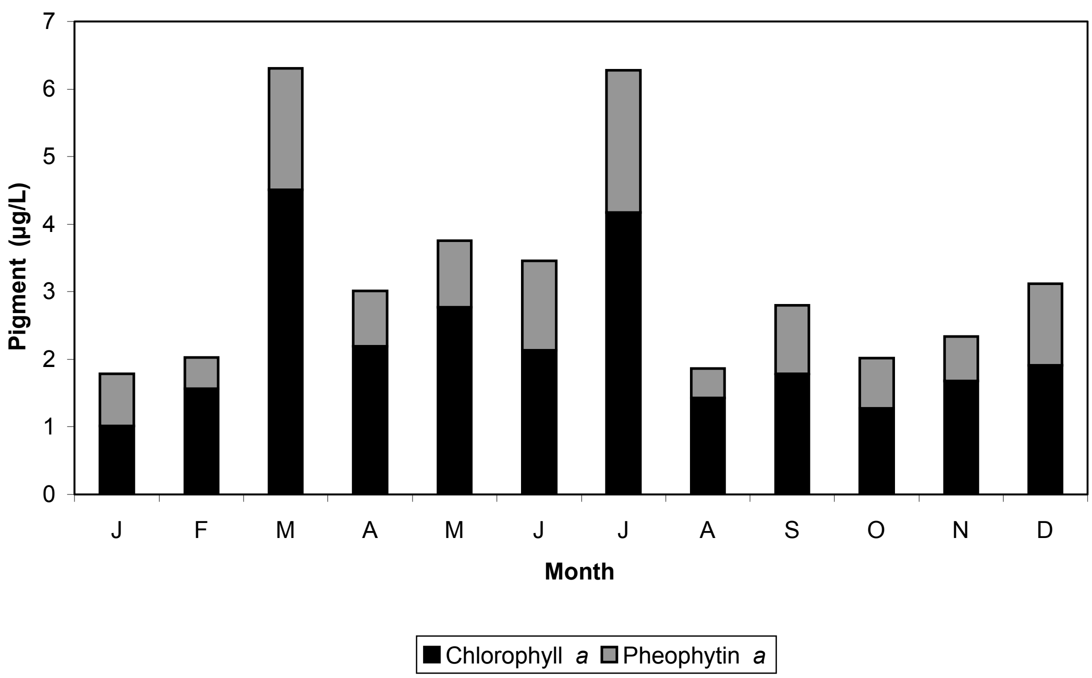


Figure 4-15 Chlorophyll *a* and pheophytin *a* concentrations at station C10, 2003

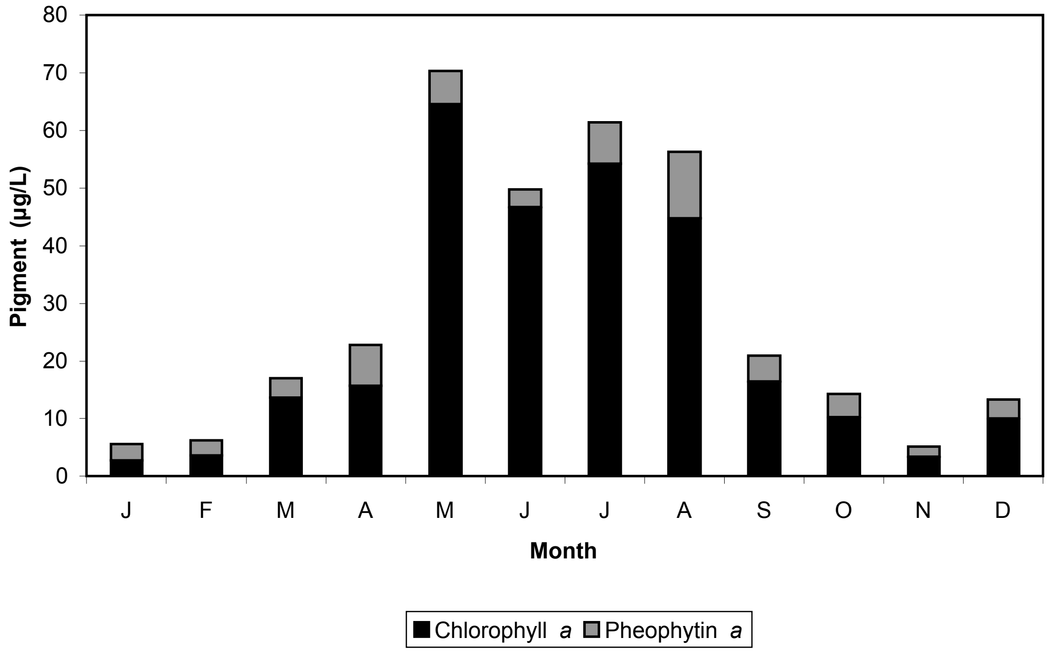


Figure 4-16 Chlorophyll *a* and pheophytin *a* concentrations at station P8, 2003

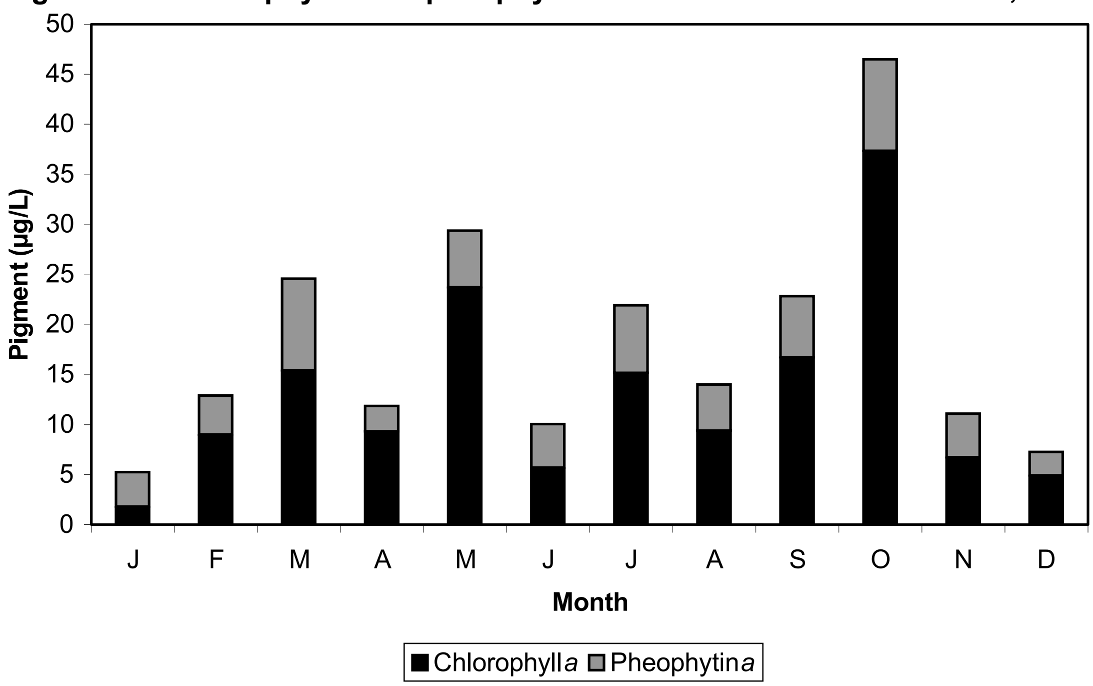


Figure 4-17 Chlorophyll *a* and pheophytin *a* concentrations at station MD10A, 2003

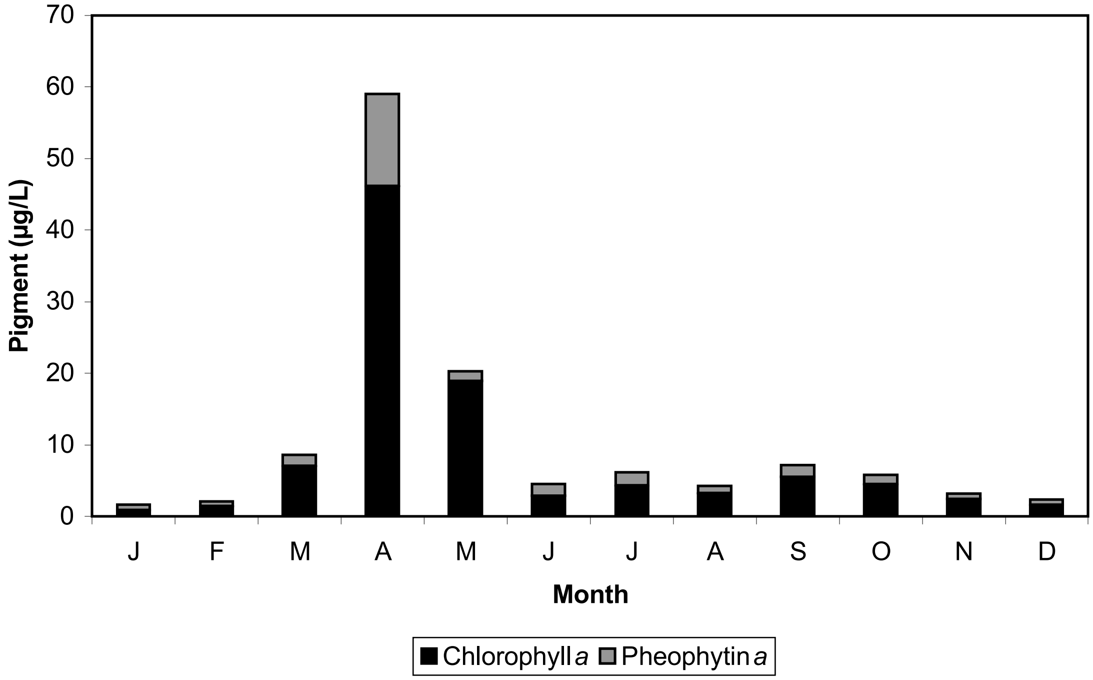


Figure 4-18 Chlorophyll *a* and pheophytin *a* concentrations at station D26, 2003

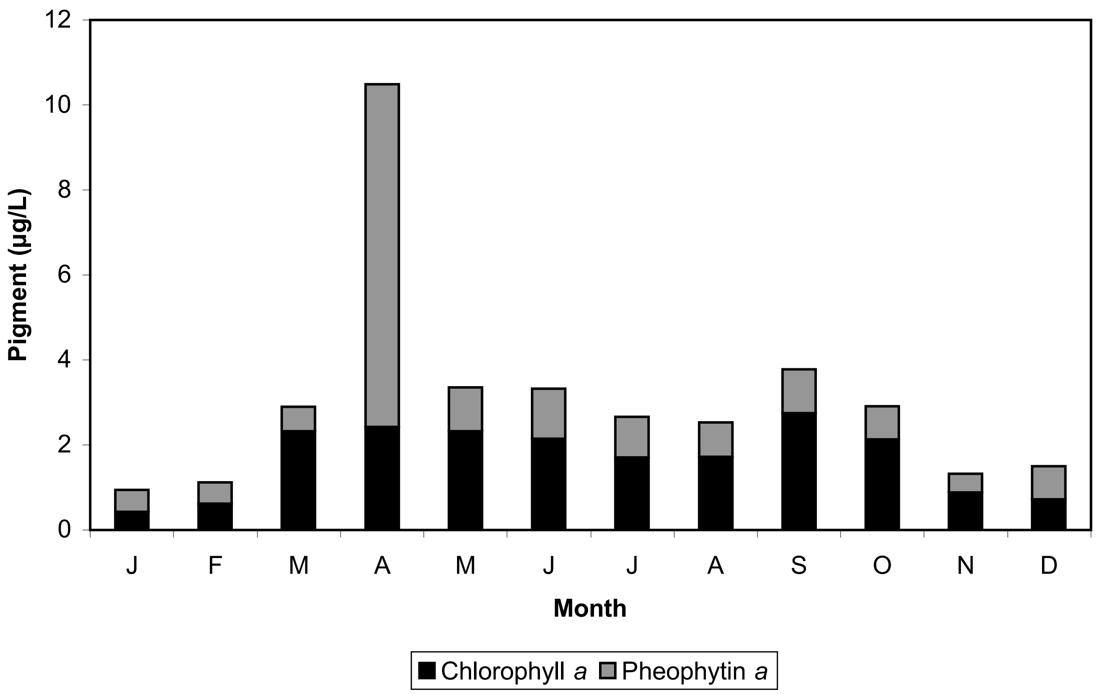


Figure 4-19 Chlorophyll *a* and pheophytin *a* concentrations at station D28A, 2003

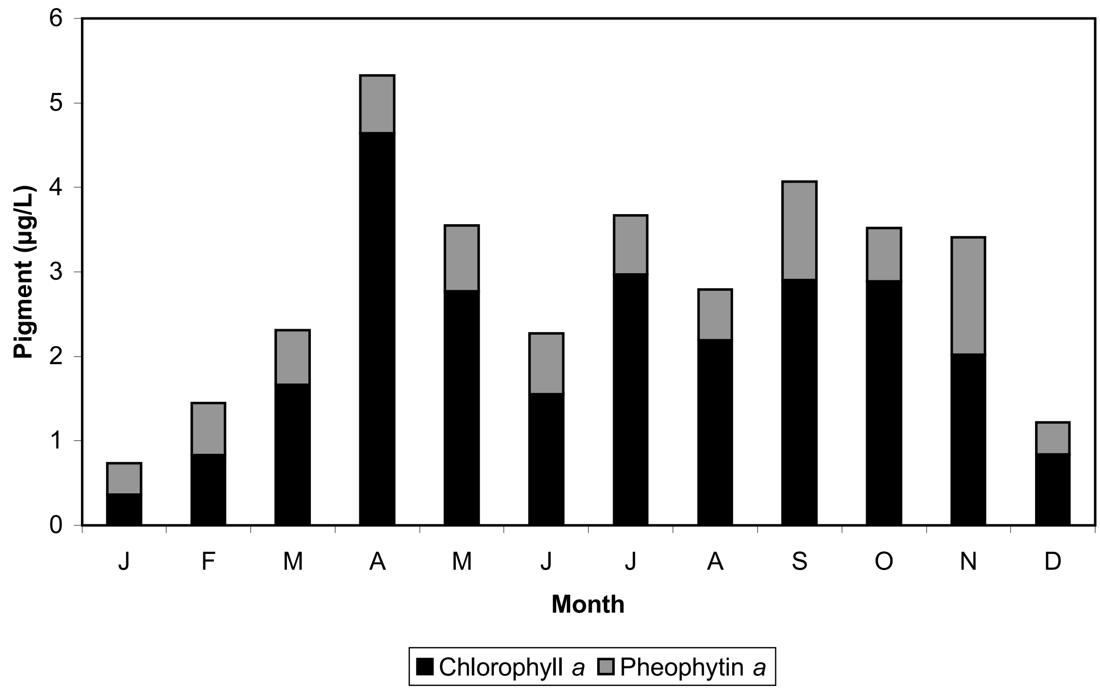


Figure 4-20 Chlorophyll *a* and pheophytin *a* concentrations at station D4, 2003

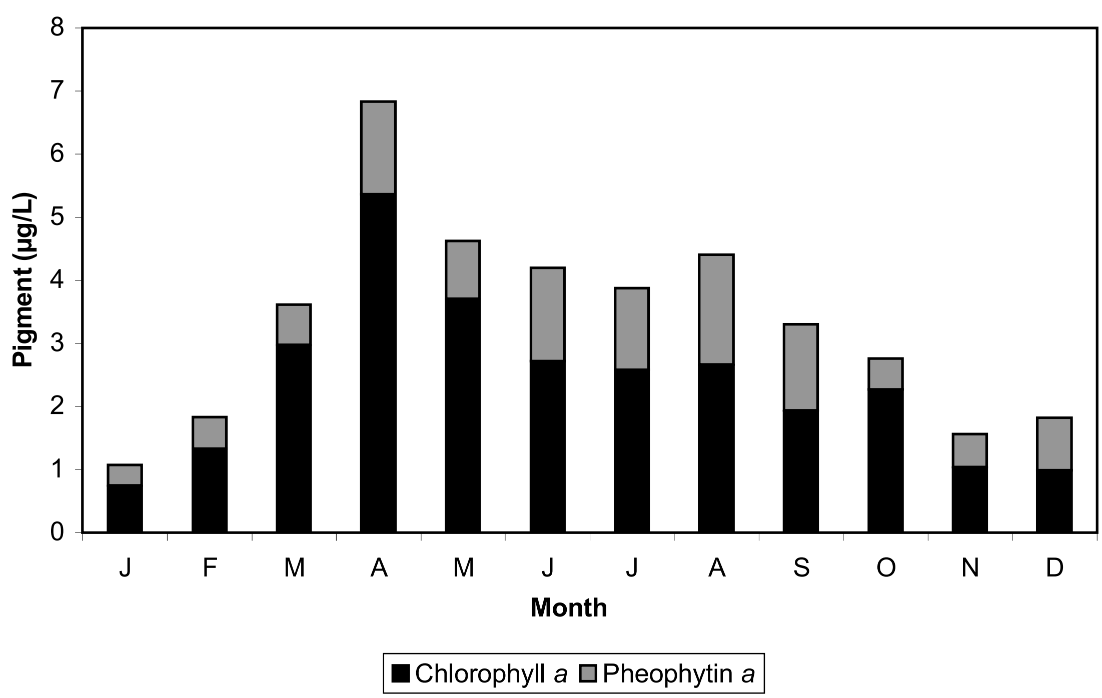


Figure 4-21 Chlorophyll *a* and pheophytin *a* concentrations at station D8, 2003

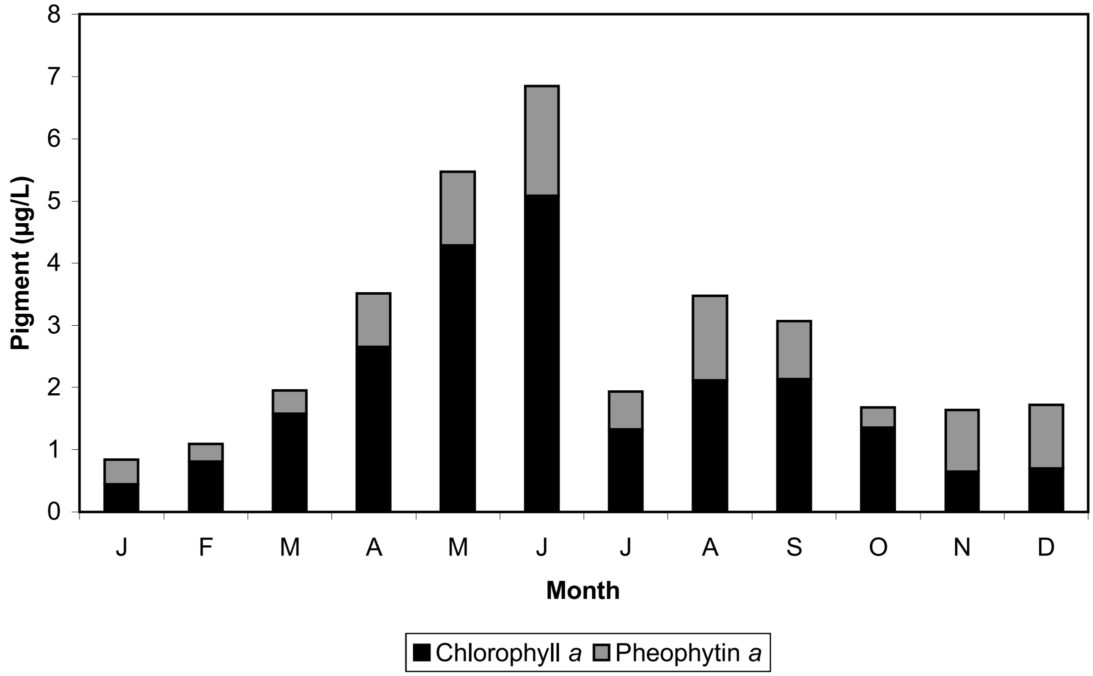


Figure 4-22 Chlorophyll *a* and pheophytin *a* concentrations at station D7, 2003

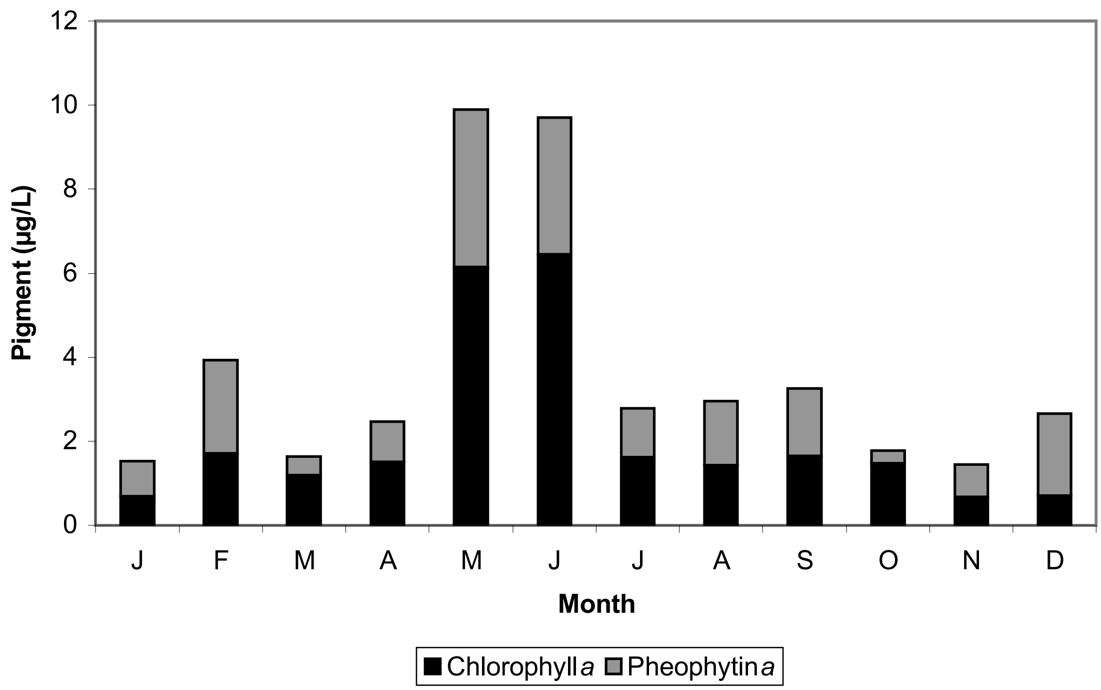


Figure 4-23 Chlorophyll *a* and pheophytin *a* concentrations at station D6, 2003

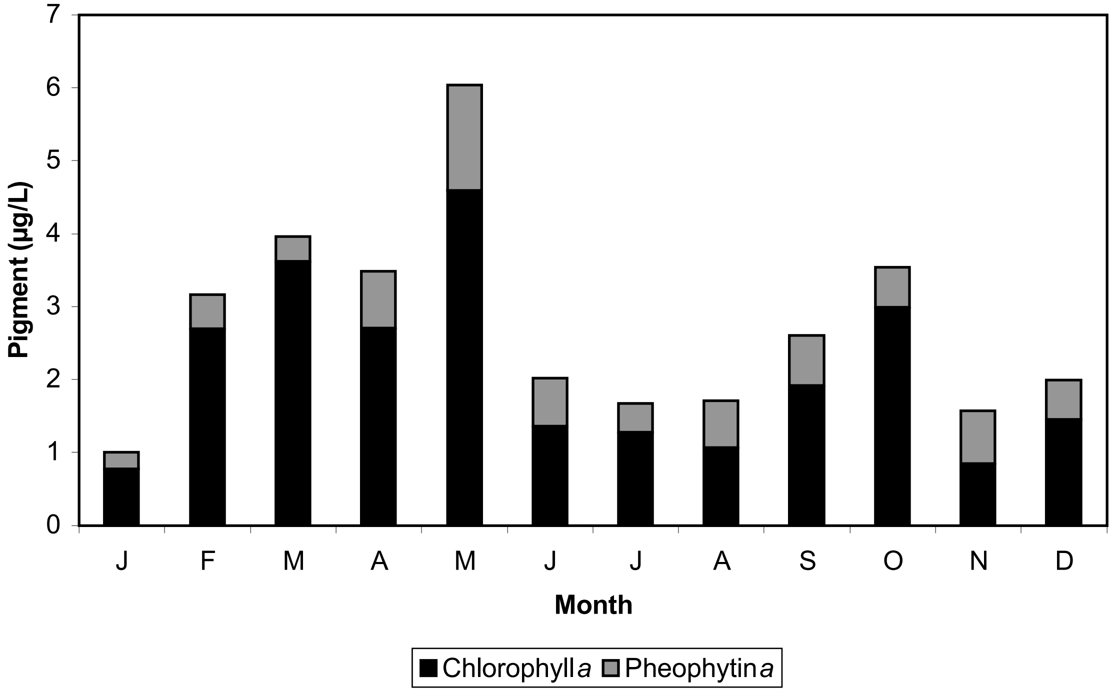


Figure 4-24 Chlorophyll *a* and pheophytin *a* concentrations at station D41, 2003

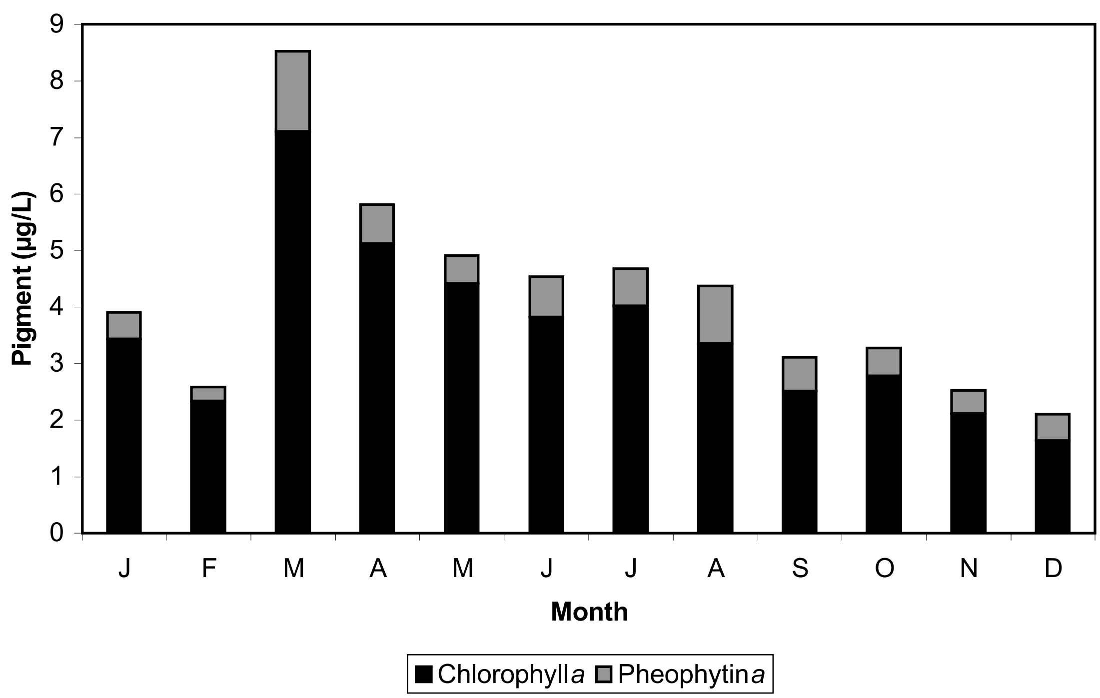
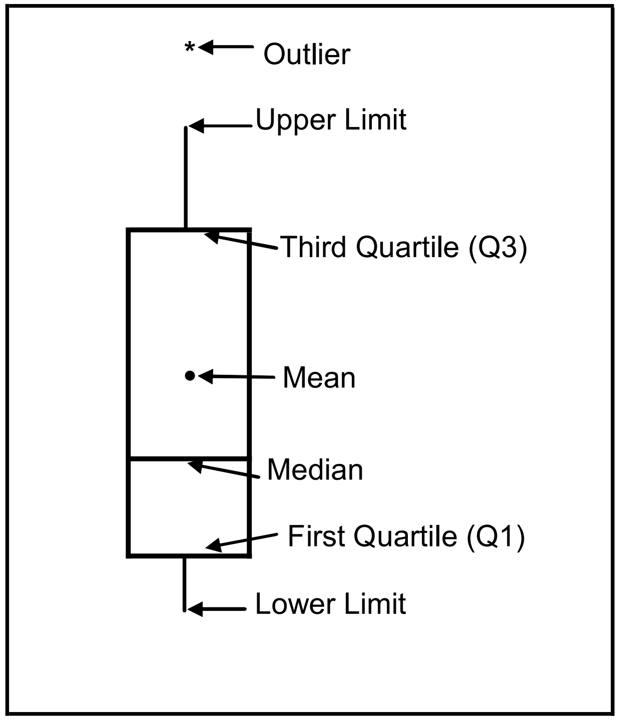


Figure 4-25 Boxplot legend



1. Outliers are data points that fall outside the upper or lower limit.
2. Upper Limit: Q1 – 1.5 (Q3 - Q1)
3. Third quartile (Q3) or the 75th percentile: 75% of the data falls below this line and 25% above it.
4. The mean is the sum of chlorophyll *a* measurements divided by the total number of measurements.
5. The median is the measurement that falls in the middle of the ordered sample. When the sample size *n* is odd, a single measurement occurs in the middle. When the sample size is even, two middle measurements occur, and the median is the midpoint between the two.
6. First quartile (Q1) or the 25th percentile: 25% of the data falls below this line and 75% above it.
7. Lower Limit: Q3 + 1.5 (Q3 – Q1)

Figure 4-26 Chlorophyll *a* boxplots for stations C3, D28A, D26, and D4, 2003

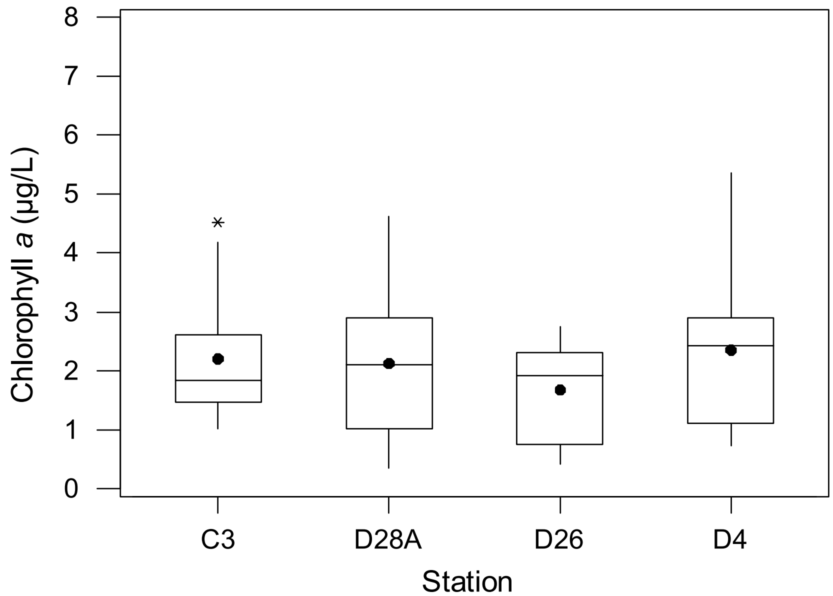


Figure 4-27 Chlorophyll *a* boxplots for stations D8, D7, D6, and D41, 2003

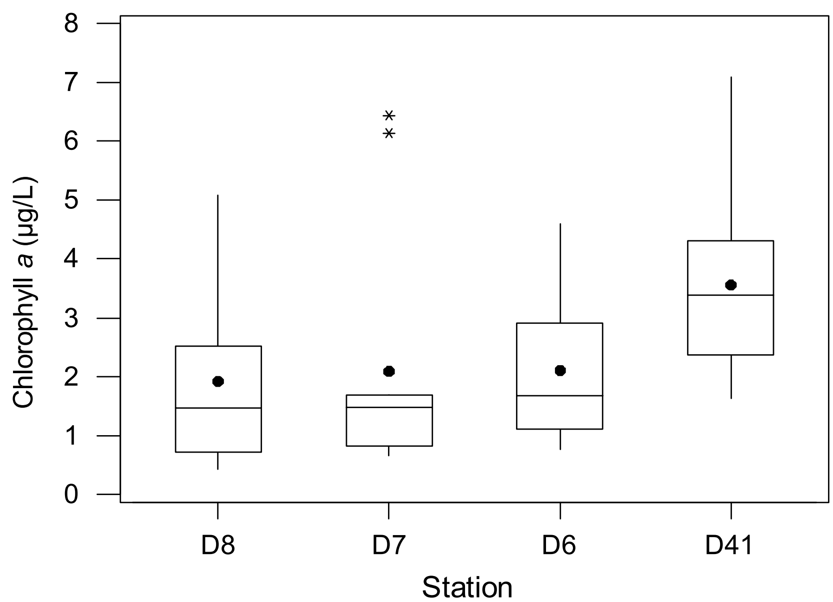


Figure 4-28 Chlorophyll *a* boxplots for stations C10, MD10, and P8, 2003

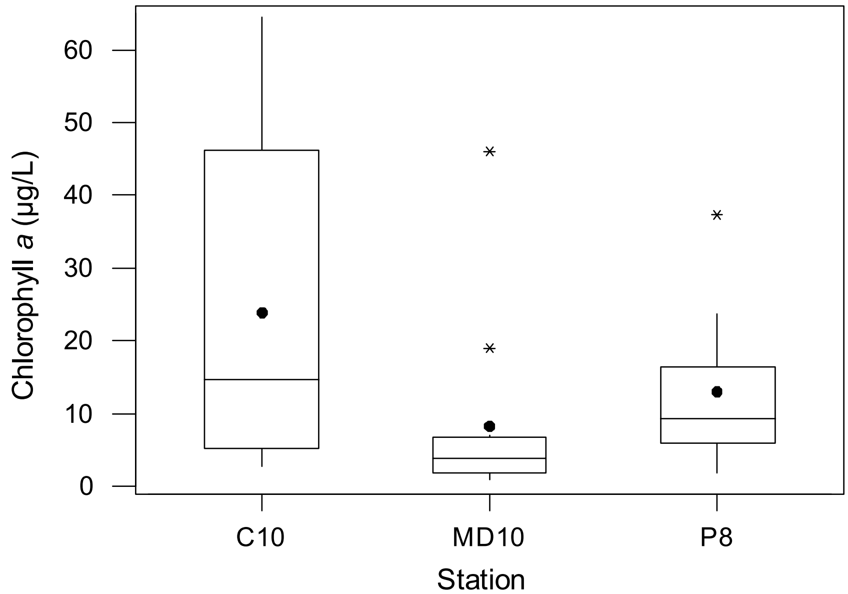


Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2003

Family	Genus
Bacillariophyceae	• Achnanthes • Amphiprora • Amphora • Asterionella • Attheya • Aulacoseira • Biddulphia • Centric Diatom • Cocconeis • Cosinodiscus • Cyclotella • Cymatopleura • Cymbella • Diatoma • Fragilaria • Gomphonema • Gyrosigma • Melosira • Meridion • Navicula • Nitzschia • Pennate Diatom • Rhoicoshpenia • Skeletonema • Stephanodiscus • Surirella • Synedra • Thalassiosira
Chlorophyceae	• Actinastrum • Ankistrodesmus • Carteria • Chlamydomonas • Chlorella • Chodatella • Closterium • Crucigenia • Elakatothrix • Gloeocystis • Kirchneriella • Micractinium • Oocystis • Pandorina • Pediastrum • Phytoconis • Planktosphaeria • Scenedesmus • Schroederia • Selenastrum • Tetraedron • Tetrastrum • Volvox • Westella
Chrysophyceae	• Chrysamoeba • Dinobryon • Synura
Cryptophyceae	• Cryptomonas • Rhodomonas

Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2003 (continued)

Family	Genus
Cyanophyceae	• Agmenellum • Anabaena • Aphanizomenon • Aphanothece • Chroococcus • Gloeothece • Lyngbya • Marssoniella • Merismopedia • Microcystis • Oscillatoria • Pseudanabaena • Synechococcus • Synechocystis

Family	Genus
Dinophyceae	• Glenodinium • Gymnodinium
Euglenophyceae	• Euglena • Phacus • Trachelomonas
Unidentified	• Unidentified Flagellates

Chapter 5
Zooplankton and Mysid Shrimp

Introduction

Mysid shrimp and zooplankton are important food organisms for larval, juvenile, and small fish, such as delta smelt, juvenile salmon, striped bass, and small splittail. The Neomysis/Zooplankton Study seeks to determine the annual population level of *Neomysis mercedis*, other mysids, and various zooplankton species or genera to assess the size of the food resource for fish. The study also seeks to detect the presence of exotic species recently introduced to the estuary, to monitor the distribution and abundance of these exotics, and to determine their impacts on native species. The study began to monitor *N. mercedis* in June 1968 and was expanded in January 1972 to include copepods, cladocera, and rotifers. *Acanthomysis bowmani* was distinguished and enumerated in 1994. Identification and counting of the other five mysid species (*A. aspera*, *A. hwanhaiensis*, *A. macropsis*, *Deltamysis holmquistae*, and *N. kadiakensis*) began in 1998.

Methods

Macro-, meso-, and micro-zooplankton were sampled monthly at 15 to 20 stations in the Delta and Suisun Bay (Figure 5-1). Eighteen of these stations were at fixed geographic locations. Two stations were located or "floated" to locations where bottom electrical conductance was 2 and 6 mS/cm, respectively. One fixed station in San Pablo Bay and two fixed stations in Carquinez Strait were sampled only when their surface salinity was less than 20 mS/cm.

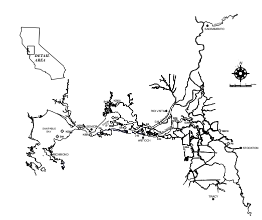


Figure 5-1 Zooplankton monitoring stations

At each station three types of gear were deployed: a *Neomysis* net, 1.48 m long and 29 cm in mouth diameter, mesh size 0.505 mm, mounted on a towing frame made of steel tubing, with a General Oceanics net meter at its mouth; a Clarke-Bumpus net for zooplankton, mouth diameter 12.5 cm and mesh size 154 µm that was mounted above the *Neomysis* net on the same frame; and a 15-liter/minute-capacity pump. At each station, while underway, 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, which was shaken, and a 1.5 to 1.9 liter sample was decanted into a jug. All samples were preserved in buffered 10% formalin and returned to the laboratory for identification. The Department of Water Resources (DWR) provided temperature (to 0.1 ^{o}C) and specific conductance (µS/cm) measurements taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at high water slack using a Seabird submersible sampler and recorded with a Seabird CTD 911+ data logger.

A zooplankton taxon's distribution within the estuary is determined by its salinity requirement rather than geography. Therefore, to calculate monthly abundance indices, the sample area was divided into the following three zones based on bottom specific conductance: (1) the entrapment zone (1.8 mS/cm to 6.6 mS/cm); (2) upstream from the entrapment zone (< 1.8 mS/cm); and (3) downstream from the entrapment zone (> 6.6 mS/cm). The density for each taxon was calculated as the number of organisms/m^3 for each station and type of gear. 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 none of the species were 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 (log10(abundance+1)) before plotting to improve interpretation by reducing month-to-month variability.

For brevity, the meso- and micro-zooplankton were divided into the following four groups: calanoid copepods, cyclopoid copepods, cladocera and rotifers. The taxa in each group were ranked by mean annual abundance and the monthly abundances of the three or four most abundant taxa in each group were presented in this report.

Results

The year 2003 saw changes in the relative abundance of mysids in the upper estuary. *Acanthomysis bowmani* and *Neomysis kadiakensis* remained the dominant mysids in the upper estuary but a native high salinity mysid, *Alienacanthomysis macropsis*, replaced *Neomysis mercedis* as the third most abundant species. The introduced *Acanthomysis hwanhaiensis*, the fourth most abundant mysid in 2001 and 2002, declined to fifth most abundant. Nearly all of the meso- and micro-zooplankton retained their respective abundance ranks from 2001 and 2002.

Mysids

Acanthomysis bowmani (mean abundance = 6.419 m^{-3}) was the most abundant mysid in all areas in 2003 (Figure 5-2). *Acanthomysis bowmani* abundance was highest in the entrapment zone and downstream from the entrapment zone. Peak *A. bowmani* abundance occurred from April through September except downstream from the entrapment zone where the peak abundance period lasted from May through August.

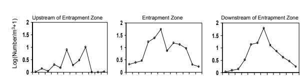


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone for 2003

Neomysis kadiakensis (mean abundance = 0.348 m^{-3}), the second most abundant mysid, was found primarily downstream from the entrapment zone, with a few found within and none found upstream from the entrapment zone (Figure 5-3). In the entrapment zone the highest abundance occurred in January. There was a second peak in May that coincided with the highest abundance value downstream from the entrapment zone. Downstream from the entrapment zone, peak abundance occurred in April through August. *Neomysis kadiakensis* abundance has been steadily increasing in the upper

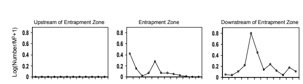


Figure 5-3 Monthly *Neomysis kadiakensis* abundance upstream, in, and downstream of the entrapment zone for 2003

estuary since 1998. In 1998 *N. kadiakensis* was the fourth most abundant mysid overall. In 1999 it was the third most abundant. Since 2001 it has been the second most abundant mysid in the upper estuary.

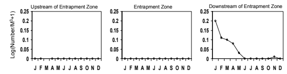


Figure 5-4 Monthly *Aliencanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone for 2003

Alienacanthomysis macropsis (mean abundance =0.036 m^{-3}), a native mysid that is normally found in high salinity water, was the third most abundant mysid. In 2003 it was taken only downstream from the entrapment zone (Figure 5-4). *A. macropsis* abundance peaked in January and declined to zero by June. Only a few *A. macropsis* were caught in November.

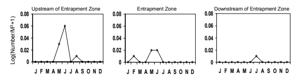


Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone for 2003

Neomysis mercedis (mean abundance = 0.015 m^{-3}), the fourth most abundant mysid, was caught primarily upstream, as well as inside, of the entrapment zone. Peak *N. mercedis* abundance occurred in May and June (Figure 5-5). Although the abundance of *N. mercedis* has been steadily declining since the introduction of *Potamocorbula amurensis* in 1989, its abundance increased slightly from 2002. *Neomysis mercedis* was taken in only May and June upstream from and in the entrapment zone and only in July downstream from the entrapment zone.

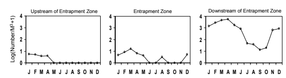


Figure 5-6 Monthly *Acartia* spp abundance upstream, in, and downstream of the entrapment zone for 2003

Calanoid Copepods

The native *Acartia* spp. (mean abundance = 460.755 m^{-3}) was the most abundant calanoid copepod in the upper estuary. It occurred primarily downstream from the entrapment zone (Figure 5-6). The period of peak abundance in and downstream from the entrapment zone was from January through May. Upstream from the entrapment zone, *Acartia* was taken only from January through April.

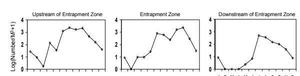


Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone for 2003

The introduced *Pseudodiaptomus forbesi* (mean abundance = 413.638 m^{-3}) was the second most abundant calanoid copepod in the upper estuary 2003 (Figure 5-7). *P. forbesi* abundance was greatest upstream from the entrapment zone and almost as high in the entrapment zone. Peak *P. forbesi* abundance upstream from and in the entrapment zone was from June through November. Downstream from the entrapment zone the peak abundance was from July through November.

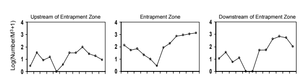


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone for 2003

The third most abundant calanoid copepod was the introduced *Acartiella sinensis* (mean abundance = 155.022 m^{-3}) (Figure 5-8). The highest abundances of this copepod were found in and downstream from the entrapment zone, although large numbers were also found upstream from the entrapment zone. The lowest abundances occurred in May and June with peak abundances occurring from July through December.

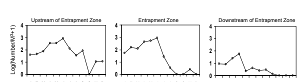


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone for 2003

Sinocalanus doerrii, (mean abundance = 135.109 m^{-3}), another introduced species, was the fourth most abundant calanoid copepod (Figure 5-9). *S. doerrii* abundance reached high levels upstream from and in the entrapment zone. The peak abundance was from April through June upstream from and in the entrapment zone and in March and April downstream from the entrapment zone.

Cyclopoid Copepods

Limnoithona tetraspina (mean abundance = 10,844.630 m^{-3}), has been the most abundant cyclopoid copepod since its introduction in 1994 (Figure 5-10). *Limnoithona tetraspina* was abundant in all three zones, but was most abundant in and downstream from the entrapment zone. In all three zones the highest abundance was in July. Upstream from the entrapment zone, the period of peak abundance was from July through September. In the entrapment zone, peak abundance ran from July through November and, downstream from the entrapment zone, peak abundance occurred from March through August.

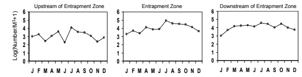


Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone for 2003

The introduced *Oithona davisae* (mean abundance = 426.288 m^{-3}) was the second most abundant cyclopoid copepod and occurred primarily downstream from the entrapment zone (Figure 5-11). *Oithona davisae* was also abundant in the other two areas but its occurrence there was erratic during the last half of the year. Upstream from the entrapment zone, the peak period was in July and August. In the entrapment zone there were two peaks; one in July and the other in September. Downstream from the entrapment zone, peak abundance was from July through December.

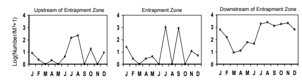


Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone for 2003

The native *Acanthocyclops vernalis* (mean abundance = 43.142 m^{-3}) was the third most abundant cyclopoid copepod and was abundant throughout the sampling area, but declined from upstream from the entrapment zone to downstream (Figure 5-12). Its peak abundance period appeared earlier with each successive downstream area. Upstream from the entrapment zone, the peak abundance period was from February through June. In the entrapment zone, the peak abundance period began in January and ended in May. Downstream from the entrapment zone, there was a peak period from January through March and another one in November and December.

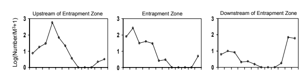


Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone for 2003

Cladocera

Bosmina longirostris (mean abundance = 561.350 m^{-3}) was the most abundant cladoceran in the upper estuary in 2003 (Figure 5-13). It was abundant throughout the year upstream from the entrapment zone with peak abundances from April through October. In the entrapment zone, *B. longirostris* had two spikes, one in May and one in July, followed by an abundance estimate of zero. Downstream from the entrapment zone, abundance also showed two spikes: one in May and one in September.

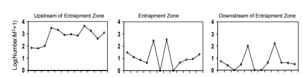


Figure 5-13 Monthly *Bosmina* spp abundance upstream, in, and downstream of the entrapment zone for 2003

Diaphanosoma spp. (mean abundance = 195.120 m^{-3}), the second most abundant cladoceran for 2003, was taken almost exclusively upstream from the entrapment zone (Figure 5-14). It was the third most abundant cladoceran in 2001 and 2002. Peak abundance for this genus occurred from June through November upstream from the entrapment zone. The 2003 abundance peaks followed the typical pattern. In the entrapment zone *Diaphanosoma* was caught in low numbers from June through September. *Diaphanosoma* occurred downstream from the entrapment zone only in July during 2003.

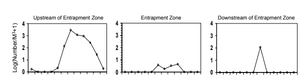


Figure 5-14 Monthly *Diaphanosoma* spp abundance upstream, in, and downstream of the entrapment zone for 2003

Although it was the second most abundant cladoceran in 2002, *Daphnia* spp. (mean abundance = 119.355) was the least abundant of the identified cladocera for 2003 (Figure 5-15). It was most abundant upstream from the

Figure 5-15 Monthly *Daphnia* spp abundance upstream, in, and downstream of the entrapment zone for 2003

entrapment zone where its peak abundance occurred from April through July with a spike in September. *Daphnia* was present from January through March, and then occasionally appeared in relatively large numbers throughout the rest of the year. *Daphnia* was absent downstream from the entrapment zone for most of the year, appearing only in January, February, and May.

Rotifers

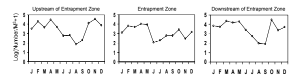


Figure 5-16 Monthly *Synchaeta* spp abundance upstream, in, and downstream of the entrapment zone for 2003

The genus *Synchaeta* (excluding *Synchaeta bicornis*) (mean abundance = 8,437.141 m^{-3}) was the most abundant rotifer taxon (Figure 5-16). The typical peak abundance period for *Synchaeta* begins in October and continues through May or June of the following year. This pattern was evident in all areas during 2003.

Figure 5-17 Monthly *Polyarthra* spp abundance upstream, in, and downstream of the entrapment zone for 2003

The genus *Polyarthra* (mean abundance = 5,491.975 m^{-3}) was the second most abundant rotifer (Figure 5-17). It was most abundant upstream from the entrapment zone and least abundant downstream from the entrapment zone. Upstream from the entrapment zone *Polyarthra* abundance remained fairly uniform throughout 2003. Inside the entrapment zone, *Polyarthra* was abundant from January through March, but very erratic throughout the rest of the year. *Polyarthra* was not taken downstream from the entrapment zone until April. Beginning in April, *Polyarthra* was moderately abundant and its abundance was stable for the rest of the year except for July when it was absent.

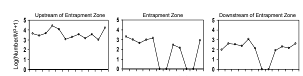


Figure 5-18 Monthly *Keratella* spp abundance upstream, in, and downstream of the entrapment zone for 2003

The third most abundant rotifer taxon was the genus *Keratella* (mean abundance = 3,372.417 m^{-3}) (Figure 5-18). The highest *Keratella* abundance occurred upstream from the entrapment zone, where its abundance was relatively stable throughout 2003. Inside the entrapment zone, *Keratella* abundance was fairly stable until June when it disappeared from the catch for a couple of months. A similar disappearance occurred in October and November. For the last six months of 2003, abundance was slightly lower. Downstream from the entrapment zone, *Keratella* abundance was stable except for a brief absence during July and August.

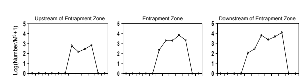


Figure 5-19 Monthly *Synchaeta bicornis* abundance upstream, in, and downstream of the entrapment zone for 2003

The fourth most abundant rotifer taxon was *Synchaeta bicornis* (mean abundance = 1,341.415 m^{-3}) (Figure 5-19). It is a small rotifer that shows wide abundance swings both inter- and intra-annually. This species was most abundant downstream from the entrapment zone and least abundant upstream from the entrapment zone. In the entrapment zone and downstream from it, this rotifer's abundance steadily rose until it dropped to zero in November. It was not caught in any area during winter or late fall.

Summary

The monthly abundance patterns were typical of those for recent years. *Acanthomysis bowmani* and *Neomysis kadiakensis* remained the two most abundant mysids. *Neomysis mercedis* dropped to fourth most abundant after *Alienacanthomysis macropsis*. The abundance ranks of the meso- and micro-zooplankton were essentially the same as for 2002.

Figure 5-1 Zooplankton monitoring stations

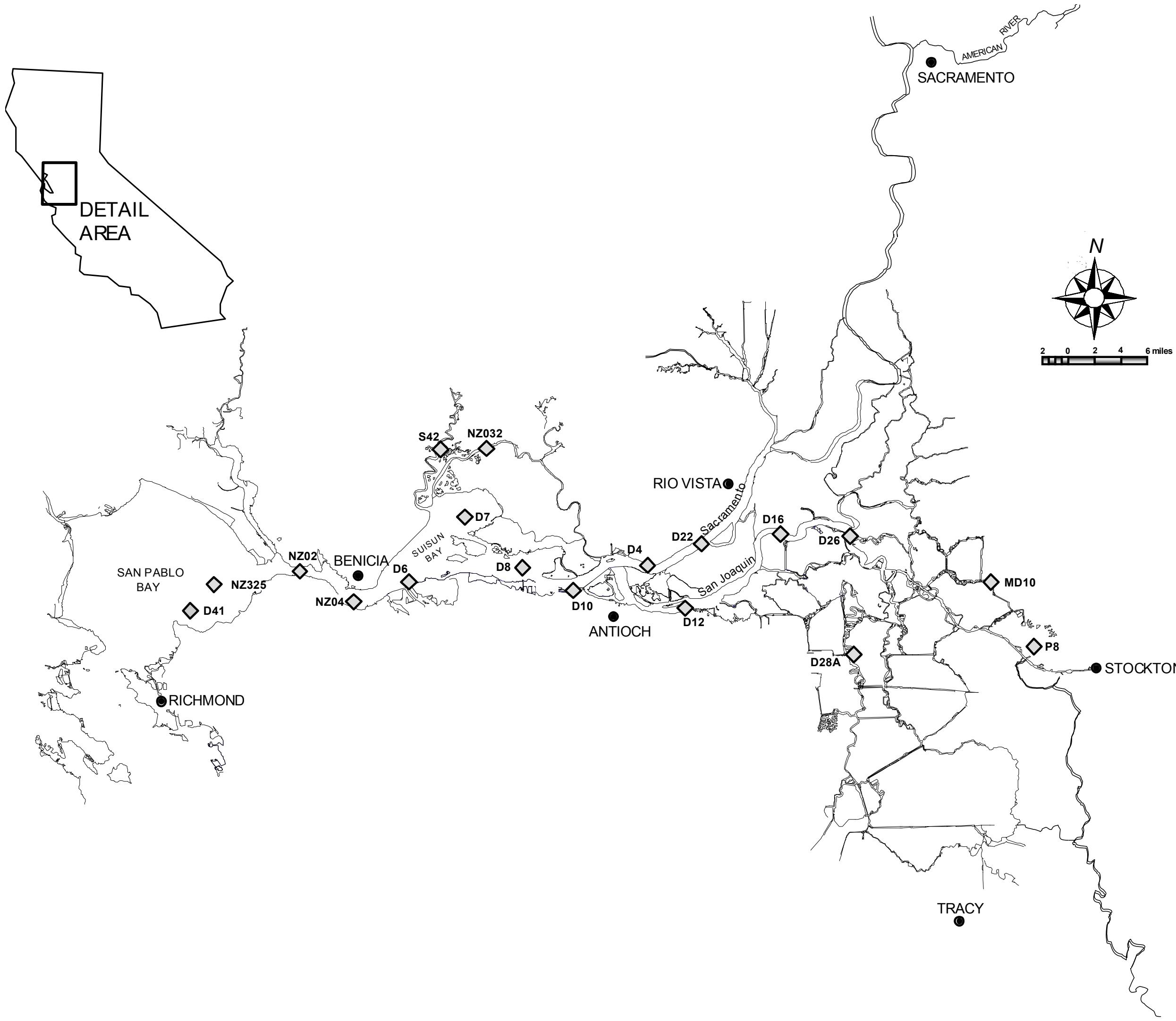


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone for 2003

Figure 5-3 Monthly *Neomysis kadiakensis* abundance upstream, in, and downstream of the entrapment zone for 2003

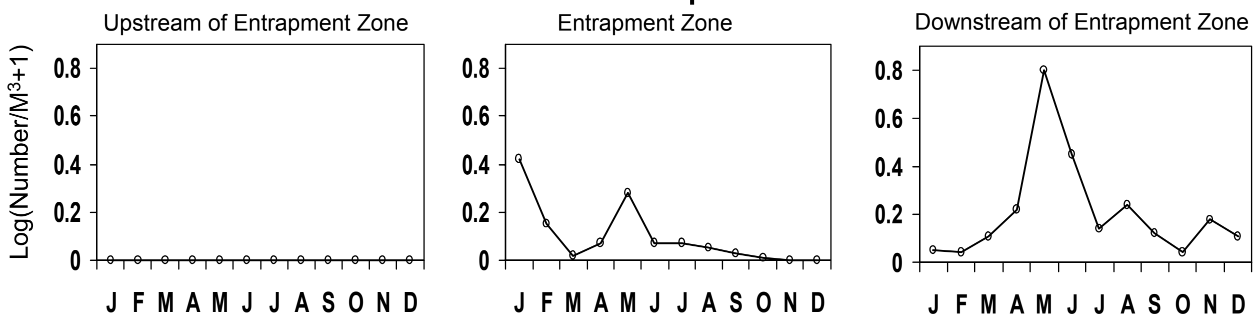


Figure 5-4 Monthly *Aliencanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone for 2003

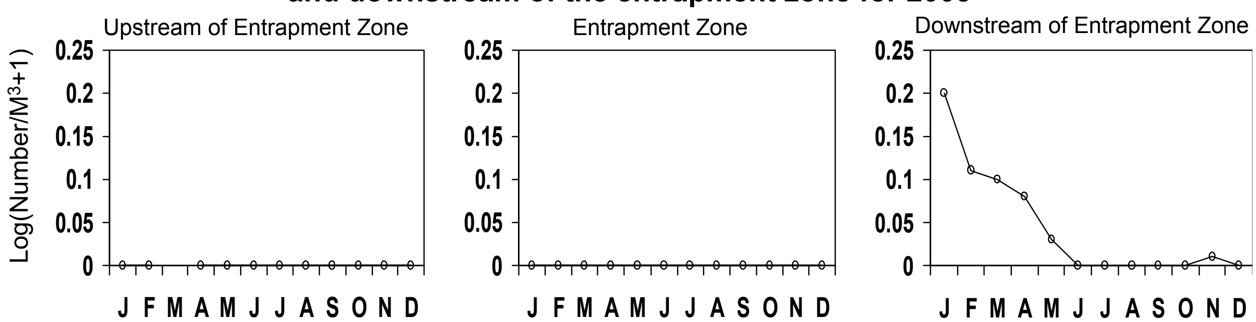


Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone for 2003

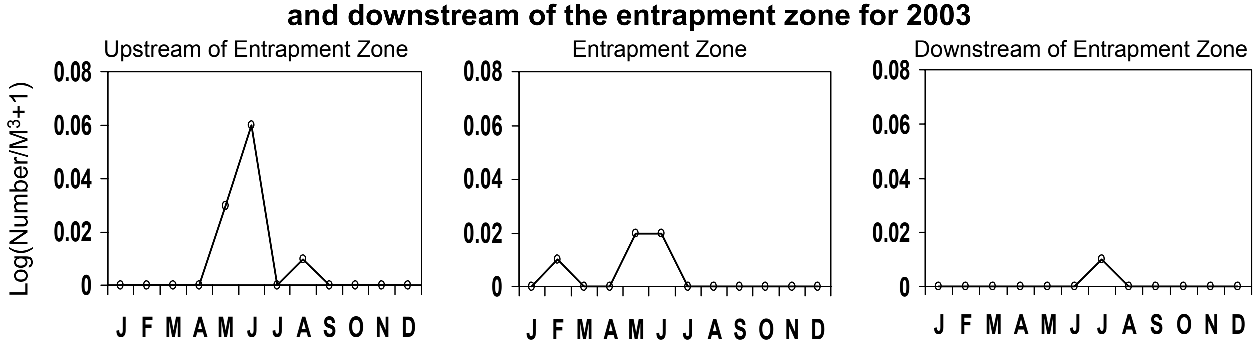


Figure 5-6 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

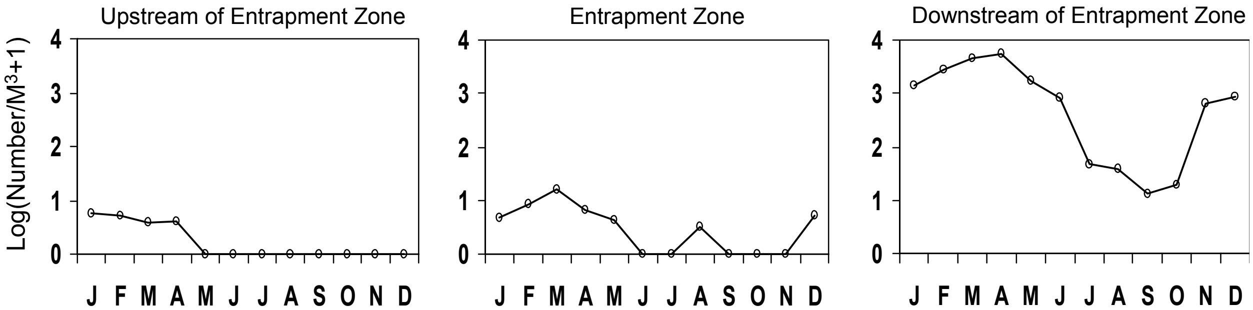


Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone for 2003

Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone for 2003

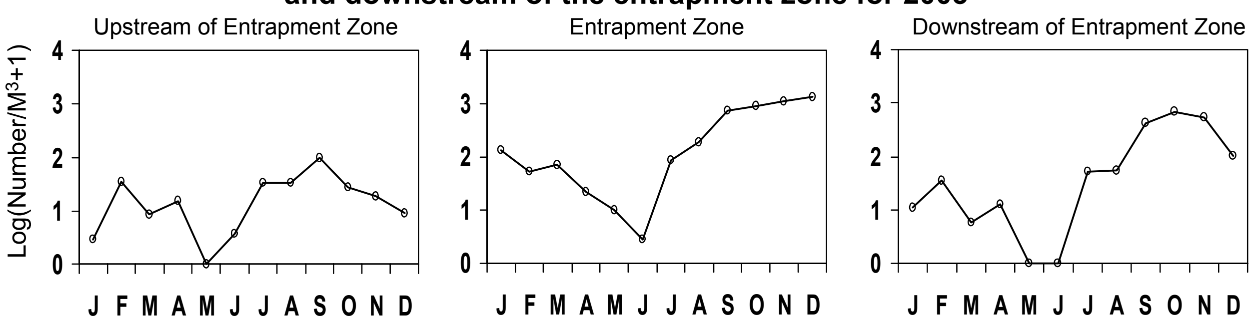


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone for 2003

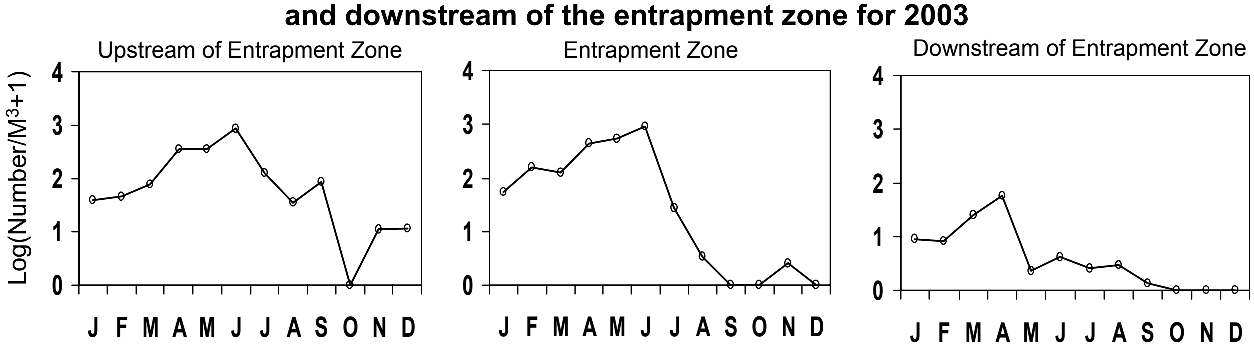


Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone for 2003

Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone for 2003

Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone for 2003

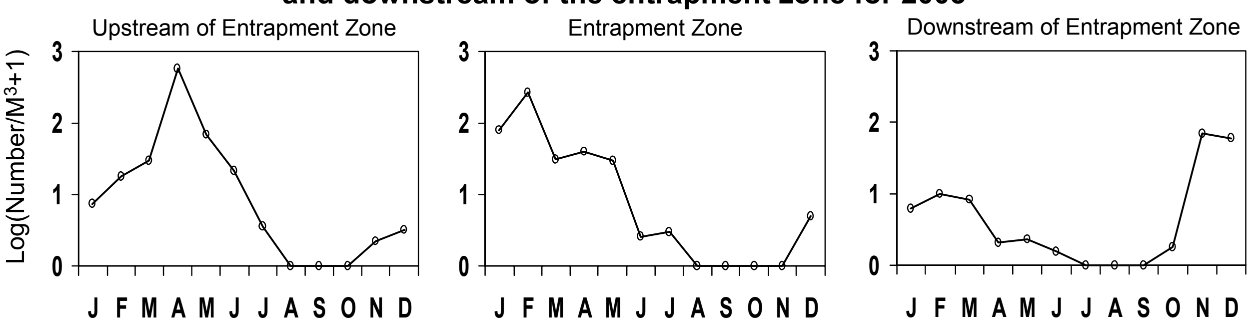


Figure 5-13 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

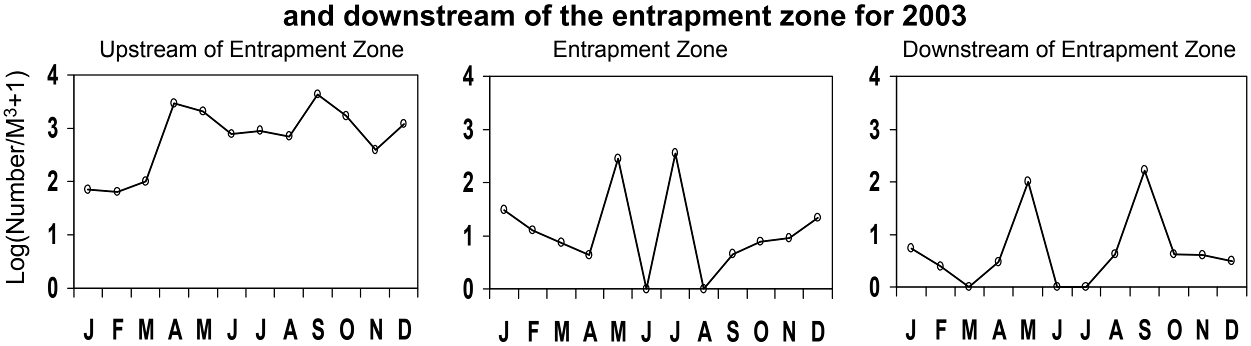


Figure 5-14 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

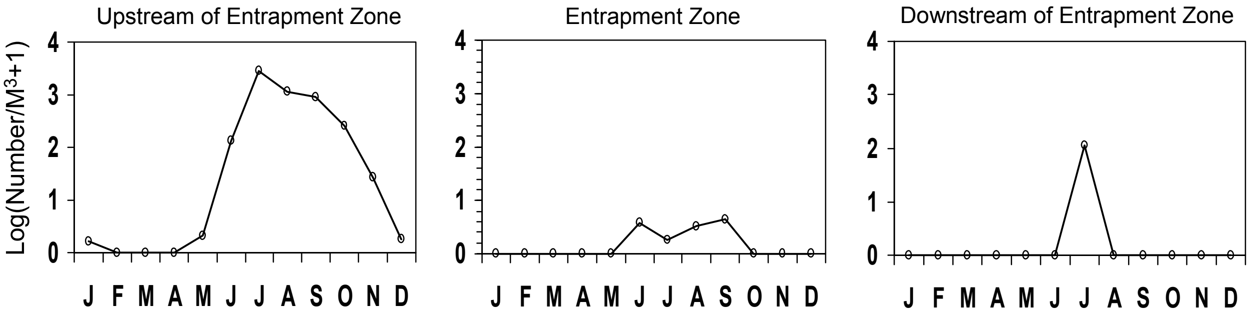


Figure 5-15 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

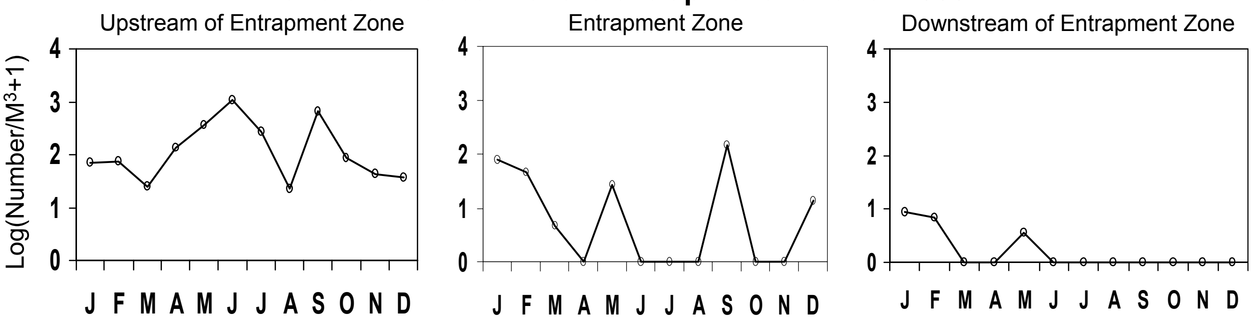


Figure 5-16 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

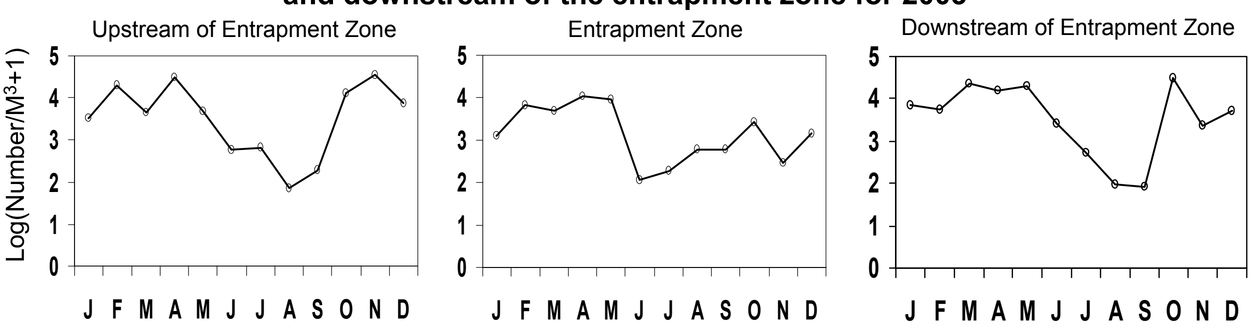


Figure 5-17 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

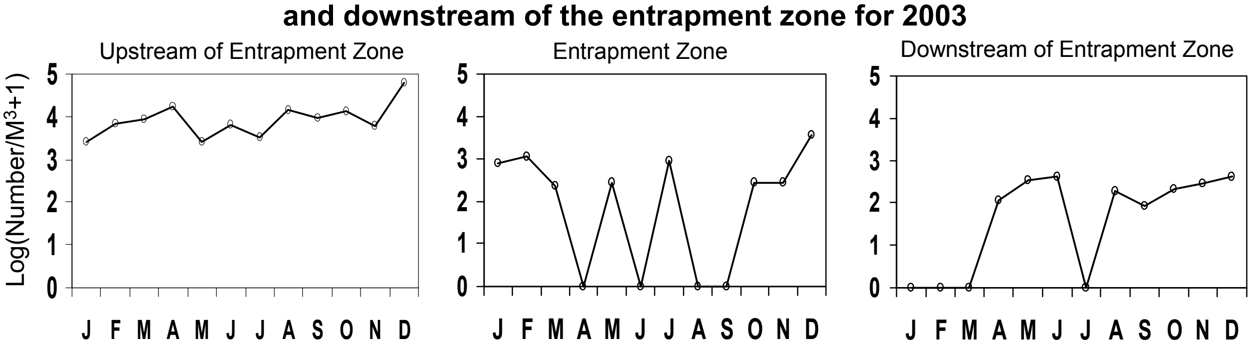


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone for 2003

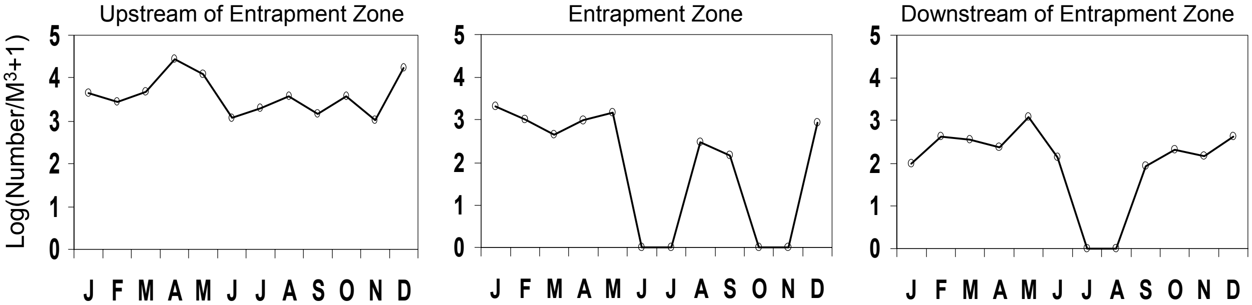
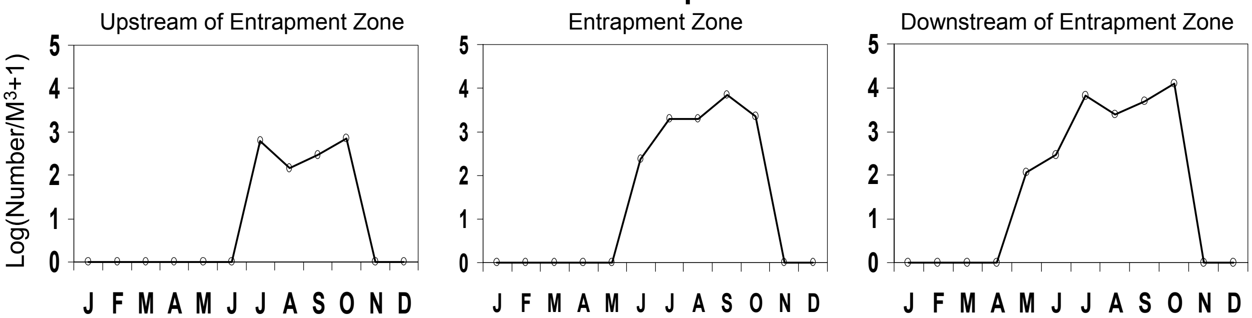


Figure 5-19 Monthly *Synchaeta bicornis* abundance upstream, in, and downstream of the entrapment zone for 2003



Chapter 6
Benthic Monitoring

Introduction

The benthic monitoring program is designed to document the distribution, diversity and abundance of benthic (bottom dwelling) organisms in the upper San Francisco Estuary (Estuary). Geographic coverage of the sampling sites ranges from San Pablo Bay east through the Sacramento-San Joaquin Delta to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. The benthic community of the upper Estuary is a diverse assemblage of organisms, which includes worms, crustaceans, insects, and molluscs. This program monitors both benthic macrofauna (organisms larger than 0.5 mm) (DWR 2001) and sediment composition. General trends in sediment composition are documented at the same sites where benthic samples are collected.

The benthic monitoring program began in 1975. From 1975 through 1979 the program collected samples biannually from 11 to 16 sites. In 1980, the Department of Water Resources (DWR) revised the benthic monitoring program and began monthly sampling at five sites. In 1995, major programmatic revisions were implemented to form the current program. Since 1996, monitoring has been conducted at ten sites that are sampled monthly. The current sites represent a wide variety of habitats that vary in size and physical characteristics. Table 6-1 has site-specific information. More detailed information about the location, number, and physical characteristics of the historical sites can be found in Interagency Ecological Program (IEP) Technical Report 12 (Markmann 1986) and IEP Technical Report 38 (Hymanson et al. 1994).

Station Region	Latitude Longitude	Substrate Composition	Approx. Salinity Range (uS/cm)
C9 *Delta-Old River*	*37° 49' 50"* *121° 33' 09"*	*Consistent.* *Over 90% sand.*	*200-800*
P8 *Delta* *San Joaquin River*	*37° 58' 42"* *121° 22' 55"*	*Consistent.* *High sand content (60%)*	*175-750*
D28A *Delta* *Old River*	*37° 58' 14"* *121° 34' 19"*	*Mixed composition of sand and fines*	*200-350*
D16 *Delta* *San Joaquin River*	*38° 05' 50"* *121° 40' 05"*	*Consistent. Mostly fines with some organic materials*	*130-500*
D24 *Delta* *Sacramento River*	*38° 09' 27"* *121° 41' 01"*	*Consistent.* *High sand content (80%).*	*200-1200*
D4 *Delta* *Sacramento River*	*38° 03' 45"* *121° 49' 10"*	*Mixed composition of sand, fines, and organic materials.*	*130-8,000*
D6 *Suisun Bay*	*38° 02' 40"* *122° 07' 00"*	*Fairly equal mixture of sand and fines*	*135-30,000*
D7 *Grizzly Bay*	*38° 07' 02"* *122° 02' 19*	*Consistent.* *Mostly Fines with some organic materials.*	*200-20,000*
D41 *San Pablo Bay*	*38° 01' 50"* *122° 22' 15"*	*Consistent.* *High content of fine material (87%)*	*20,000-45,000*
D41A *San Pablo Bay*	*38° 03' 75"* *122° 24' 40"*	*Consistent.* *High content of fine material*	*30,000-44,000*

Table 6-1 Macrobenthic monitoring station characteristics, 2003

Water Right Decision D-1641 (SWRCB) requires a review of the EMP every three years "to ensure that the goals of the monitoring program are attained". The most recent programmatic review of the EMP provided plans for modifications to the benthic monitoring element. As a result, the EMP was to reduce its benthic monitoring from monthly to quarterly sampling during water years 2004 and 2005 to reserve enough resources to conduct special studies and perform a retrospective analysis of the historic EMP benthic monitoring data in order to develop a new sampling design. At the beginning of the 2003-2004 water year, the benthic monitoring program temporarily switched to quarterly sampling.

Methods

Benthic Organisms

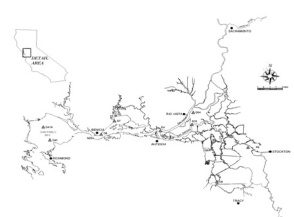


Figure 6-1 Location of 10 Environmental Monitoring Program benthic sampling sites

Field sampling was conducted at ten sites monthly, until October 2003 when the sampling regime changed to quarterly. Figure 6-1 shows the location of each site and Table 6-1 summarizes latitude and longitude, salinity range, and substrate composition for each site. The research vessel *San Carlos,* equipped with a hydraulic winch and a Ponar dredge, was used to conduct this sampling. The Ponar dredge samples a bottom area of 0.053 m^2. The contents of the dredge were washed over a Standard No. 30 stainless steel mesh screen (0.595 mm openings) to remove as much of the substrate as possible. All material remaining on the screen was preserved in approximately 20% buffered formalin containing Rose Bengal dye and transported to the laboratory for analysis. The benthic macroinvertebrate sampling methodology used in this program is described in Standard Methods for the Examination of Water and Wastewater (APHA 1998).

In the laboratory, the field preservative was decanted and the sample was washed with deionized water over a Standard No. 30 stainless steel mesh screen. Organisms were then placed in 70% ethyl alcohol for identification and enumeration. Hydrozoology[1], a private laboratory under contract with DWR, identified and enumerated organisms in the macrofaunal samples. A stereoscopic dissecting microscope (70-120X) was used to identify most organisms. When taxonomic features were too small for identification under the dissecting scope, the organism was mounted permanently on a slide and examined under a compound microscope. If more than four hours of sorting were required and a sample contained many organisms but few species, a one-fourth volume subsample was chosen at random from the sample. The subsample was sorted and the results were multiplied by four to represent the total sample. The remainder of the sample was inspected to make sure no taxa were overlooked. Individual species counts were multiplied by 19 to convert the number of organisms per grab sample to organisms per square meter (where $19 = 1.0\ m^2 / 0.53\ m^2$ and $0.53\ m^2$ = sample area of the ponar).

All organisms identified and enumerated were recorded onto datasheets by Hydrozoology staff. These datasheets were returned to DWR staff for entry into the benthic monitoring program's database.

Sediment

Sediment composition samples were collected monthly in the field from the RV *San Carlos* using the same hydraulic winch and Ponar dredge used in the benthic sampling. A random subsample of the sediment was placed into a 1-liter plastic jar for storage and transported to the DWR's Soils and Concrete Laboratory for analysis.

Particle size analysis and dry weight measurements for each sediment sample were performed. Sediment was analyzed for particle size according to the American Society of Testing and Materials Protocol D422 (ASTMa 2000). Particles were sorted into the following categories: sand (>75 µm) and fine (<75 µm). Organic content of the sediment was determined using the American Society of Testing and Materials Protocol D2974, Method C (ASTMb 2000). For this method, the ash-free dry weight of the sample was used to determine the organic content of the sediment.

[1] Hydrozoology. P.O. Box 682, Newcastle, CA 95658

Results

Benthic Organisms

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 180 species, ten species represented 90 percent of all organisms collected. Listed below, these species were also the ten numerically dominant species during the 2003 reporting period.

Numerically Dominant Species

Amphipods

- *Americorophium stimpsoni*
- *Americorophium spinicorne*
- *Corophium alienense*
- *Monocorophium acherusicum*
- *Ampelisca abdita*
- *Gammarus daiberi*

Cumacean Crustacean

- *Nippoleucon hinumensis*

Aquatic Oligochaete (phylum Annelida)

- *Varichaetadrilus angustipenis*

Asian Clams

- *Potamocorbula amurensis*
- *Corbicula fluminea*

Of the 10 dominant species, four species, *Ampelisca abdita*, *Nippoleucon hinumensis, Monocorophium acherusicum,* and *Corbula amurensis,* represent macrofauna that inhabit a typically high saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. The amphipods *Corophium alienense, Americorophium stimpsoni* and *Americorophium spinicorne* tolerate a wider range of salinity. They were collected both in the higher saline western sites and the more brackish to fresh water eastern sites, such as the San Joaquin River at Twitchell Island and the Sacramento River above Point Sacramento. The remaining three species, *Gammarus daiberi*, *Varichaetadrilus angustipenis,* and *Corbicula fluminea,* are predominantly freshwater species and were collected at sites east of Suisun Bay.

Data Management and Summarization

The EMP maintains a database containing all information on benthic organisms identified within the upper Estuary. This database continuously undergoes peer review and updating. When a new organism is found at any of the sampling sites, the organism is identified to the lowest possible taxonomic level and added to the database. Sixteen new organisms were added to the benthic species list during 2003. These new organisms were found at 4 of the 10 monitoring sites. One species was found near the Clifton Court Forebay, a freshwater site in the south Delta. Four species were found near the city of Rio Vista, a freshwater site on the Sacramento River. Eleven species were found in San Pablo Bay, a saline to brackish-water region with two sites west of the Delta. Table 6-2 lists the new species,

Phylum	Genus Species	Date	Station
Annelida	Aricidea species A	Feb-03	D41
Annelida	Tharyx parva	Feb-03	D41
Annelida	Pholoides aspera	Feb-03	D41
Arthropoda	Tipula species a	Feb-03	D24
Arthropoda	Hygrobates species A	Feb-03	D24
Arthropoda	Psychoda species A	Mar-03	D24
Arthropoda	Neoplasta species A	Mar-03	D24
Annelida	Arcteonais lomondi	Apr-03	C9
Arthropoda	Simulium Species A	May-03	D41A
Arthropoda	Callianassa species A	May-03	D41
Arthropoda	Cancer magister	May-03	D41
Arthropoda	Ampithoe valida	Jul-03	D41
Arthropoda	Monocorophium uenoi	Jul-03	D41, D41A
Annelida	Pista pacifica	Sep-03	D41
Mollusca	Melanochlamys diomedea	Sep-03	D41
Mollusca	Macoma species A	Sep-03	D41

Table 6-2 New species, 2003

locations, and the date when they were found. All data is available at http://www.baydelta.ca.gov.

All organisms collected during 2003 fell into eight 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)

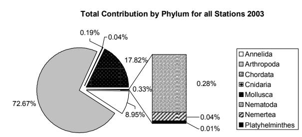


Figure 6-2 Total contribution by phyla for all stations during 2003

Of the eight phyla identified, Annelida, Arthropoda, and Mollusca constituted 99.4% of the organisms collected during the study period. Figure 6-2 shows the total percent contribution by phylum for all sites. Figures 6-3 through 6-7 show the total contribution by phylum for each site and organism abundance for each site.

Organism abundance (organism per meter squared or org/m^2) and dominant phyla varied between sites. Temporal changes in organism abundance (for example, intra- and interannual) also varied greatly between sites. These variations and trends (for example, maximum, minimum, abundance, dominant species, and seasonal patterns) will be discussed for each individual site (Figures 6-3 through 6-7). Sediment composition is also discussed for each site (Figures 6-8 through 6-17).

Site C9: Benthic Abundance

Maximum abundance in 2003 occurred in June with a total of 44,565 organisms per meter squared (Figure 6-3). *Americorophium stimpsoni* (30,158 org/m^2) and *Gammarus daiberi* (12,835 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in February with a total of 442 organisms per meter squared. *Corbicula fluminea* (219 org/m^2) and *Varichaetadrilus angustipenis* (157 org/m^2) were the dominant species.

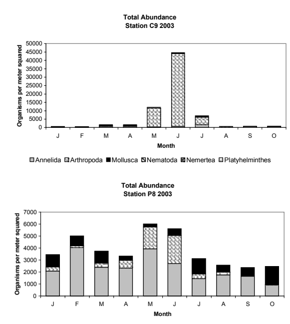


Figure 6-3 Benthic abundance at stations C9 and P8, 2003

This site demonstrated a clear seasonal pattern with the highest abundance values recorded during the spring and early summer and the lowest values recorded during the winter and fall. The 2001-2002 reporting period exhibited similar abundance patterns as those observed in 2003, with higher values in the spring and lower values in the winter and the same organism, *Americorophium stimpsoni,* as the most abundant.

Site P8: Benthic Abundance

Maximum abundance in 2003 occurred in May with a total of 6,019 organisms per meter squared (Figure 6-3). The dominant species were *Limnodrilus hoffmeisteri* (1,710 org/m^2), *Chironomus attenuatus* (1,245 org/m^2), and *Ilyodrilus frantzi* (993 org/m^2). The minimum abundance in 2003 occurred in September with a total of 2,384 organisms per meter squared. The dominant species were *Varichaetadrilus angustipenis* (637 org/m^2), *Corbicula fluminea* (618 org/m^2), and *Limnodrilus hoffmeisteri* (328 org/m^2).

This site demonstrated a seasonal pattern with the highest abundance values in the late spring and early summer and the lowest values in the late summer and fall. The annelid population is relatively stable at this site, while the arthropod population fluctuates dramatically and is the cause of the two highest peaks throughout the year.

The 2001-2002 reporting period did not demonstrate any clear interannual or intra-annual abundance patterns. This site was dominated by annelids, with the exception of the late spring and early summer months of 2002 when amphipods dominated.

Site D28A: Benthic Abundance

Maximum abundance in 2003 occurred in June with a total of 9,329 organisms per meter squared (org/m^2) (Figure 6-4). *Gammarus daiberi* (2,199 org/m^2), *Cyprideis* species *A* (1,952 org/m^2) and *Limnodrilus hoffmeisteri* (1,387 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in August with a total of 1,121 organisms per meter squared. *Corbicula fluminea* (342 org/m^2), *Varichaetadrilus angustipenis* (233 org/m^2), and *Pristina breviseta* (119 org/m^2) were the dominant species.

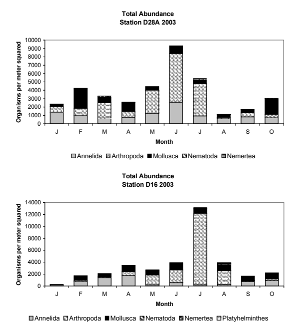


Figure 6-4 Benthic abundance at stations D28A and D16, 2003

This site demonstrated a clear seasonal pattern, with highest abundance occurring in the spring and early summer. Abundance remained moderate (< 4,000 org/m^2) for the remaining months. Amphipods were the dominant organisms during peak abundance at this site. During the remaining months, when abundance was low to moderate, annelids and clams were the dominant organisms. The 2001-2002 reporting period exhibited similar abundance and organism composition patterns as the 2003 reporting period.

Site D16: Benthic Abundance

Maximum abundance in 2003 occurred in July with a total of 13,101 organisms per meter squared (Figure 6-4). *Americorophium spinicorne* (8,104 org/m^2), *Gammarus daiberi* (3,330 org/m^2), and *Corbicula fluminea* (860 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in January with a total of 285 organisms per meter squared. *Varichaetadrilus angustipenis* (186 org/m^2) and *Corbicula fluminea* (72 org/m^2) were the dominant species.

Abundance values at this site were moderate (< 4,000 org/m^2) and fairly stable, with the exception of a peak in July. This peak was dominated by amphipods, as were the late spring and summer months.

The 2001-2002 reporting period demonstrated a seasonal pattern with low abundance during the late fall and winter and higher values during the summer and early fall. During 2001-2002 this site was dominated by amphipods.

Site D24: Benthic Abundance

Maximum abundance in 2003 occurred in May with a total of 21,109 organisms per meter squared (Figure 6-5). *Americorophium stimpsoni* (17,499 org/m^2) and *Corbicula fluminea* (2,005 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in October with a total of 3,791 organisms per meter squared. *Corbicula fluminea* (1,976 org/m^2) and *Americorophium stimpsoni* (1,544 org/m^2) were the dominant species.

Abundance was stable at this site (>12,000 org/m^2) with the exception of two spikes that occurred during May (21,109 org/m^2) and June (17,328 org/m^2). These two peaks were dominated by the amphipod *Americorophium stimpsoni.* The 2001-2002 reporting period exhibited patterns similar to those observed in the 2003 reporting period. Abundance values remained fairly constant, with the exception of a few spikes. This site was dominated by amphipods during 2001-2002.

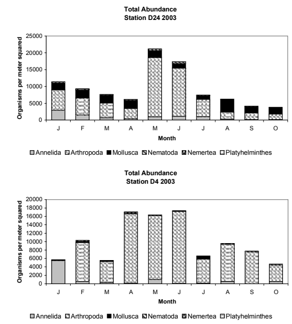


Figure 6-5 Benthic abundance at stations D24 and D4, 2003

Site D4: Benthic Abundance

Maximum abundance in 2003 occurred in June with a total of 17,347 organisms per meter squared (Figure 6-5). *Americorophium spinicorne* (15,352 org/m^2) and *Gammarus daiberi* (1,796 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in October with a total of 4,622 organisms per meter squared. *Americorophium spinicorne* (2,931 org/m^2) and *Gammarus daiberi* (1,007 org/m^2) were the dominant species.

Station D4 exhibited a seasonal pattern of higher abundance values during the spring and early summer months and lower abundance during the other months. *Americorophium spinicorne*, an amphipod, was the overall dominant organism at this site. The 2001-2002 reporting period exhibited values similar to the current reporting period. *Americorophium spinicorne* was also the dominant organism for this site during 2001-2002.

Site D6: Benthic Abundance

Maximum abundance in 2003 occurred in October with a total of 13,514 organisms per meter squared (Figure 6-6). *Potamocorbula amurensis* (13,049 org/m^2) was the dominant species. The minimum abundance in 2003 occurred in March with a total of 4,066 organisms per meter squared. *Nippoleucon hinumensis* (2,931 org/m^2) and *Potamocorbula amurensis* (1,112 org/m^2) were the dominant species.

The invasive Asian clam, *Potamocorbula amurensis,* was the dominant species found at this site. The cumacean, *Nippoleucon hinumensis*, became the dominant species during the spring.

The 2001-2002 reporting period exhibited similar abundance and organism composition patterns as those observed in the 2003 reporting period.

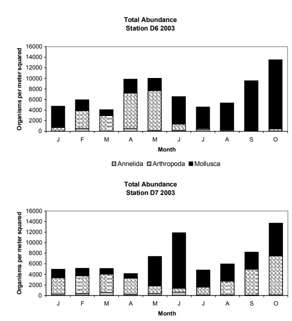


Figure 6-6 Benthic abundance at stations D6 and D7, 2003

Site D7: Benthic Abundance

Maximum abundance in 2003 occurred in October with a total of 13,718 organisms per meter squared (Figure 6-6). *Corophium alienense*

(7,306 org/m^2) and *Potamocorbula amurensis* (6,204 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in April with a total of 4,157 organisms per meter squared. *Corophium alienense* (1,748 org/m^2), *Nippoleucon hinumensis* (1,307 org/m^2) and *Potamocorbula amurensis* (884 org/m^2) were the dominant species.

During 2003 the abundance was relatively stable with the exception of June (11,875 org/m^2) and October (13,718 org/m^2). In June the Asian clam *Potamocorbula amurensis* was dominant and in October *Potamocorbula amurensis* and *Corophium alienense* were dominant.

The 2001-2002 reporting period was very dynamic. During 2001, site D7 exhibited a seasonal pattern, with the highest values occurring in the fall and winter and the lower values during the spring. During 2002, the highest values were in the late summer and fall and the lower values during the winter and spring. For both reporting periods, 2001-2002 and 2003, the mollusc population appears to be stable, while changes in overall abundance at this site are due to fluctuations in the arthropod populations.

Site D41: Benthic Abundance

Maximum abundance in 2003 occurred in July with a total of 57,589 organisms per meter squared (Figure 6-7). *Monocorophium acherusicum* (26,201 org/m^2) and *Ampelisca abdita* (22,325 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in March with a total of 2,100 organisms per meter squared. *Ampelisca lobata* (409 org/m^2), *Cirriformia spirabrancha* (399 org/m^2), *Tubificoides wasselli* (290 org/m^2), and *Diadumene* sp. *A* (285 org/m^2) were the dominant species.

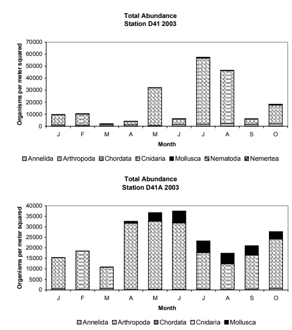


Figure 6-7 Benthic abundance at stations D41 and D41A, 2003

This site exhibits a seasonal pattern with the highest abundance during the late summer and the lowest abundance occurring during the winter and early spring. Two large spikes in population occurred during the study period. These spikes occurred in May (32,243 org/m^2), July (57,589 org/m^2), and August (46,669 org/m^2). This station was dominated by arthropods. The 2001-2002 reporting period exhibited similar abundance and organism composition patterns as those observed in the 2003 reporting period.

Site D41A: Benthic Abundance

Maximum abundance in 2003 occurred in June with a total of 37,463 organisms per meter squared (Figure 6-7). *Ampelisca abdita* (28,044 org/m^2), *Potamocorbula amurensis* (5,581 org/m^2), *Monocorophium acherusicum* (1,876 org/m^2), and *Nippoleucon hinumensis* (1,501 org/m^2) were the dominant species. The minimum abundance in 2003 occurred in March with a total of 10,911 organisms per meter squared. *Ampelisca abdita* (6,669 org/m^2) and *Nippoleucon hinumensis* (2,926 org/m^2) were the dominant species.

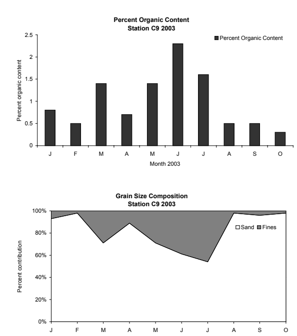


Figure 6-8 Sediment organic content and grain size at Station C9 during 2003

This site exhibits a seasonal pattern with the highest abundance occurring during the spring and early summer. This site is dominated by arthropods, but molluscs appear during the summer and fall. The 2001-2002 reporting period exhibited similar abundance and organism composition patterns as those observed in the 2003 reporting period.

Sediment

Site C9: Sediment Composition

Sand was the dominant sediment type at site C9 for 2003 (Figure 6-8). The percentage of organic content is relatively low (< 2.5%) and ranges from 0.3% to 2.3%. Higher measurements of organic matter coincide with higher amounts of finer sediments, both of which occurred during the summer.

During the 2001-2002 reporting period, site C9 exhibited similar sediment composition patterns as the 2003 reporting period.

Site P8: Sediment Composition

Sand dominated the sediment at site P8 for most of 2003, with a pulse of finer sediments appearing every few months (Figure 6-9). The organic matter had several peaks throughout the year, each coinciding with an influx of finer sediments.

During the 2001-2002 reporting period, site P8 exhibited a sediment composition different from the current reporting period. Finer sediments were the dominant sediment type with pulses of sand appearing every few months.

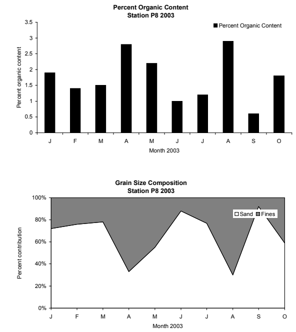


Figure 6-9 Sediment organic content and grain size at Station P8 during 2003

Site D28A: Sediment Composition

Finer sediment usually dominated sediment at D28A, with the exception of the winter months (Figure 6-10). Higher percentages of organic matter occurred during the months with the highest percentages of fines.

During the 2001-2002 reporting period, this site exhibited similar sediment composition patterns as the 2003 reporting period.

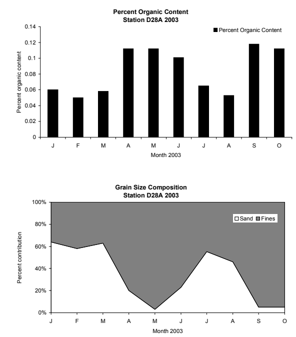


Figure 6-10 Sediment organic content and grain size at Station D28A during 2003

Site D16: Sediment Composition

Sediment characteristics at this site were very dynamic during 2003 (Figure 6-11). Consequently, the percentage of organic matter changed every few months. The higher percentages of organic matter coincided with the higher percentages of finer sediments.

During the 2001-2002 reporting period, site D16 was dominated by fines, with the exception of the spring and fall, when sand dominated the sediment composition at this site.

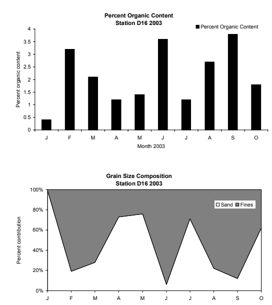


Figure 6-11 Sediment organic content and grain size at Station D16 during 2003

Site D24: Sediment Composition

Sand dominated the sediment at D24, except for one peak of finer sediments in January (Figure 6-12). The percent of organic matter at this site remained fairly stable during 2003 (ranging between 0.8% and 2.3%).

During the 2001-2002 reporting period, this site exhibited similar sediment composition patterns as the 2003 reporting period.

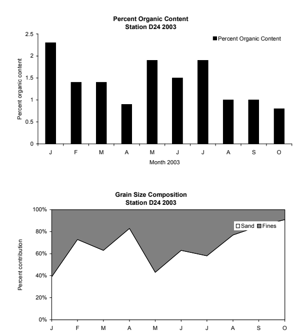


Figure 6-12 Sediment organic content and grain size at Station D24 during 2003

Site D4: Sediment Composition

Sand dominated the sediment at D4 during 2003, with the exception of January and May (Figure 6-13). The percent of organic matter at this site was high for most of the year, except in cases where the percent of fines increased.

During the 2001-2002 reporting period, this site was dominated by finer sediments from January to July 2001. From June 2001 to December 2002 the sediment composition was dominated by sand.

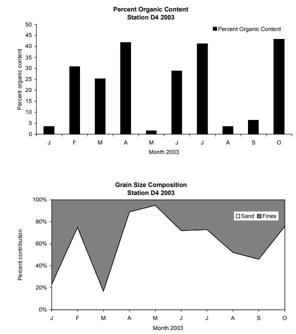


Figure 6-13 Sediment organic content and grain size at Station D4 during 2003

Site D6: Sediment Composition

Finer sediments were the dominant sediment at D6 (Figure 6-14). Organic matter at this site was stable during 2003 (average 4.3%).

During the 2001-2002 reporting period, this site exhibited similar sediment composition patterns as the 2003 reporting period.

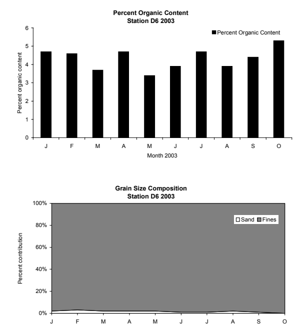


Figure 6-14 Sediment organic content and grain size at Station D6 during 2003

Site D7: Sediment Composition

Finer sediments were the dominant type at D7 (Figure 6-15). The organic matter at this site was stable throughout the study period (average 3.9%).

During the 2001-2002 reporting period, this site exhibited similar sediment composition patterns as the 2003 reporting period.

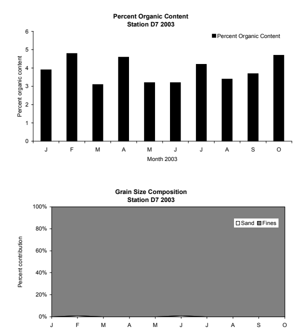


Figure 6-15 Sediment organic content and grain size at Station D7 during 2003

Site D41: Sediment Composition

Finer sediments usually dominated the sediment at D41 with the exception of two spikes during March and June, when sand was the dominant sediment type (Figure 6-16). The organic matter at this site was relatively stable with lower values occurring during the spring and summer months.

During the 2001-2002 reporting period, site D41 exhibited similar sediment composition patterns as the 2003 reporting period.

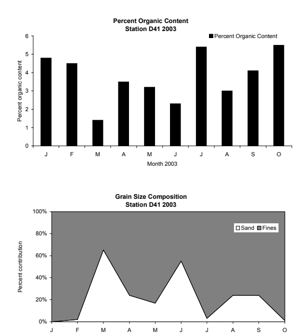


Figure 6-16 Sediment organic content and grain size at Station D41 during 2003

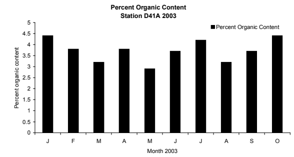
Site D41A: Sediment Composition

Finer sediments dominated the sediment at D41A (Figure 6-17). The percent organic matter at this site was stable (average 3.7%).

During the 2001-2002 reporting period, this site exhibited similar sediment composition patterns as the 2003 reporting period.

Summary

The benthic monitoring program is designed to document the distribution, diversity and abundance of benthic organisms in the upper San Francisco Estuary. The monitoring program collects a large number of organisms, but a relatively small number of species. All organisms collected during 2003 fell into eight phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, and Platyhelminthes. Of these eight phyla, Annelida, Arthropoda and Mollusca constituted 99.4% of the organisms collected during the study period. Ten species represent 90% of all organisms collected during this period. These species are: (1) the amphipods, *Americorophium stimpsoni, Americorophium spinicorne, Corophium alienense, Monocorophium acherusicum*, *Gammarus daiberi* and *Ampelisca abdita*; (2) the cumacean, *Nippoleucon hinumensis*; (3) the aquatic oligochaete, *Varichaetadrilus angustipenis*; and (4) the Asian clams, *Potamocorbula amurensis* and *Corbicula fluminea*.



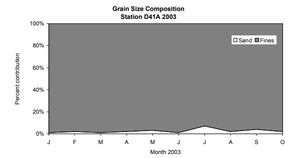


Figure 6-17 Sediment organic content and grain size at Station D41A during 2003

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[APHA] American Public Health Association, American Waterworks, and Water Environmental Federation. 1998. *Standard Methods for the Examination of Water and Wastewater.* 20th ed. Washington, D.C.: American Public Health Association, 10.60-10.74.

[ASTMa] American Society of Testing and Materials, 2000. *Soil and Rock (I): D420 - D5779,* Vol. 04.08: protocol D422

[ASTMb] American Society of Testing and Materials, 2000. *Soil and Rock (I): D420 - D5779,* Vol. 04.08: ASTM protocol D2974 method C.

[DWR] California Department of Water Resources, 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1996.*

Hymanson, Z., D. Mayer, J. Steinbeck, 1994. Long-Term Trends in Benthos Abundance and Persistence in the Upper Sacramento-San Joaquin Estuary. Summary Report: 1980-1990. *Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 38*. California Department of Water Resources, Sacramento California.

Markmann, C, 1986. *Benthic Monitoring in the Sacramento-San Joaquin Delta. Results from 1975 through 1981. Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Technical Report 12*. California Department of Water Resources, Sacramento California.

[SWRCB] State Water Resources Control Board. 1999. *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh*. Sacramento, California.

Figure 6-1 Location of 10 Environmental Monitoring Program benthic sampling sites

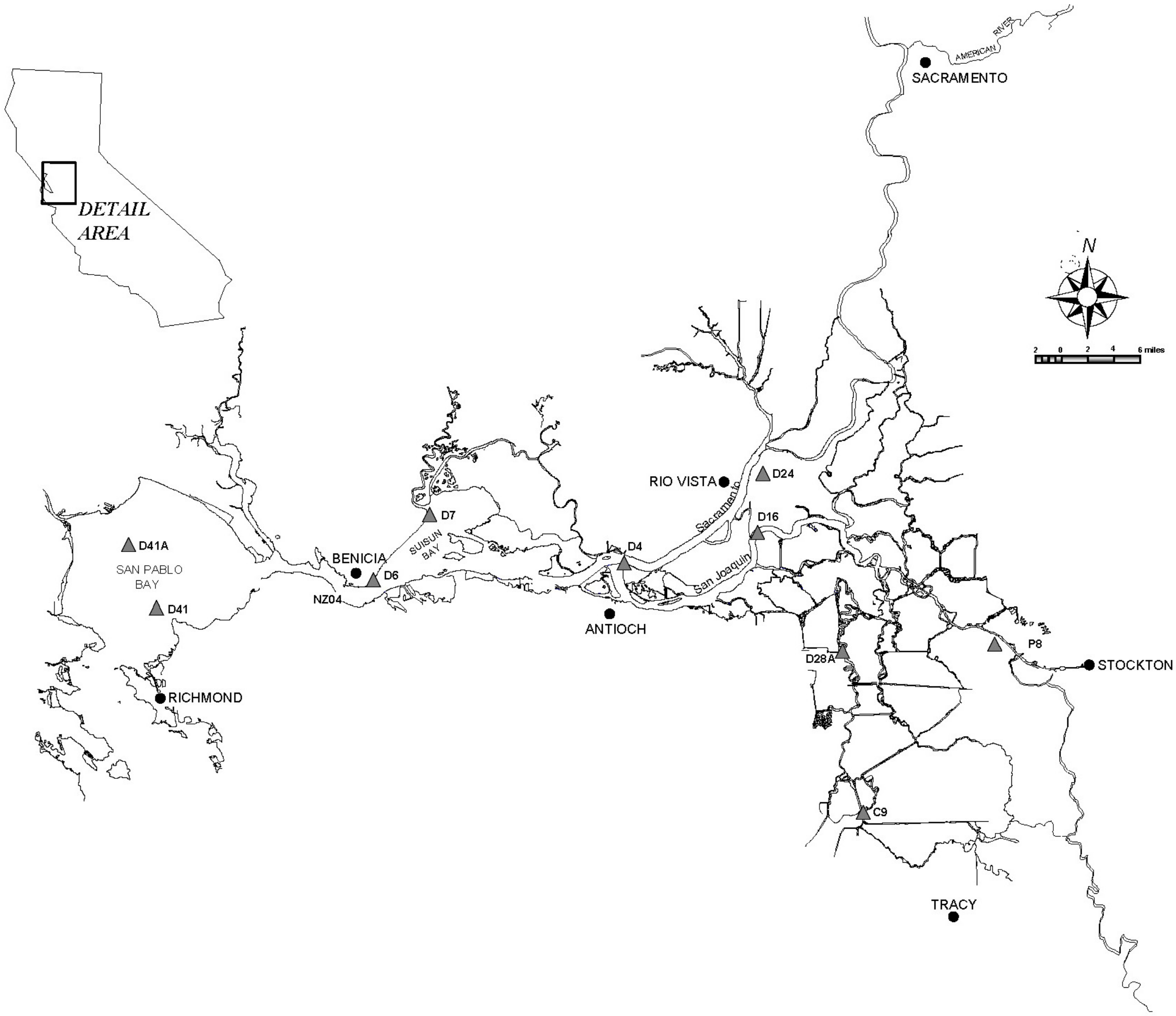


Figure 6-2 Total contribution by phyla for all stations during 2003

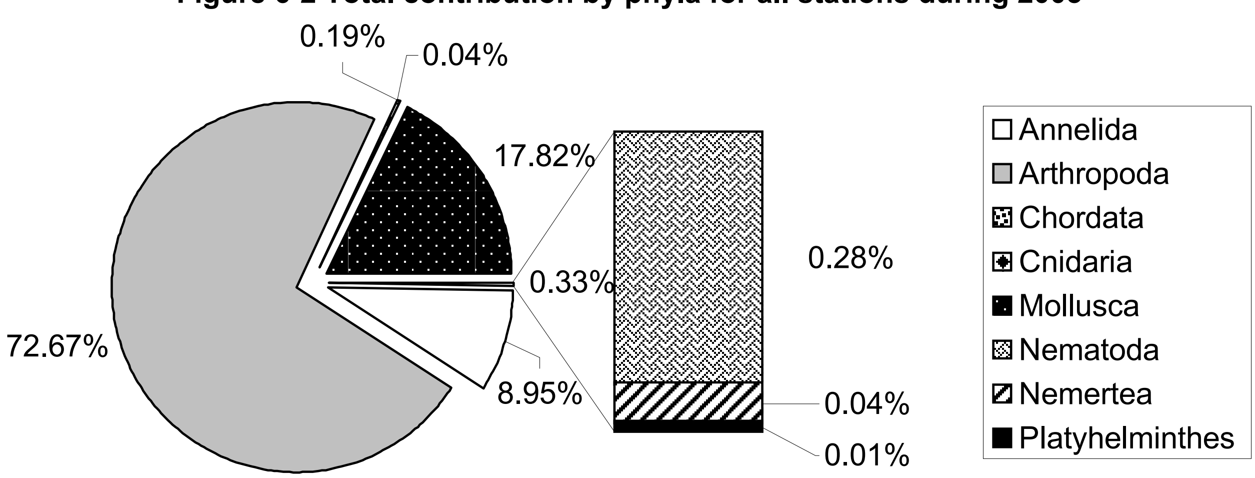
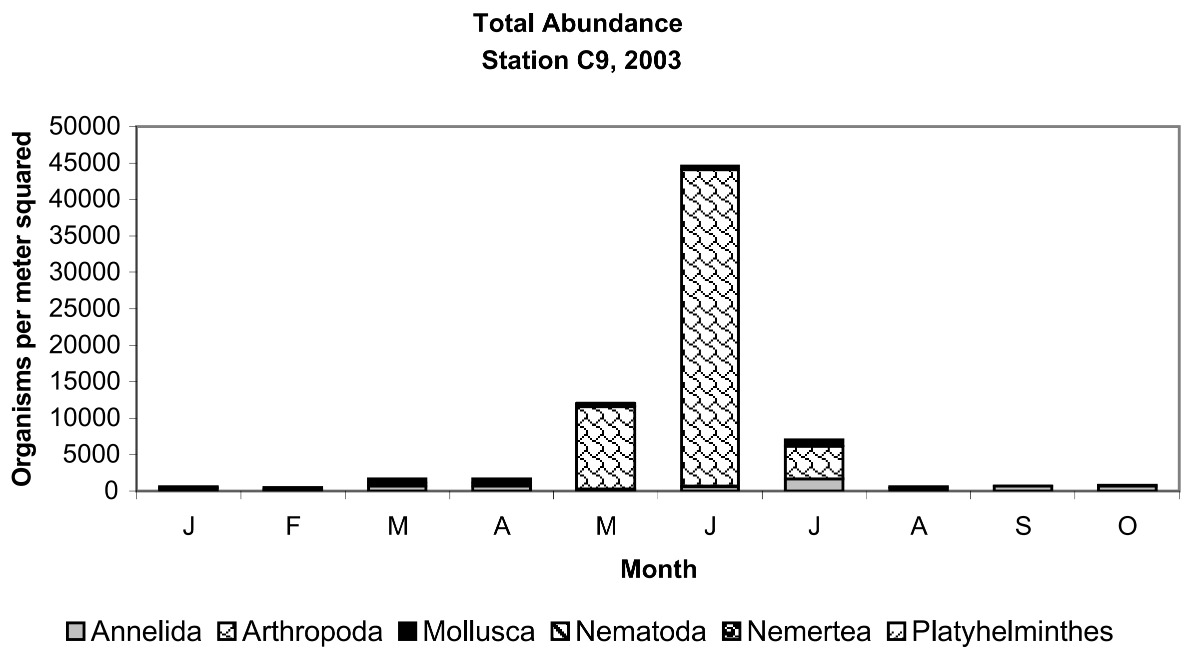


Figure 6-3 Benthic abundance at stations C9 and P8, 2003



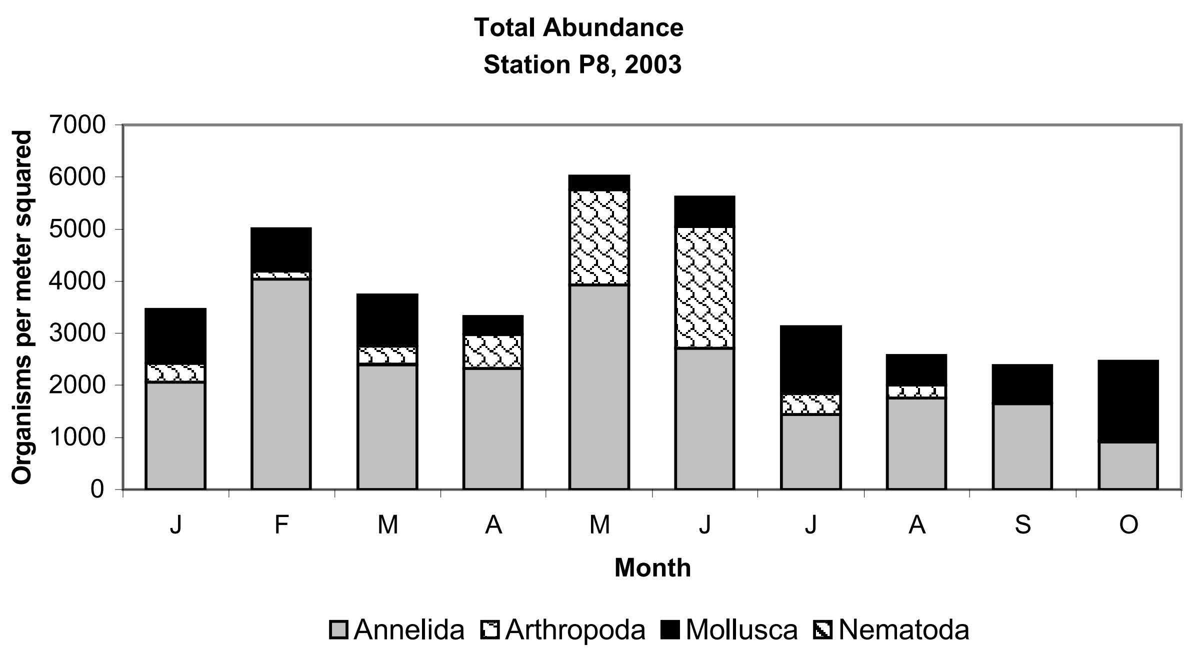
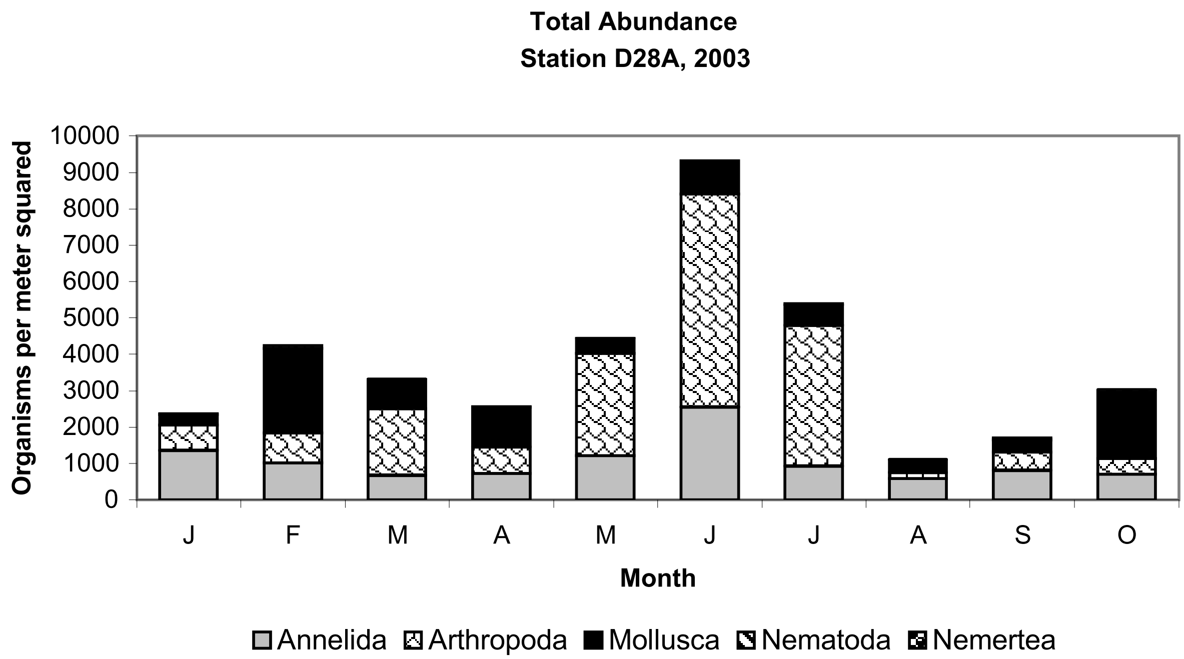


Figure 6-4 Benthic abundance at stations D28A and D16, 2003



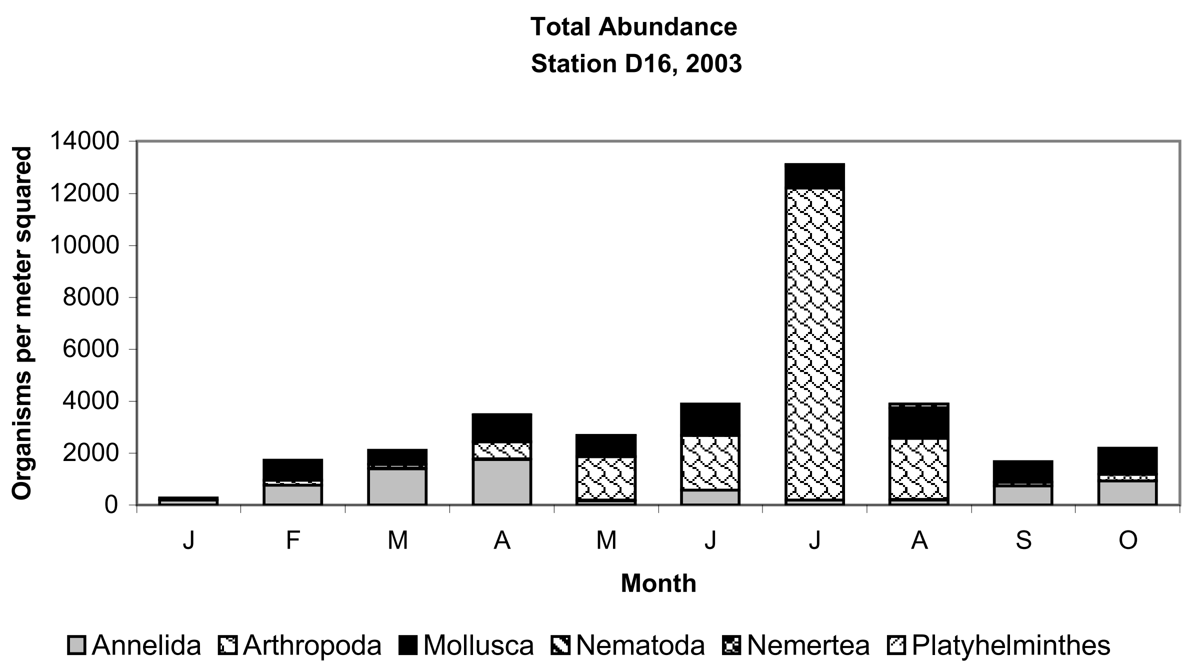
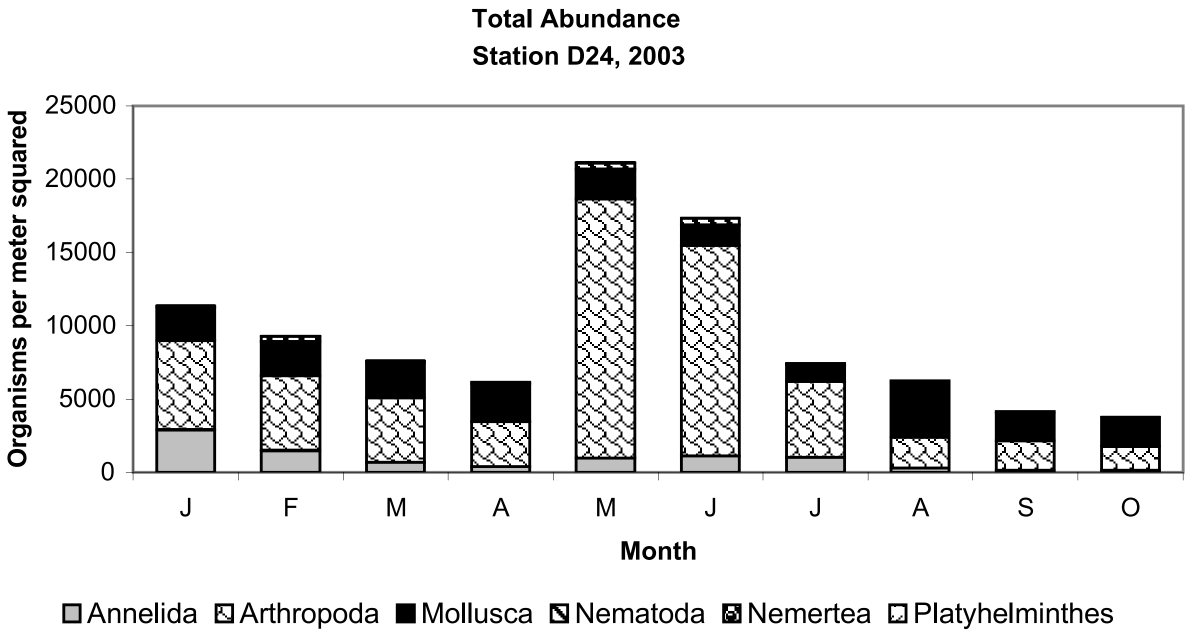


Figure 6-5 Benthic abundance at stations D24 and D4, 2003



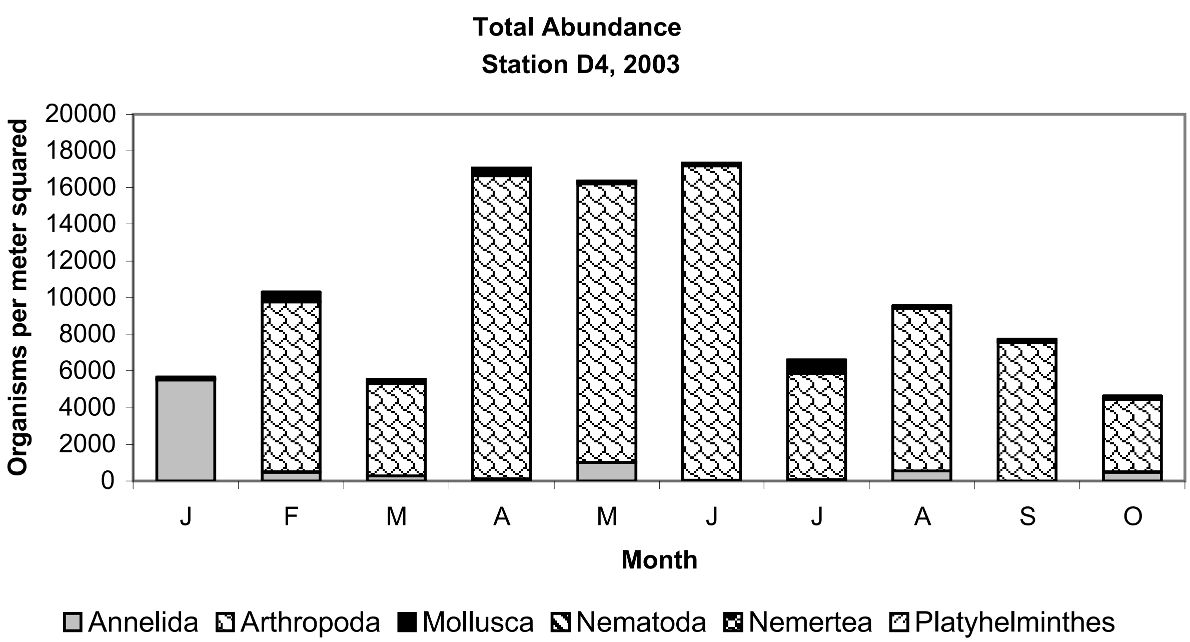
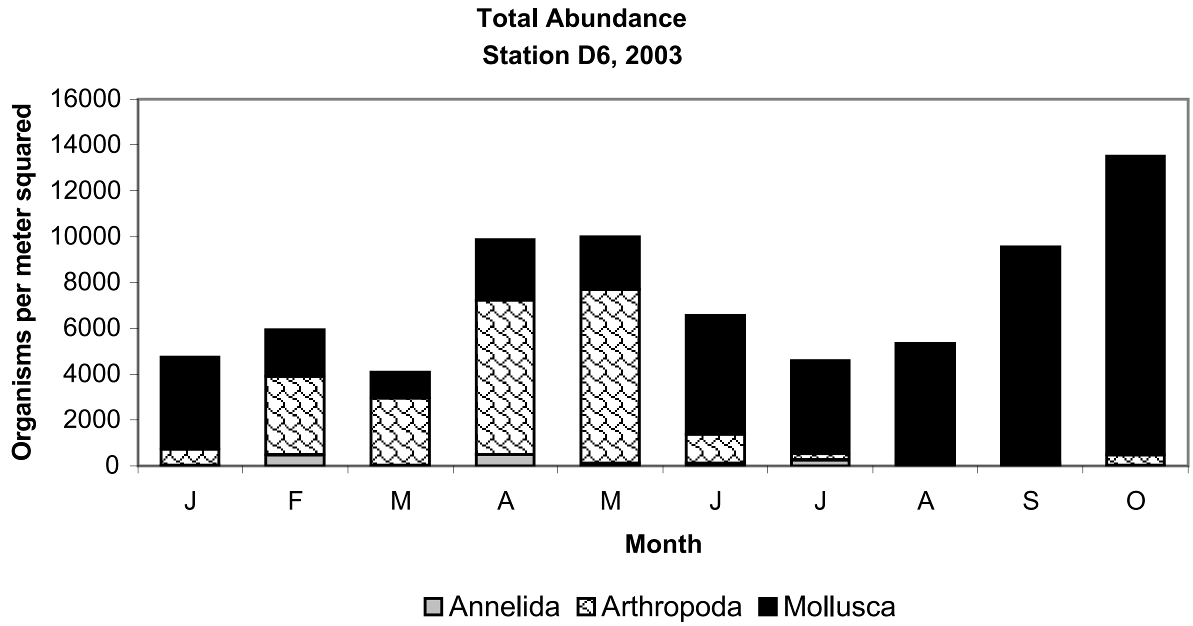


Figure 6-6 Benthic abundance at stations D6 and D7, 2003



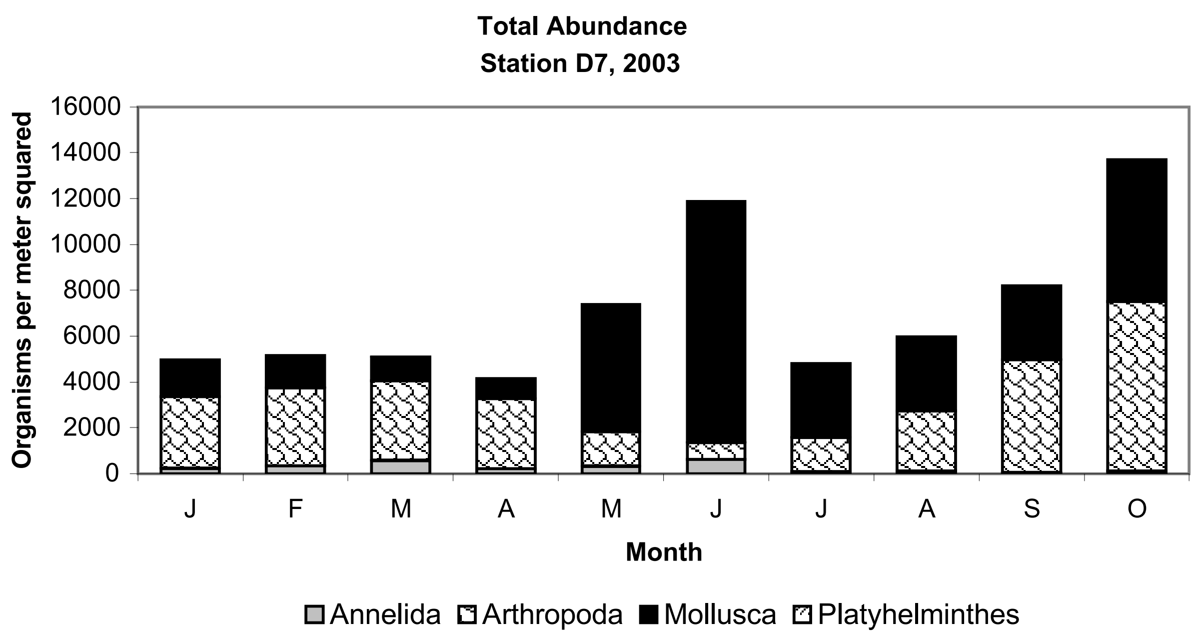
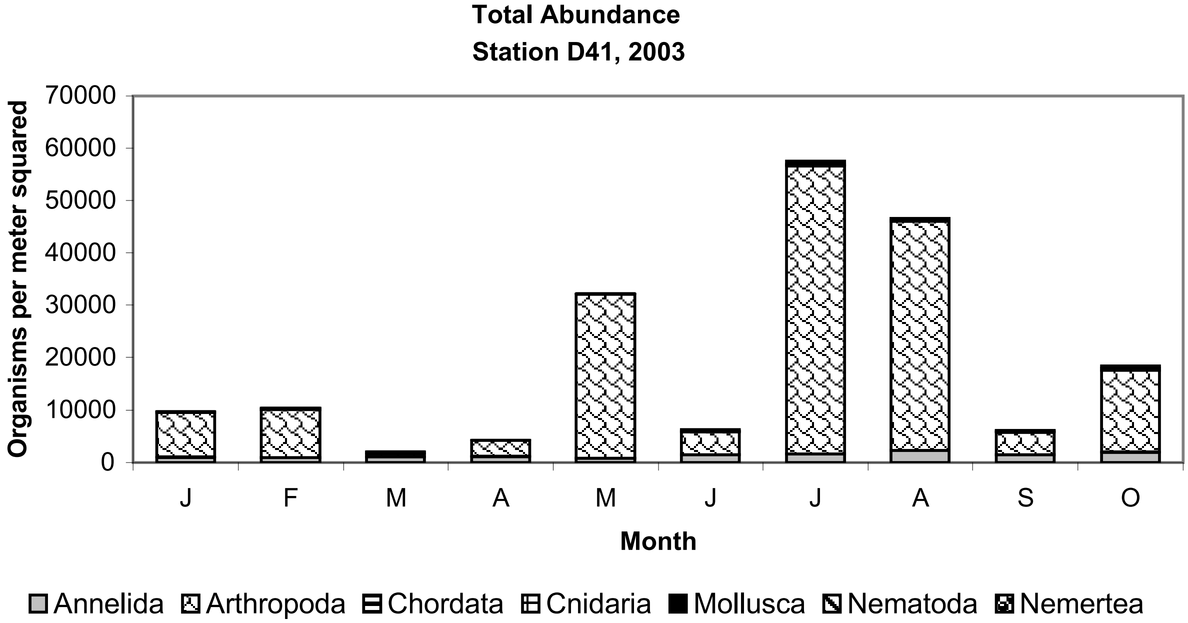


Figure 6-7 Benthic abundance at stations D41 and D41A, 2003



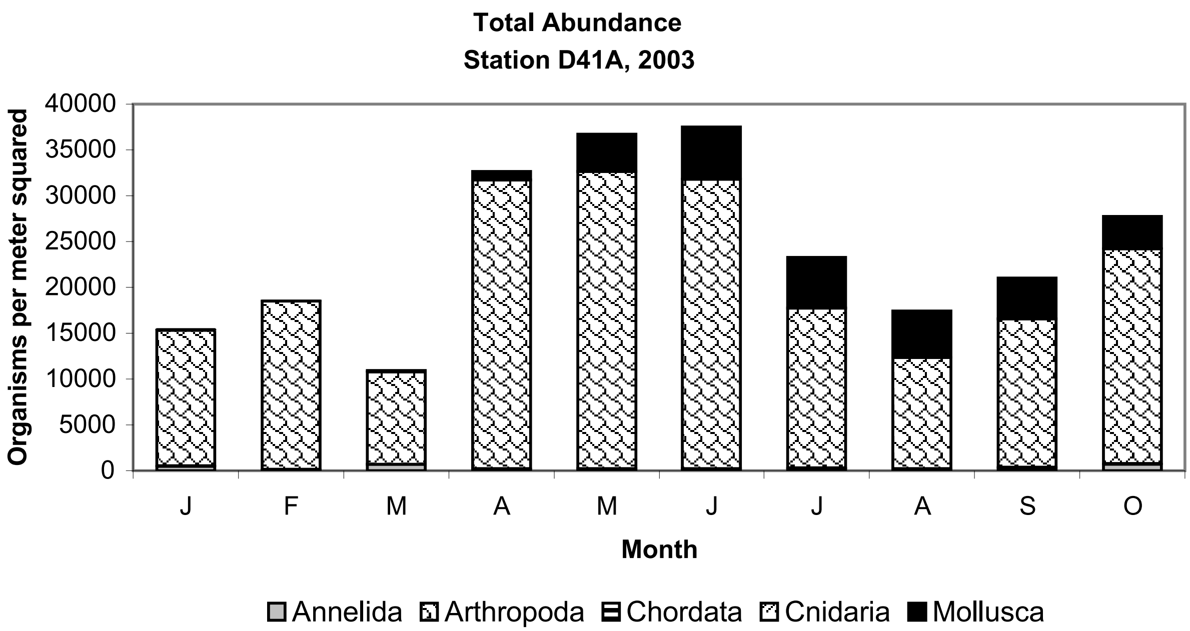
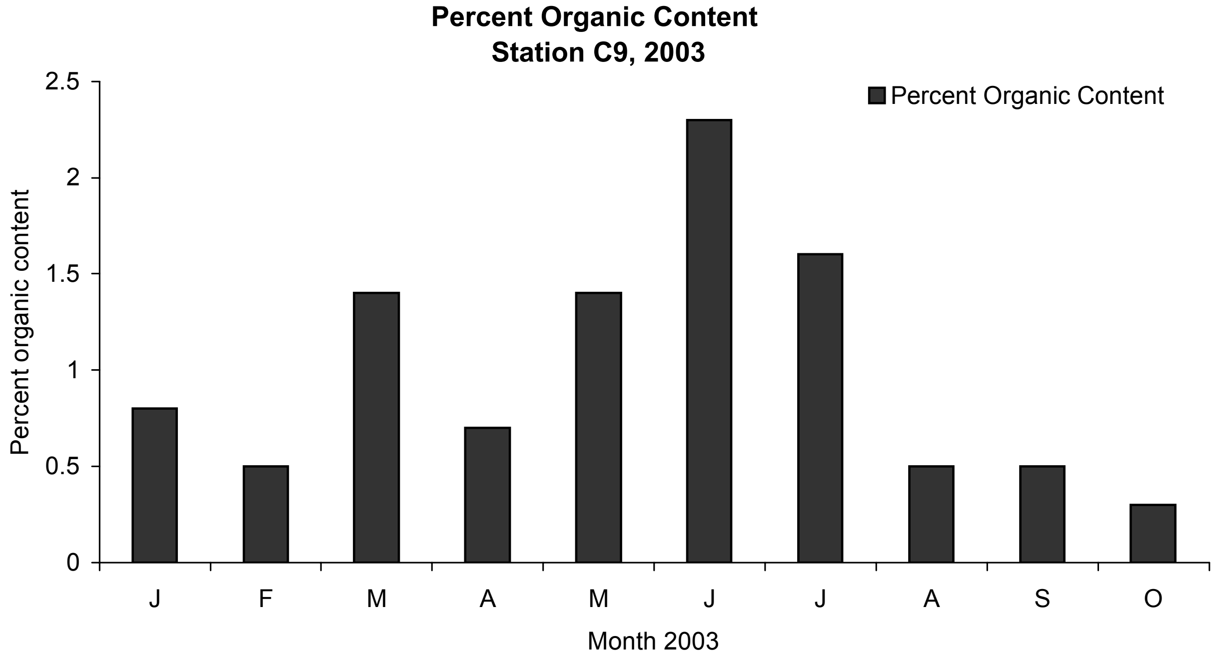


Figure 6-8 Sediment organic content and grain size at Station C9 during 2003



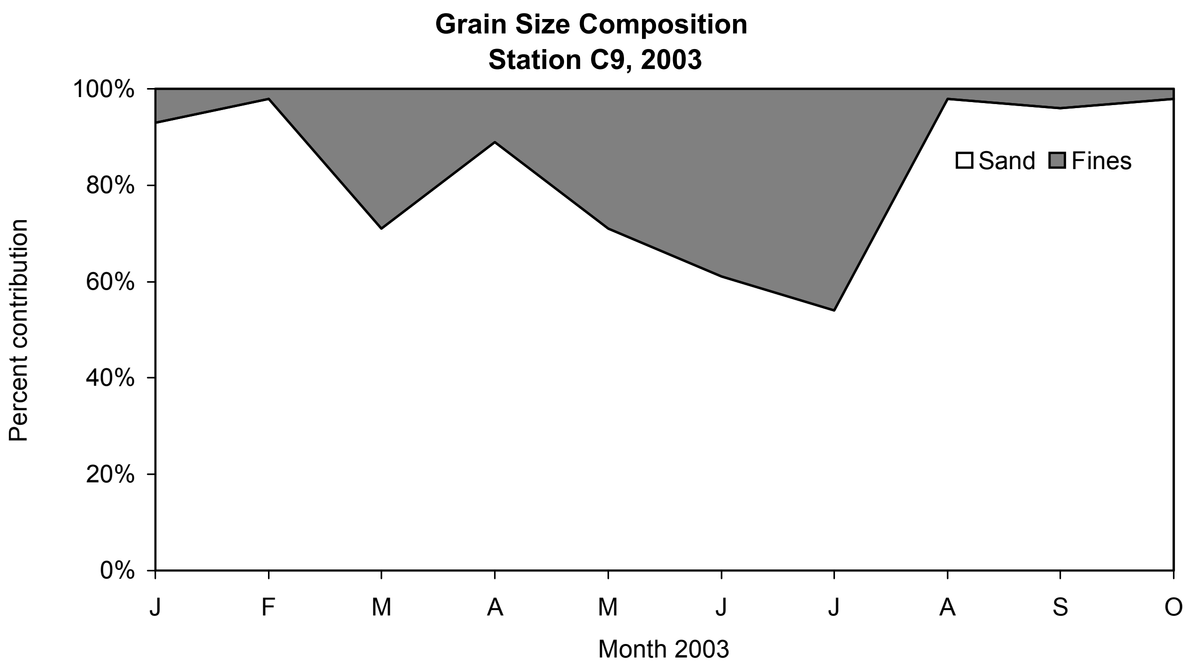
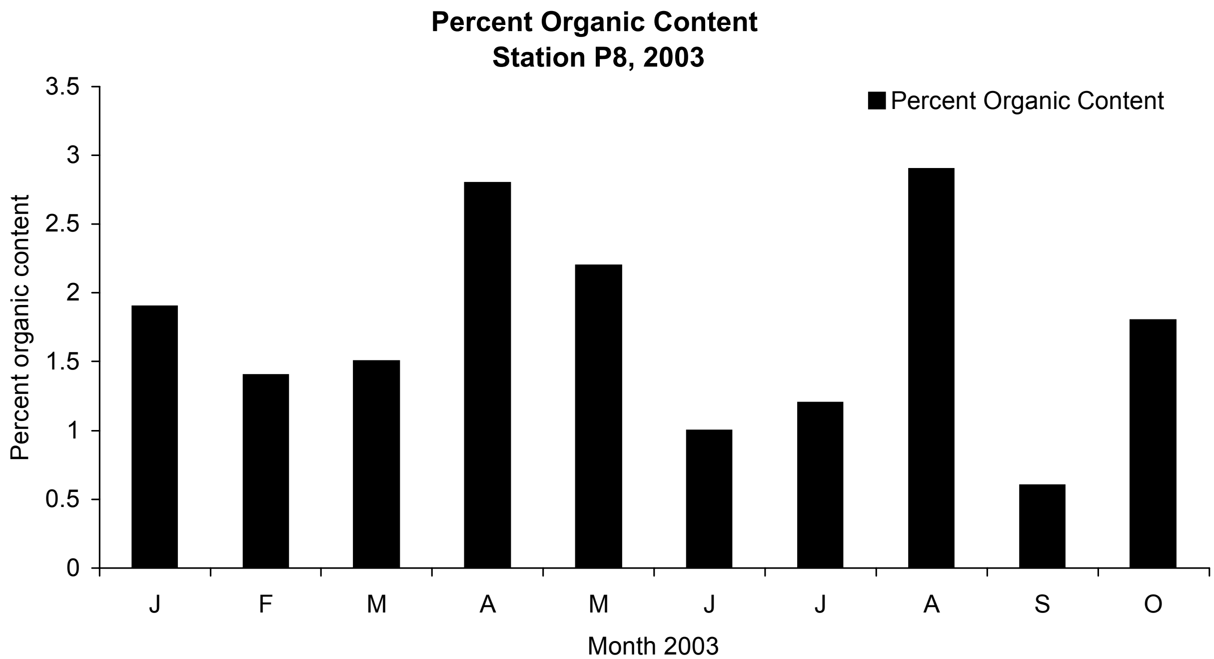


Figure 6-9 Sediment organic content and grain size at Station P8 during 2003



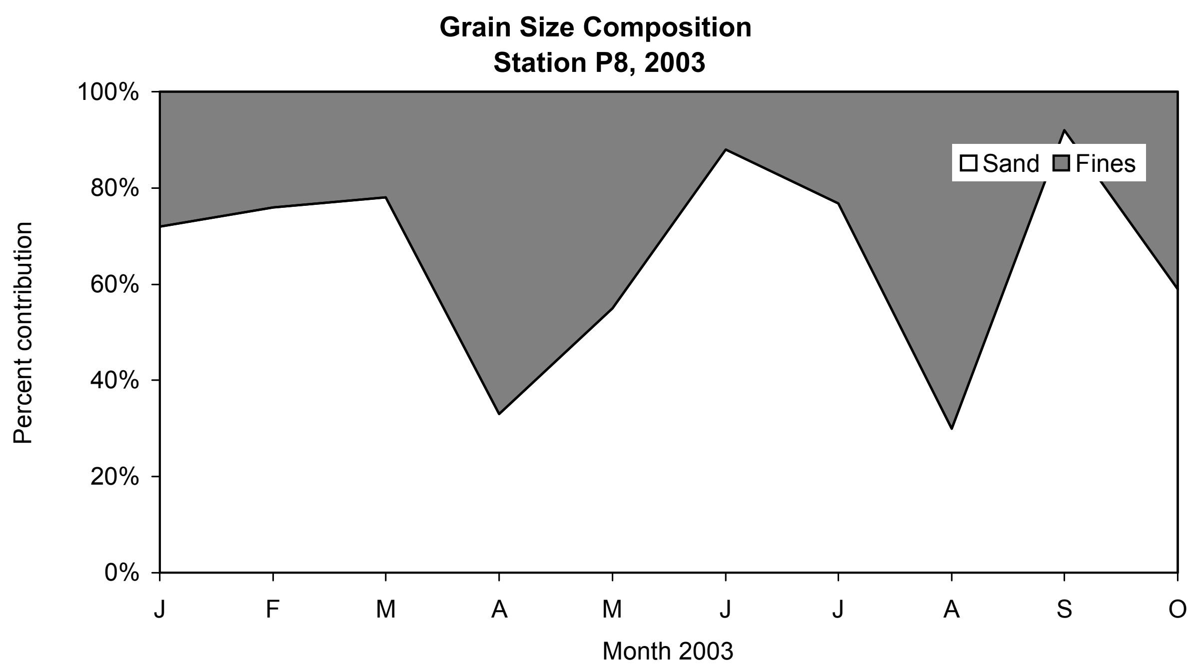
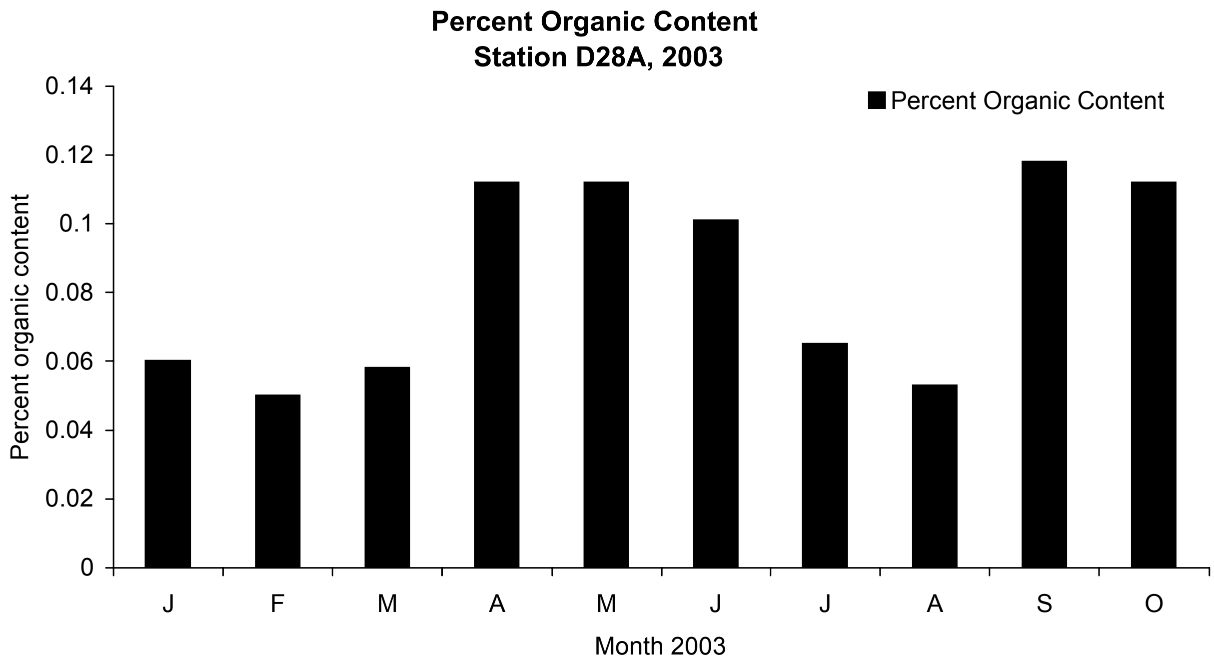


Figure 6-10 Sediment organic content and grain size at Station D28A during 2003



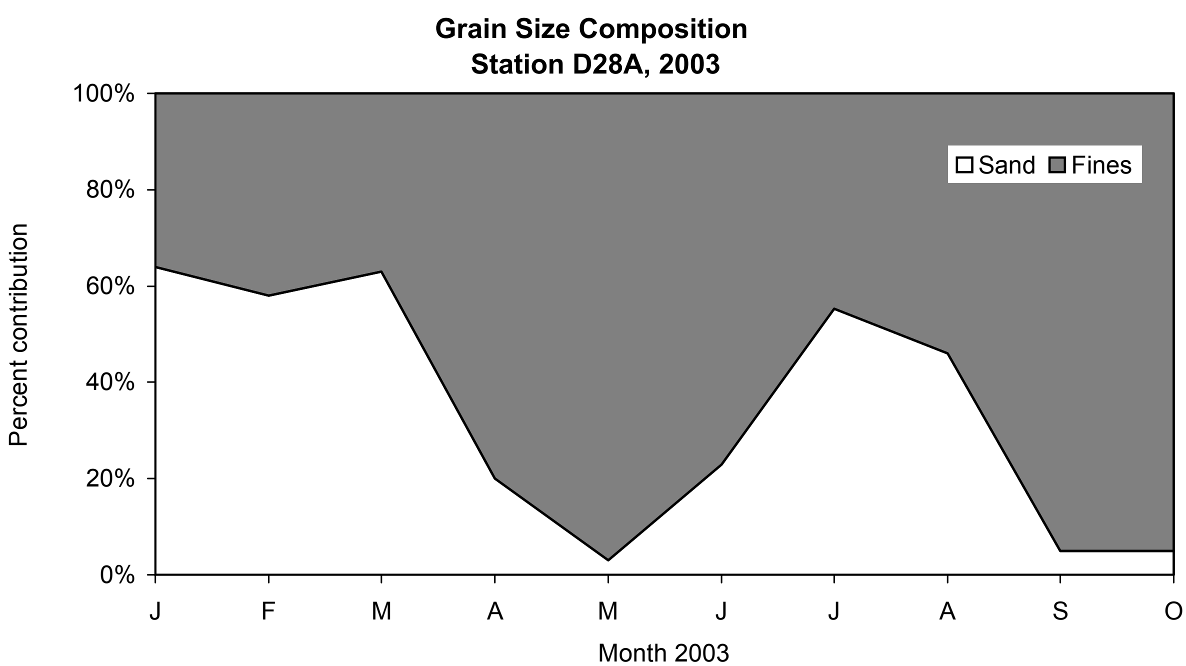
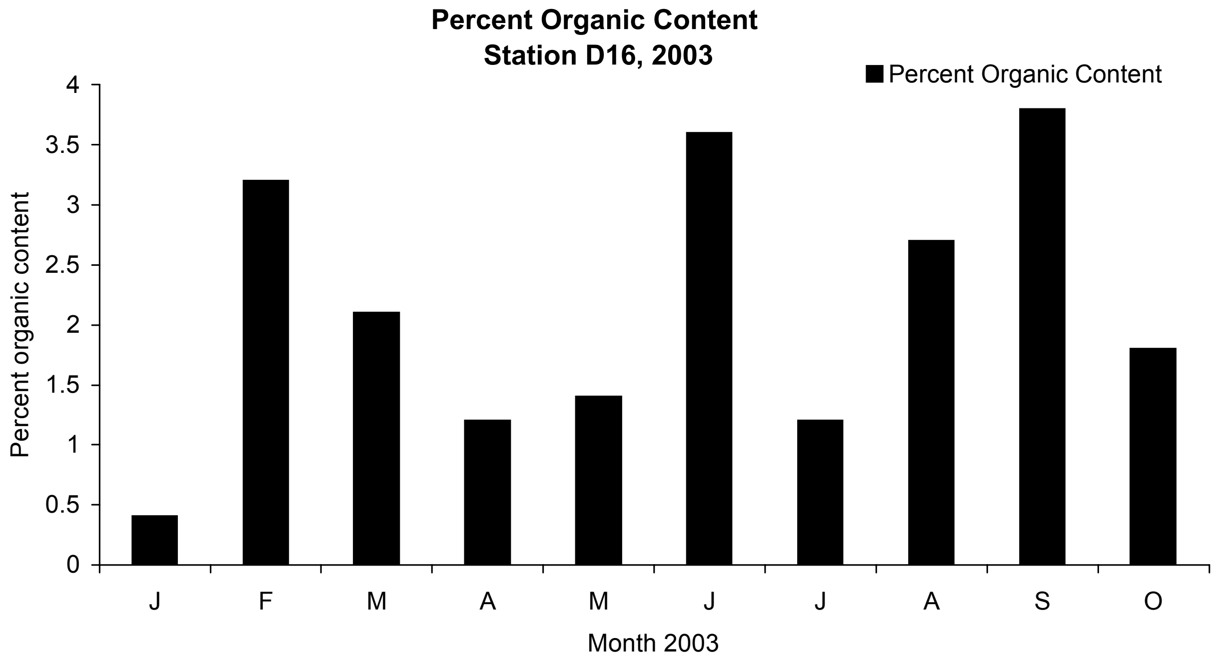


Figure 6-11 Sediment organic content and grain size at Station D16 during 2003



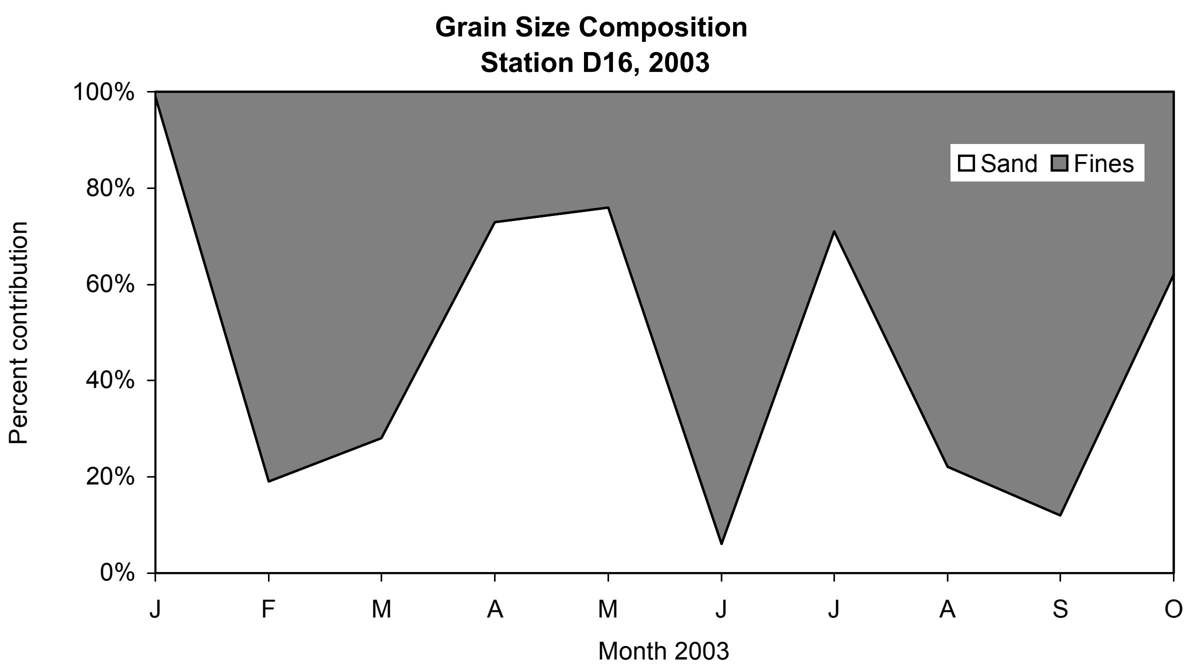
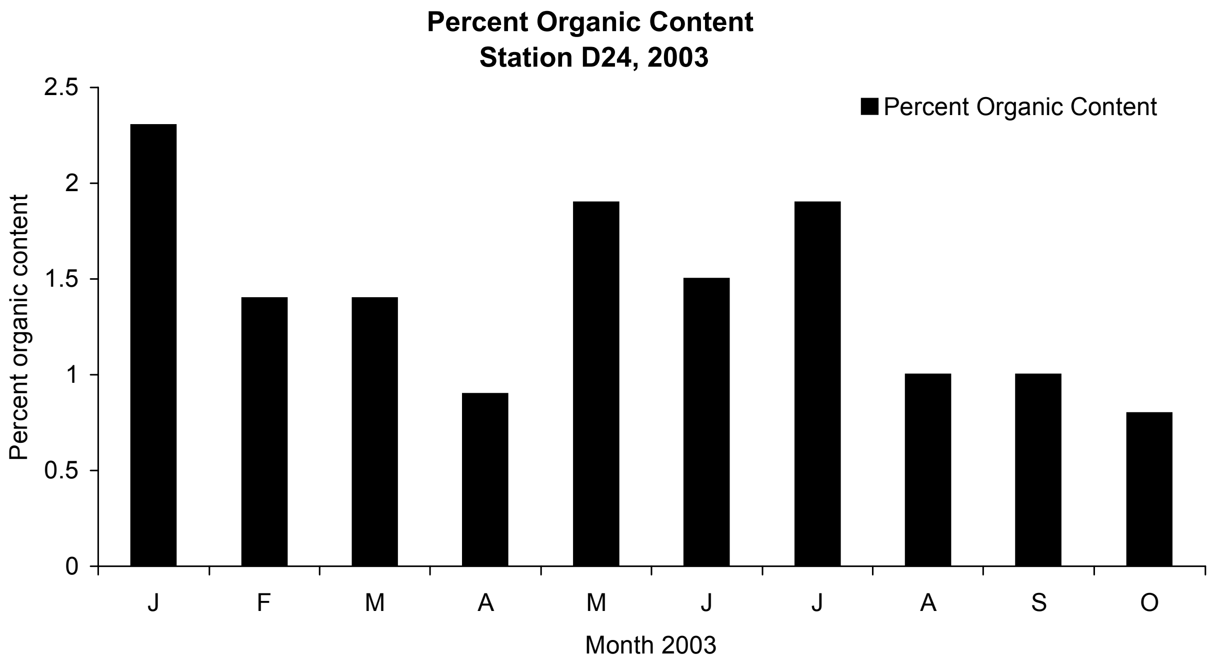


Figure 6-12 Sediment organic content and grain size at Station D24 during 2003



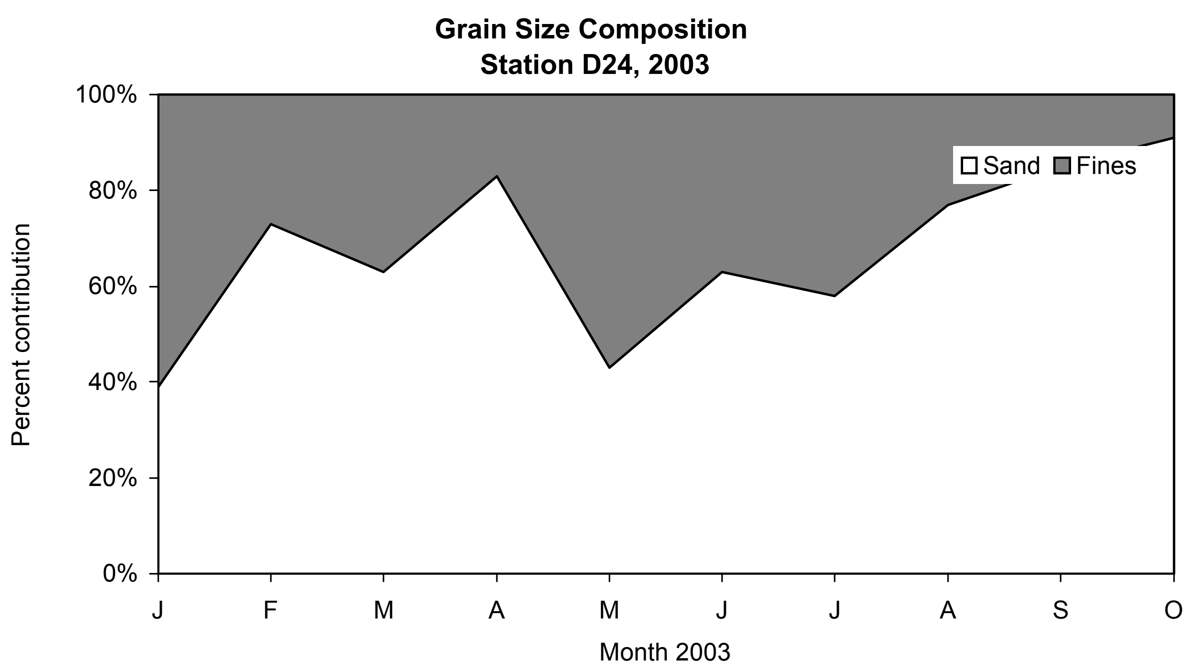
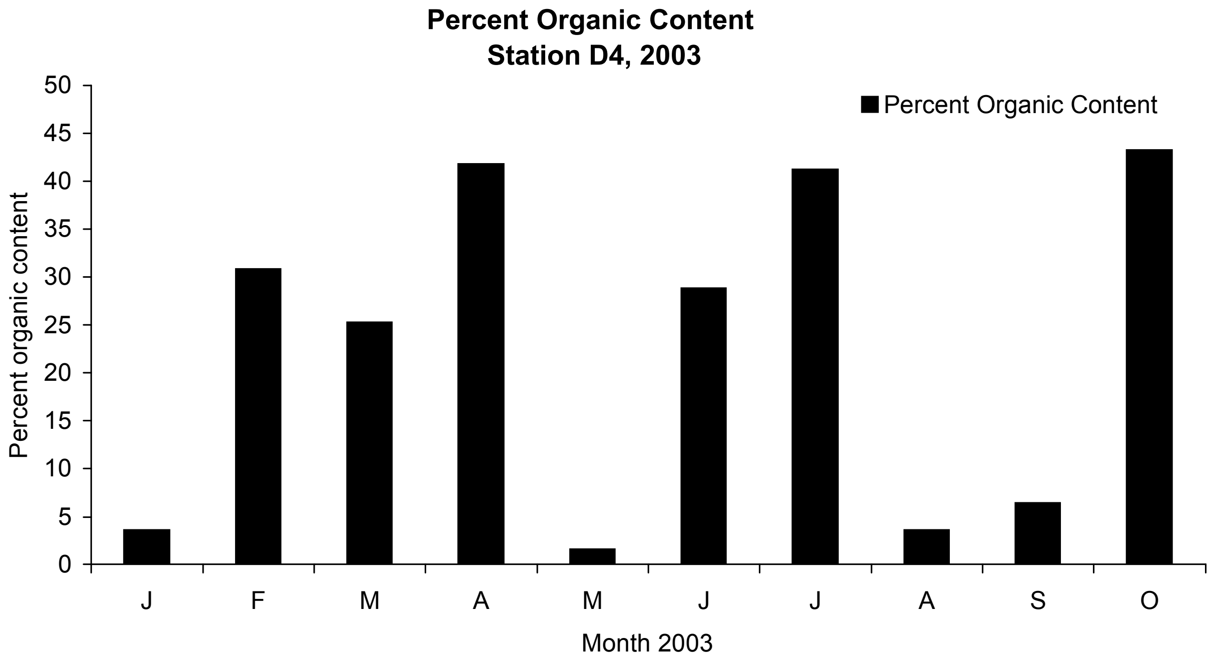


Figure 6-13 Sediment organic content and grain size at Station D4 during 2003



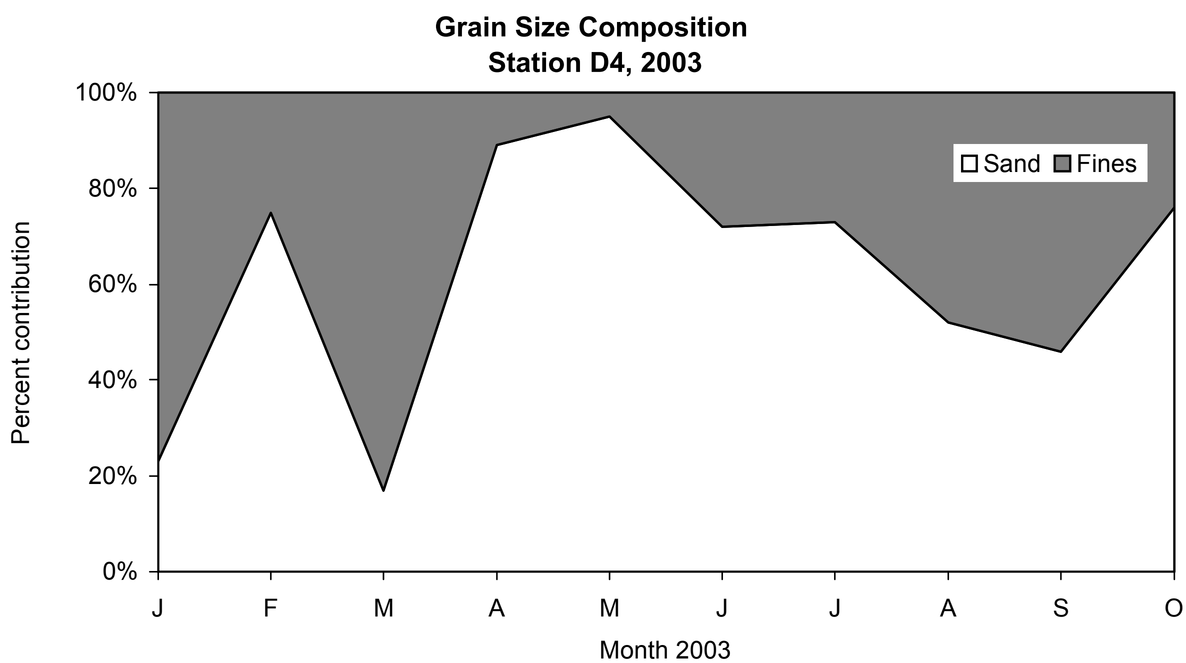
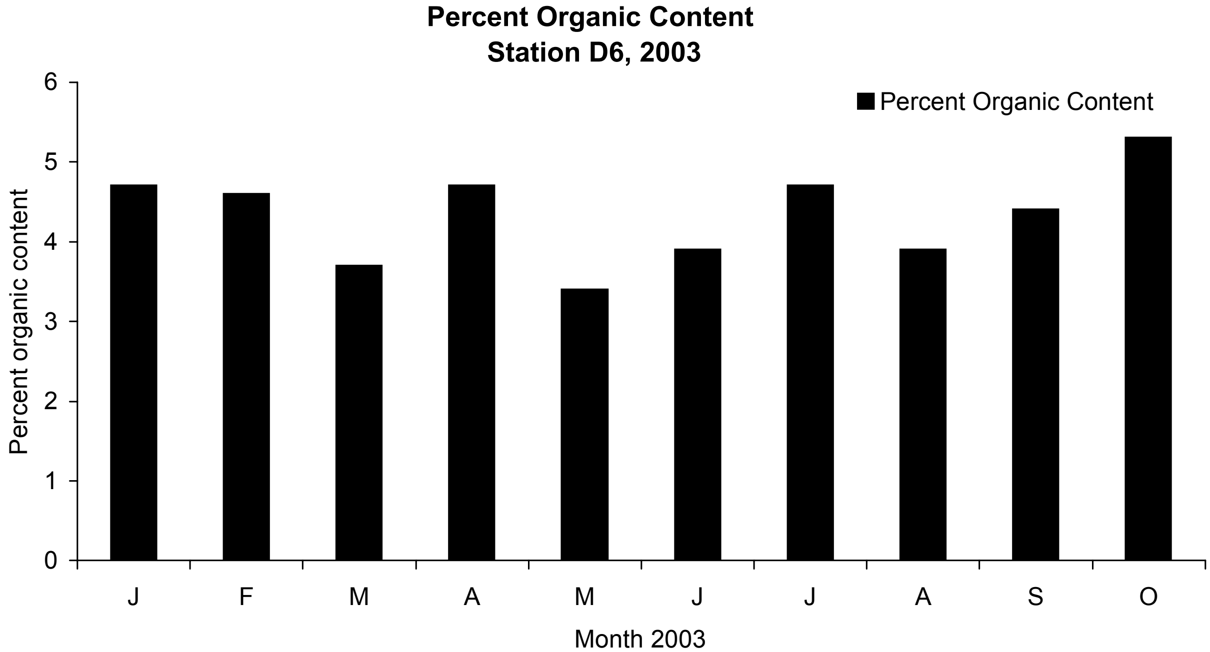


Figure 6-14 Sediment organic content and grain size at Station D6 during 2003



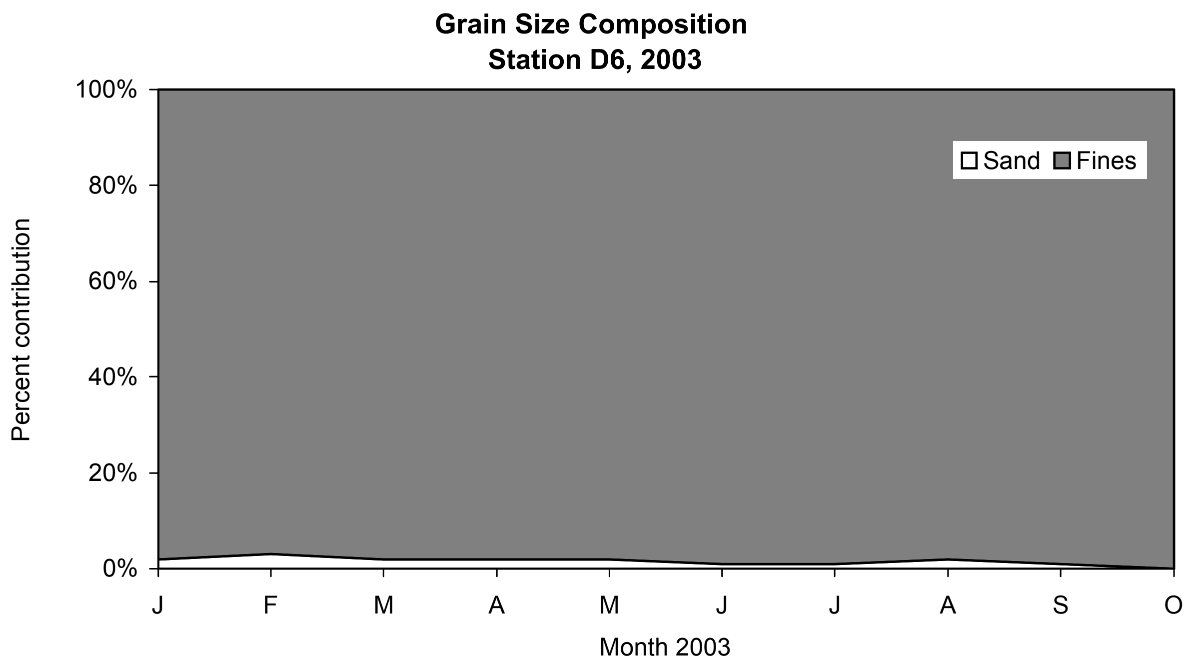
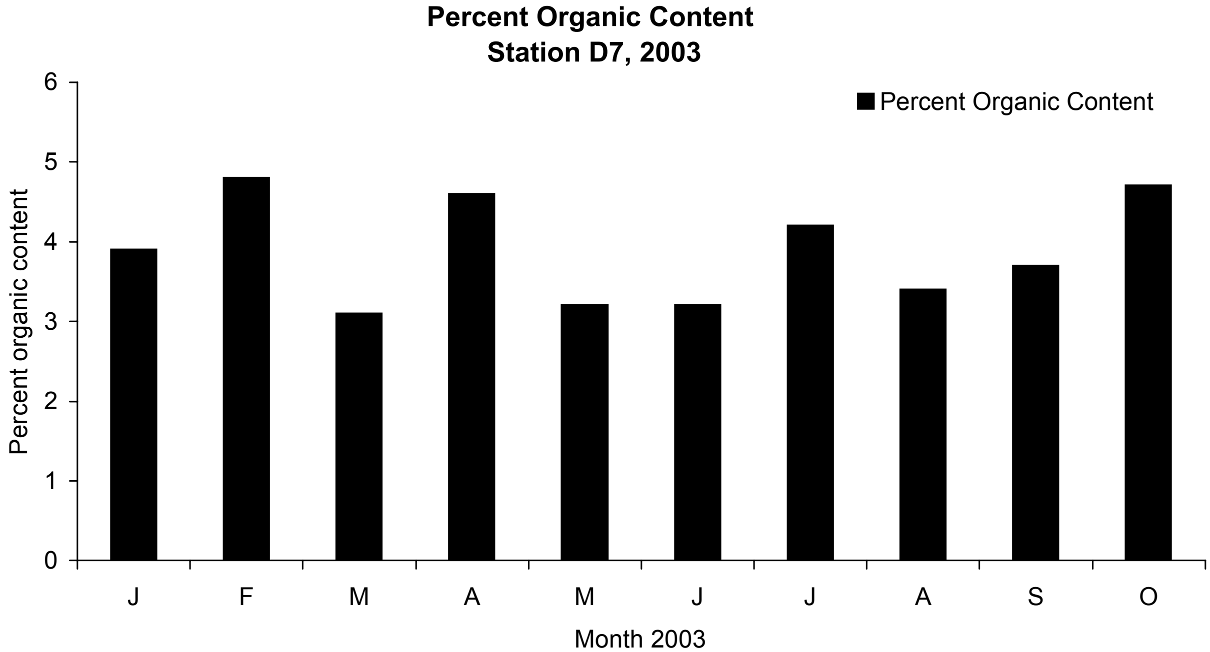


Figure 6-15 Sediment organic content and grain size at Station D7 during 2003



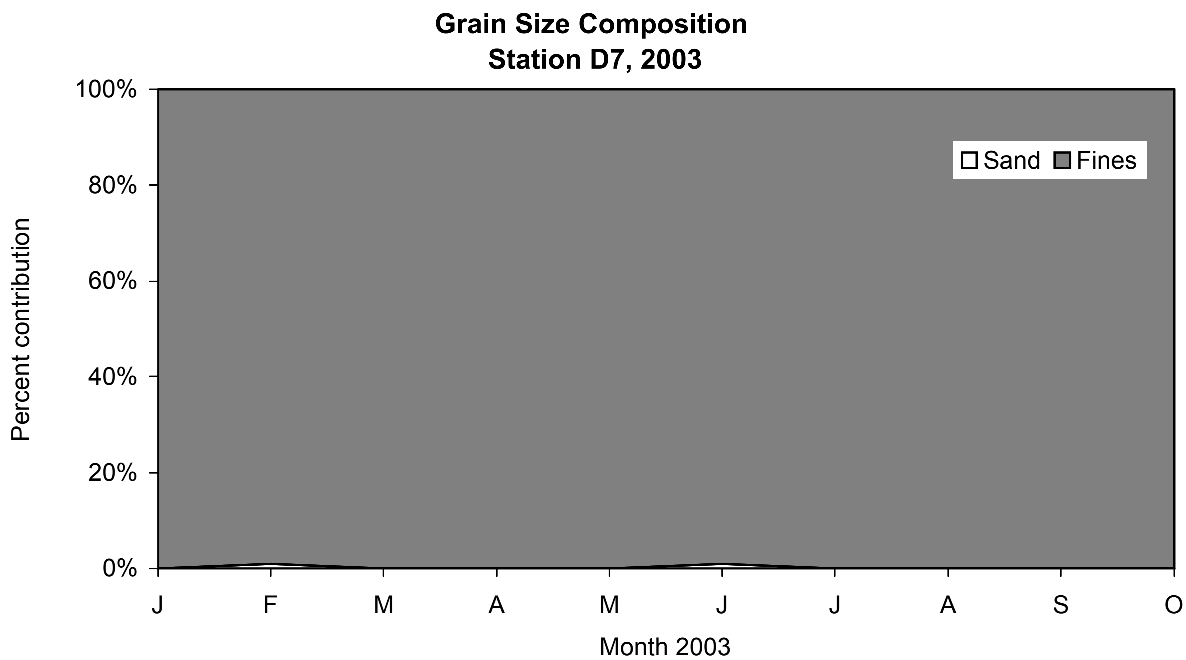
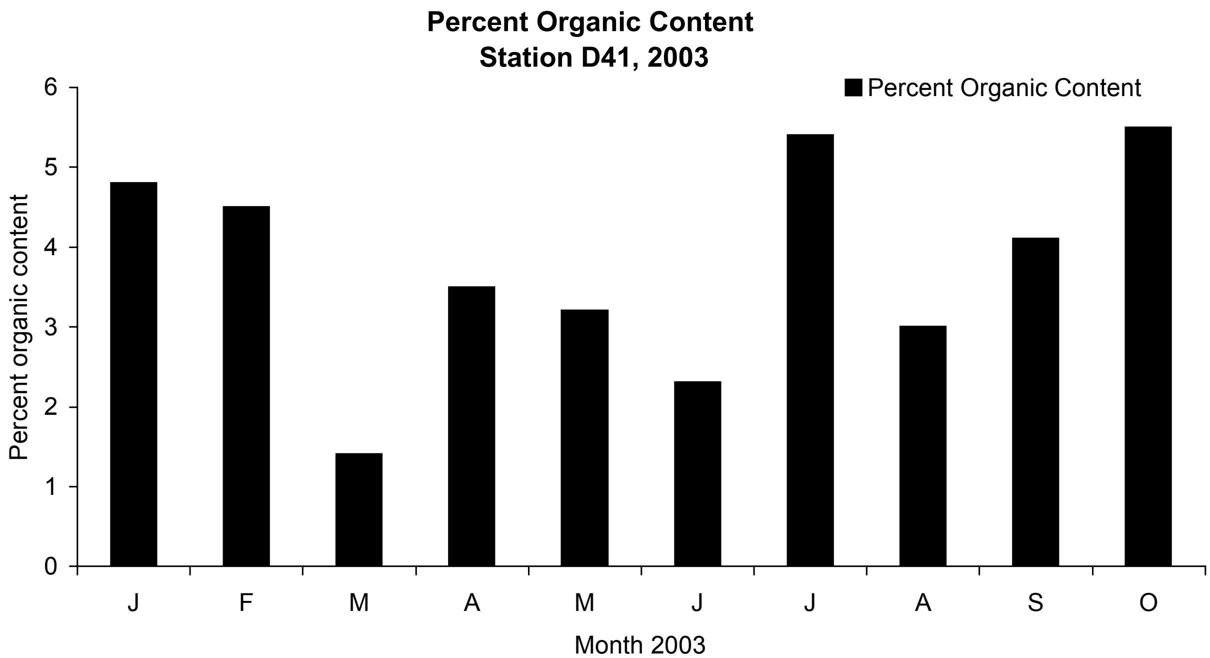


Figure 6-16 Sediment organic content and grain size at Station D41 during 2003



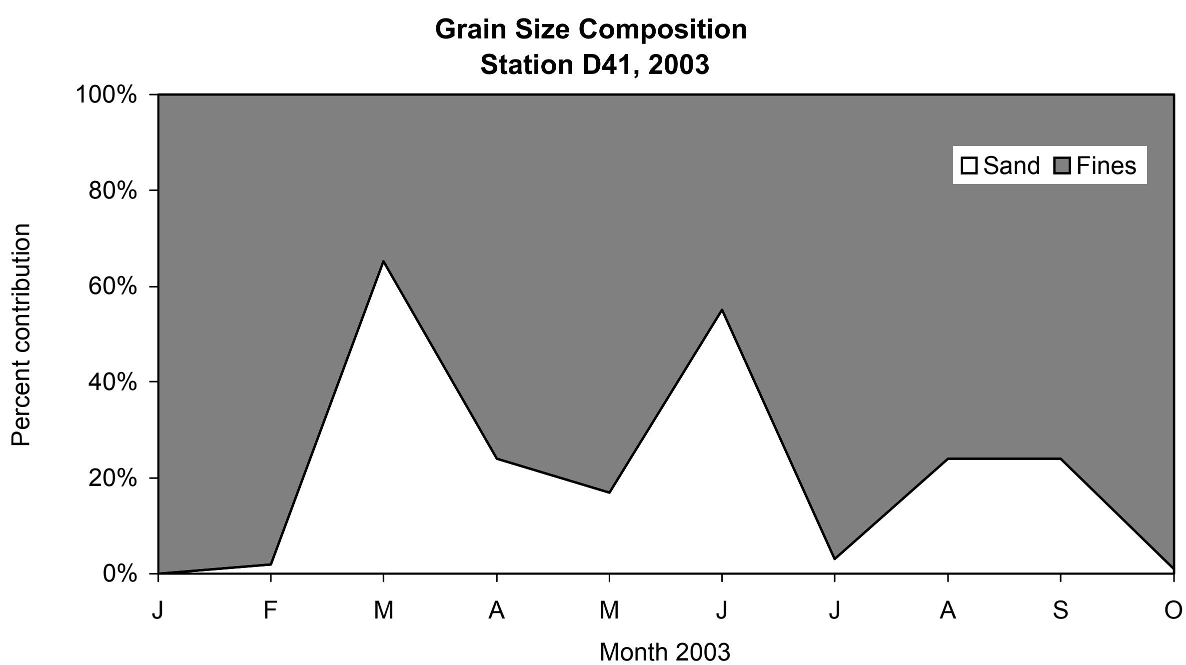
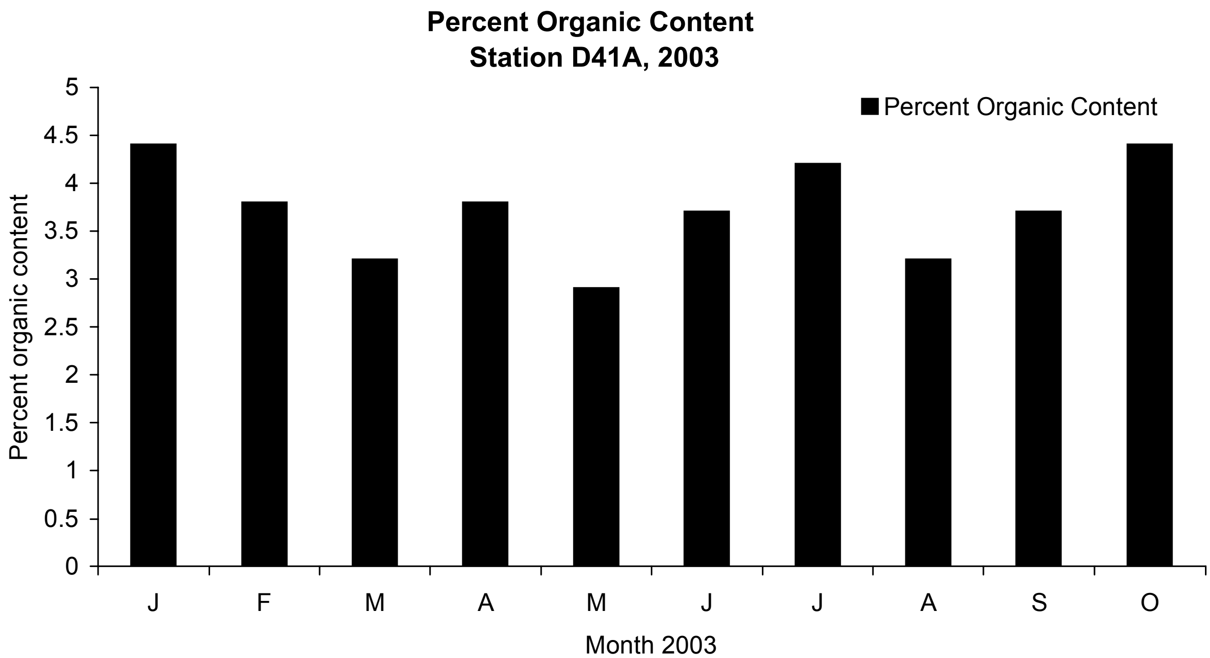


Figure 6-17 Sediment organic content and grain size at Station D41A during 2003



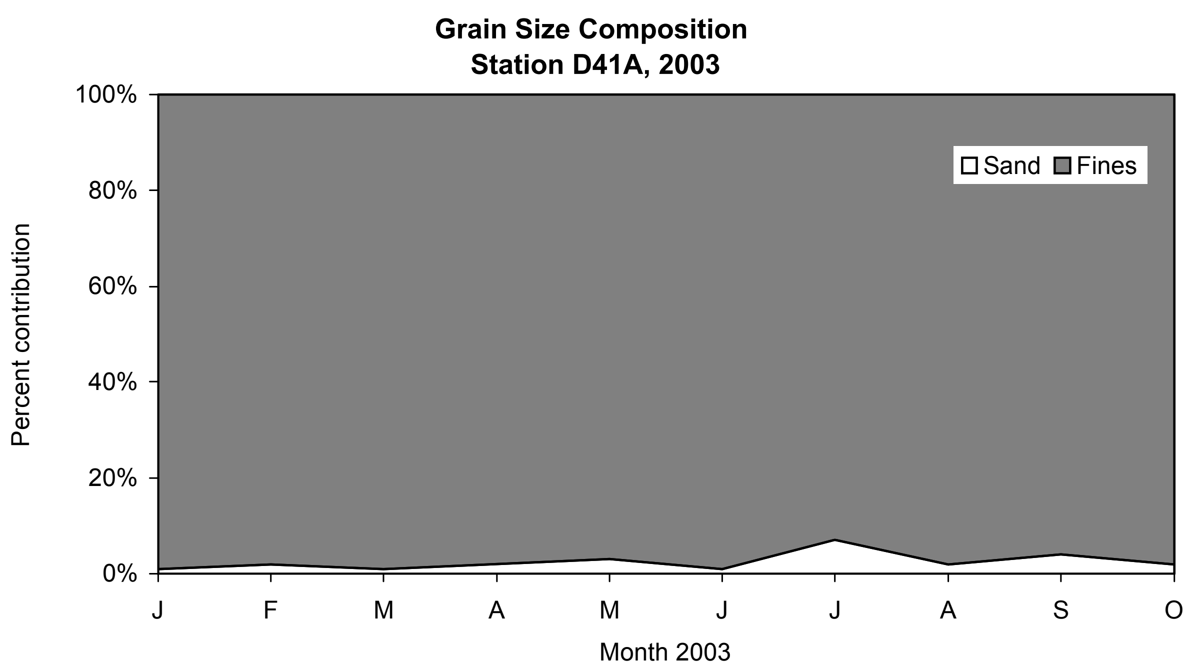


Table 6-1 Macrobenthic monitoring station characteristics, 2003

Station Region	Latitude Longitude	Substrate Composition	Approx. Salinity Range (µS/cm)
C9 Delta-Old River	37°49'50" 121°33'09"	Consistent. Over 90% sand.	200-800
P8 Delta San Joaquin River	37°58'42" 121°22'55"	Consistent. High sand content (60%)	175-750
D28A Delta Old River	37°58'14" 121°34'19"	Mixed composition of sand and fines	200-350
D16 Delta San Joaquin River	38°05'50" 121°40'05"	Consistent. Mostly fines with some organic materials	130-500
D24 Delta Sacramento River	38°09'27" 121°41'01"	Consistent. High sand content (80%).	200-1,200
D4 Delta Sacramento River	38°03'45" 121°49'10"	Mixed composition of sand, fines, and organic materials.	130-8,000
D6 Suisun Bay	38°02'40" 122°07'00"	Fairly equal mixture of sand and fines	135-30,000
D7 Grizzly Bay	38°07'02" 122°02'19	Consistent. Mostly Fines with some organic materials.	200-20,000
D41 San Pablo Bay	38°01'50" 122°22'15"	Consistent. High content of fine material (87%)	20,000-45,000
D41A San Pablo Bay	38°03'75" 122°24'40"	Consistent. High content of fine material (90%)	30,000-44,000

Table 6-2 New species, 2003

Phylum	Genus Species	Date	Station
Annelida	*Aricidea* species *A*	February 2003	D41
Annelida	*Tharyx parva*	February 2003	D41
Annelida	*Pholoides aspera*	February 2003	D41
Arthropoda	*Tipula* species *A*	February 2003	D24
Arthropoda	*Hygrobates* species *A*	February 2003	D24
Arthropoda	*Psychoda* species *A*	March 2003	D24
Arthropoda	*Neoplasta* species *A*	March 2003	D24
Annelida	*Arcteonais lomondi*	April 2003	C9
Arthropoda	*Simulium* species *A*	May 2003	D41A
Arthropoda	*Callianassa* species *A*	May 2003	D41
Arthropoda	*Cancer magister*	May 2003	D41
Arthropoda	*Ampithoe valida*	July 2003	D41
Arthropoda	*Monocorophium uenoi*	July 2003	D41, D41A
Annelida	*Pista pacifica*	September 2003	D41
Mollusca	*Melanochlamys diomedea*	September 2003	D41
Mollusca	*Macoma* species *A*	September 2003	D41

Chapter 7 Dissolved Oxygen Monitoring in the Stockton Ship Channel

Introduction

Dissolved oxygen levels in the Stockton Ship Channel have been monitored by staff of the Bay-Delta Monitoring and Analysis Section during the late summer and fall of each year since 1968. Due to a variety of factors, dissolved oxygen levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River past Stockton.

Because low dissolved oxygen levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, California has established specific water quality objectives to protect these uses. Within the channel, two separate dissolved oxygen objectives have been established. The Central Valley Regional Water Quality Control Board has adopted a dissolved oxygen standard of 5.0 mg/L for the entire Delta throughout the year to protect all beneficial uses (CVRWQCB 1998). The State Water Resources Control Board (SWRCB) has an objective of 6.0 mg/L in the lower San Joaquin River between Stockton and Turner Cut (which includes the eastern portion of the Stockton Ship Channel). The SWRCB's objective applies from September through November to provide greater protection to migrating fall-run Chinook salmon (SWRCB 1995).

As part of a 1969 Memorandum of Understanding between the Department of Water Resources (DWR), the US Fish and Wildlife Service, the US Bureau of Reclamation, and the Department of Fish and Game (DFG), DWR has installed a rock barrier across the head of Old River during periods of projected low fall San Joaquin River outflow. This Head of Old River Barrier (Barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving dissolved oxygen concentrations within the channel. Because of bank erosion and barrier overtopping concerns, the Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

DWR completed installation of the Barrier on September 15, 2003, (the closure was fully operational by September 22) because late summer San Joaquin River flows past Vernalis were low (average September daily San Joaquin River flow past Vernalis was 1,383 cfs), and early fall flows were not projected to be sufficient to alleviate dissolved oxygen concerns in the eastern channel. Removal of the Barrier occurred between November 3 and November 13, 2003.

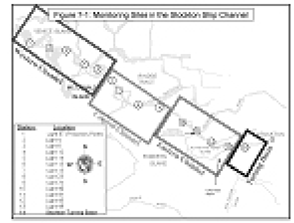


Figure 7-1 Monitoring sites in the Stockton Ship Channel

Methods

Dissolved oxygen concentrations in the Stockton Ship Channel were monitored by vessel on eight monitoring runs from August 11 to December 10, 2003[1]. During each of the monitoring runs, fourteen sites were sampled at low water slack, beginning at Prisoners Point (Station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the ship channel (Station 14). An exception to this standard protocol occurred during the November 14 sampling run, when stations 1 through 9 were sampled at high water slack due to a miscalculation of the vessel departure schedule. For geographic reference and to simplify reporting, the sampling stations are keyed to channel light markers[2] as shown in Figure 7-1.

Because monitoring results differ along the channel[3], sampling stations are grouped into western, central, and eastern regions within the channel; these regions are highlighted in Figure 1. The western channel begins at Prisoners Point (Station 1) and ends at Light 14 (Station 5). The central channel begins at Light 18 (Station 6) and ends at Light 34 (Station 9). Finally, the eastern channel begins at Light 40 (Station 10) and ends at Light 48 (Station 13). The Turning Basin (Station 14) is unique within the channel because it is east of the entry point of the San Joaquin River into the channel and isolated from down-channel flow. Because of the unique hydromorphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at low water slack, and analyzed for dissolved oxygen concentrations and temperature. Top dissolved oxygen samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom dissolved oxygen samples were obtained using a Seabird submersible sampler and measured using aYSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger. Surface and bottom water temperatures were measured using a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe, or a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data at Vernalis compiled by DWR[4]. Average daily flows past Vernalis were obtained by averaging 15-minute data for a daily average flow rate. Tidal cycles of ebb and flood are not seen in flows at Vernalis and flow is downstream (positive) throughout the year. The San Joaquin River flows past Stockton used in this report were obtained from data recorded by the

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1 Funding for these special studies was provided by the Division of Operations and Maintenance, DWR

2 Channel light markers are ship navigational aides placed in navigable waters. Although they are not spaced at fixed intervals, they provide convenient landmarks for identifying sample locations.

3 The findings of previous fall studies have shown that fall dissolved oxygen levels are typically: robust and high (7.0-9.0 mg/L) in the western Channel; transitional, variable (4.0-7.0 mg/L), and stratified in the central Channel; and low (3.0-5.0 mg/L) and stratified in the eastern Channel.

4 Station information: DWR Station SJR at Vernalis, RSAN112

US Geological Survey (USGS) flow monitoring station southeast of Rough and Ready Island [5].

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[6] to yield net daily flow. Because of low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse direction. Although net flows at Stockton frequently approached zero during this study period, net daily reverse flows were seen only during the end of fall 2003.

In this report, we define a dissolved oxygen “sag” as a region within the channel where dissolved oxygen levels are < 5.0 mg/L. A dissolved oxygen “depression” is defined as a region within the channel where dissolved oxygen levels are ≥ 5.0 mg/L but < 6.0 mg/L.

Results

During this study period (August 11 to December 10), dissolved oxygen levels varied considerably between regions within the channel from a low of 3.0 mg/L to a high of 10.7 mg/L. In the western channel dissolved oxygen concentrations were relatively high and stable, ranging from 6.9 to 9.4 mg/L. The robustness of dissolved oxygen concentrations in this portion of the channel is apparently due to greater tidal mixing, the absence of conditions creating BOD, and shorter hydrological residence time. In the central portion of the channel, dissolved oxygen concentrations were more variable than the concentrations observed in the western channel, ranging from 4.1 to 9.3 mg/L. In the eastern channel, the dissolved oxygen levels were the most variable and stratified, ranging from a low of 3.0 mg/L to a high of 10.7 mg/L. Changing inflows from the San Joaquin River into the eastern channel may partially account for the variability of the dissolved oxygen levels within the eastern channel.

The findings for the late summer and fall of 2003 are briefly summarized by month as follows.

August

Monitoring on August 11 showed surface dissolved oxygen levels ranging from 4.7 mg/L at stations 9 and 10 in the central and east channels, respectively to 8.5 mg/L at Station 1 in the west channel (Figure 7-2). Bottom dissolved oxygen levels ranged from 3.8 mg/L at Station 12 in the east channel to 8.9 mg/L at Station 2 in the west channel. Both a dissolved oxygen sag and a depression were observed at the surface and bottom in the central and eastern channels. The depression extended from stations 8 to 13, while the sag occurred from stations 9 to 12 in the eastern channel. The western channel exhibited the highest dissolved oxygen and all stations maintained dissolved oxygen levels above 7.5 mg/L.

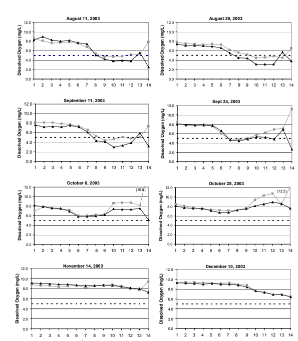

Figure 7-2 Surface and bottom dissolved oxygen concentrations in the Stockton Ship Channel, Fall 2003

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[5] Station information: USGS 304810 SJR at Stockton, RSAN063.

[6] The 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 that represents net river flow exclusive of tidal cycles.

On August 11, water temperature values ranged from surface values of 21.8 °C in the west channel to 26.1 °C in the east channel, and bottom values ranged from 21.6 °C in the east to 25.3 °C in the west channel (Figure 7-3).

Monitoring on August 29 showed surface dissolved oxygen levels ranging from 4.5 mg/L in the east channel to 7.8 mg/L in the west. Bottom dissolved oxygen levels ranged from 3.1 mg/L in the east channel to 7.4 mg/L in the west. A dissolved oxygen sag occurred at both the surface and bottom of the water column from stations 10 to 12 in the eastern channel. The western channel exhibited the highest dissolved oxygen concentrations and all stations maintained surface dissolved oxygen levels above 7.3 mg/L.

August 29 water temperature values ranged from surface values of 22.6 °C in the west channel to 26.2 °C in the east. Bottom values ranged from 22.5 °C in the west to 25.4 °C in the east channel (Figure 7-3).

Average daily flows in the San Joaquin River past Vernalis in August ranged from 1,265 to 1,655 cfs. Net flow in the San Joaquin River past Stockton ranged from 124 to 626 cfs from August 1 through 26, the period of time the flow meter was in operation (Figure 7-4).

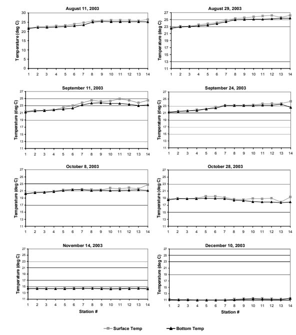


Figure 7-3 Surface and bottom water temperatures in the Stockton Ship Channel, Fall 2003

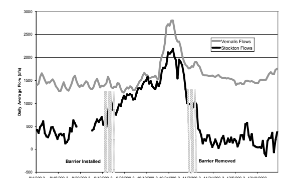


Figure 7-4 Fall 2003 San Joaquin River Flow at Stockton and Vernalis

September

On September 11, surface dissolved oxygen levels ranged from 4.4 mg/L at Station 9 in the central channel to 8.2 mg/L at Station 1 in the west channel. Bottom dissolved oxygen levels ranged from 3.0 mg/L at station 10 in the east channel to 7.6 mg/L at Station 1 in the west channel. A dissolved oxygen sag occurred at both the surface and bottom, extending from stations 8 to 13 in the eastern channel. The western channel exhibited the highest dissolved oxygen and all stations there maintained surface dissolved oxygen levels above 7.2 mg/L (Figure 7-2).

On September 11, surface water temperatures ranged from 21.4 °C at Station 1 in the west channel to 24.9 °C at Station 11 in the east channel. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.8 °C at Station 9 in the central channel (Figure 7-3).

On September 24, surface dissolved oxygen levels ranged from 4.7 mg/L at Station 8 in the central channel to 8.4 mg/L at Station 1. Bottom dissolved oxygen levels ranged from 4.4 mg/L at Station 8 in the central channel to 8.0 mg/L at Station 1. Dissolved oxygen sags occurred at the surface in the central channel at stations 7 and 8; at the bottom in the central channel from stations 7 to 9; and in the eastern channel at Station 12. The western channel exhibited the highest dissolved oxygen and all stations there maintained surface dissolved oxygen levels above 7.6 mg/L (Figure 7-2).

Surface water temperature ranged from 21.3 °C at Station 1 to 23.7 °C at stations 12 and 13 in the eastern channel on September 24. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.5 °C at Station 13 (Figure 7-3).

September flows in the San Joaquin River at Vernalis were similar to those in August and remained fairly steady, ranging from 1,233 to 1,535 cfs. DWR began installation of the barrier at the head of Old River on September 2. The closure was completed on September 15 and all culverts were closed on September 22. Coincident with the Barrier placement, net flow past Stockton increased steadily during the month, which resulted in an increase in flow rates from 406 cfs in early September to 1,206 cfs at the end of the month[7] (Figure 7-4).

October

On October 8, surface dissolved oxygen levels ranged from 6.0 mg/L at stations 6 and 7 in the central channel to 8.7 mg/L at stations 11 and 12 in the east channel. Bottom dissolved oxygen levels ranged from 5.9 mg/L in the central channel at stations 6, 7 and 8 to 8.1 mg/L at Station 1. A dissolved oxygen sag was not observed within the channel; however, a very slight dissolved oxygen depression occurred on the bottom at stations 6, 7 and 8 in the central channel.

On October 8, surface water temperatures ranged from 20.3 °C at Station 1 in the west channel to 21.9 °C at Station 12 in the east channel. Bottom temperatures ranged from 20.2 °C at Station 1 to 21.3 °C at stations 6, 7, and 13.

Surface dissolved oxygen levels on October 28 ranged from 7.1 mg/L at Station 7 in the central channel to 10.7 mg/L at Station 12 in the east channel. Bottom dissolved oxygen levels ranged from 6.7 mg/L at stations 6 and 7 to 8.9 mg/L at Station 12. A dissolved oxygen sag was not observed within the channel during this sampling run. The eastern channel exhibited the highest dissolved oxygen and all stations maintained surface dissolved oxygen levels above 7.1 mg/L.

On October 28 surface water temperatures ranged from 17.9 °C in the east channel at Station 13 to 19.5 °C in the west channel at stations 4 and 5. Bottom temperatures ranged from 17.7 °C at Station 13 to 19.0 °C at Station 5.

Average daily flows of the San Joaquin River at Stockton ranged from 1,085 to 2,182 cfs, increasing steadily throughout the month (Figure 7-4). Flows recorded at Stockton were very similar to those measured at Vernalis for much of the month, indicating that little upstream diversion was occurring. The Barrier at Old River was in place with all culverts closed for the entire month of October. Flow rates at Vernalis ranged from 1,283 to 2,804 cfs and also increased steadily throughout the month.

November

Dissolved oxygen readings throughout the channel remained well above state objectives in November, and the Barrier was removed in early November. On November 14 surface dissolved oxygen levels ranged from 7.7 mg/L at Station 13 to 8.8 mg/L at stations 1 and 10. Bottom dissolved oxygen levels ranged from 8.0 mg/L at Station 13 to 9.1 mg/L at stations 1 and 2 (Figure 7-

[7] USGS flow data for the San Joaquin River at Stockton was not available for the first four days in September (9/1 – 9/4).

2). Although dissolved oxygen readings were fairly consistent throughout the channel, dissolved oxygen levels in the east were slightly lower than those seen in the central and western channels, and bottom dissolved oxygen levels were slightly higher than surface readings in the western channel.

Water temperatures on November 14 were consistent throughout the channel within a half a degree, with surface temperatures ranging from 14.2 °C at Station 1 to 14.6 °C at Station 12. Bottom temperatures ranged from 14.2 °C at Station 10 to 14.4 °C at stations 1, 2, 6, 7 and 8 (Figure 7-3).

Flow rates past Vernalis continued to decline from 2,043 cfs on November 1 to 1,546 cfs by the 30th. Net daily flows past Stockton also fell markedly from 1,828 cfs on November 1 to 233 cfs by November 30 (Figure 7-4). The reduced flows seen at Stockton coincided with the removal of the Barrier, which allowed a diversion of flow from the San Joaquin River down Old River.

December

Dissolved oxygen readings remained steady in the west and central channels, but declined slightly in the eastern channel during December; however, all levels were well above state objectives. On December 10, surface dissolved oxygen levels ranged from 6.9 mg/L at stations 12 and 13 to 9.4 mg/L at stations 2 and 3. Bottom dissolved oxygen levels ranged from 6.9 mg/L at stations 12 and 13 to 9.3 mg/L at Station 1 (Figure 7-2). The western channel exhibited the highest dissolved oxygen, and all stations maintained surface dissolved oxygen levels above 6.9 mg/L.

Water temperatures throughout the channel declined further from November, and were consistent throughout the channel, within a half a degree Celsius. On December 10, surface temperatures ranged from 11.0 °C at stations 4, 5 and 6 to 11.5 °C at stations 10 and 11. Bottom temperatures ranged from 11.0 °C at stations 4, 5, 6, and 7 to 11.4 °C at Station 10 (Figure 7-3).

Flow rates past Vernalis in December ranged from 1,400 to 1,753 cfs, with an increase of flow occurring towards the end of the month. Net daily flows past Stockton continued to decline, with negative flows and flows approaching zero recorded on several occasions. December net daily flows at Stockton ranged from 573 to -150 cfs.

Stockton Turning Basin

Stratified dissolved oxygen conditions were recorded in the Stockton Turning Basin (Basin) (Station 14) throughout much of fall 2003 (Figure 7-2). Surface dissolved oxygen levels in late September and October were supersaturated, while bottom levels were at or below state objectives. The highest stratification was observed on October 8 when sampling showed surface dissolved oxygen concentrations of 16.0 mg/L, with a bottom concentration of 5.1 mg/L. Vertical dissolved oxygen stratification at Station 14 was observed on all sampling runs except the final run of December 10.

The periodic dissolved oxygen stratification appears to be the result of localized biological and water quality conditions occurring in the Basin. The

Basin is at the eastern dead-end terminus of the ship channel and is subject to reduced tidal activity, restricted water circulation, and increased residence times when compared to the remainder of the channel. As a result, water quality and biological conditions within the Basin have historically differed from those within the main downstream channel, and have led to extensive late summer and fall algal blooms and die-offs. The late summer and early fall of 2003 were no exception, as intense algal blooms composed primarily of green algae, flagellates, diatoms, and Cryptomonads were detected.

Stratified dissolved oxygen conditions often occur in the water column as a result of these blooms. At the surface, these blooms are highly productive and can produce markedly high surface dissolved oxygen levels. However, dead or dying bloom algae can sink to the bottom to contribute to high BOD and low bottom dissolved oxygen levels. Bottom dissolved oxygen levels in the basin are further degraded by additional BOD loadings in the area from sources such as regulated discharges into the San Joaquin River and nonpoint pollution adjacent to the basin. When bloom activity subsides, the dissolved oxygen stratification is reduced, and basin surface and bottom dissolved oxygen levels become less stratified.

Summary

Dissolved oxygen concentrations in the eastern Stockton Ship Channel fell below both the State's 5.0 mg/L and 6.0 mg/L objectives in August and September 2003, a period which coincided with relatively low net flows in the San Joaquin River past Stockton and warm water temperatures. A temporary barrier across the head of Old River was installed on September 15, 2003, to increase flows down the San Joaquin River into the channel. The Barrier became fully operational on September 22 when all culverts were closed. Subsequent sampling on October 8 showed an improvement of dissolved oxygen conditions, with all stations showing levels above the 5.0 mg/L objective and only the central channel with levels slightly below the 6.0 mg/L objective. By October 28, dissolved oxygen levels had improved to 6.0 mg/L or greater throughout the channel and remained above state objectives for the remainder of the sampling program. The Barrier was fully removed by November 13, and although flows past Stockton were subsequently reduced, dissolved oxygen levels remained within compliance. The fall sampling program was suspended after sampling on December 10.

References

[APHA] American Public Health Association. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. Washington, D.C.

[CVRWQCB 1975] Central Valley Regional Water Quality Control Board. 1975. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. First Edition.

[CVRWQCB 1998] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. Fourth Edition.

[SWRCB] 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.

Figure 7-1 Monitoring sites in the Stockton Ship Channel

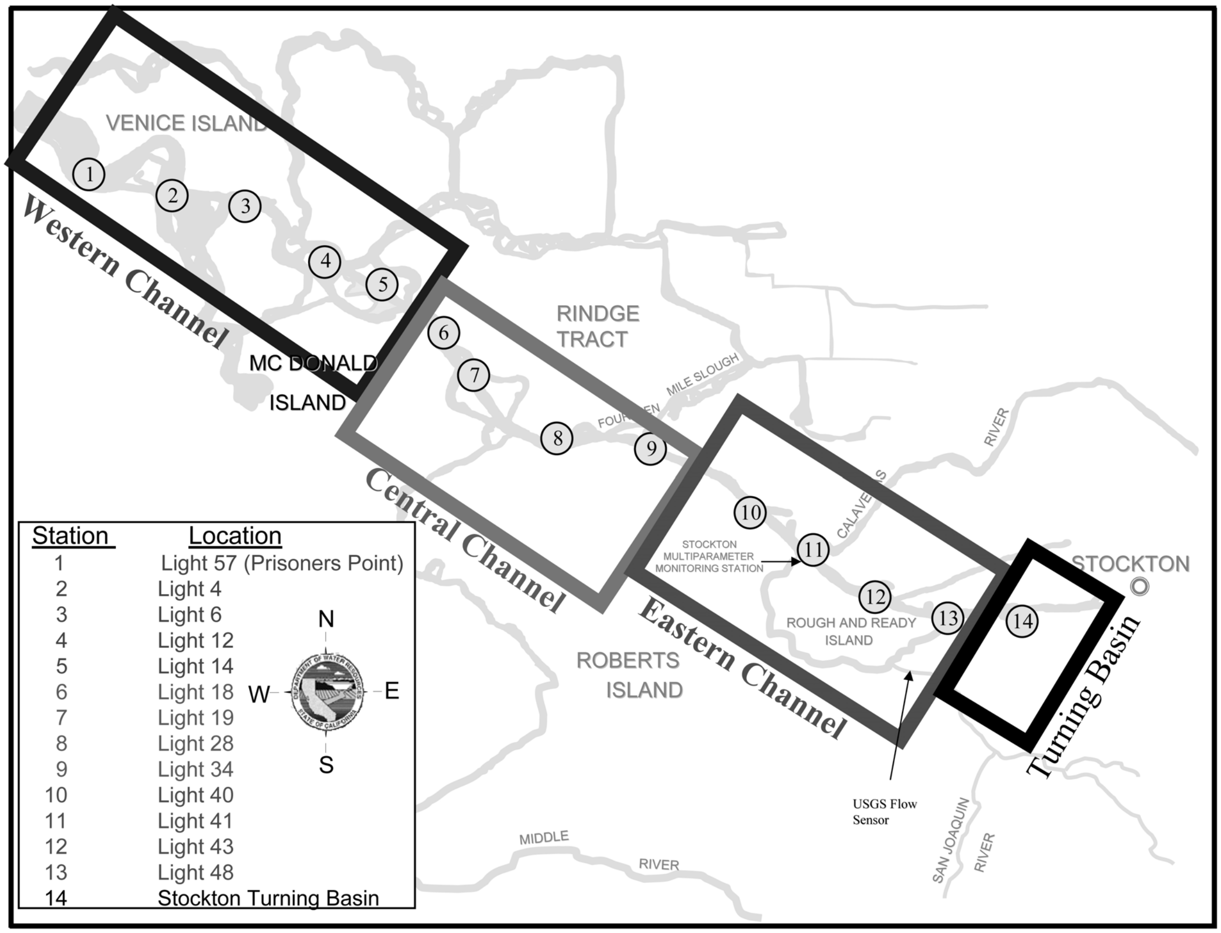


Figure 7-2 Surface and bottom dissolved oxygen concentrations in the Stockton Ship Channel, Fall 2003

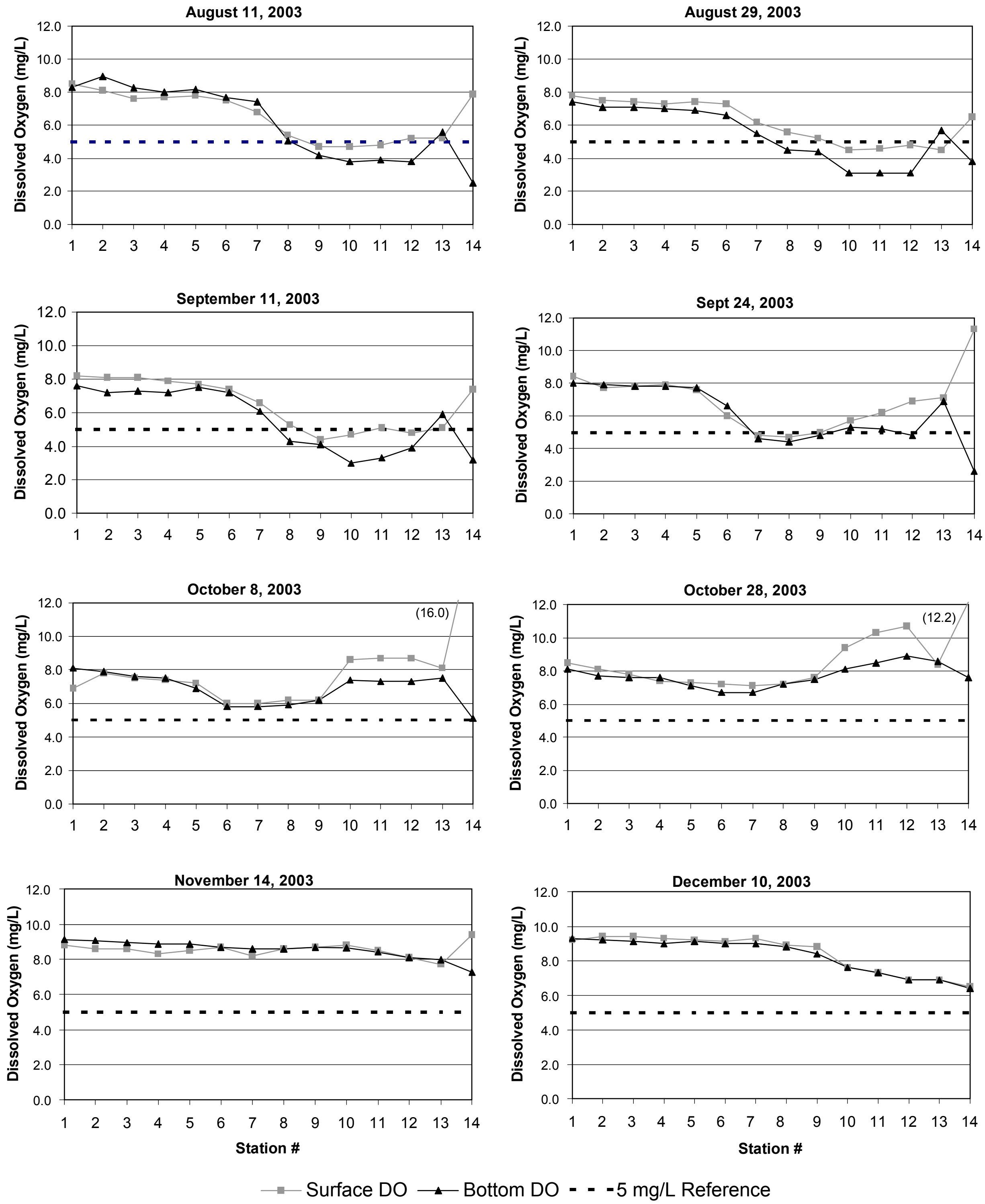


Figure 7-3 Surface and bottom water temperatures in the Stockton Ship Channel, Fall 2003

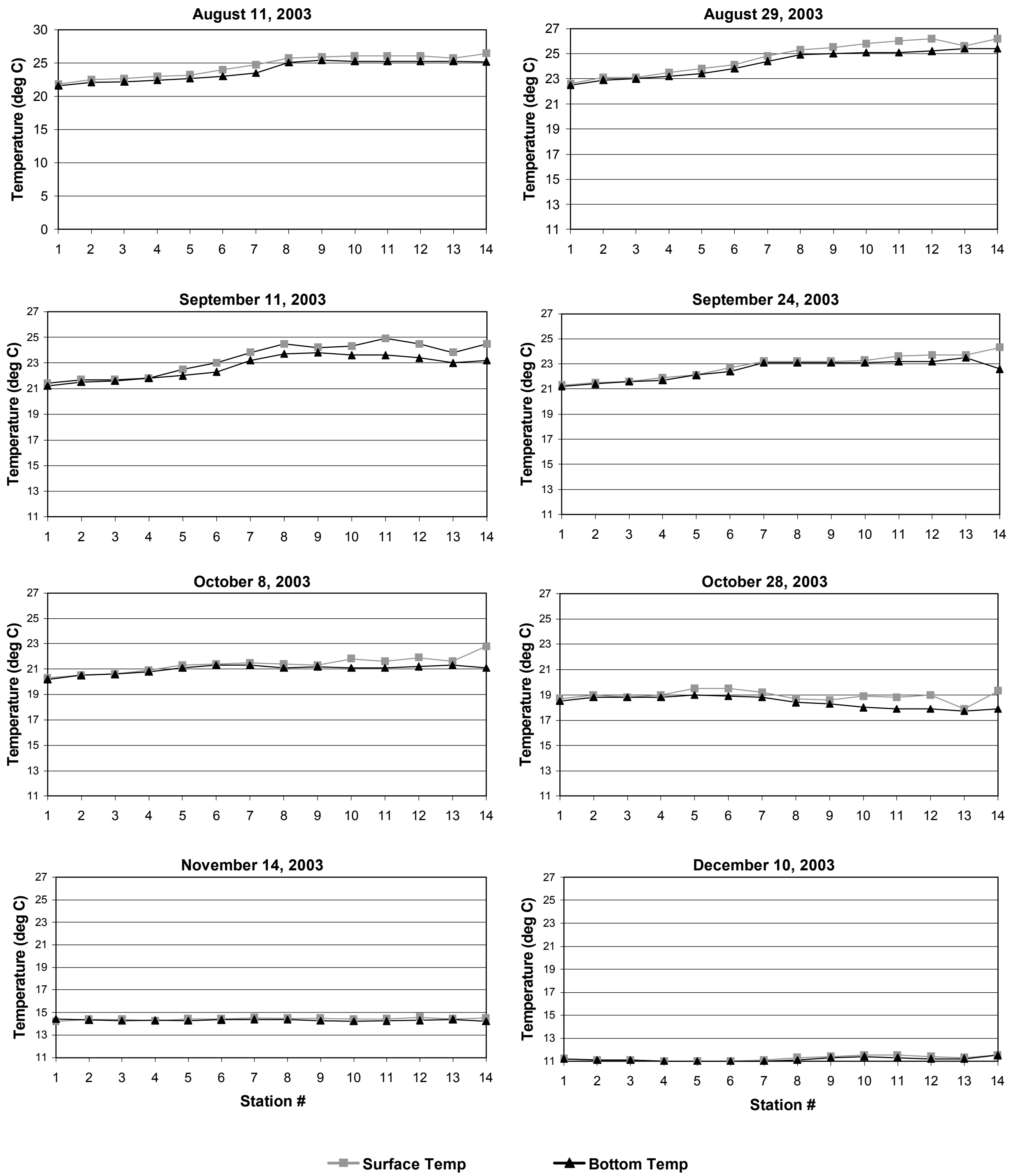
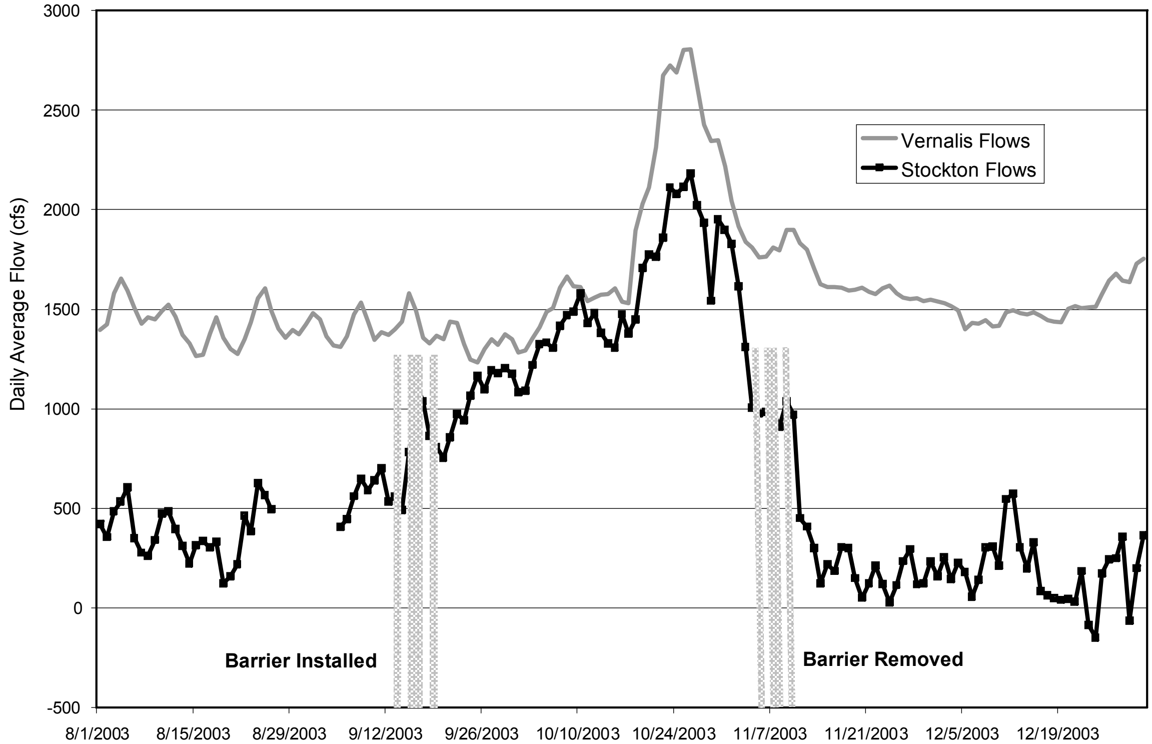


Figure 7-4 Fall 2003 San Joaquin River Flow at Stockton and Vernalis



Chapter 8
Data Management

Introduction

All data collected by the Environmental Monitoring Program (EMP) are stored in digital format for data management and dissemination. Each monitoring element (discrete and continuous water quality, benthic, phytoplankton and zooplankton) has a particular process for data entry, quality control, management and dissemination. All data, except zooplankton and sediment composition can be downloaded via the Internet, from the Bay Delta and Tributaries database (BDAT). At present, the EMP continuous water quality data are available on BDAT under the category “time series.”

BDAT consolidates and provides public access to environmental data contributed by more than fifty organizations. The database includes water quality, biological and meteorological data from throughout the San Francisco Estuary’s watershed. The EMP water quality, benthic and phytoplankton data stored in this database are available on the Internet at: http://baydelta.water.ca.gov.

Information about the various EMP monitoring elements and detailed information about the EMP can be found at:
http://www.iep.water.ca.gov/emp/.

Metadata information describing sampling site locations, sampling methodology, and field and laboratory processing for all the data variables is available on the IEP website at:
http://www.iep.water.ca.gov/emp/metadata_index.html.

Complete metadata files are available for the benthic, phytoplankton, and discrete water quality monitoring elements of this program. Metadata files are currently being developed for the continuous water quality monitoring elements and the zooplankton. These files also provide contact information for the staff member responsible for each monitoring element.

Data Management Procedures

The procedures for handling each type of EMP data are described below. The description includes: where the data are stored, how the data are checked for quality, what data are available, how to obtain these data, and who is responsible for data management of each monitoring element. Water quality is monitored with both discrete and continuous sampling. The discrete monitoring sites are surveyed monthly, primarily by vessel. The continuous monitoring stations are equipped with automated probes and data recorders that log data every 10 minutes to 1 hour depending on the water quality variable.

Discrete Water Quality Data

During monthly sampling runs, field measurements are recorded on paper datasheets and entered into the field module of the Department of Water Resources' Field and Laboratory Information Management System (FLIMS), using a portable computer. Later, laboratory analyses are performed at DWR's Bryte Laboratory and the results are entered by laboratory staff into the lab module of the FLIMS database. Data are then loaded electronically into the EMP's Discrete Water Quality database, which is a Microsoft Access database. This database is the reference database for this program element. EMP staff periodically reviews the data for accuracy, completeness and consistency against paper datasheet records. Data are then exported electronically to BDAT.

Discrete water quality data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding management and access to discrete water quality data, contact Scott Waller at: swaller@water.ca.gov.

Continuous Water Quality Data

Data from automated continuous water quality monitoring stations are retrieved by downloading from each station's data recorders onto a handheld "pocket PC." Upon return to the office, data are loaded into the EMP's Continuous Water Quality database, which is an IBM/Informix database. This database is the reference database for this program element. EMP staff reviews these data for accuracy, completeness and consistency using probe verification and calibration records. Data that are determined to be the result of a measuring instrument that was operating out of proper calibration are flagged as "bad" and are retained in the database. The values of data flagged as "bad" are not available on the BDAT web site but may be obtained from EMP staff upon request.

Continuous water quality data from 1983 to present are available for download through the BDAT interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding management and access to continuous water quality data, contact Mike Dempsey at: mdempsey@water.ca.gov.

Benthic Data

Until October 2003, benthic sampling sites were surveyed monthly by vessel. They are now sampled quarterly. Laboratory identification and enumeration of macro-benthic organisms in each sample is performed by Hydrozoology, a private laboratory under contract with DWR. The results are reported to DWR on standard paper datasheets. Laboratory analysis of sediment samples is performed by the DWR's Soils and Concrete Laboratory. The results of the sediment analyses are provided to EMP staff in a written report.

Both sediment and benthic organism data are entered into the EMP Benthic database, which is a Microsoft Access database. This is the reference database for the benthic program element. EMP staff periodically reviews the data for accuracy, completeness and consistency. Data are exported electronically to BDAT on a quarterly basis.

Benthic data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

Sediment composition data gathered by the benthic monitoring element are exported to BDAT but not yet available for download via the Internet.

For more information regarding benthic or sediment data, contact Karen Gehrts at: kagehrts@water.ca.gov.

Phytoplankton Data

Phytoplankton sampling sites are surveyed monthly, primarily by vessel. Bryte Laboratory identifies, enumerates, and measures the size of phytoplankton from these samples. These data are entered into the EMP phytoplankton database using Microsoft Access software. This is the reference database for the phytoplankton monitoring element. EMP staff periodically reviews the data for accuracy, completeness, and consistency. Data are then exported electronically to BDAT.

Phytoplankton data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding phytoplankton data, contact Dean Messer at: dmesser@water.ca.gov.

Zooplankton Data

Zooplankton sampling sites are surveyed monthly by vessel. Laboratory identification and enumeration of zooplankton and mysid organisms is performed by the Department of Fish and Game's Central Valley Bay-Delta Branch Laboratory. The results are entered into a computer and stored electronically in a SAS statistical package format. Data are periodically reviewed for accuracy and completeness by DFG staff. Currently zooplankton data are only available through DFG; however, construction of a zooplankton database able to export data to BDAT is underway.

Data are available upon request from Randy Baxter at: rbaxter@delta.dfg.ca.gov.

Chapter 9
Continuous Monitoring

Introduction

The Department of Water Resource's Continuous Monitoring Program supplements DWR's monthly discrete Compliance Monitoring Program by providing real-time hourly and quarter-hourly water quality and environmental data from seven shore-based automated sampling stations located in the Upper San Francisco Estuary (Figure 9-1). These stations provide continuous measurements of seven water quality parameters and four environmental parameters, which are 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 mandated water quality standards. The Continuous Monitoring Program has been in operation since 1983. This chapter summarizes the results of continuous water quality monitoring at seven sites for calendar year 2003. The stations were divided into three regions for the purposes of detail in the plots:

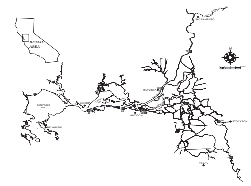


Figure 9-1 Station locations

Sacramento River stations:	Hood and Rio Vista
San Joaquin River stations:	Mossdale and Stockton
Tidally influenced stations:	Antioch, Mallard Island, and Martinez

Methods

Continuous data are collected for the water quality and environmental parameters shown in Table 9-1. Each of the seven monitoring stations collects continuous data for water temperature, pH, dissolved oxygen, and surface specific conductance. Beginning in April 2003, chlorophyll fluorescence and turbidity data were added for all seven stations. Additional sensors are installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom specific conductance, one and one-half meters above the channel bottom. These measurements, along with river stage data measured at the Mallard and Martinez stations, are needed to determine compliance with the salinity standard (also known as X2) mandated by the Bay-Delta Plan (SWRCB 1995). Environmental data—such as air temperature, solar radiation, wind speed and direction—are measured at all stations except Mossdale (only air temperature) and Hood (none).

Parameter	*Units*	*Frequency*
Water temperature	*°C*	*Hourly average*
Air temperature	*°C*	*Hourly average*
Dissolved oxygen	*mg/L*	*Hourly average*
pH	*unitless*	*Hourly average*
Chlorophyll fluorescence	*fluorescence units*	*Hourly average*
Surface specific conductance	*µS/cm*	*Hourly average*
Bottom specific conductance	*µS/cm*	*15 minute instantaneous*
River stage	*feet Mean Sea Level (NGVD1929)*	*15 minute instantaneous*
Wind speed	*kph*	*15 minute instantaneous*
Wind direction	*degrees*	*15 minute instantaneous*
Solar radiation	*cal/min/cm²*	*15 minute instantaneous*

Table 9-1 Parameters measured by the Continuous Monitoring Program

Except for bottom specific conductance, all water samples are collected at one meter below the water surface using a float-mounted pump and distributed to the water quality sensors. An Ocean Data Equipment model DACTS-80-26 Data Acquisition, Control and Telemetry System scans the output from the sensors once per second and records the hourly average of these approximately 3,600 readings on the hour. Bottom specific conductance and environmental data, such as solar radiation, wind speed and wind direction data, is recorded at 15-minute intervals.

Complete hourly or quarter-hourly data for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, and river stage are available on the Interagency Ecological Program (IEP) database http://wwwiep.water.ca.gov/dss/all/ unless otherwise noted. Data for all other measured parameters are available by request to the Chief of the Real Time Monitoring and Support Section[1].

Results

The monthly averages of the continuous 15-minute or hourly data collected for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, chlorophyll fluorescence and turbidity for calendar year 2003 are shown in Figures 9-2 to 9-10.

Water Temperature

Water temperature was measured in degrees Celsius (°C) using a Schneider Instruments RM25C-031 Temperature Parametric System.

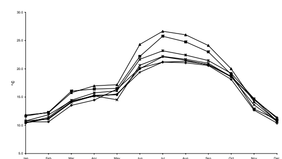


Figure 9-2 Average monthly water temperature at seven stations, 2003

Monthly average water temperatures in the San Francisco Estuary ranged from 10.4 °C in January 2003 at the Mallard Island station on the Sacramento River to 26.6 °C in July 2003 at the Stockton station on the San Joaquin River (Figure 9-2).

Average monthly water temperatures at the Sacramento River stations were lower in comparison to the San Joaquin River stations, with the greatest divergence occurring in the months of June through September at the San Joaquin River stations of Stockton and Mossdale.

Dissolved Oxygen

Dissolved oxygen was measured using a Schneider Instruments RM25C-033 measuring circuit with a Clark-polarographic probe.

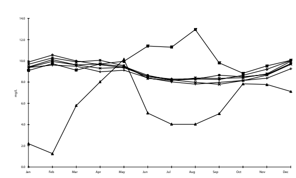


Figure 9-3 Average monthly dissolved oxygen at seven stations, 2003

Average monthly dissolved oxygen values for the seven monitoring stations ranged from 1.2 mg/L to 13.3 mg/L (Figure 9-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton and Mossdale. A monthly average of 1.2 mg/L was calculated for the Stockton station in February 2003, and a value of 13.3 mg/L was calculated for the Mossdale station for August 2003. All other stations showed average monthly averages between 7.8 mg/L and 10.6 mg/L. All compliance monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the Central Valley Water Resources Control Board in the Basin Plan. Monthly average dissolved oxygen values at the Stockton station were highly variable and ranged from 1.2 mg/L to 10.2 mg/L. The Stockton station, located in the Stockton Deep Water Ship Channel, showed a significant DO sag of 1.2 mg/L in February 2003. This pattern of winter sag was first identified in 2000.

During the summer and fall of 2003, monthly average dissolved oxygen values at the Mossdale station were exceptionally high. Dissolved oxygen

[1] Chief Real -Time Monitoring and Support Section, Division of Environmental Services, Office of Water Quality, Environmental Water Quality and Estuarine Studies Branch, 901 P Street, Sacramento CA 95814

during the months of June, July, and August 2003 ranged from 11.4 mg/L to 13.0 mg/L. Monthly average dissolved oxygen values in 2002 showed a similar pattern from June to September, ranging from 12.5 mg/L to 13.6 mg/L. The high average summer DO levels seen at the Mossdale station coincided with high chlorophyll fluorescence during the same period. (Figure 9-8)

Specific Conductance

Specific conductance was measured using a Schneider Instruments RM25C-032 system.

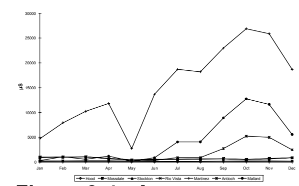


Figure 9-4a Average monthly specific conductance at seven stations, 2003

Figure 9-4b Average monthly specific conductance at four stations, 2003

Monthly average surface specific conductance for the San Francisco Estuary for the period ranged from 111 µS/cm to 26,882 µS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 9-4). Data gathered upstream from the Mossdale and Stockton stations on the San Joaquin River show a higher average specific conductance than the data upstream from the Hood and Rio Vista stations on the Sacramento River (Figure 9-4a).

Bottom specific conductance measured at the Antioch, Mallard Island, and Martinez stations exhibited seasonal patterns and ranges similar to the surface specific conductance (Figure 9-5).

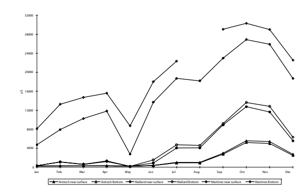


Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2003

pH

pH was measured using a Schneider Instruments RM25C-035 system.

Monthly average pH levels for the San Francisco Estuary for all stations ranged from 7.1 to 7.9 pH units, with the exception of Mossdale where pH values in June, July, August, and September ranged from 8.2 to 8.8 pH units (Figure 9-6). This increased pH coincided with high chlorophyll fluorescence observed at Mossdale during the same period (Figure 9-9b).

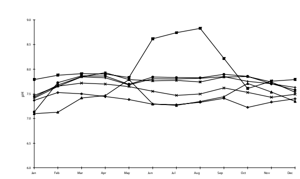


Figure 9-6 Average monthly pH at seven stations, 2003

Air Temperature

Air temperature was measured using a Schneider Instruments RM25C-036 system.

Monthly average air temperatures in the San Francisco Estuary ranged from 9.6 °C in January 2003 at the Rio Vista station on the Sacramento River to 26.6 °C at the Mossdale station on the San Joaquin River (Figure 9-7).

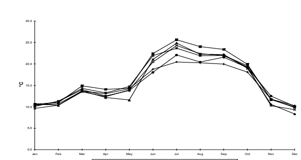


Figure 9-7 Average monthly air temperature at six stations, 2003

Chlorophyll *a* Fluorescence

Chlorophyll *a* fluorescence was measured using a Turner Designs SCUFA Fluorometer set-up with a continuous flow system using chlorophyll *a* filters.

Monthly average chlorophyll *a* fluorescence was recorded at the stations in the San Francisco Estuary from the installation in April 2003 to December 2003 when the instruments were removed for factory upgrade (Figure 9-8a-c). The recorded values ranged from minima of 0.94 fluorescence units (FU) in December 2003 at the Rio Vista station on the Sacramento River to

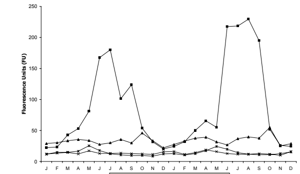


Figure 9-8a-c Average monthly chlorophyll fluorescence at various stations, 2003

maxima of 48.4 FU on August 2003 at the Mossdale station on the San Joaquin River.

Turbidity

Turbidity was measured using a Turner Designs Self-contained Underwater Fluorescence Apparatus (SCUFA®).

Monthly average turbidity was recorded at the stations in the San Francisco Estuary from the installation in April 2003 to December 2003 when the instruments were removed for factory upgrade (Figure 9-9a-c). The recorded values ranged from minima of 3 Nephelometric Turbidity Units (NTU) at the Stockton station on the San Joaquin River in November 2003 to maxima of 46 NTU at the Martinez station near Carquinez Strait in May 2003.

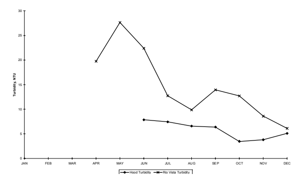


Figure 9-9 a-c Average monthly turbidity at two Sacramento River, San Joaquin River, and tidally influenced stations, 2003

Stockton Ship Channel Dissolved Oxygen

As part of DWR's mandate to monitor water quality in the Delta, a special monitoring study is focused on dissolved oxygen (DO) conditions in the Stockton Ship Channel from Prisoner's Point to the Stockton Turning Basin (See Chapter 7). Continuous data from a monitoring station located in the ship channel (Stockton Station #20) supplements monthly discrete sampling and alerts DWR personnel when DO levels become critical.

The Central Valley Regional Water Quality Control Board has established a baseline objective of 5.0 mg/L for the entire delta (CVRWQCB 1998); however, due to the special concerns in the Stockton Ship Channel to protect fall-run Chinook salmon, a DO objective of 6.0 mg/L has been established for September through November by the State Water Resources Control Board (SWRCB 1995).

For 2003, average monthly DO values at the Stockton station remained above 6.0 mg/L during October and November, but fell below 6.0 mg/L in September (Figure 9-10).

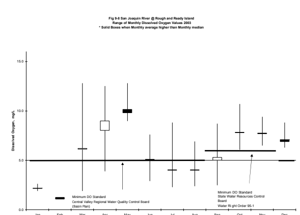


Figure 9-10 Range of monthly dissolved oxygen values at San Joaquin River, Rough and Ready Island 2003

Monthly average DO values in 2003 ranged from 1.2 to 10.2 mg/L. The lowest DO value occurred in February 2003, and the highest value of 10.2 occurred in May 2003. Monthly average DO values dropped well below the state mandated standards from June through September. In 2003, hourly values ranged from 0.1 to 12.8 mg/L. The minimum value of 0.1 mg/L recorded in February 2003 was the lowest value recorded in the last five years. As seen in previous years, the DO levels drop during the summer months of July, August, and September; however, low monthly and hourly DO levels occurred in winter months as well. The pattern of falling DO levels in the winter, first observed in 2000, was again observed in 2003 with a period of near zero DO values from February 9 to February 19.

The box plots (Figure 9-10) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal "whiskers" indicate the range of hourly DO values for each month. Boxes represent monthly medians and means. Open boxes indicate that the monthly median is greater than the monthly mean, with the top of the box indicating the median, and the bottom of the box indicating the mean. Filled boxes indicate that the monthly mean is greater than the median, with the top of the box indicating the mean and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the mean are equal.

Summary

Water quality conditions in the upper San Francisco Estuary for the calendar year 2003 were in the expected range of values for water temperature, dissolved oxygen, specific conductance, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. The exceptions were found on the San Joaquin River.

The San Joaquin River station at Mossdale showed higher dissolved oxygen, pH, and chlorophyll *a* fluorescence values in the months of June, July, August, and September than any other station in the Estuary. The dissolved oxygen ranged from 9.8 mg/L to 13 mg/L. The pH values ranged from 8.2 to 8.8 pH units. The chlorophyll *a* fluorescence values ranged from 25 FU to 48 FU.

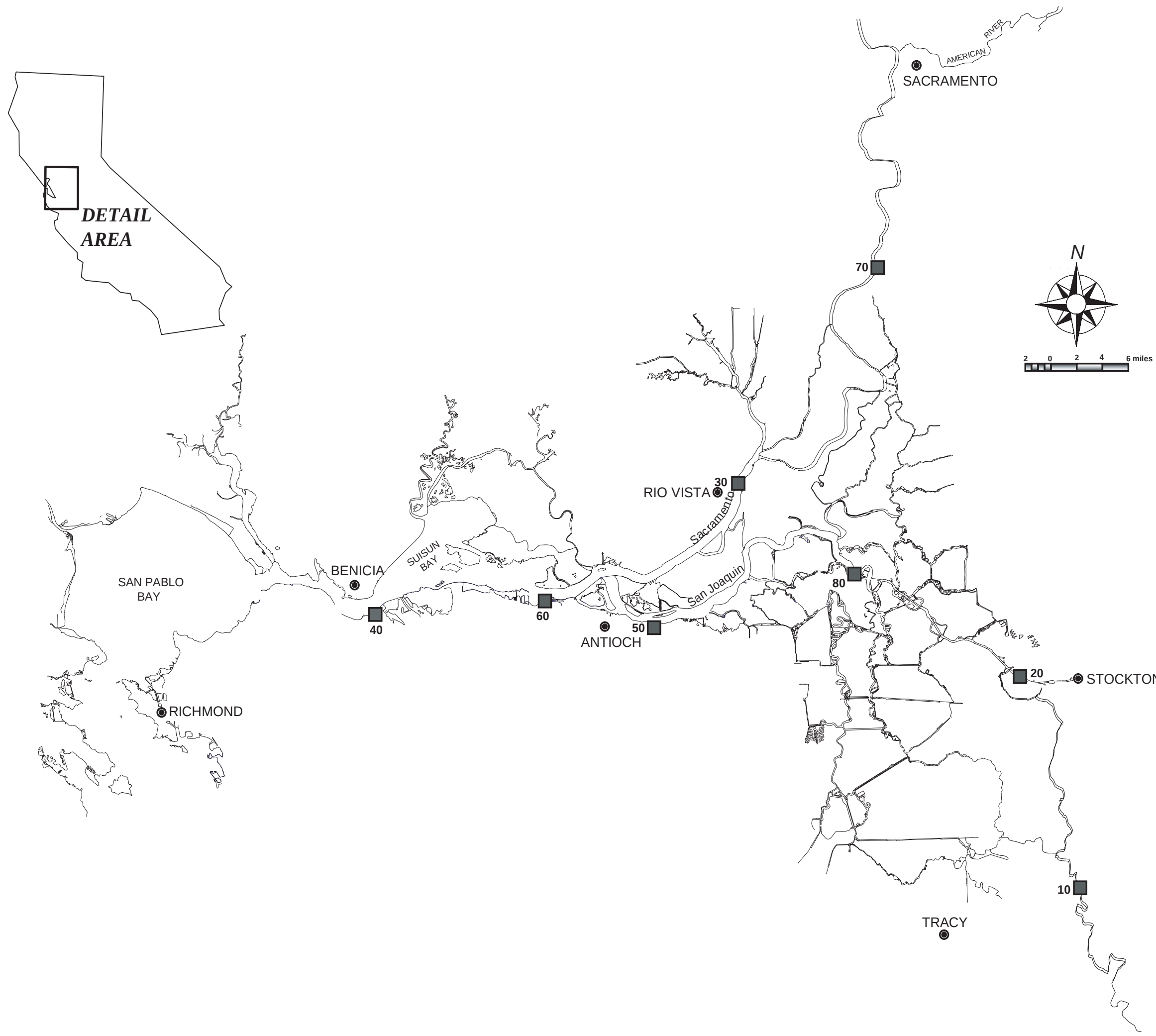
The San Joaquin River station at Stockton showed a dissolved oxygen sag below the 5.0 mg/L objective set by the Central Valley Regional Water Quality Control Board (1998)—unlike any other station in the Estuary for the months of June, July, and August 2003—as well as a second sag below 5.0 mg/L in January and February 2003. The month of September was below the 6.0 mg/L objective set by the State Water Resources Control Board (1995) for the passage of fall-run Chinook salmon through the Stockton Deep Water Channel.

References

[CVRWQCB] Central Valley Regional Water Quality Control Board. 1998. *Water Quality Control Plan (Basin Plan) for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin*. Fourth Edition.

[SWRCB] 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.

Figure 9-1 Station locations



Station #	Location	IEP HEC-DSS database ID
10	San Joaquin River at Mossdale	RSAN087
20	San Joaquin River at Stockton	RSAN058
30	Sacramento River at Rio Vista	RSAC101
40	Sacramento River at Martinez	RSAC054
50	San Joaquin River at Antioch	RSAN007
60	Sacramento River at Mallard Island	RSAC075
70	Sacramento River at Hood	RSAC142
80	San Joaquin River at Prisoners Point (seasonal station)	RSAN037

Figure 9-2 Average monthly water temperature at seven stations, 2003

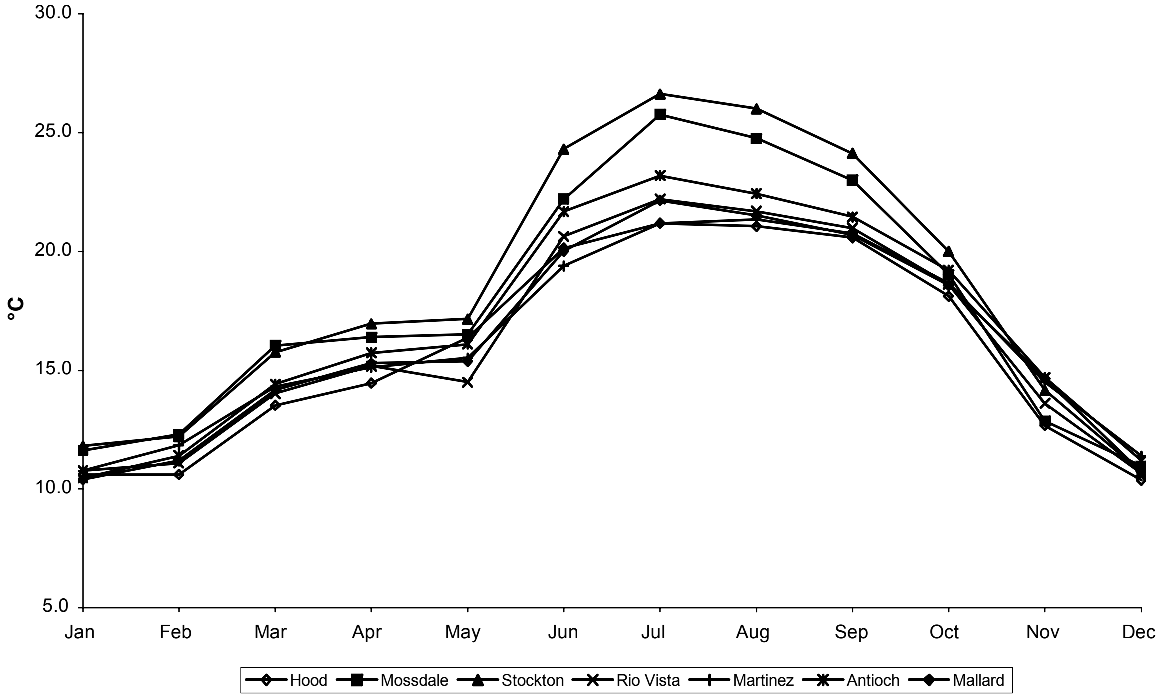


Figure 9-3 Average monthly dissolved oxygen at seven stations, 2003

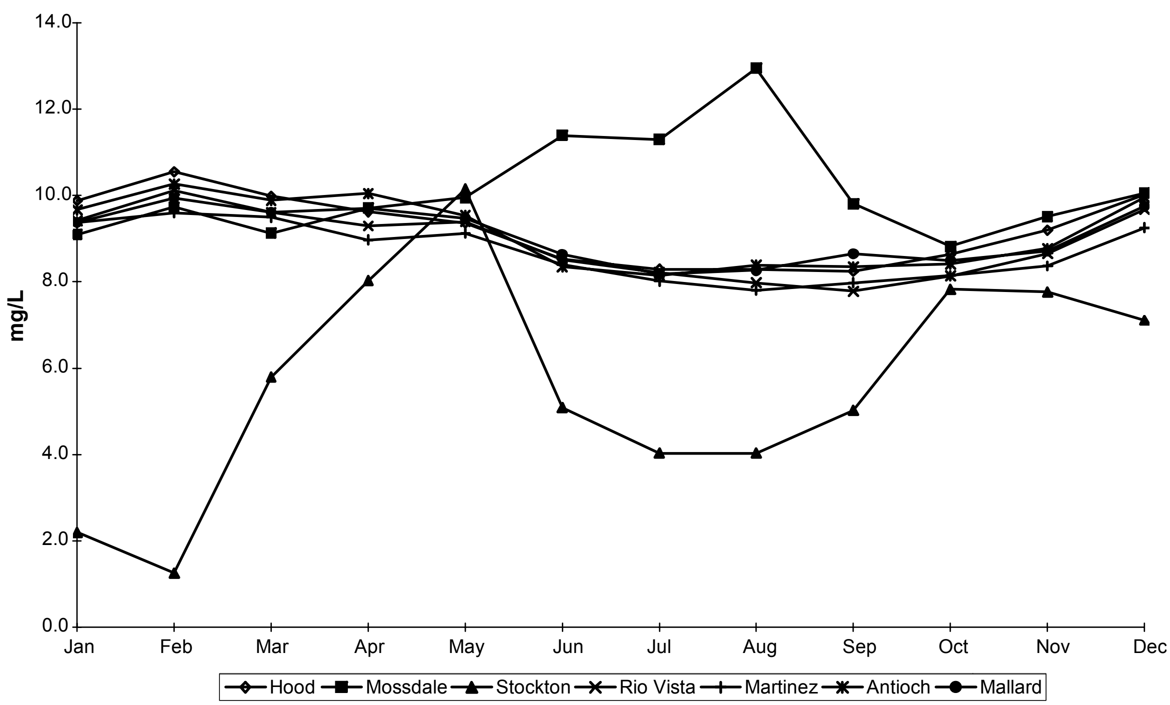


Figure 9-4a Average monthly specific conductance at seven stations, 2003

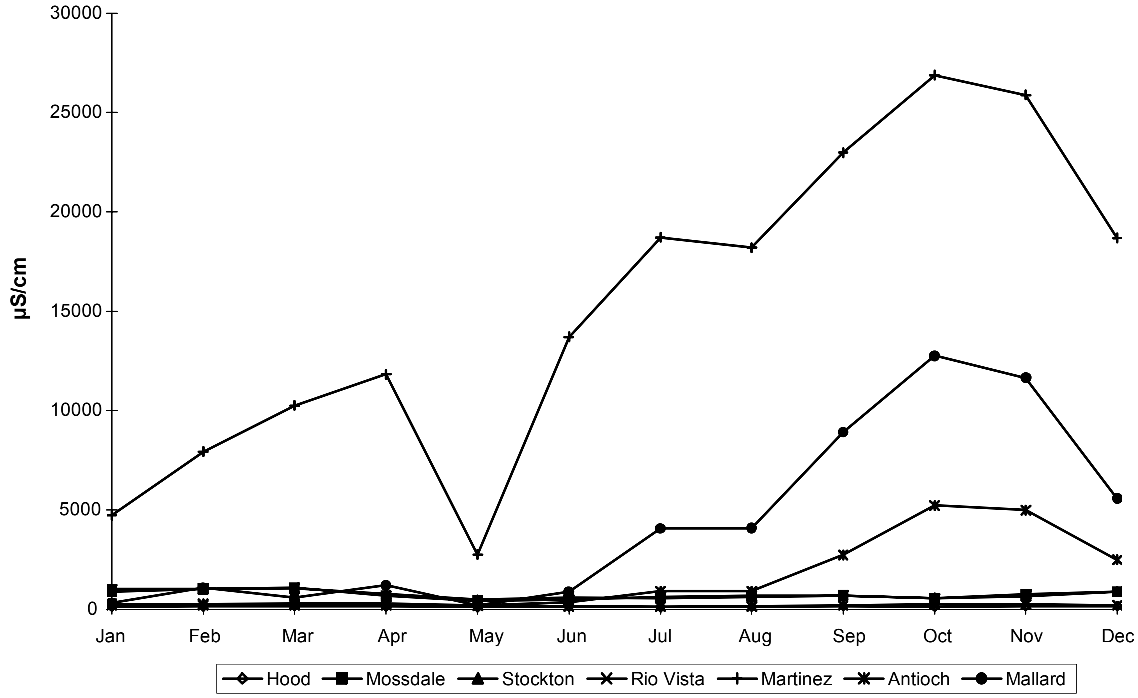


Figure 9-4b Average monthly specific conductance at four stations, 2003

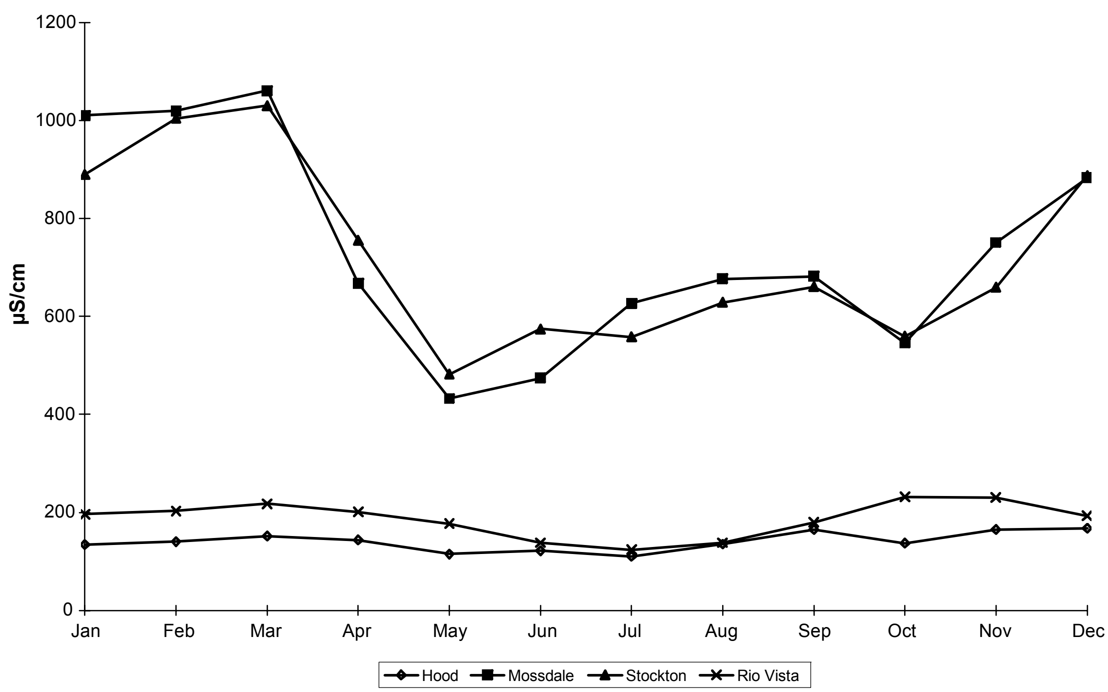


Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2003

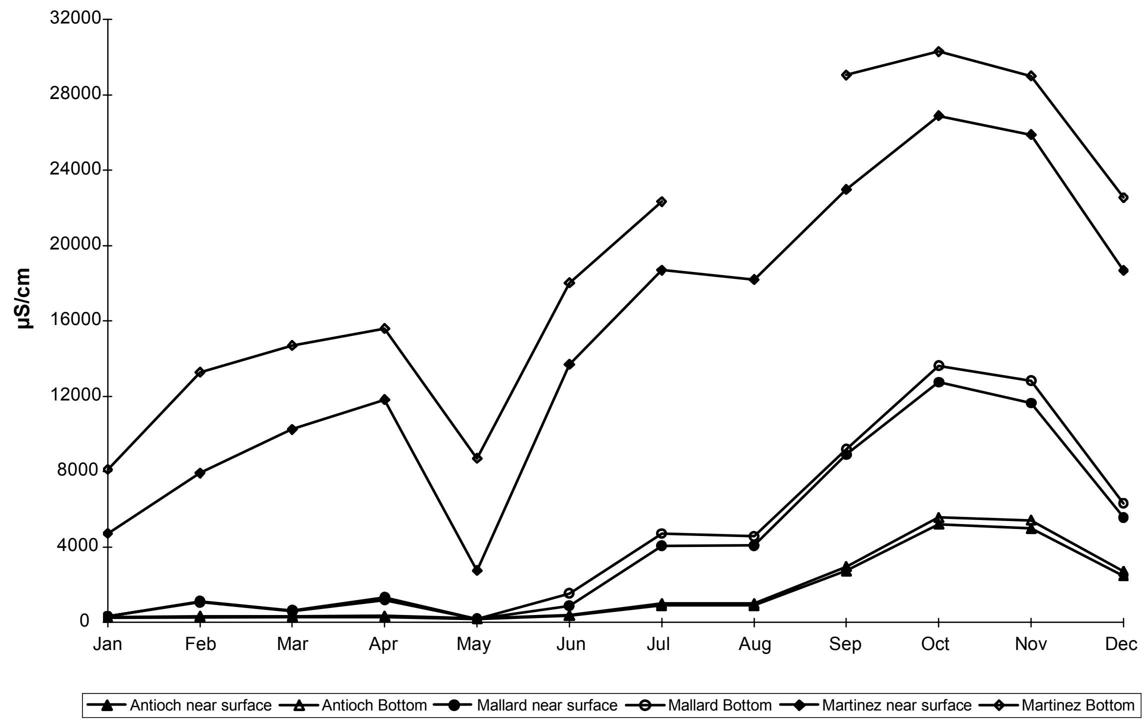


Figure 9-6 Average monthly pH at seven stations, 2003

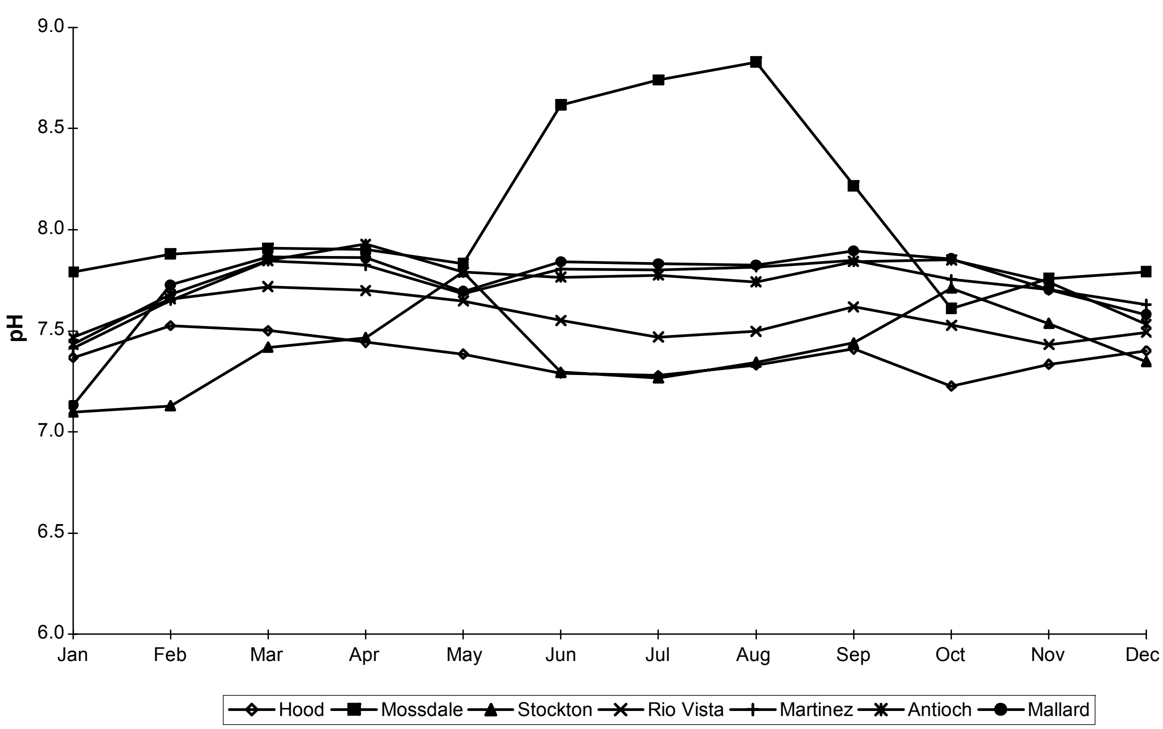


Figure 9-7 Average monthly air temperature at six stations, 2003

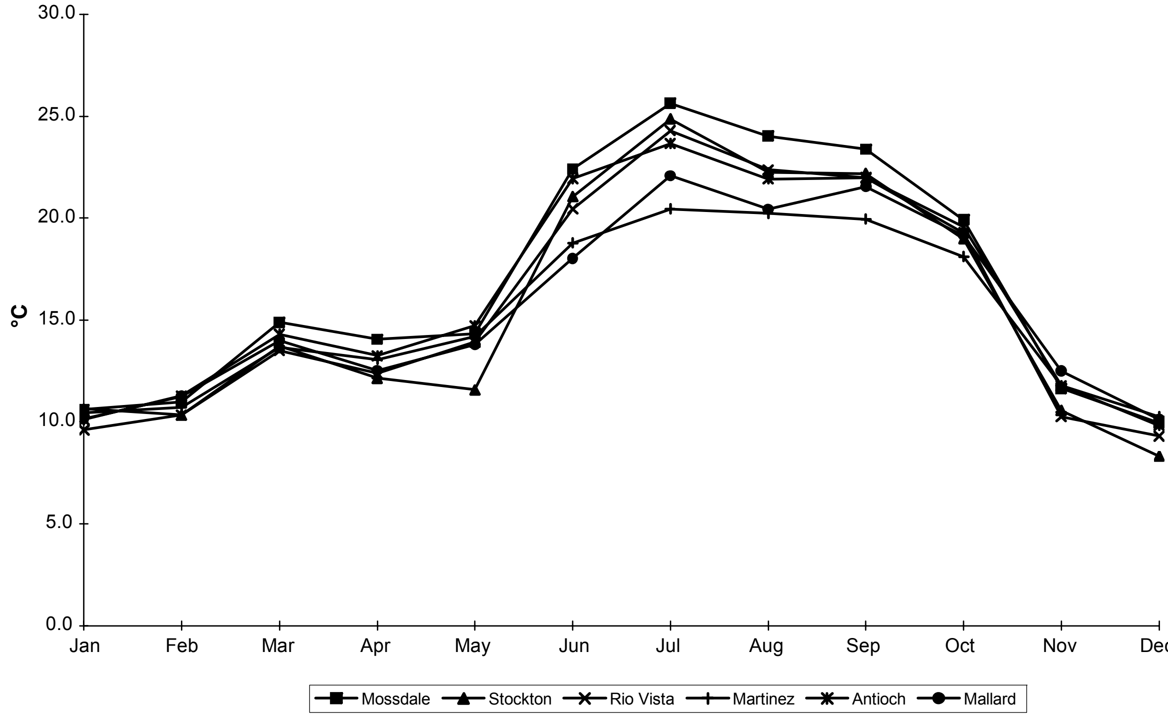


Figure 9-8a Average monthly chlorophyll fluorescence at two Sacramento River stations, 2003

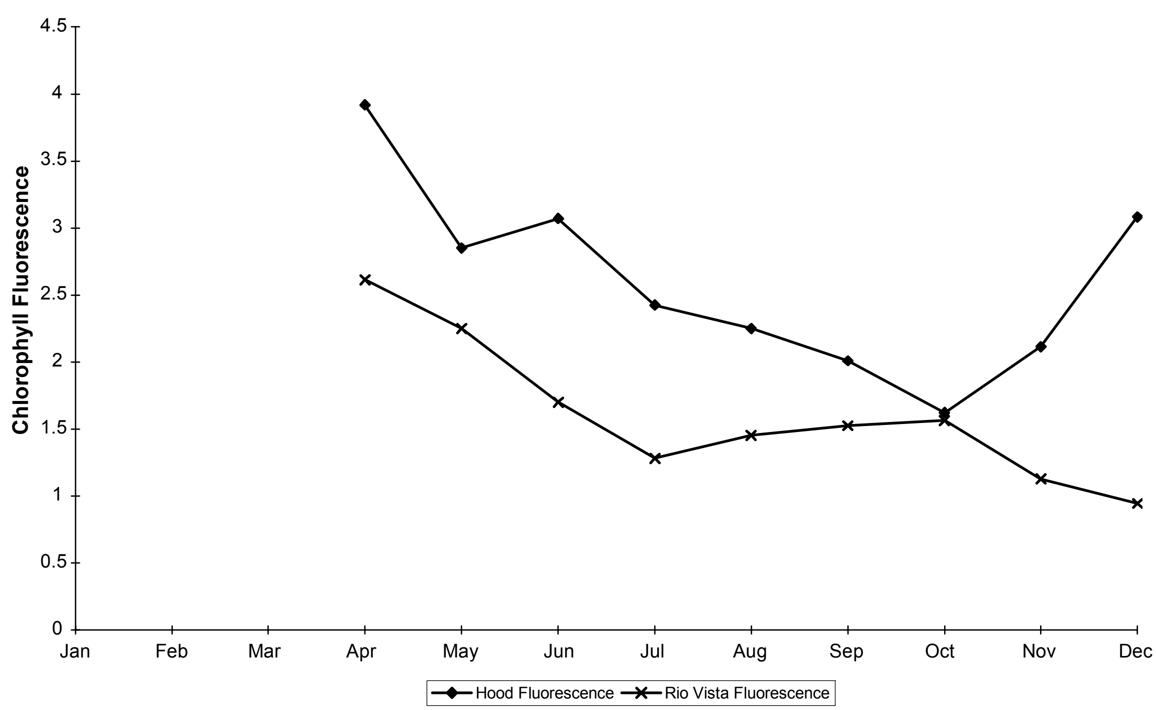


Figure 9-8b Average monthly chlorophyll fluorescence at two San Joaquin River stations, 2003

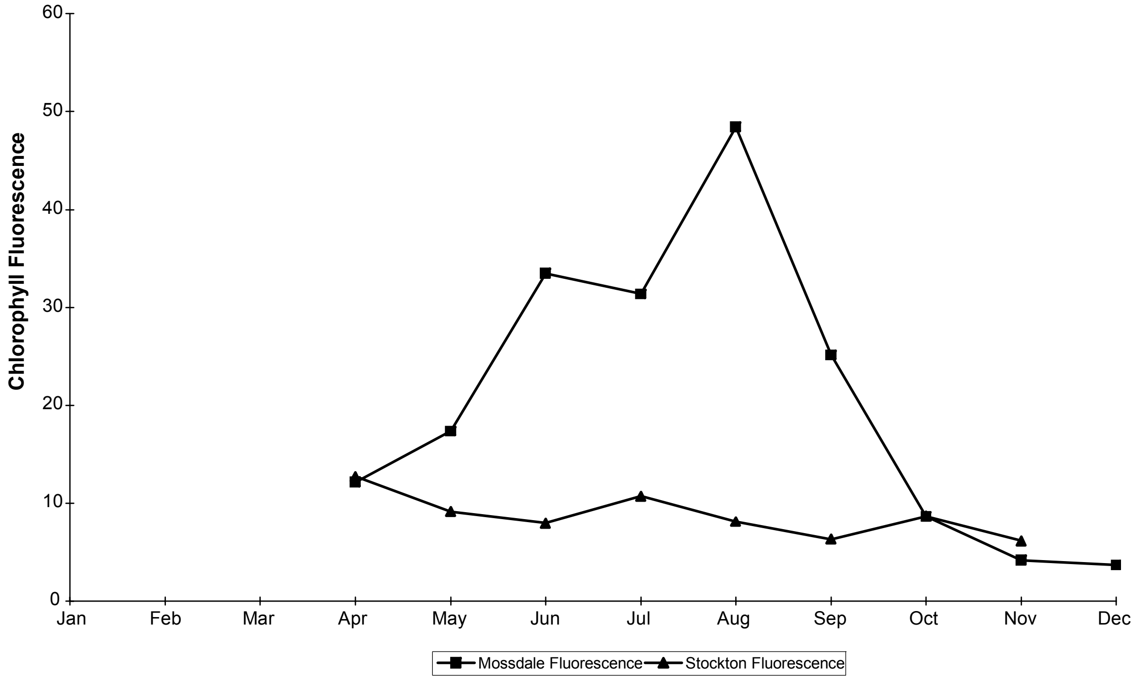


Figure 9-8c Average monthly chlorophyll fluorescence at three tidally influenced stations, 2003

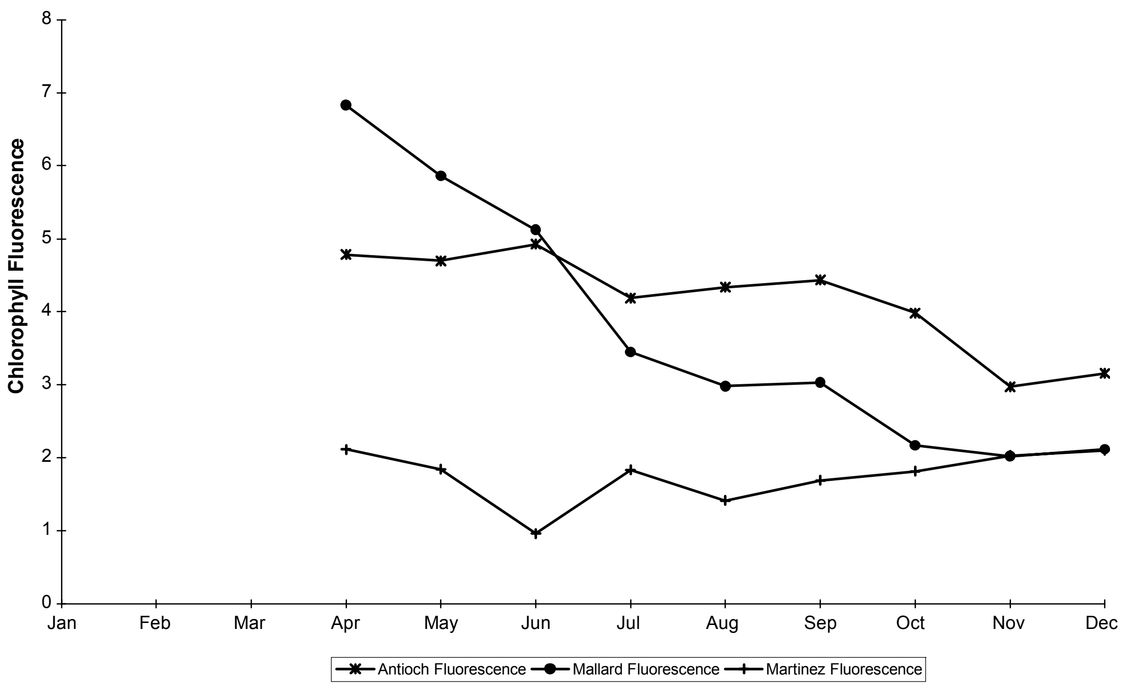


Figure 9-9a Average monthly turbidity at two Sacramento River stations, 2003

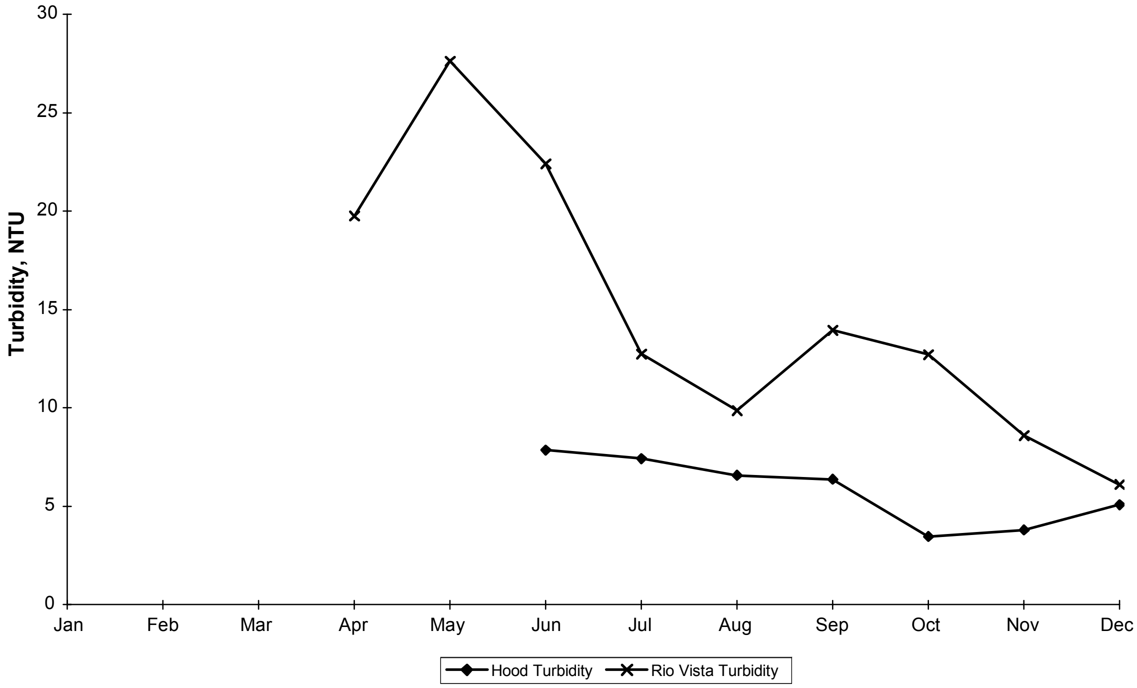


Figure 9-9b Average monthly turbidity at two San Joaquin River stations, 2003

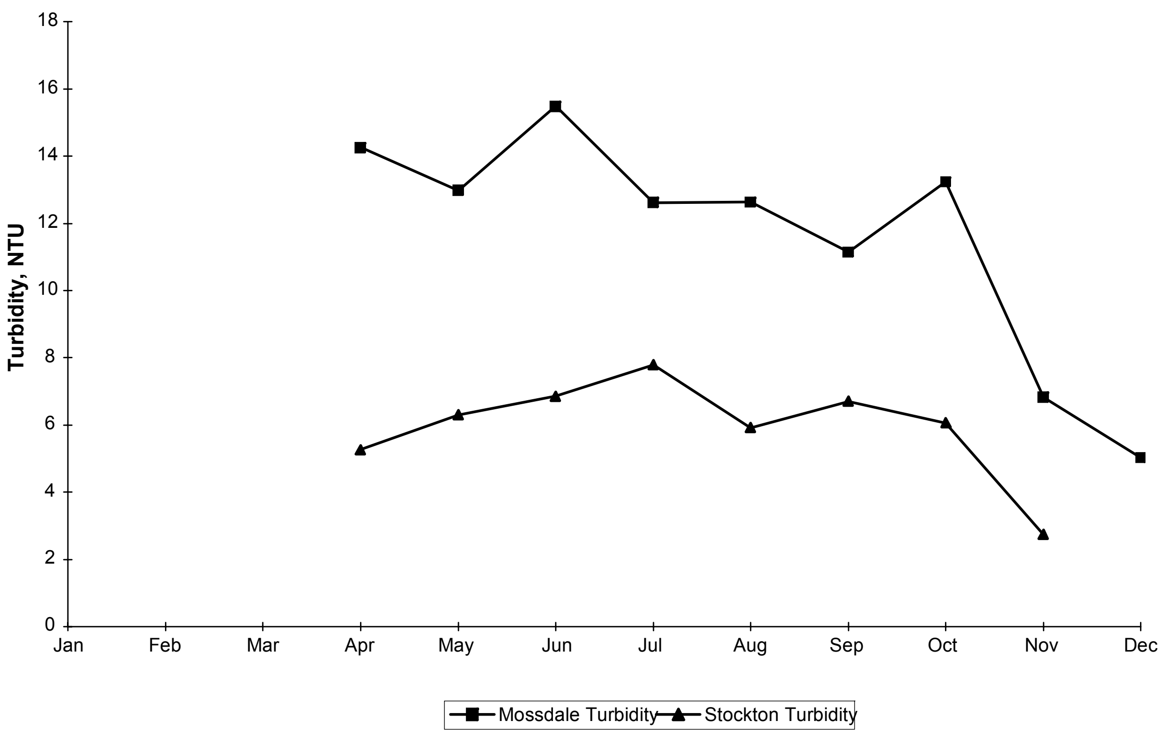


Figure 9-9c Average monthly turbidity at three tidally influenced stations, 2003

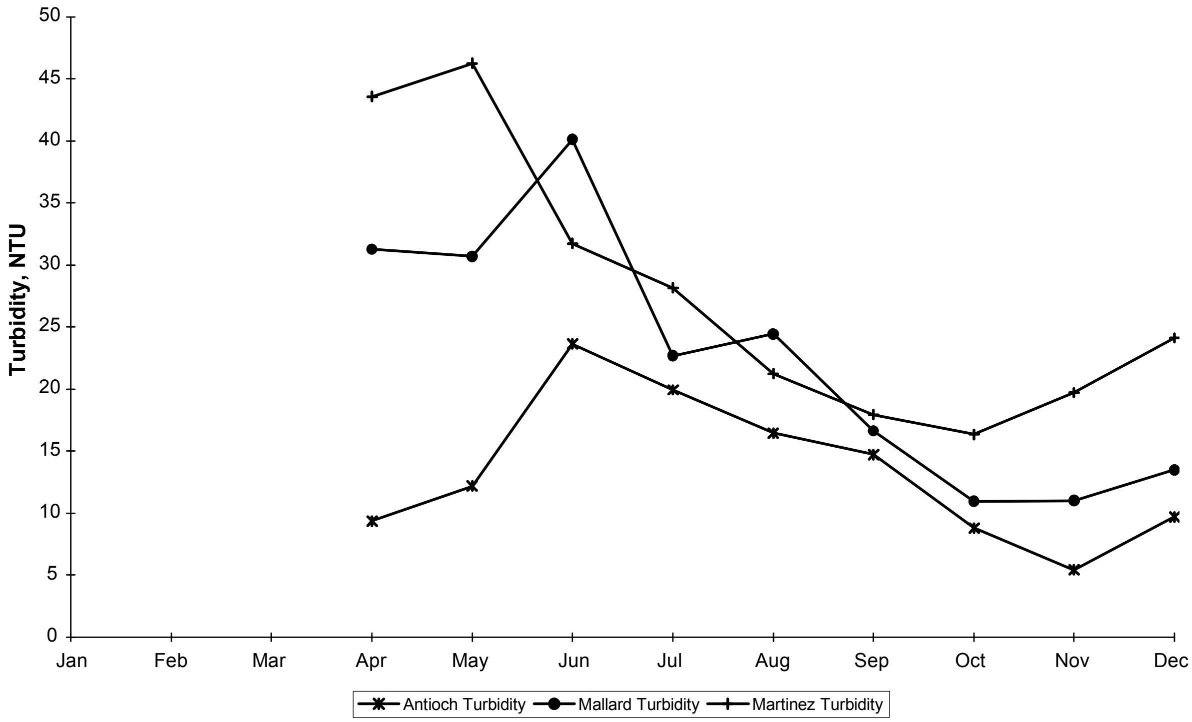


Figure 9-10 Range of monthly dissolved oxygen values at San Joaquin River, Rough and Ready Island, 2003 * Solid boxes when monthly average higher than monthly median

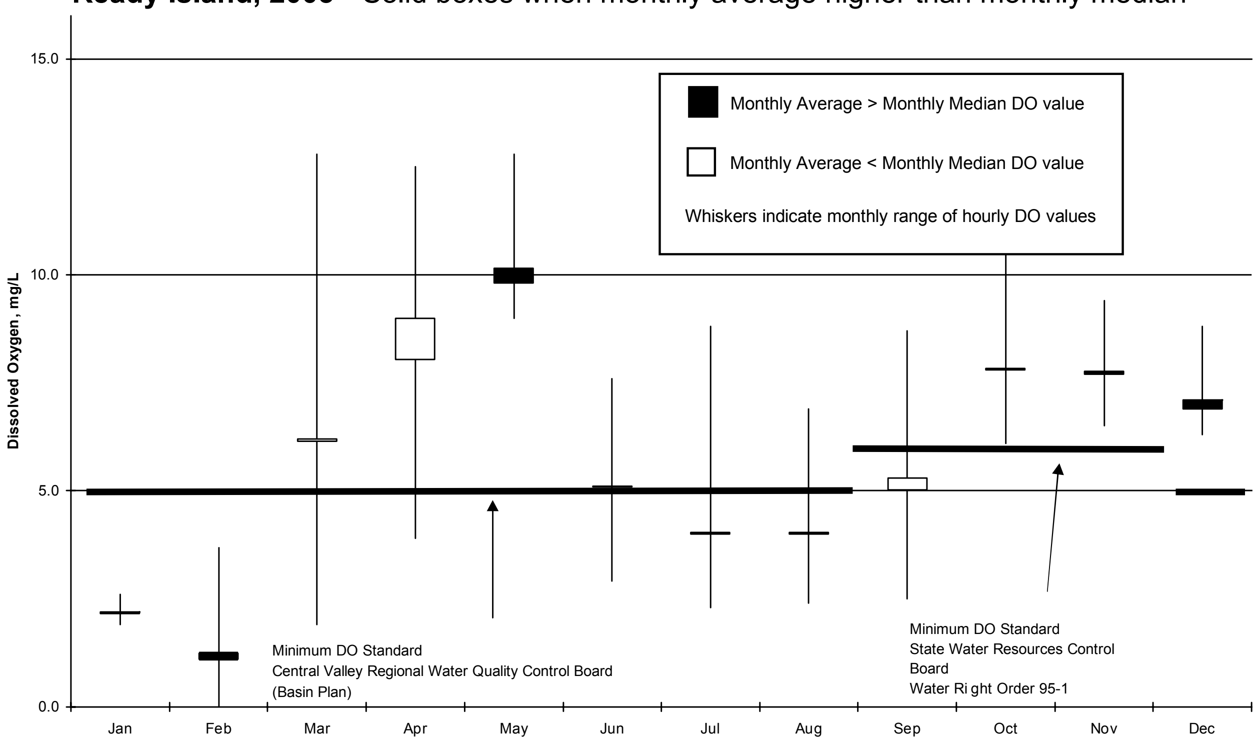


Table 9-1 Parameters measured by the Continuous Monitoring Program

Parameter	Units	Frequency
Water temperature	°C	Hourly average
Air temperature	°C	Hourly average
Dissolved oxygen	mg/L	Hourly average
pH	unitless	Hourly average
Chlorophyll fluorescence	fluorescence units	Hourly average
Surface specific conductance	µS/cm	Hourly average
Bottom specific conductance	µS/cm	15 minute instantaneous
River stage	feet Mean Sea Level (NGVD1929)	15 minute instantaneous
Wind speed	kph	15 minute instantaneous
Wind direction	degrees	15 minute instantaneous
Solar radiation	cal/min/cm^2	15 minute instantaneous