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 2005

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

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Arnold Schwarzenegger
Governor
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Mike Chrisman
Secretary for Resources
The Resources Agency

Lester A. Snow
Director
Department of Water Resources

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 2005. This monitoring is mandated by Water Right Decision 1641 (D-1641) of December 1999 and 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), were 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. 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, or 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 were taken at 13 sampling sites in the Estuary. Chlorophyll *a* and pheophytin concentrations for 2005 showed typical seasonal patterns and were generally below 15 µg/L for most regions. Chlorophyll *a* concentrations ranged between 0.40 µg/L and 21.5 µg/L throughout the Estuary. Zooplankton were collected at 22 sampling sites in the estuary. The introduced *Acanthomysis bowmani* and the *Neomysis kadiakensis/japonica* complex remained the two most abundant mysids, followed by the native *Neomysis mercedis* and *Alienacanthomysis macropsis*. *Pseudodiaptomus forbesi* was the most common calanoid copepod. The native *Acartia* spp. was second, and the introduced *Acartiella sinensis* was third. The three most common cyclopoid copepods remained the introduced *Limnoithona tetraspina* and *Oithona davisae*, followed by the native *Acanthocyclops vernalis.* The three most abundant cladocerans were *Bosmina* spp., *Diaphanosoma* spp., and *Daphnia* spp. *Synchaeta* spp. was the most common rotifer, followed by *Keratella* spp. and *Polyarthra* spp. In 2004, *Polyarthra* spp. was the most common.

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). All organisms collected during 2005 fell into nine phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida and Platyhelminthes. Of these seven phyla, Annelida, Arthropoda, and Mollusca constituted 98.7% of the organisms collected during the study

period. Ten species in these phyla represent 88% of all organisms collected during this period.

DWR also conducted a series of special studies to monitor dissolved oxygen (DO) levels within the Stockton Ship Channel during the late summer and early fall of 2004. The studies were conducted to determine if DO levels dropped below Central Valley Regional Water Quality Control Board (5.0 mg/L) and State Water Resources Control Board (6.0 mg/L) water quality objectives established for the channel. Monitoring was typically conducted biweekly from August 3 to November 15 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 4.1 mg/L to 8.9 mg/L and consistently fell below both the 5.0 mg/L and 6.0 mg/L objectives in 2005 probably due, in part, to relatively low net flows in the San Joaquin River past Stockton and to warm water temperatures.

Dr. Dean Messer, Chief
Bay-Delta Monitoring and Analysis Section
Division of Environmental Services

Contents

Figures

Tables

This report was prepared under the supervision of

Dean F. Messer
Chief, Bay-Delta Monitoring and Analysis Section

By

Rachel Barnett .... Fish and Wildlife Scientific Aide
Tiffany Brown .... Environmental Scientist
Michael Dempsey .... Control System Tech. II
Karen Gehrts .... Environmental Scientist
Kathy Hieb .... Associate Fisheries Biologist
Brianne Noble .... Environmental Scientist
Marc Vayssières .... Environmental Scientist

With assistance from:

Nick Sakata .... Mate, Research Vessel
Eric Santos .... Chief Engineer, Fisheries Vessel
Gregg Schmidt .... Mate, Fisheries Vessel
Scott Waller .... Water Resources Engineering Associate

Editorial and design services were provided by

Nikki Blomquist .... Research Writer, Division of Planning and Local Assistance

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 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 macrobenthic 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 are 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 2005*, summarizes the findings of the EMP for calendar year 2005. 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.

[1] For specific questions regarding availability of 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 e-mail: kjacobs@water.ca.gov.

Chapter 2. Hydrologic Conditions

Introduction

Hydrologic conditions are typically discussed using water years. Therefore, the 2005 period covered by this report will cover the period from October 2004 to September 2005, unless otherwise noted.

Methods

Water years are classified using the Sacramento Valley 40-30-30 Water Year Hydrological Classification Index[1,2] (the Sacramento Valley Index) and the San Joaquin Valley 60-20-20 Water Year Hydrological Classification Index[3,4] (the San Joaquin Valley Index) (SWRCB 1999). The Sacramento Valley Index is used to characterize water years statewide because the predominance of precipitation falls within the northern half of the state and much of that precipitation flows down the Sacramento River through the upper San Francisco Estuary. The index is also used because the Sacramento River watershed provides the majority of water to the State Water Project and to the Central Valley Project (SWRCB 1999). Using this index[5], water year 2005 was classified as above normal. Although the San Joaquin Valley Index is used predominantly for regional applications, it provides supporting information concerning water conditions within the San Joaquin Valley. Using the San Joaquin Valley Index[6], water year 2005 was classified as wet. Figures 2-1 and 2-2 summarize these findings and include the prior 10 years for reference.

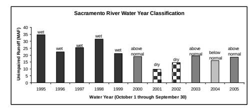

Figure 2-1 Sacramento River Hydrologic Region 40-30-30 Indices from 1995 through 2005

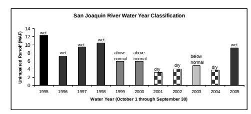

Figure 2-2 San Joaquin River Hydrologic Region 60-20-20 Indices from 1995 through 2005

Summary

Water year 2005 was classified as above normal for precipitation, below normal for seasonal runoff, above normal for reservoir storage, and above

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1 The Sacramento Valley 40-30-30 Water Year Hydrological Index is equal to 0.4X current April to July unimpaired runoff + 0.3X current October to March unimpaired runoff + 0.3X 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 60-20-20 Water Year Hydrological Classification Index is equal to 0.6X current April to July unimpaired runoff + 0.2X current October to March unimpaired runoff + 0.2X 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 that 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 is 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).

normal for snow water content. Statewide figures for May 1 are summarized in Table 2-1 and include the prior four years for reference.

Accounting for precipitation, runoff, reservoir storage, and snowpack water content, unimpaired runoff for the Sacramento River was above normal for 2005. Unimpaired runoff for the San Joaquin River was high for 2005. Table 2-2 summarizes these conditions and Figure 2-3 demonstrates these flow periods. The prior 10 years are included for reference.

The Net Delta Outflow Index[7] (Figure 2-4) is used to determine the freshwater outflow from the San Francisco Estuary. Much of the water that flows through the estuary does so during the late winter and early spring months. Water year 2005 had maximum Delta outflow indices exceeding 3,100,000 acre-feet in March and minimum outflow indices approaching 345,000 acre-feet in August.

Water Year	*Precipitation (% of normal)*	*Seasonal Runoff (% of normal)*	*Reservoir Storage (% of normal)*	*Snow Water Content (% of normal)*
2001	75	45	100	65
2002	80	80	100	60
2003	110	100	105	105
2004	90	90	100	50
2005	135	80	105	150

Table 2-1 Summary of the major hydrologic characteristics of water years 2001-2005

	Sacramento River				*San Joaquin River*		
Year	*Oct 1.-Mar. 30 (MAF)*	*Apr. 1-Jul. 30 (MAF)*	*Whole Year (MAF)*	*Year*	*Oct. 1-Mar. 30 (MAF)*	*Apr. 1-Jul. 30 (MAF)*	*Whole Year (MAF)*
2001	5.64	3.46	9.81	2001	0.92	2.23	3.18
2002	9.32	4.57	14.6	2002	1.27	2.75	4.06
2003	10.71	7.74	19.31	2003	1.25	3.49	4.87
2004	10.95	4.4	16.04	2004	1.51	2.25	3.81
2005	8.3	9.29	18.44	2005	2.73	6.3	9.25

Table 2-2 Average runoff for water years 2001, 2002, 2003, 2004, and 2005

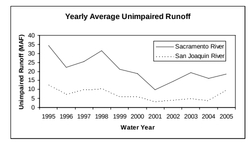


Figure 2-3 Unimpaired runoff for the Sacramento and San Joaquin Rivers for water years 1995-2005

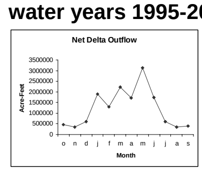


Figure 2-4 Net Delta Outflow Indices, 2005

References

[CDEC] California Data Exchange Center. 2005. [online] Available via the Internet at http://cdec.water.ca.gov [accessed February 2006].

[DWR] Department of Water Resources, 2004. *Water Conditions California. California Cooperative Snow Surveys Bulletin 120.* Reports 1-4. Department of Water Resources, Sacramento, CA.

[DWR] Department of Water Resources, 2006. WY 2002-2005 totals. Personal comm. Tracy Hinojosa, Chief of Compliance and Modeling Section, Division of Operations and Maintenance.

[SWRCB] State Water Resources Control Board, 1999. Water Rights Decision 1641. State Water Resources Control Board, Sacramento, CA.

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

Figure 2-1 Sacramento River Hydrologic Region 40-30-30 Indices from 1995 through 2005

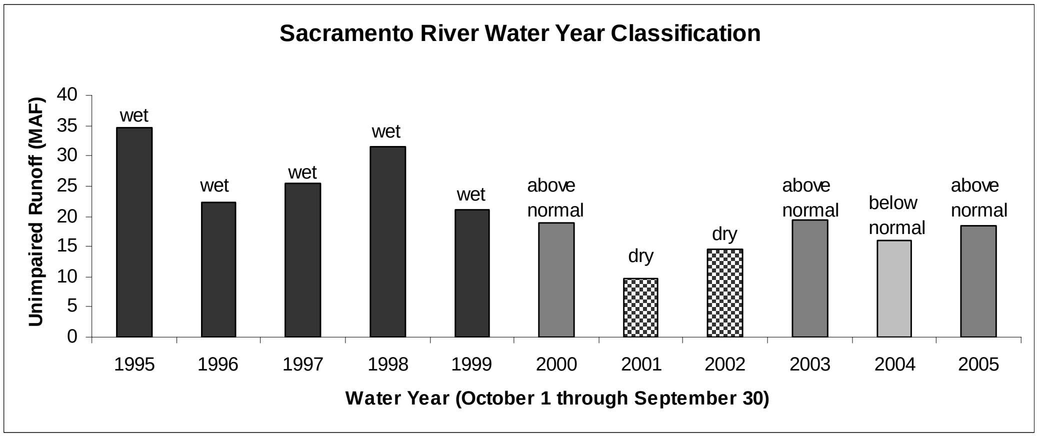
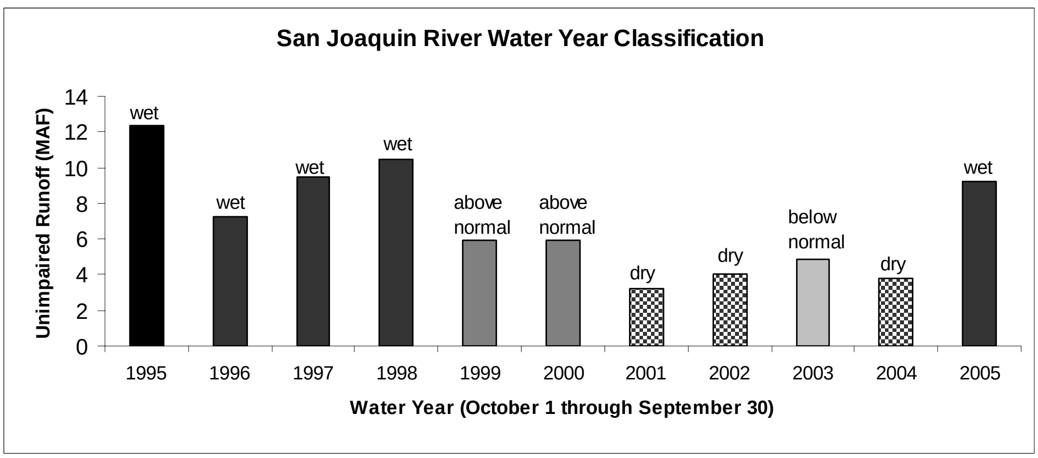


Figure 2-2 San Joaquin River Hydrologic Region 60-20-20 Indices from 1995 through 2005



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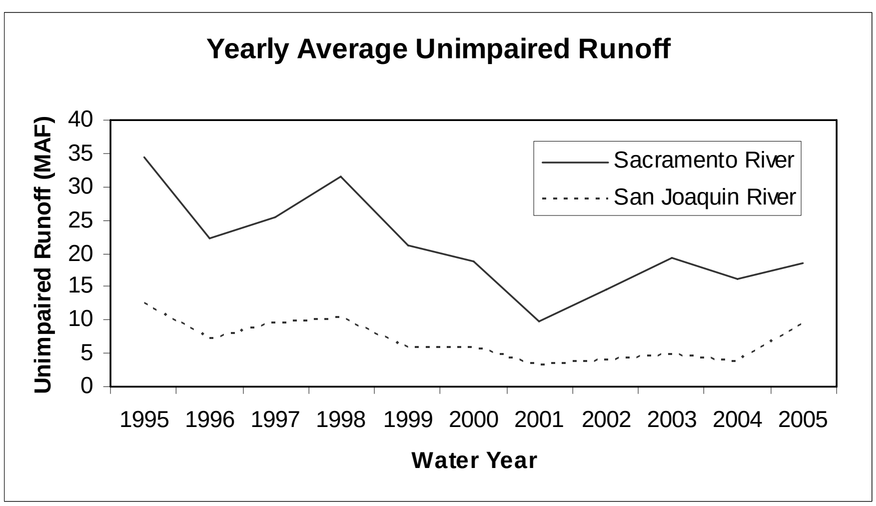
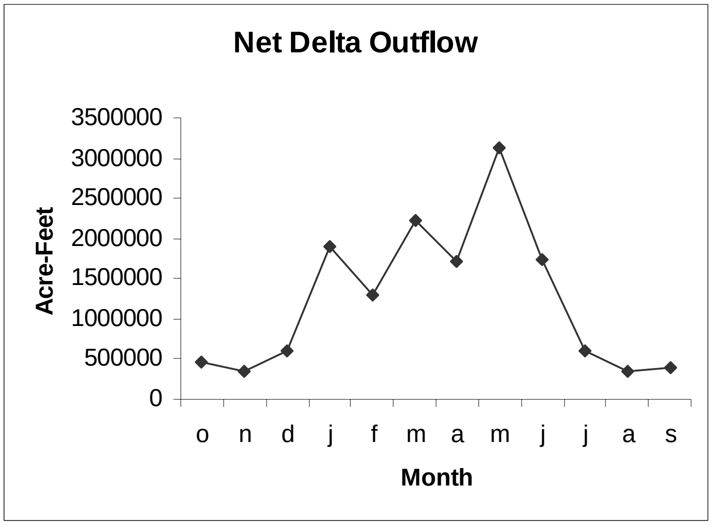


Figure 2-4 Net Delta Outflow Indices, 2005



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2004	10.95	4.4	16.04	2004	1.51	2.25	3.81
2005	8.3	9.29	18.44	2005	2.73	6.3	9.25

Chapter 3. Water Quality Monitoring

Introduction

Water quality monitoring in 2005 continued according to the amended protocol implemented by the Department of Water Resources (DWR) in 1996, with the incorporation of a few changes recommended by the 2001-2002 Environmental Monitoring Program (EMP) review (http://www.iep.ca.gov/emp/EMP_Review_Final.html). Discrete water quality sampling sites included the 11 representative sites described in the 1996 water quality report (DWR 2001), with the addition of two more sampling sites in May 2004, a move from station C3 to C3A in November 2004, and a move from station C10 to C10A in 2005.

Figure 3-1 Discrete water quality sampling stations

Discrete samples were taken monthly at each site (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 the 15 physical and chemical parameters shown in Table 3-1. The complete database is available online at http://baydelta.water.ca.gov.

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

As shown in Table 3-2, 13 sampling sites were used in this study to represent eight regions of the Bay-Delta system. In previous reports, data from multiple sample sites within each region were averaged using the hierarchical cluster analysis protocol; however, for clarity, data results in this report are shown for each sample site.

Region	Sampling Sites
Lower Sacramento River	D4
Lower San Joaquin River	D26 and D19
North Delta	C3A
Central Delta	D28A
East Delta	MD10A
South Delta	C10A and P8
Suisun Bay	D6, D7 and D8
San Pablo Bay	D41 and D41A

Table 3-2 Water quality sampling sites and regions

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 north and south Delta (C3A and C10A, respectively). Secchi disk depth is not taken at site C10A due to restrictions of the sample site, which requires sampling equipment to be deployed from 50 feet above the water's surface.

Water Temperature

Water temperature was measured in degrees Celsius (°C) with a YSI thermistor. For all sites except the south Delta, temperatures were measured from water collected at a depth of 1 meter. In the south Delta, temperatures were measured by submerging the YSI thermistor to a 1-meter depth.

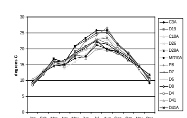


Figure 3-2 Water temperature

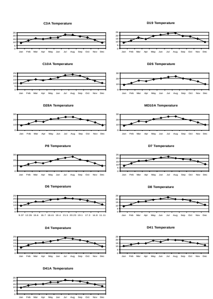


Figure 3-3 Water temperature (°C)

A water temperature minimum of 8.5 °C was recorded in January 2005 at station D7 in the Suisun Bay (Figures 3-2 and 3-3). This minimum temperature represents a decrease of 0.9 °C from the previously recorded minimum for the 2004 study period (DWR 2006).

Temperature minima at most sites during 2005 occurred during the months of January and December. The timing of these temperature minima is the same as the 2004 study period (DWR 2006).

A water temperature maximum of 26.6 °C was recorded in August at station P8 in the south Delta. This maximum is a 0.2 °C increase over the temperature maximum reported for the 2004 study period (DWR 2006). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

Dissolved Oxygen

Dissolved oxygen was measured using the modified Winkler iodometric method described in Standard Methods (APHA 1992). A sample aliquot was collected at a depth of 1 meter. The samples were collected in 300-mL glass-stoppered bottles and immediately analyzed.

During 2005, dissolved oxygen concentrations ranged from 4.5 mg/L at site P8 in the south Delta in August to 10.9 mg/L at site MD10A in the east Delta in April (Figures 3-4 and 3-5). Seasonal trends were evident in most regions, with dissolved oxygen concentrations decreasing during the summer and rising in the winter. Reduced summer DO levels coincided with warmer water temperatures.

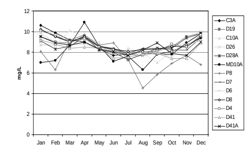


Figure 3-4 Dissolved oxygen

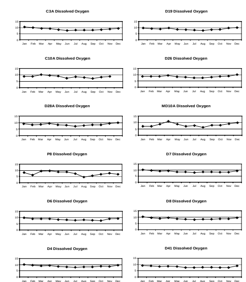


Figure 3-5 Dissolved oxygen (mg/L)

Specific Conductance

Specific conductance, an estimate of salinity, was determined from samples collected at a depth of 1 meter. The samples were analyzed for specific conductance using a Seabird model CTD 911+ data logger with temperature compensation set to 25 °C.

Specific conductance varied greatly between sites monitored, ranging from 127 µS/cm at site D26 in the lower San Joaquin River in June to 43,303 µS/cm at site D41 in San Pablo Bay in October (Figures 3-6 and 3-7). This range of specific conductance was slightly less than the 120-43,495 µS/cm range reported for the 2004 study period (DWR 2006).

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

Sites with high average specific conductivity—such as D4, D6, D7, D8, D41 and D41A—tended to show stronger seasonal variations, with specific conductance varying from lows in May and June to highs in October and November. At sites with lower specific conductance, this seasonal trend was less apparent.

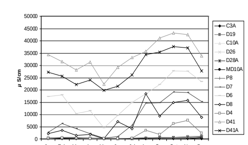


Figure 3-6 Specific conductance

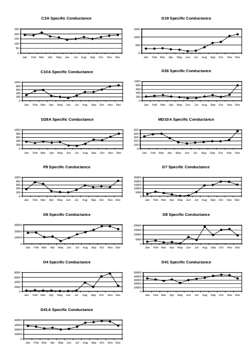


Figure 3-7 Specific conductance (µ/cm)

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 centimeters. 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.

A Secchi depth minimum of 20 cm was recorded at sampling site D7 in the Suisun Bay in May (Figures 3-8 and 3-9). A Secchi depth maximum of 192 cm was recorded at sampling site D28A in the central Delta in September. By comparison, Secchi values during 2004 ranged from 14 to 182 cm (DWR 2006).

Secchi disk depth varied considerably at all sites with little apparent seasonal correlation. Average Secchi depths were lowest at sites D6, D7, D8, and D4, while sites D28A, MD10A, D19, and D41 had the highest overall average Secchi depths.

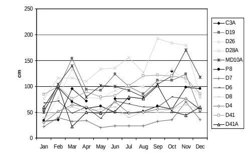


Figure 3-8 Secchi depth

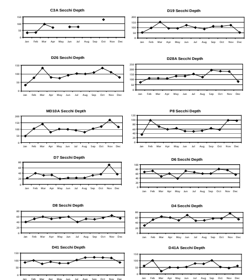


Figure 3-9 Secchi depth (cm)

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 1-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). Turbidity was measured at sites C3A and C10A from a grab sample using a Hawk 2100P Turbidimeter.

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 1.5 NTU at site D28A (central Delta region) in August to 127 NTU at site C10A (south Delta region) in January. This range of turbidity was greater than the 3.7 to 85.6 NTU range reported for 2004 (DWR 2006).

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

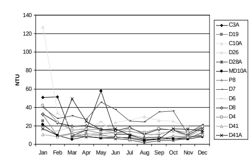


Figure 3-10 Turbidity

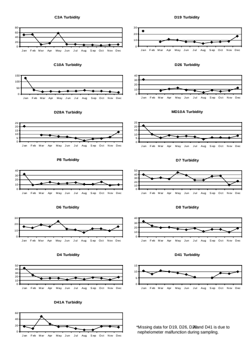


Figure 3-11 Turbidity (NTU)

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 frozen immediately and later transported to Bryte Laboratory[1] for analysis according to the

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

US Environmental Protection Agency (1983) colorimetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate was 0.01 mg/L.

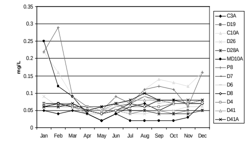


Figure 3-12 Orthophosphate

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest values, recorded at station MD10A from July through October and station C3A in May, showed orthophosphate levels at 0.02 mg/L. The 2004 study period also showed the lowest values (0.02 mg/L) of orthophosphate occurring at site MD10A (DWR 2006).

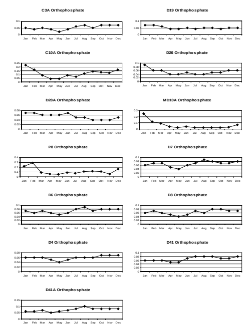


Figure 3-13 Orthophosphate (mg/L)

The highest value of orthophosphate, 0.29 mg/L, was recorded at site P8 in the south Delta in February 2005. In the 2004 study period, site P8 also showed the highest orthophosphate concentration (0.48 mg/L) in February (DWR 2006).

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

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 frozen immediately and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colorimetric semi-automated method 365.4. The minimum reporting limit for total phosphorus was 0.01 mg/L.

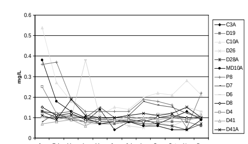


Figure 3-14 Total phosphorus

Values for total phosphorus varied considerably between sites and across seasons (Figures 3-14 and 3-15) and showed distributions similar to those reported for orthophosphate. The lowest value of 0.04 mg/L was recorded at site C3A in June, site D28A in November, and site MD10A in October and November. This value is slightly higher than the minimum value of 0.03 mg/L recorded for the 2004 study period at site MD10A in November (DWR 2006). A maximum value of 0.54 mg/L was recorded at site C10A in January 2005. This value is slightly lower than the maximum value recorded during the 2004 study period of 0.58 mg/L at site P8 in February (DWR 2006).

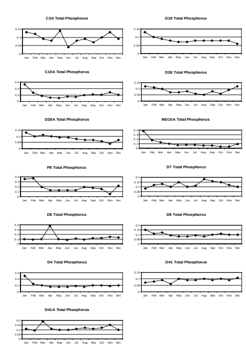


Figure 3-15 Total phosphorus (mg/L)

Except for sites D4, D6, P8, MD10A and C10A, total phosphorus levels did not exceed 0.19 mg/L during 2005. This is in contrast to the 2004 study period, where sites P8, MD10A, and C10 exceeded 0.19 mg/L (DWR 2006).

Kjeldahl Nitrogen

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

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 frozen immediately and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colorimetric semi-automated method 352.1. The minimum reporting limit for Kjeldahl nitrogen is 0.01 mg/L.

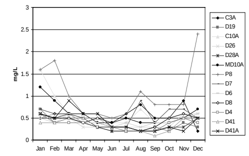


Figure 3-16 Kjeldahl nitrogen

Kjeldahl nitrogen concentrations ranged from 2.4 mg/L at station P8 in the south Delta in December to 0.1 mg/L at site D41 in September 2005 (Figures 3-16 and 3-17). Kjeldahl nitrogen levels during the 2004 study period also peaked at site P8 with a high of 3.8 mg/L (DWR 2006). Minimum levels for the 2005 study period were greater than those for the 2004 study period, which had lows below the 0.01 mg/L reporting limit (DWR 2006).

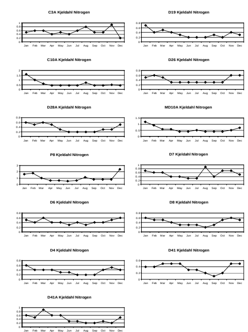


Figure 3-17 Kjeldahl nitrogen (mg/L)

Kjeldahl nitrogen concentrations were generally highest in the south and east Delta regions (Sites P8, C10, and MD10A). No strong seasonal or interannual trends were apparent among all the sites.

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is a measure of total ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2), which are 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 frozen immediately and later transported to Bryte Laboratory for analysis for total ammonia according to the USEPA (1983) colorimetric, automated, phenate method 350.1; and for nitrate and nitrite according to the colorimetric automated cadmium reduction method 353.2 (USEPA 1983). DIN was calculated as the sum of total ammonia plus nitrate and nitrite. The minimum reporting limit for inorganic nitrogen was 0.01 mg/L.

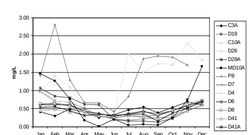


Figure 3-18 Dissolved inorganic nitrogen

Dissolved inorganic nitrogen concentrations ranged from 2.8 mg/L in the south Delta (site P8) in February to 0.01 mg/L in the east Delta (site MD10A) in May (Figures 3-18 and 3-19). This range is smaller than the 2004 study period, which recorded a maximum of 5.7 mg/L at station P8 and a minimum value of 0.01 mg/L at station MD10A.

Dissolved inorganic nitrogen values were consistently high in the south Delta stations C10A and P8, as compared to other stations. In contrast, all other stations had most DIN values below 1.0 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.

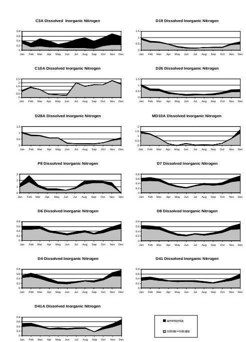


Figure 3-19 Dissolved inorganic nitrogen

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.

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).

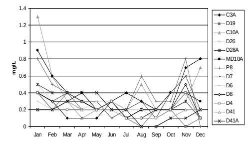


Figure 3-20 Dissolved organic nitrogen

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 frozen immediately and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colorimetric, semi-automated method 351.2. The minimum reporting limit for DON was 0.10 mg/L.

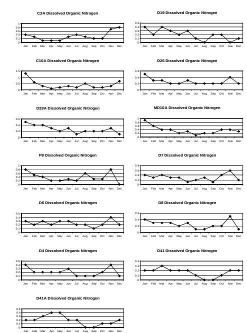


Figure 3-21 Dissolved organic nitrogen (mg/L)

DON concentrations ranged from 1.3 mg/L at station C10A in January to concentrations below detectable levels (< 0.10 mg/L) at stations D41 and D41A in August and September, station P8 in December, and station D19 in August and November 2005 (Figures 3-20 and 3-21). Peak DON levels during the 2004 study period were considerably higher, reaching 2.4 mg/L at station P8 in January 2004 (DWR 2006).

DON concentrations showed no clear seasonal or inter-annual pattern of variation; however, most sites showed increases in DON concentrations during the winter.

Total Dissolved Solids

Total dissolved solids (TDS) are 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).

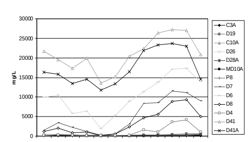


Figure 3-22 Total dissolved solids

Total dissolved solids 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 frozen immediately and later transported to Bryte Laboratory for analysis, using USEPA (1983) method 160.1.

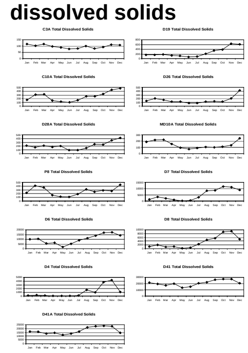


Figure 3-23 Total dissolved solids (mg/L)

TDS in the Bay-Delta varied over a wide range from 27,200 mg/L in the San Pablo Bay (site D41) in October to 71 mg/L in the east Delta (site MD10A) in June (Figures 3-22 and 3-23). The values covered a slightly smaller range than the 2004 study period, which had a range of 28,840 mg/L to 67 mg/L. The high values seen in San Pablo and Suisun bays and the western Delta are likely due to tidal influences; e.g. seawater entering the bays and, eventually, the Delta. The lower TDS values seen at site MD10A are due to spring flows of low TDS freshwater entering the Delta from the Sacramento Valley basin.

All sites subject to significant tidal exchange (sites D41, D41A, D6, D7, D8, and D4) showed increasing TDS concentrations the closer they were to the coast. These sites also showed high seasonal variability in TDS concentrations. For these sites, low TDS values occurred in May and the highest values occurred in the fall.

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.

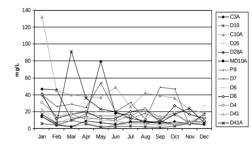


Figure 3-24 Total suspended solids

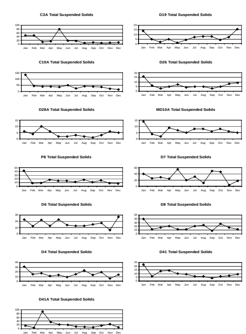


Figure 3-25 Total suspended solids (mg/L)

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 USEPA (1983) method 160.2.

TSS in the San Francisco Bay-Delta varied over a wide range, from 132 mg/L at station C10A in January to 1.0 mg/L at station D28A in September (Figures 3-24 and 3-25). These results are in contrast to the 2004 study period, when the highest TSS value was recorded in the north Delta (97 mg/L) and the lowest TSS value was 3.0 mg/L in the central Delta (DWR 2006).

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.

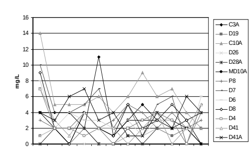


Figure 3-26 Volatile suspended solids

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.

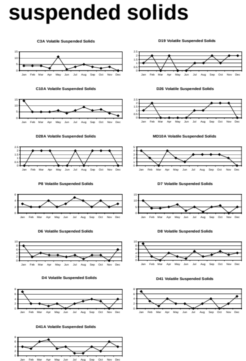


Figure 3-27 Volatile suspended solids (mg/L)

VSS levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions and reached a high of 14.0 mg/L in the south Delta (site C10A) in January (Figures 3-26 and 3-27). These results were similar to those observed in the 2004 reporting period (DWR 2006). Most sites showed a high degree of variability with no apparent seasonal trends.

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 29.1 mg/L at site D41A in February to 5.6 mg/L at site D41 in September (Figures 3-28 and 3-29). These values are in contrast to those observed in the 2004 reporting period, with a range of 19.5 mg/L at site D4 in March to 2.0 mg/L at site D6 in November (DWR 2006). A slight seasonal trend of declining silica levels in spring months followed by increased silica concentrations in late summer was observed at the majority of sites.

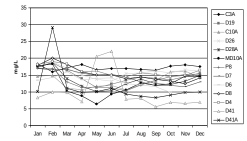


Figure 3-28 Silica

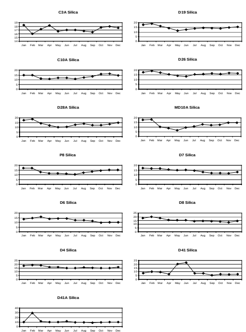


Figure 3-29 Silica (mg/L)

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 16,200 mg/L in San Pablo Bay (site D41) in September to 5 mg/L in the north Delta (site C3A) in June (Figures 3-30 and 3-31). These results are very similar to those observed in the 2004 reporting period, which recorded a high of 15,800 mg/L chloride in the San Pablo Bay (site D41) in October and a low of 3 mg/L in the north Delta (site C3) in April (DWR 2006). The high values seen in San Pablo and Suisun bays and the western Delta are likely due to tidal influences; e.g. seawater entering the bays and, eventually, the Delta, while the low values seen at site C3A are likely due to spring flows of freshwater down the Sacramento River. Values of chloride concentrations are closely correlated to the values reported for specific conductance and total dissolved solids (TDS) reported earlier in this chapter.

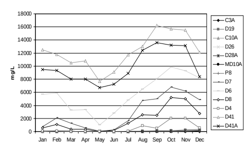


Figure 3-30 Chloride

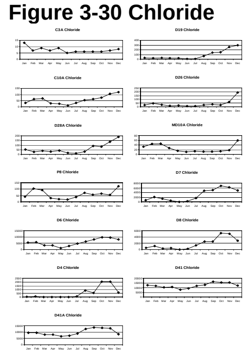


Figure 3-31 Chloride (mg/L)

Summary

DWR has a mandate to monitor and report water quality data 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. Influenced by natural forces and project operations, flow rates are a primary determinant of water quality dynamics at each site described. 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. 2006. *Water Quality Conditions in the Sacramento-San Joaquin Delta and San Pablo and Suisun Bays during 2004.*

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

Figure 3-1 Discrete water quality sampling stations

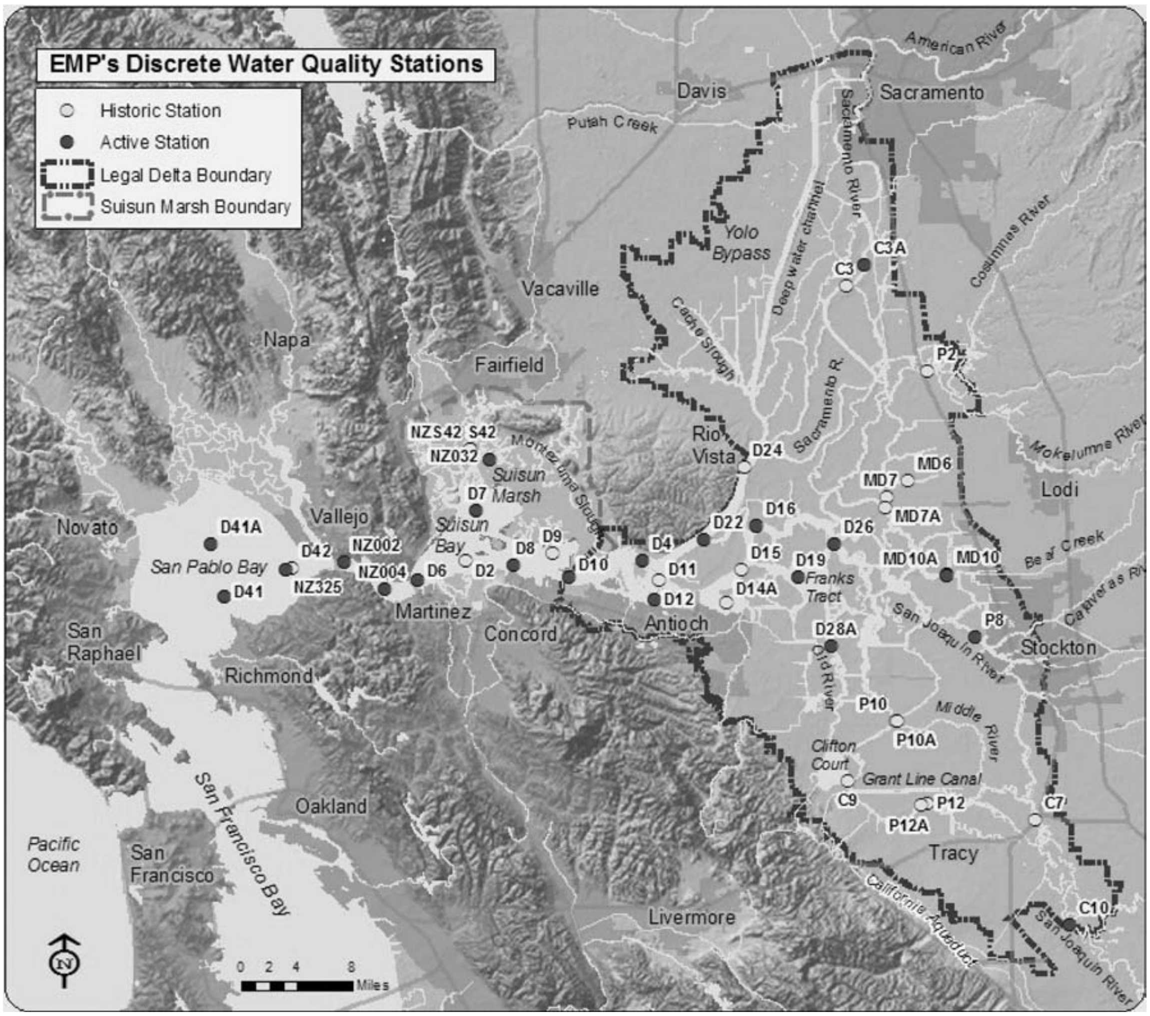


Figure 3-2 Water temperature

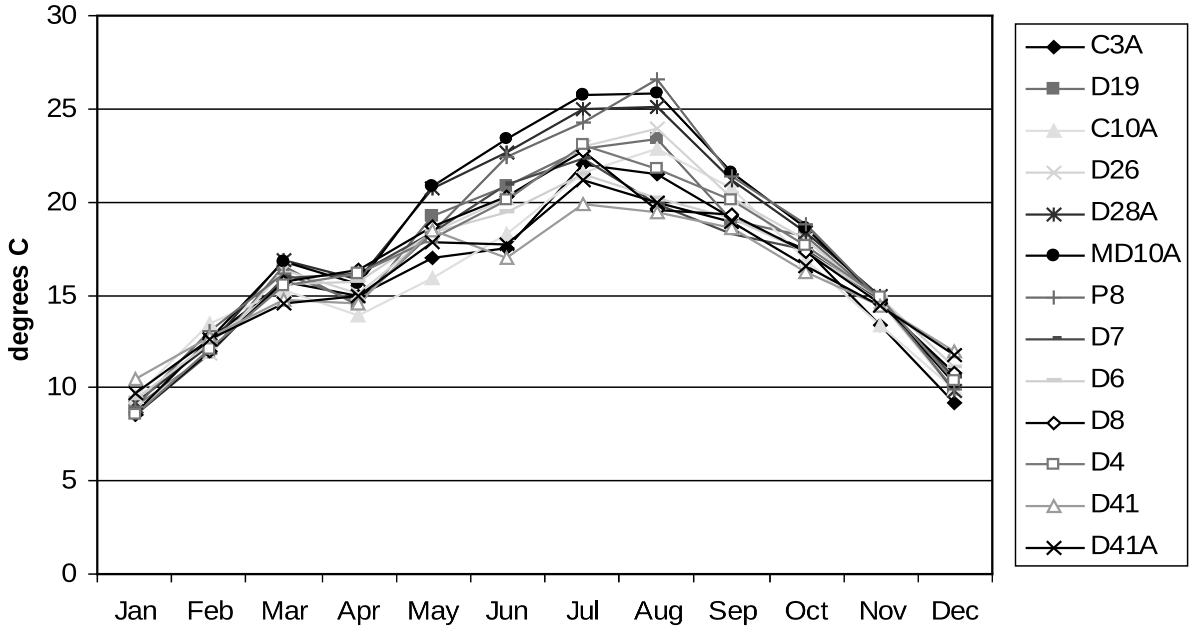


Figure 3-3 Water temperature (°C)

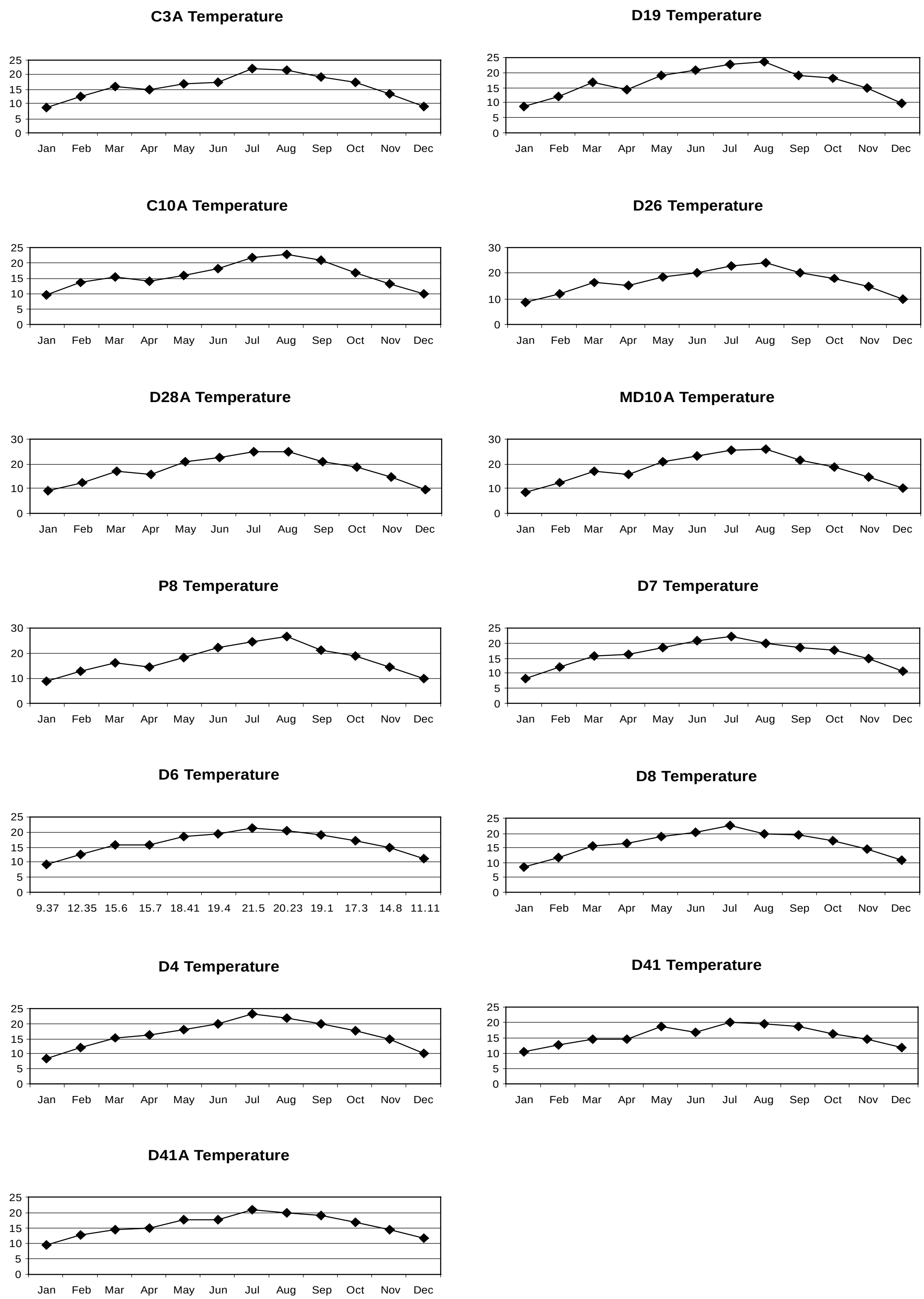


Figure 3-4 Dissolved oxygen

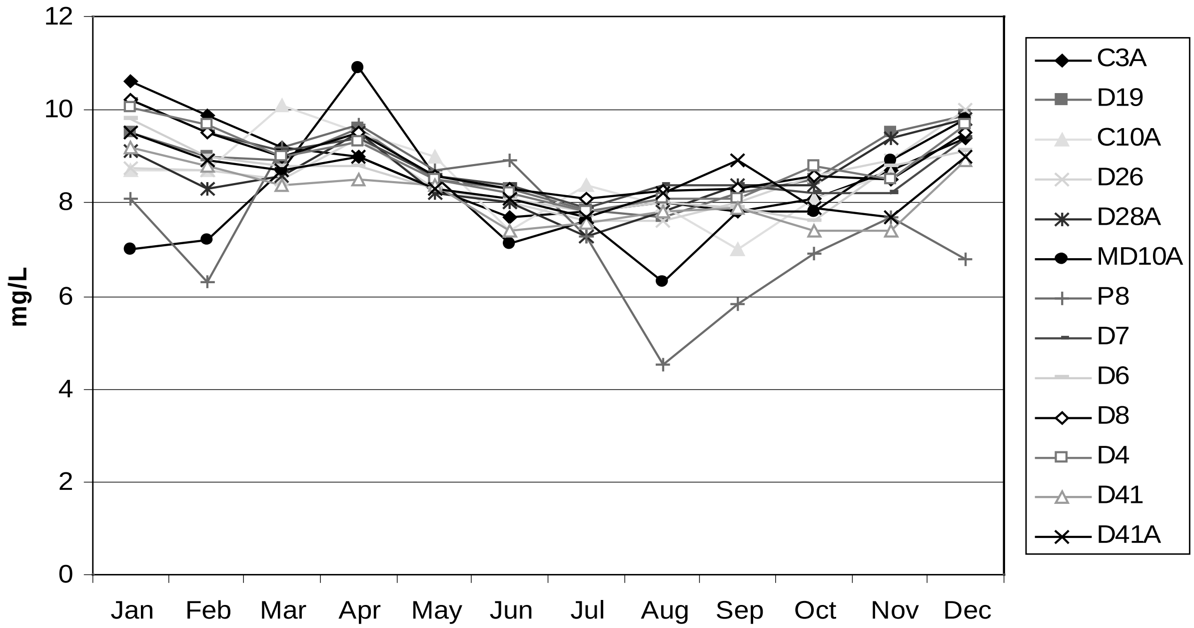


Figure 3-5 Dissolved oxygen (mg/L)

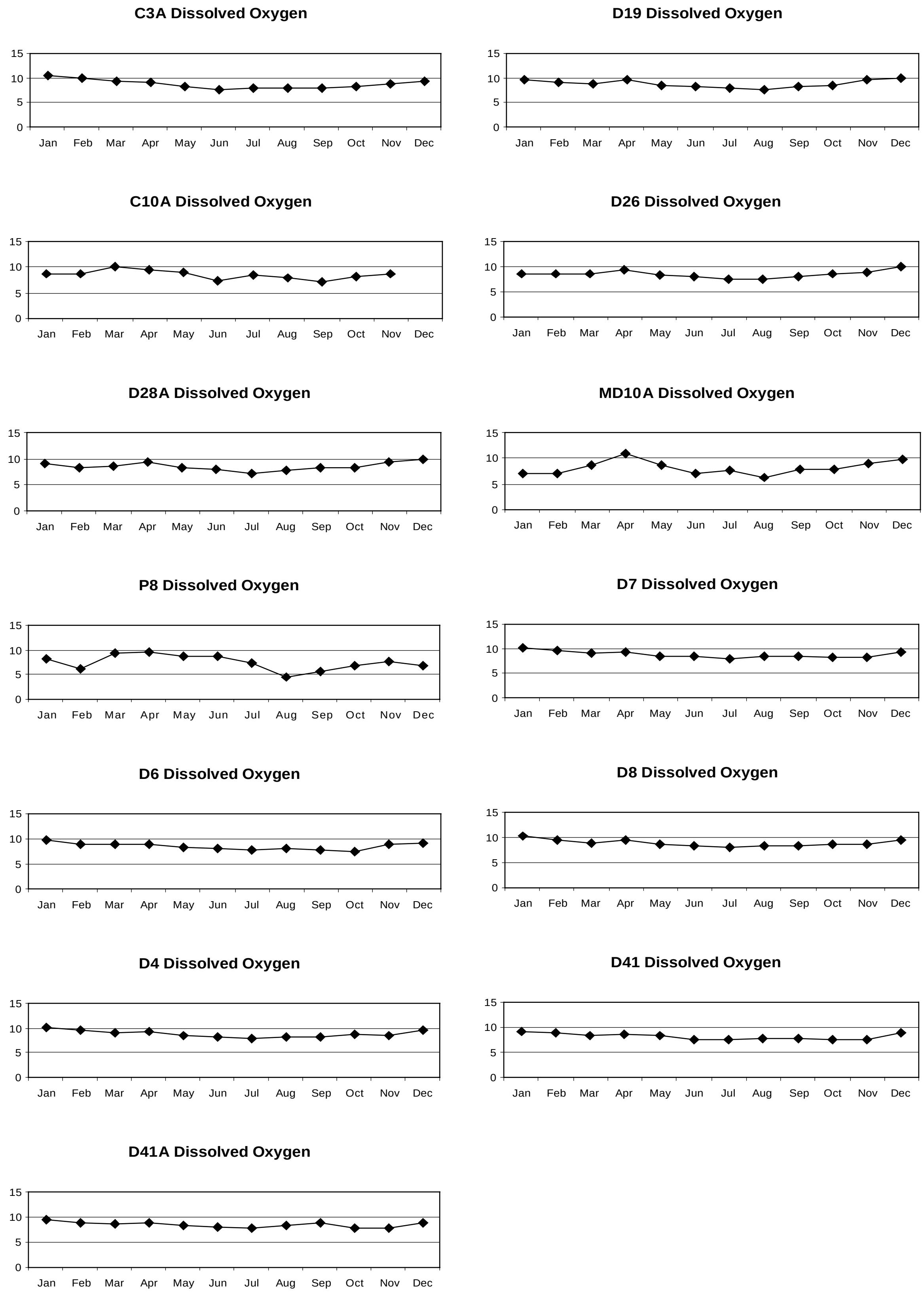


Figure 3-6 Specific conductance

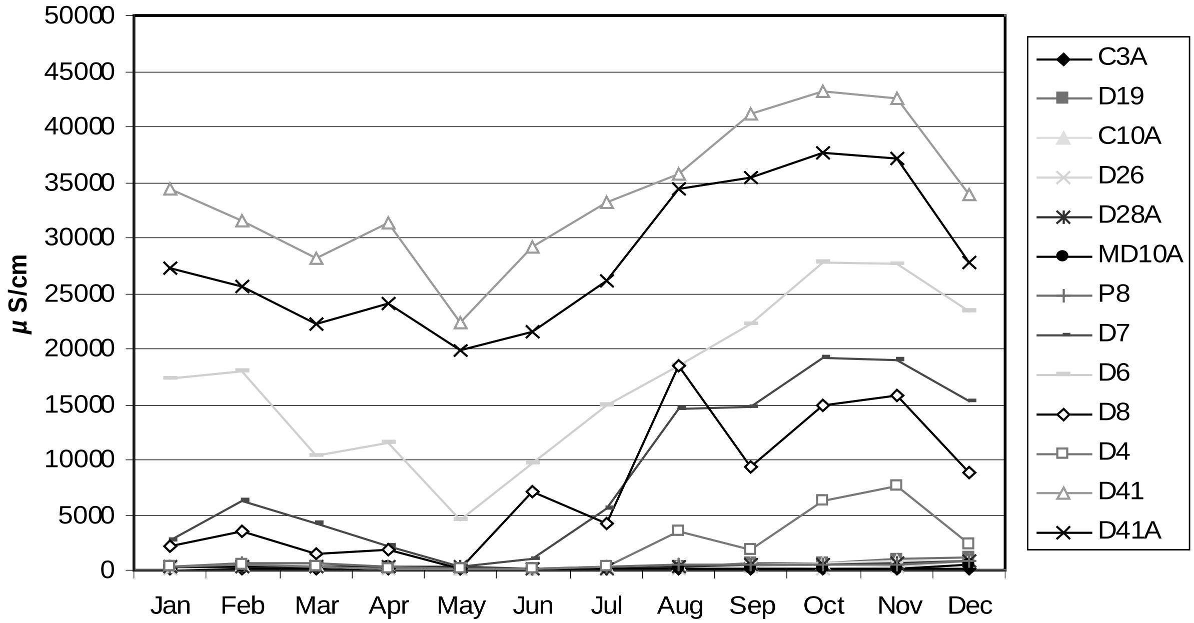


Figure 3-7 Specific conductance (µ/cm)

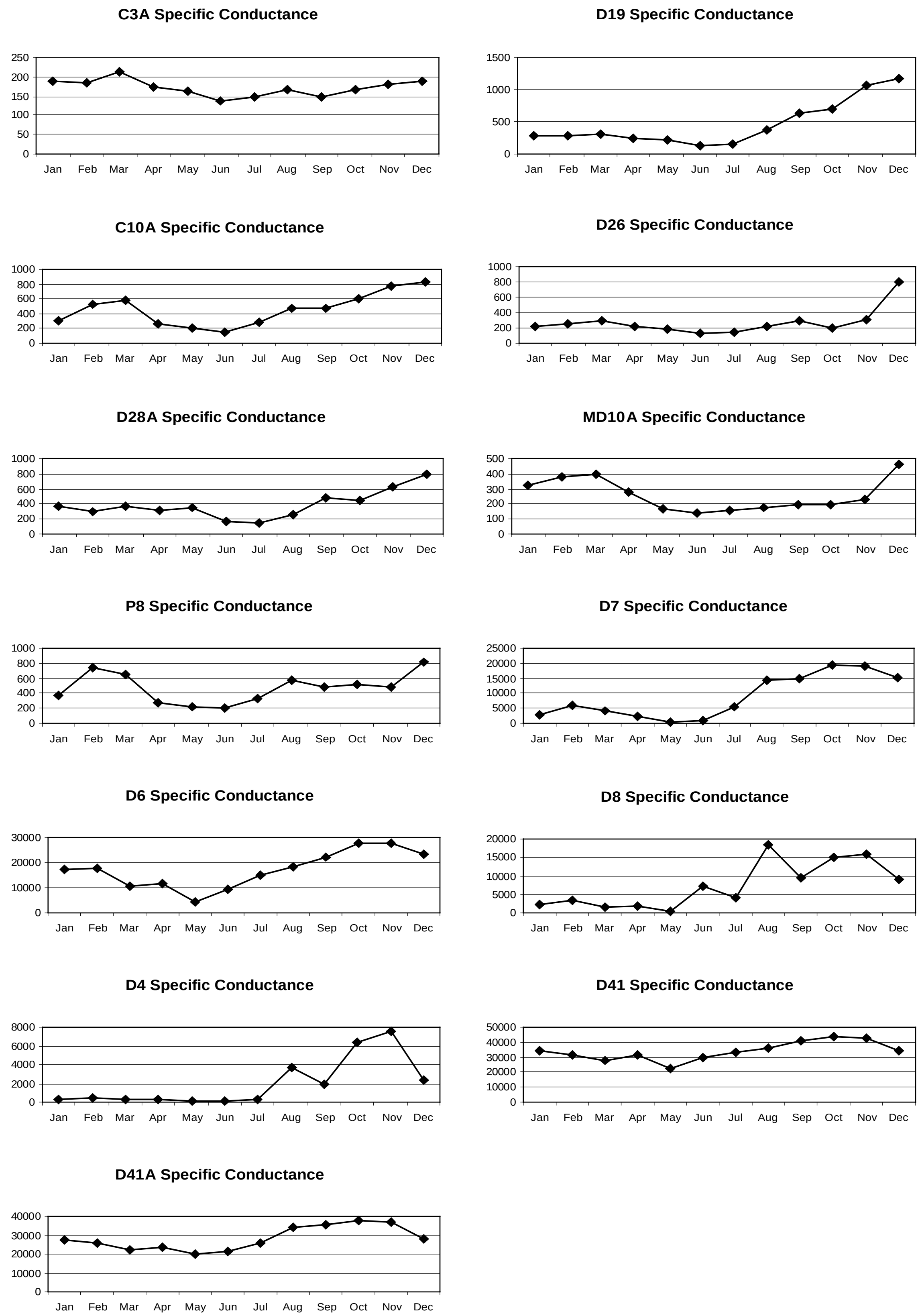


Figure 3-8 Secchi depth

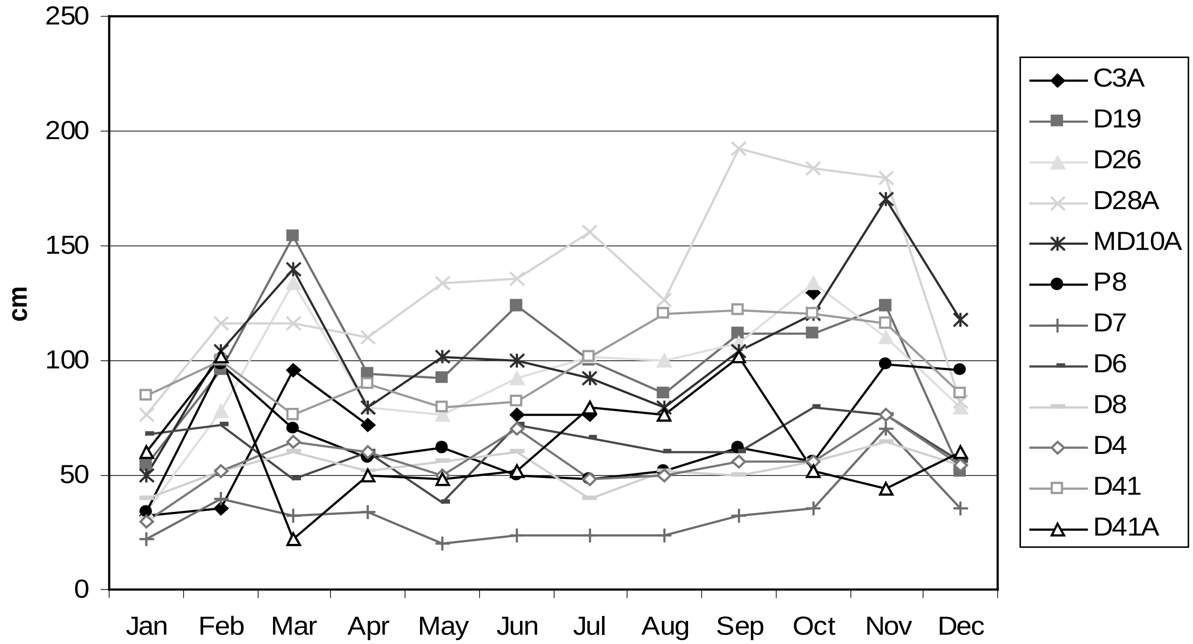


Figure 3-9 Secchi depth (cm)

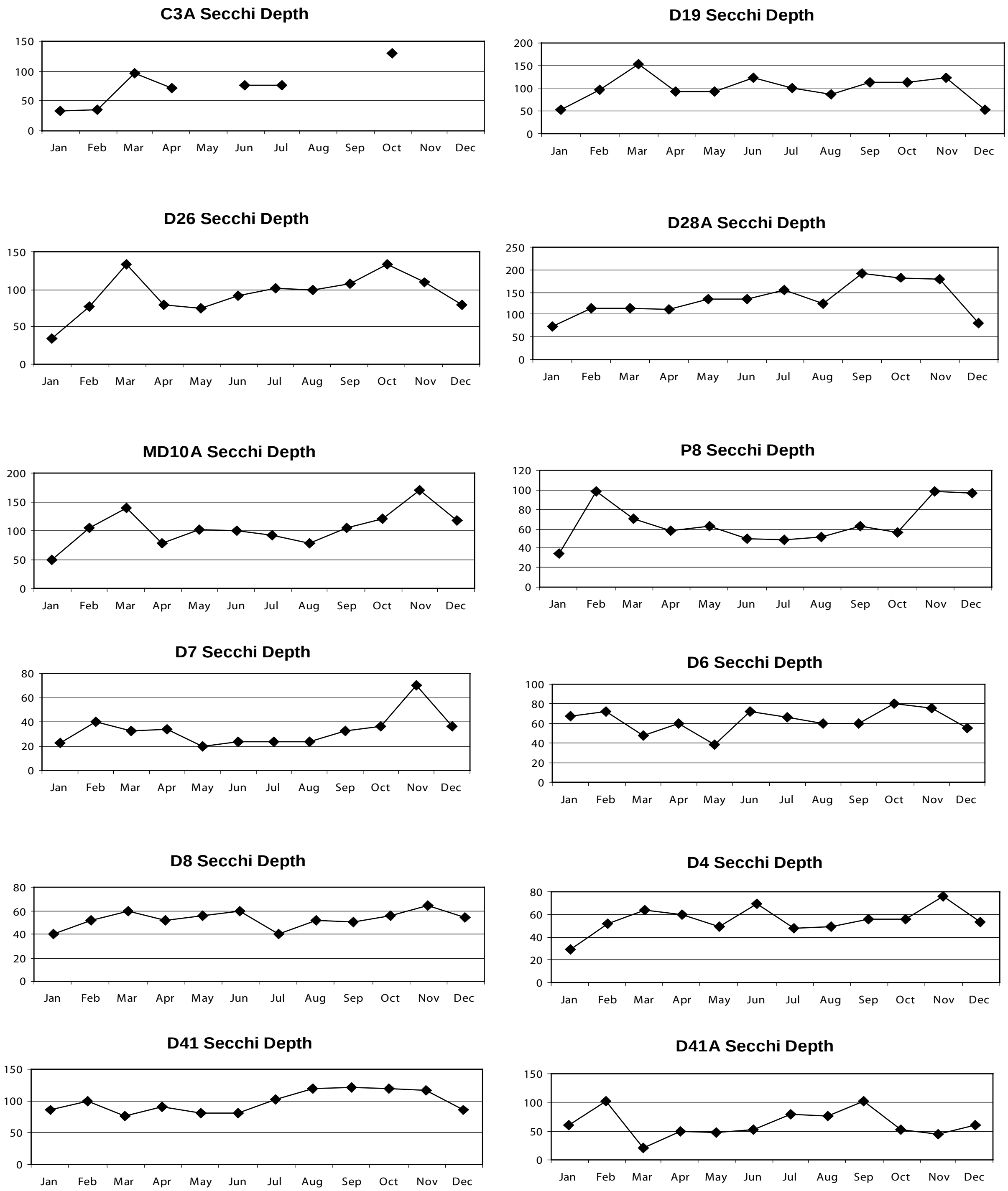


Figure 3-10 Turbidity

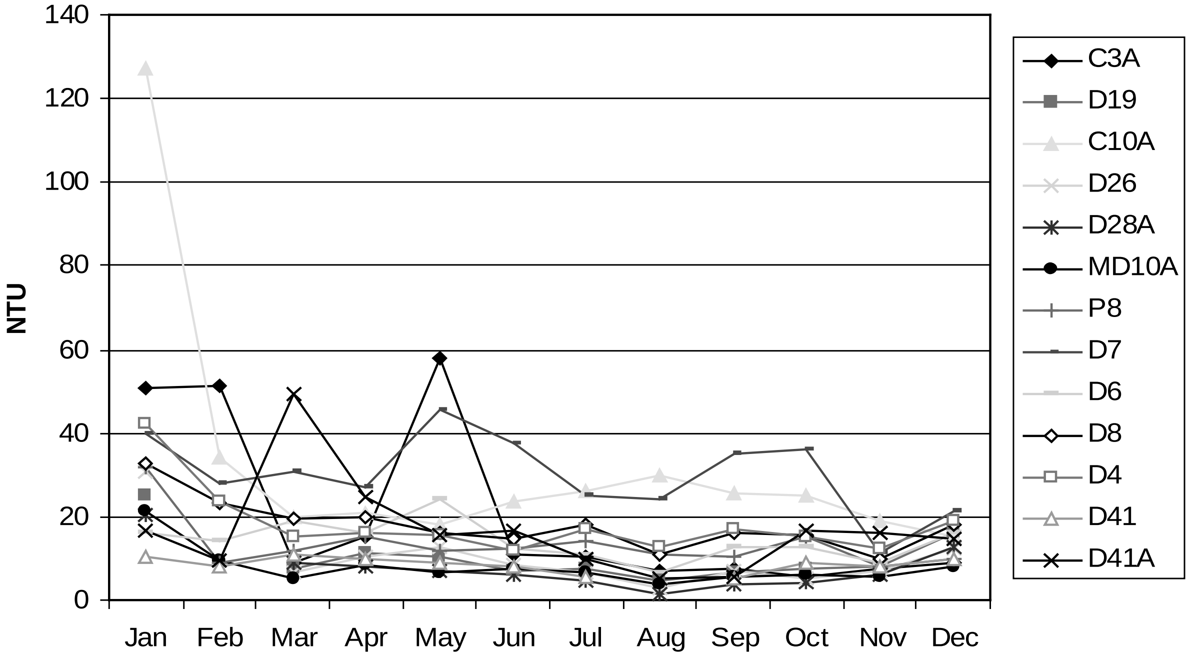
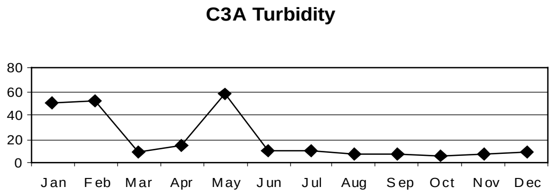
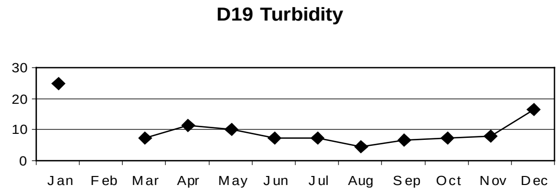
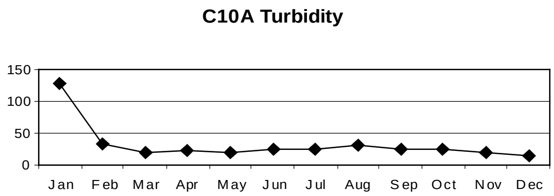
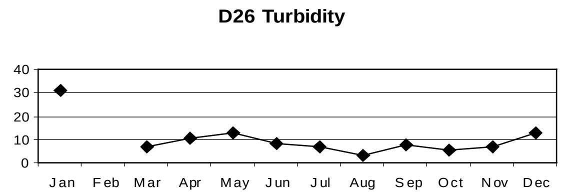


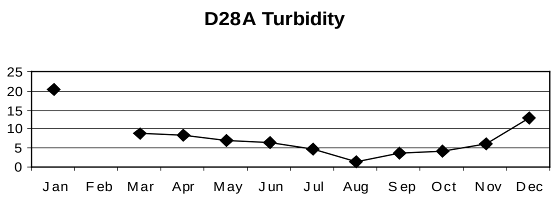
Figure 3-11 Turbidity (NTU)

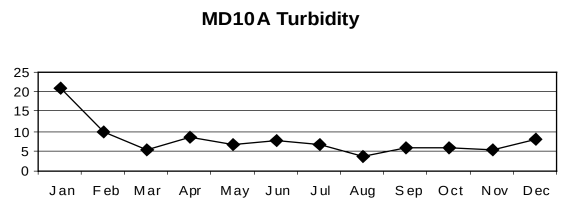


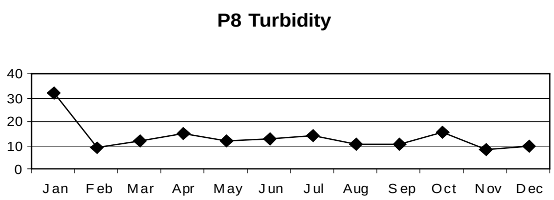


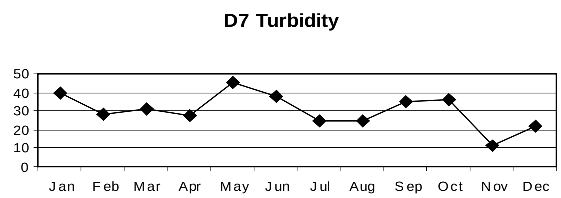


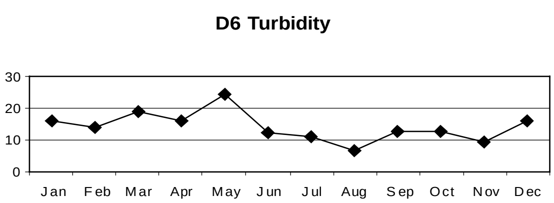


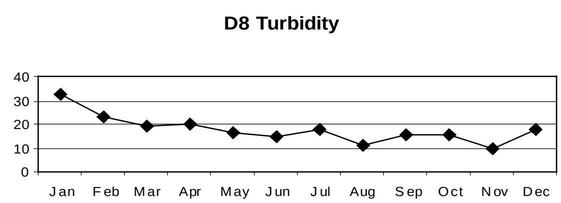


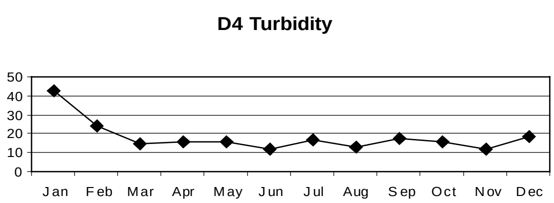


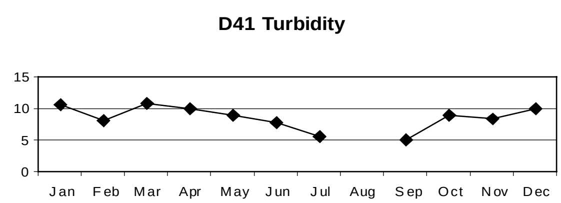


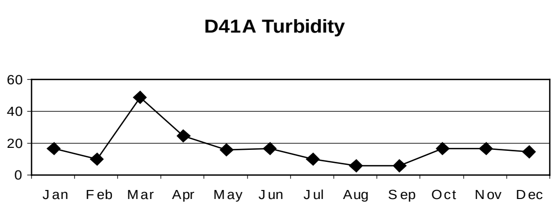












*Missing data for D19, D26, D28A and D41 is due to nephelometer malfunction during sampling.

Figure 3-12 Orthophosphate

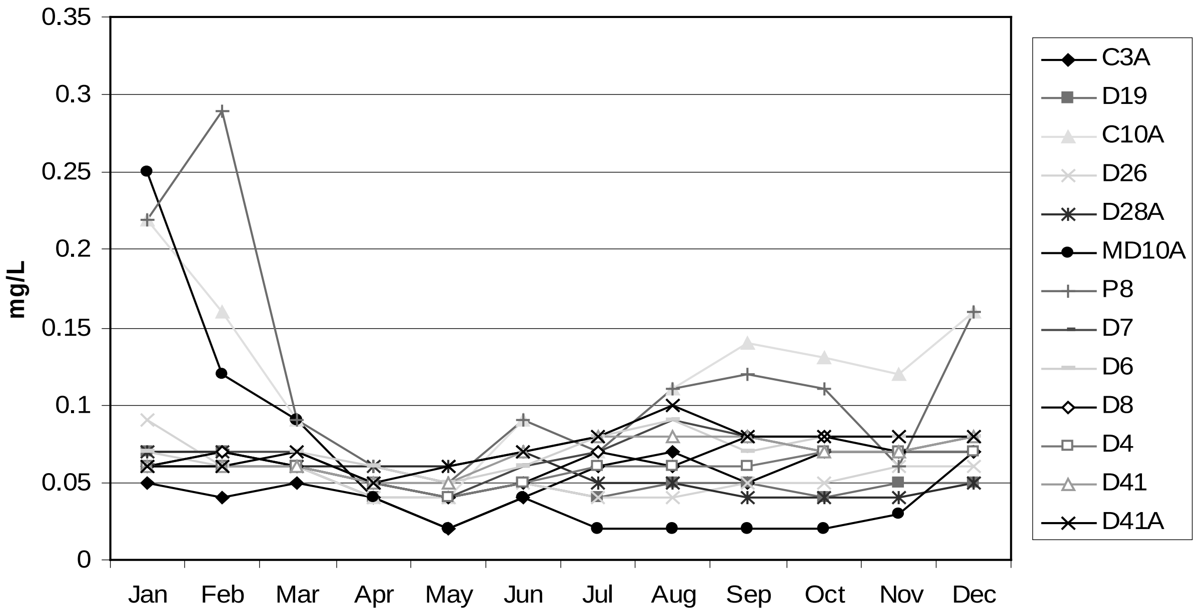


Figure 3-13 Orthophosphate (mg/L)

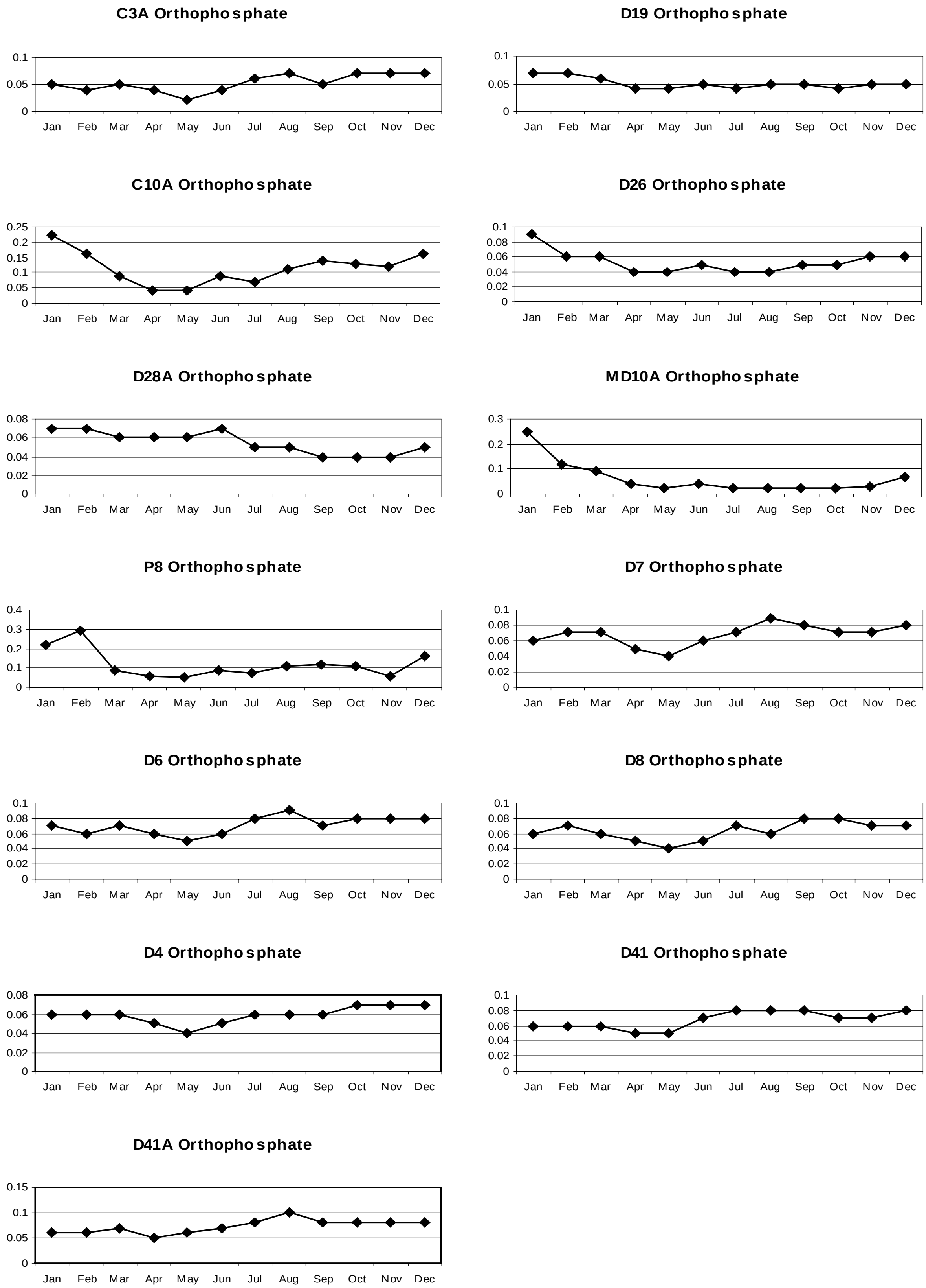


Figure 3-14 Total phosphorus

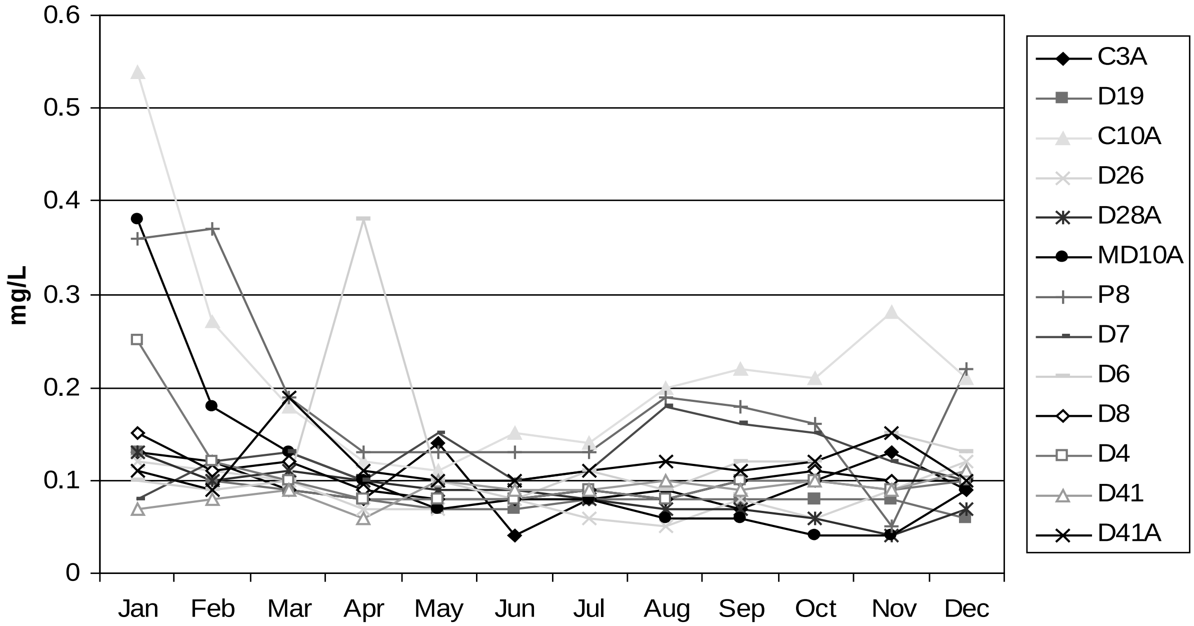


Figure 3-15 Total phosphorus (mg/L)

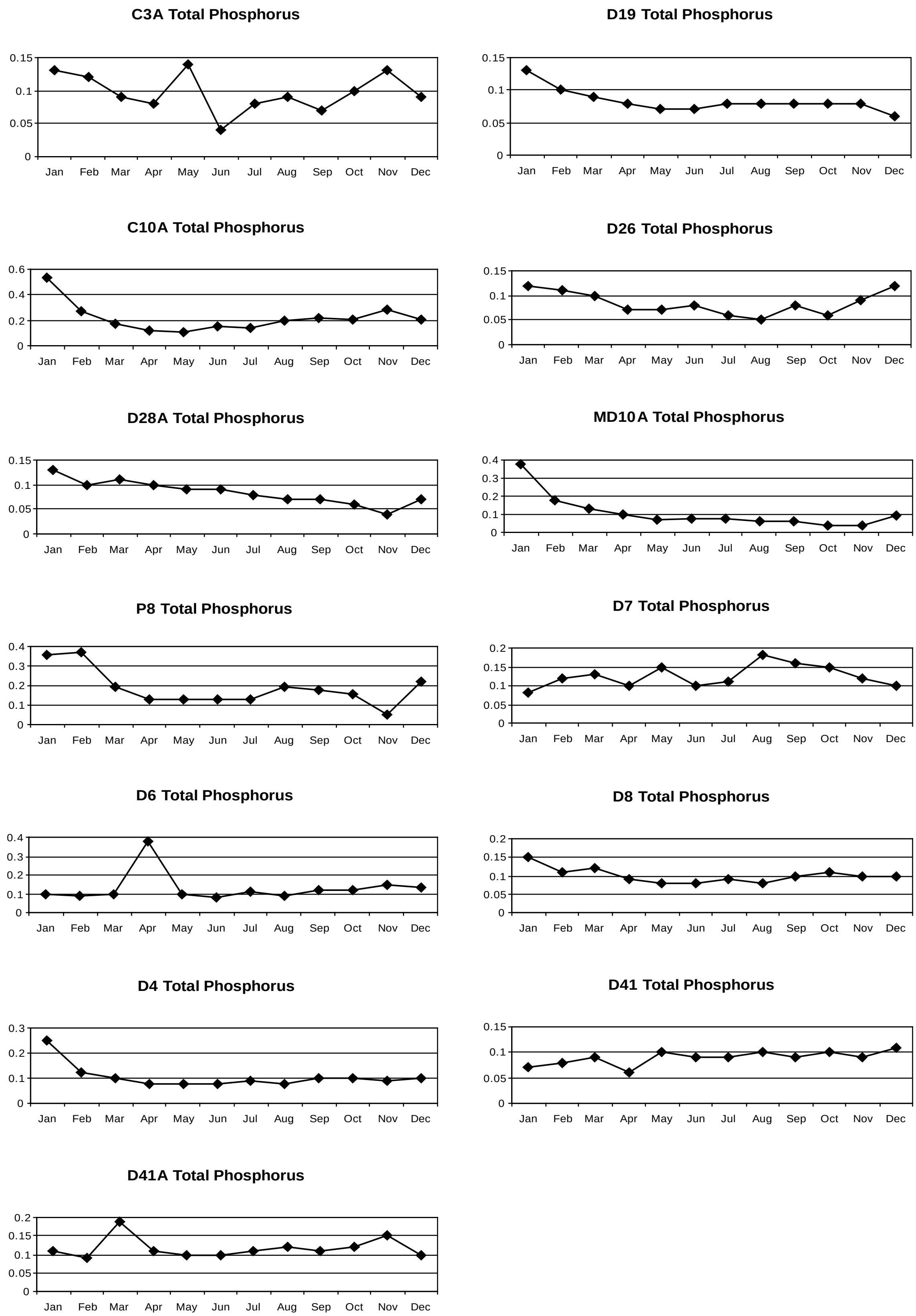


Figure 3-16 Kjeldahl nitrogen

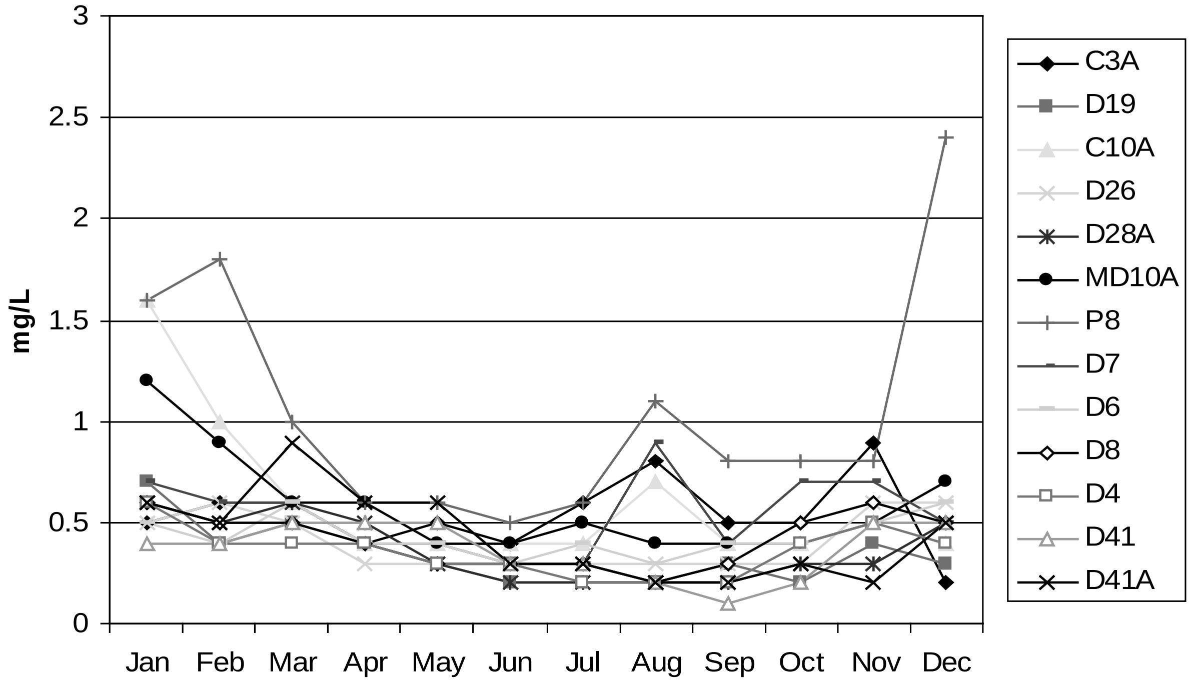


Figure 3-17 Kjeldahl nitrogen (mg/L)

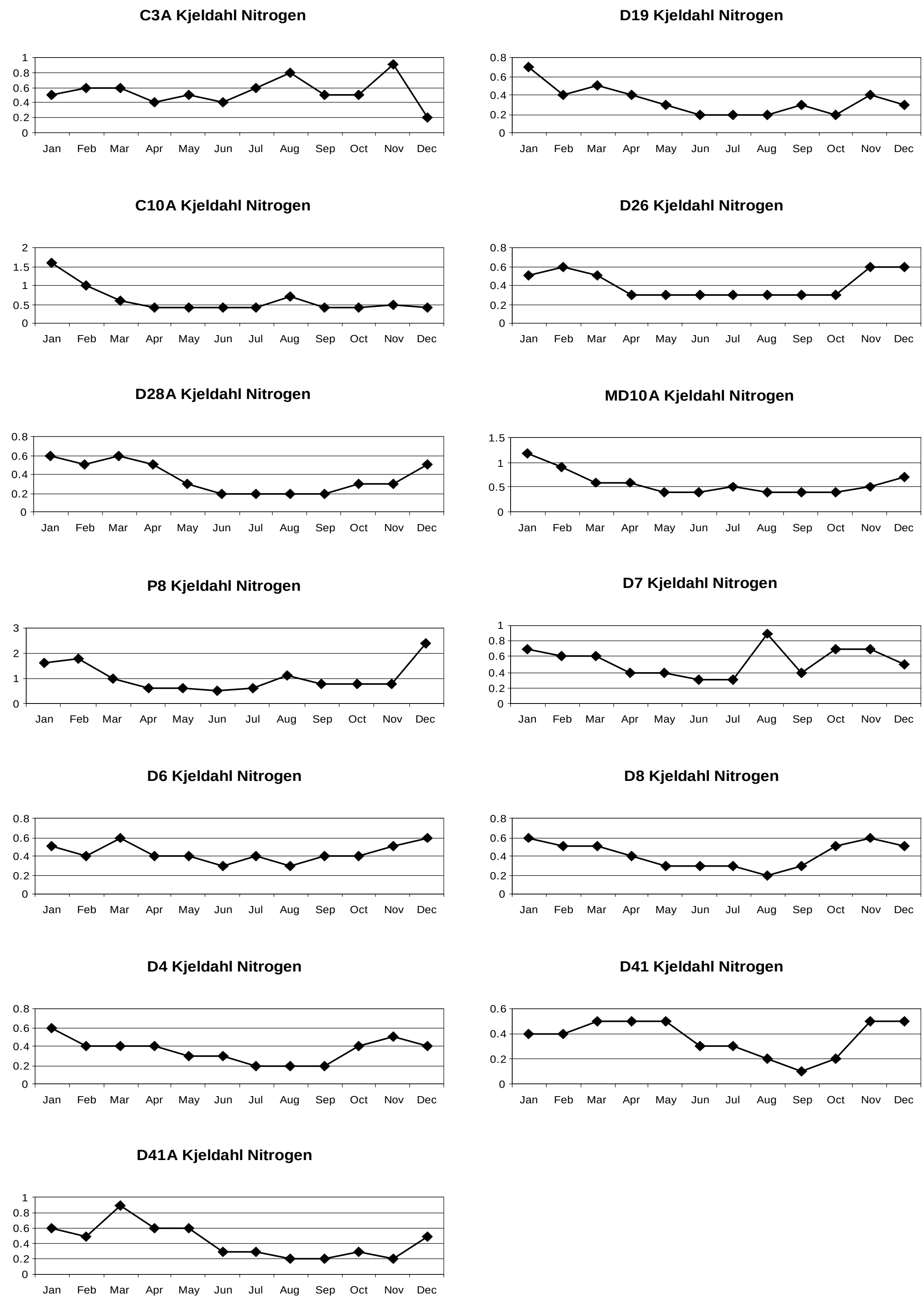


Figure 3-18 Dissolved inorganic nitrogen

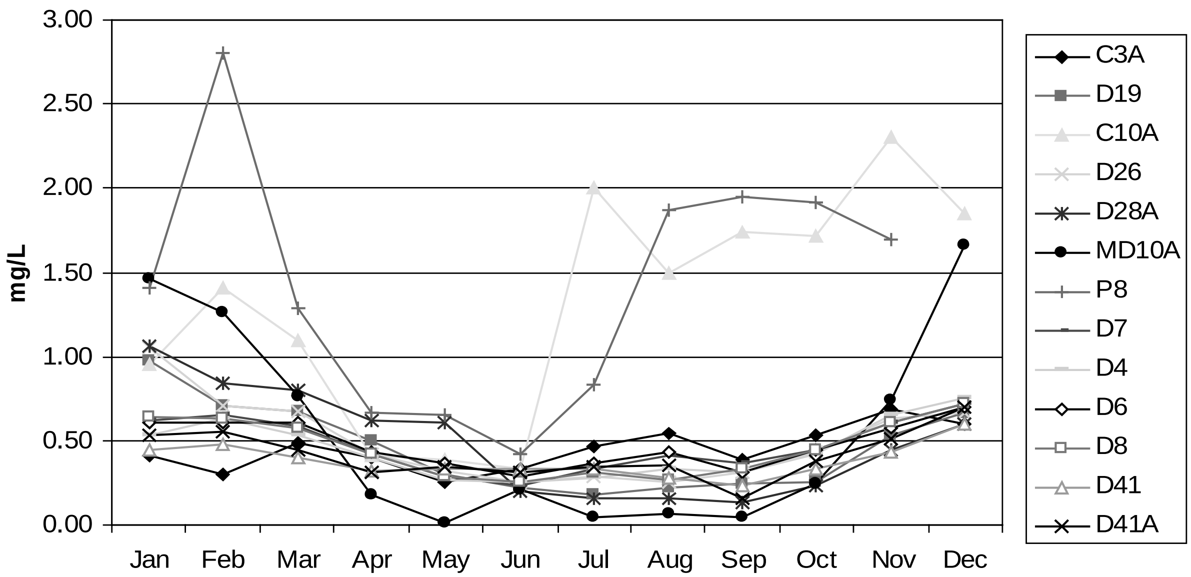


Figure 3-19 Dissolved inorganic nitrogen (mg/L)

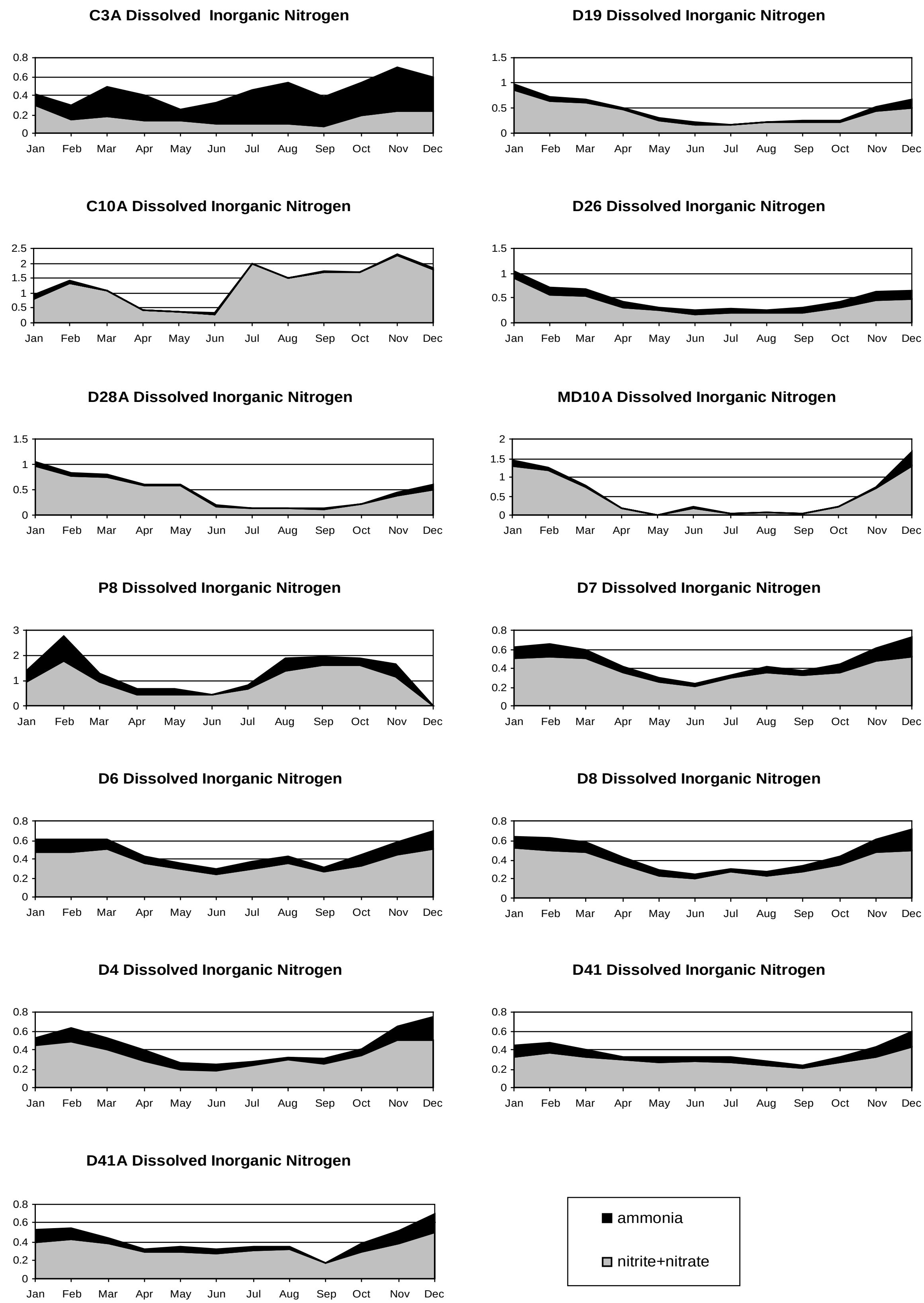


Figure 3-20 Dissolved organic nitrogen

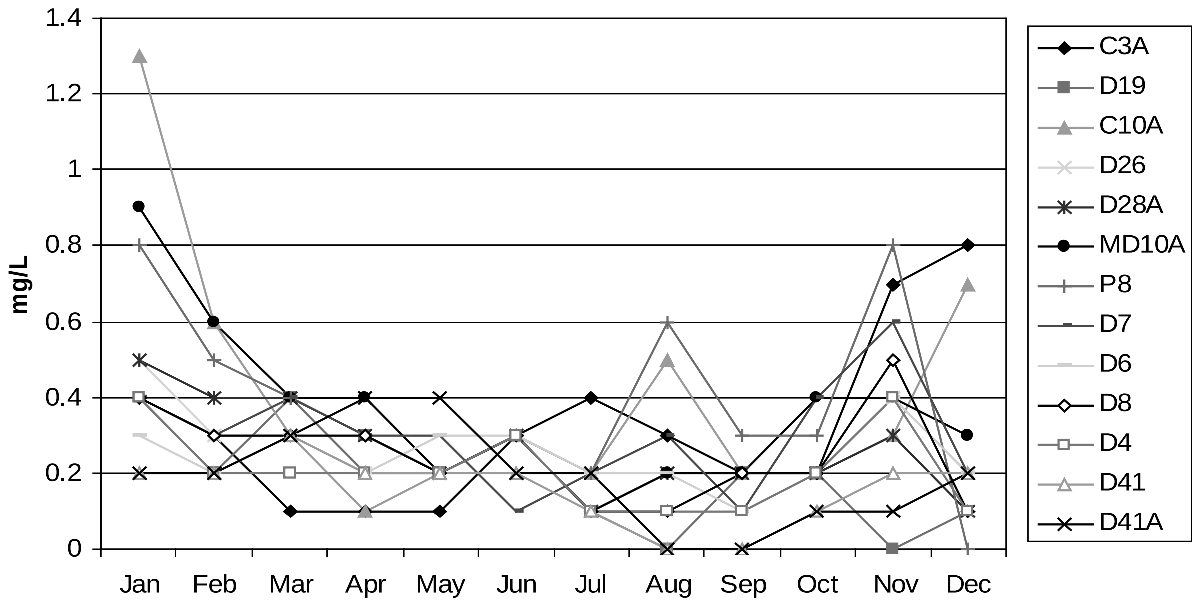


Figure 3-21 Dissolved organic nitrogen (mg/L)

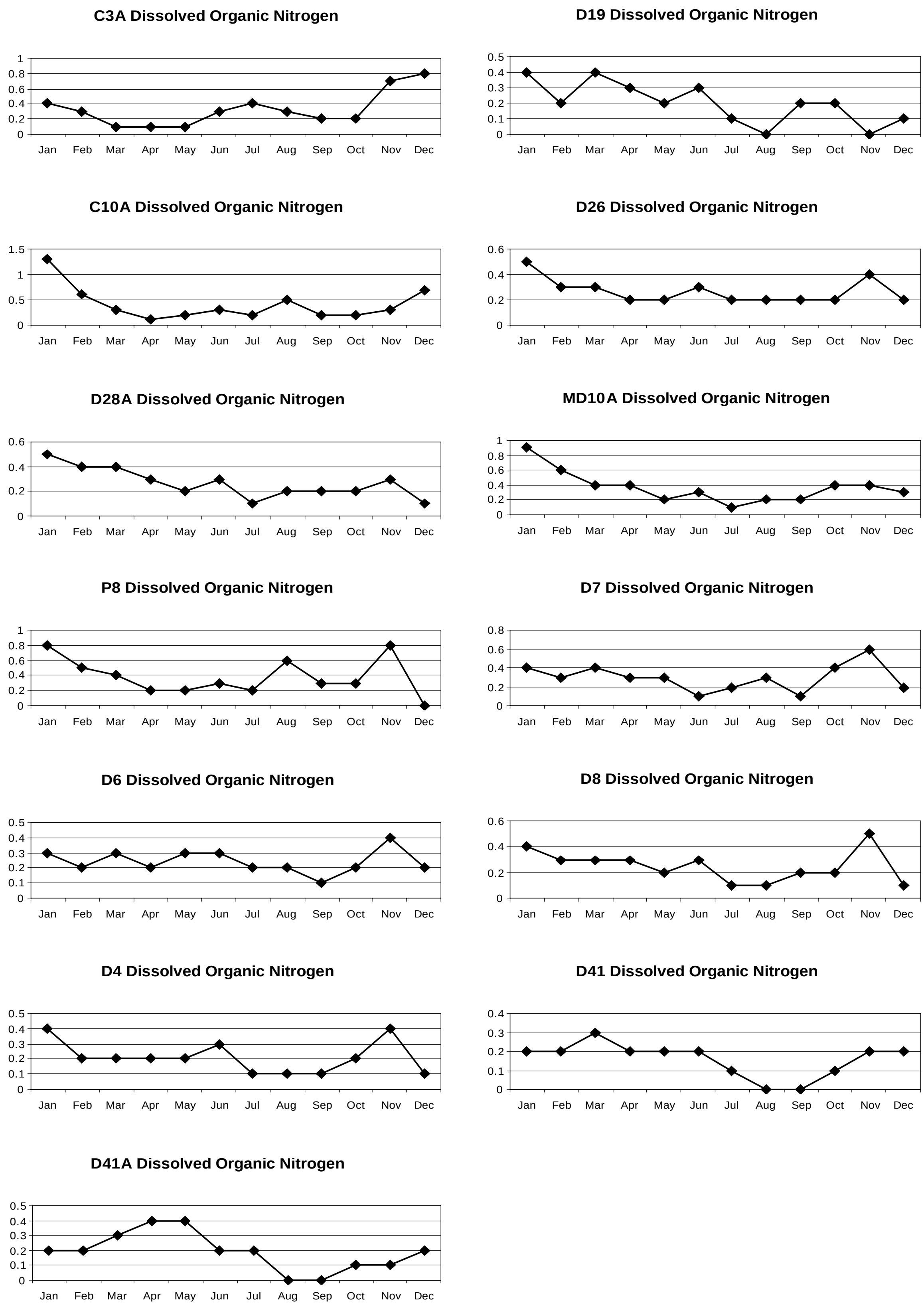


Figure 3-22 Total dissolved solids

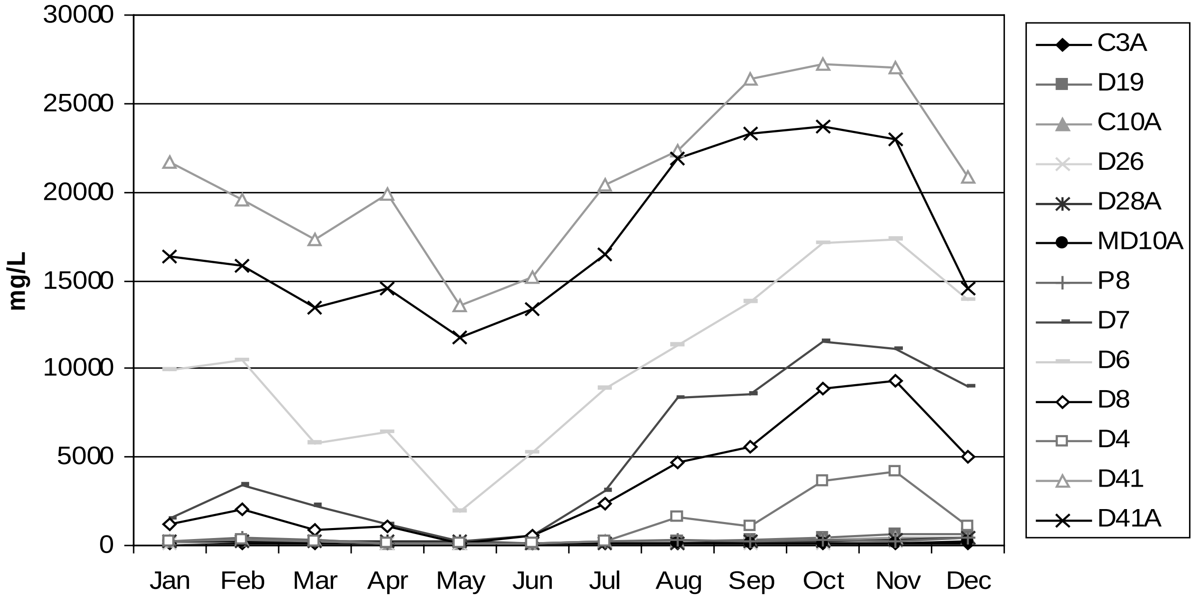


Figure 3-23 Total dissolved solids (mg/L)

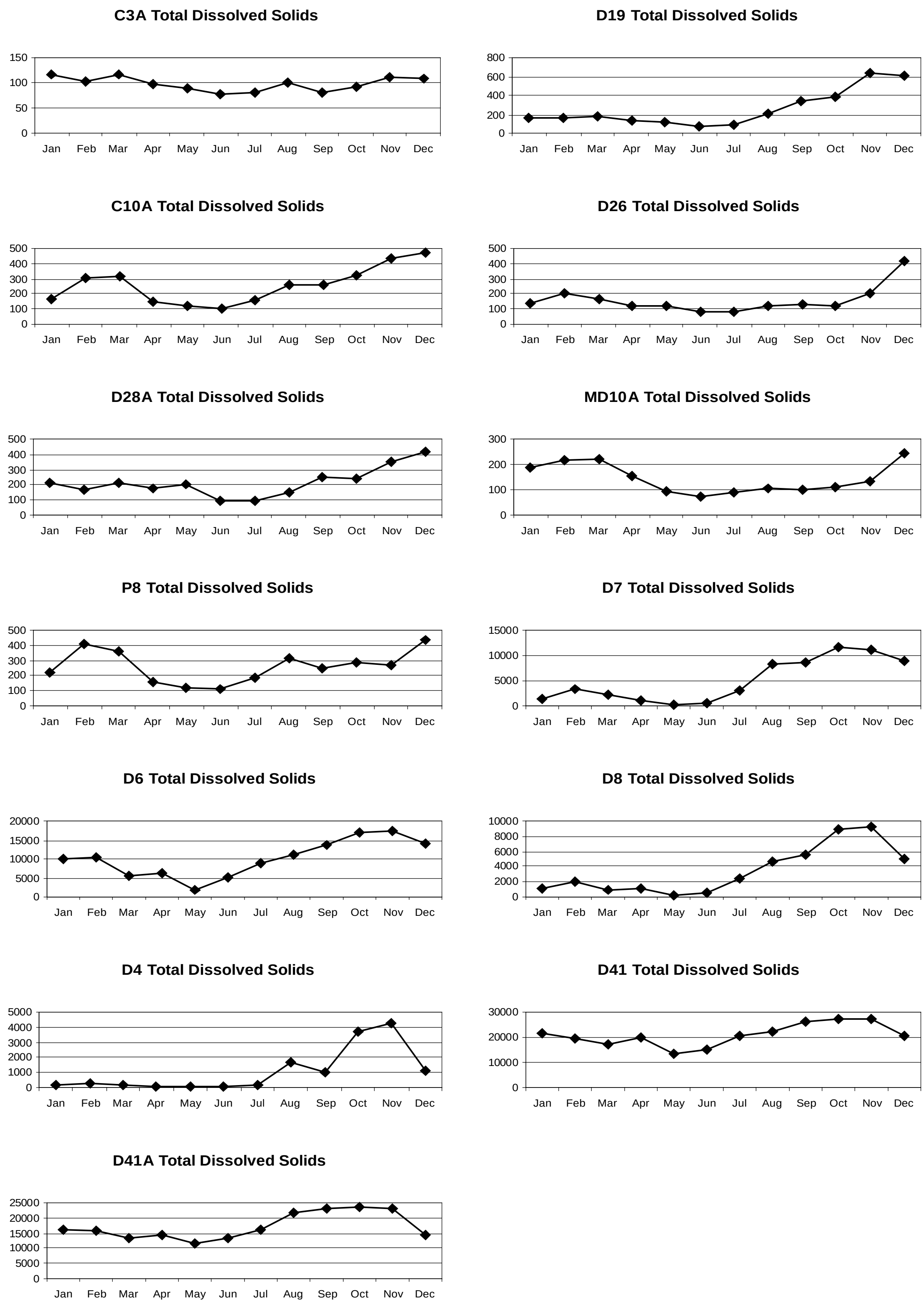


Figure 3-24 Total suspended solids

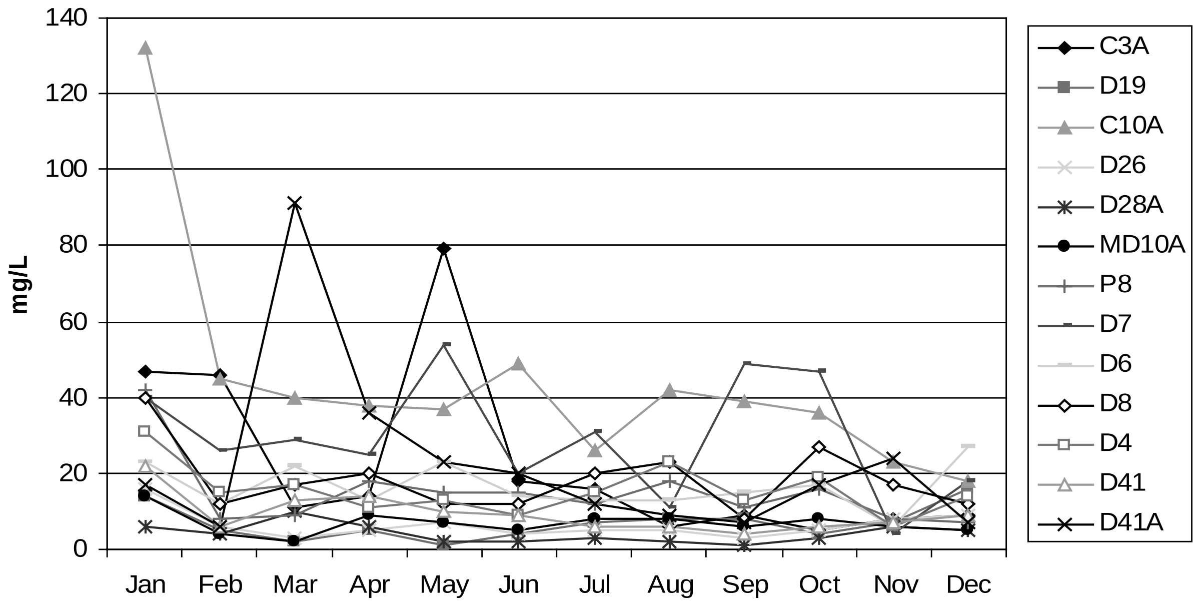
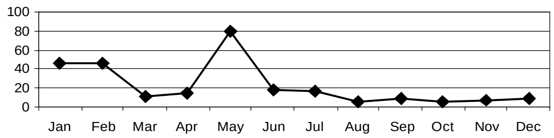
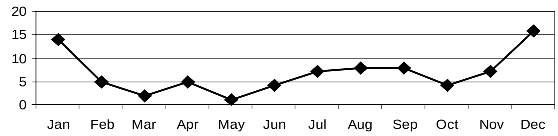


Figure 3-25 Total suspended solids (mg/L)

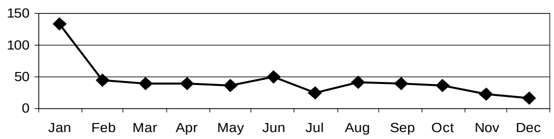
C3A Total Suspended Solids



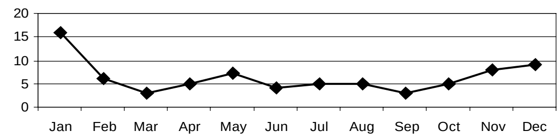
D19 Total Suspended Solids



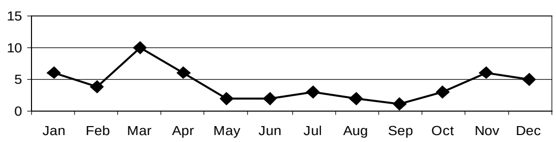
C10A Total Suspended Solids



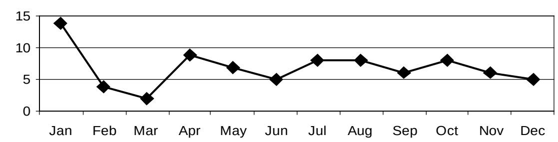
D26 Total Suspended Solids



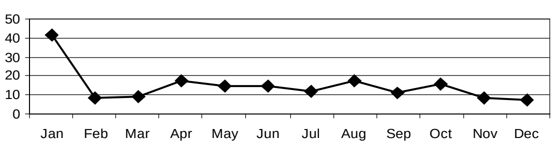
D28A Total Suspended Solids



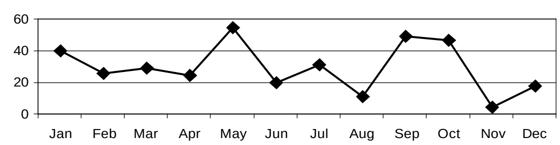
MD10A Total Suspended Solids



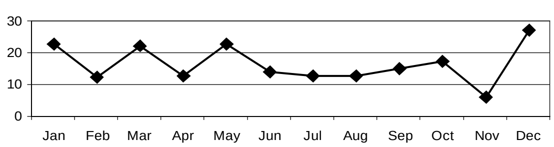
P8 Total Suspended Solids



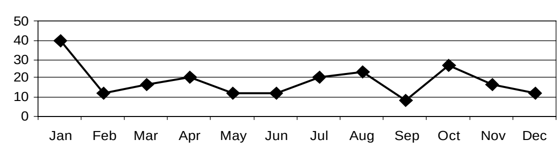
D7 Total Suspended Solids



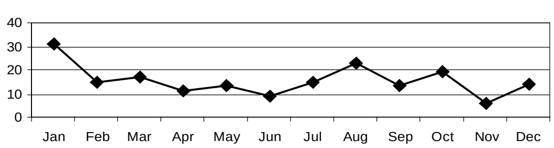
D6 Total Suspended Solids



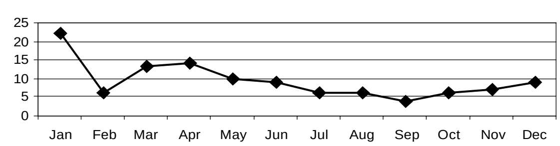
D8 Total Suspended Solids



D4 Total Suspended Solids



D41 Total Suspended Solids



D41A Total Suspended Solids

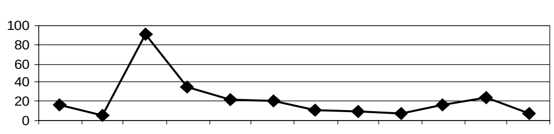


Figure 3-26 Volatile suspended solids

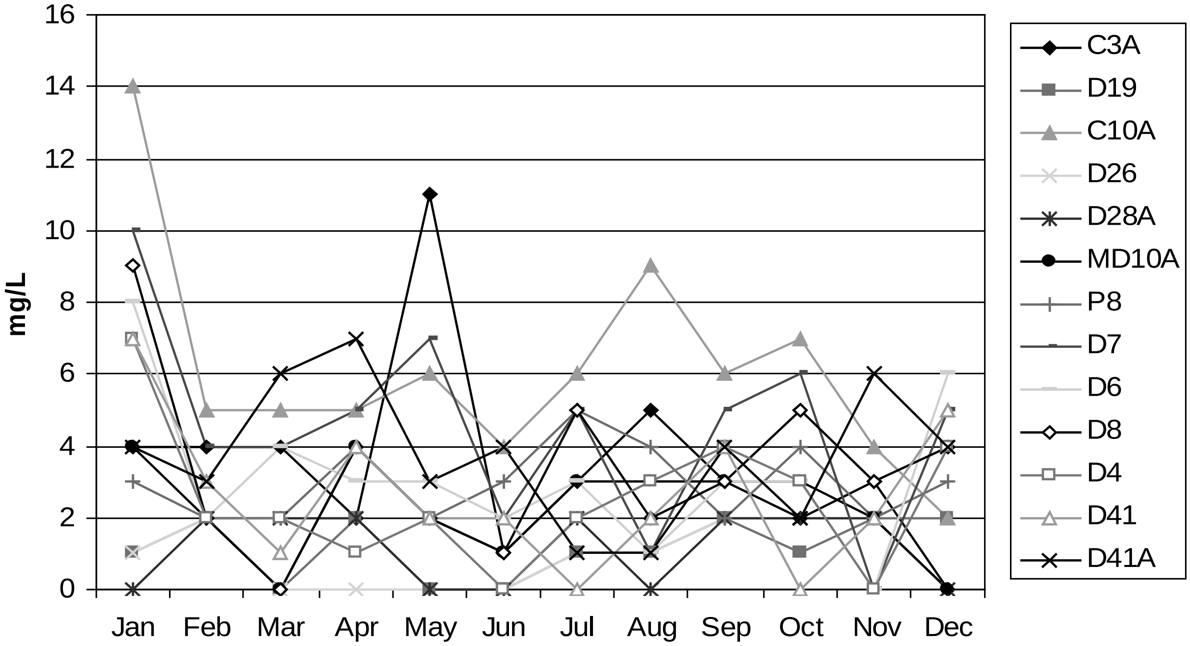


Figure 3-27 Volatile suspended solids (mg/L)

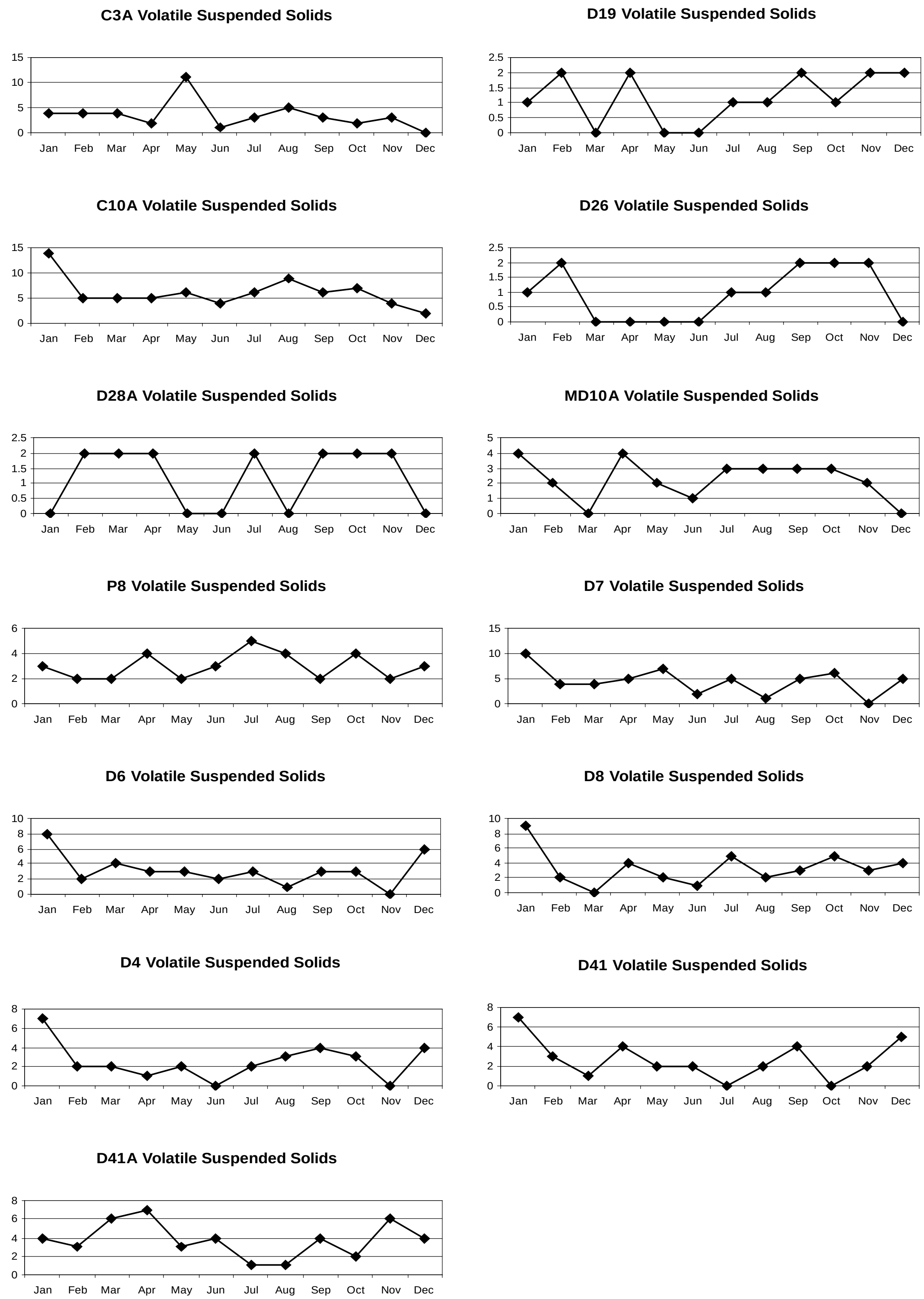


Figure 3-28 Silica

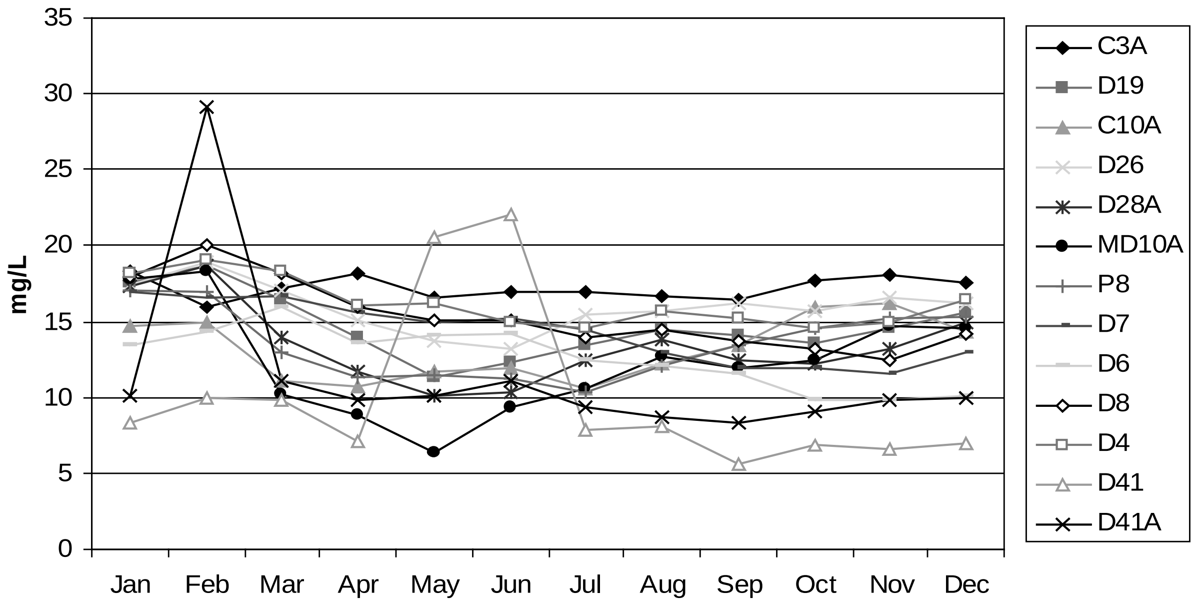


Figure 3-29 Silica (mg/L)

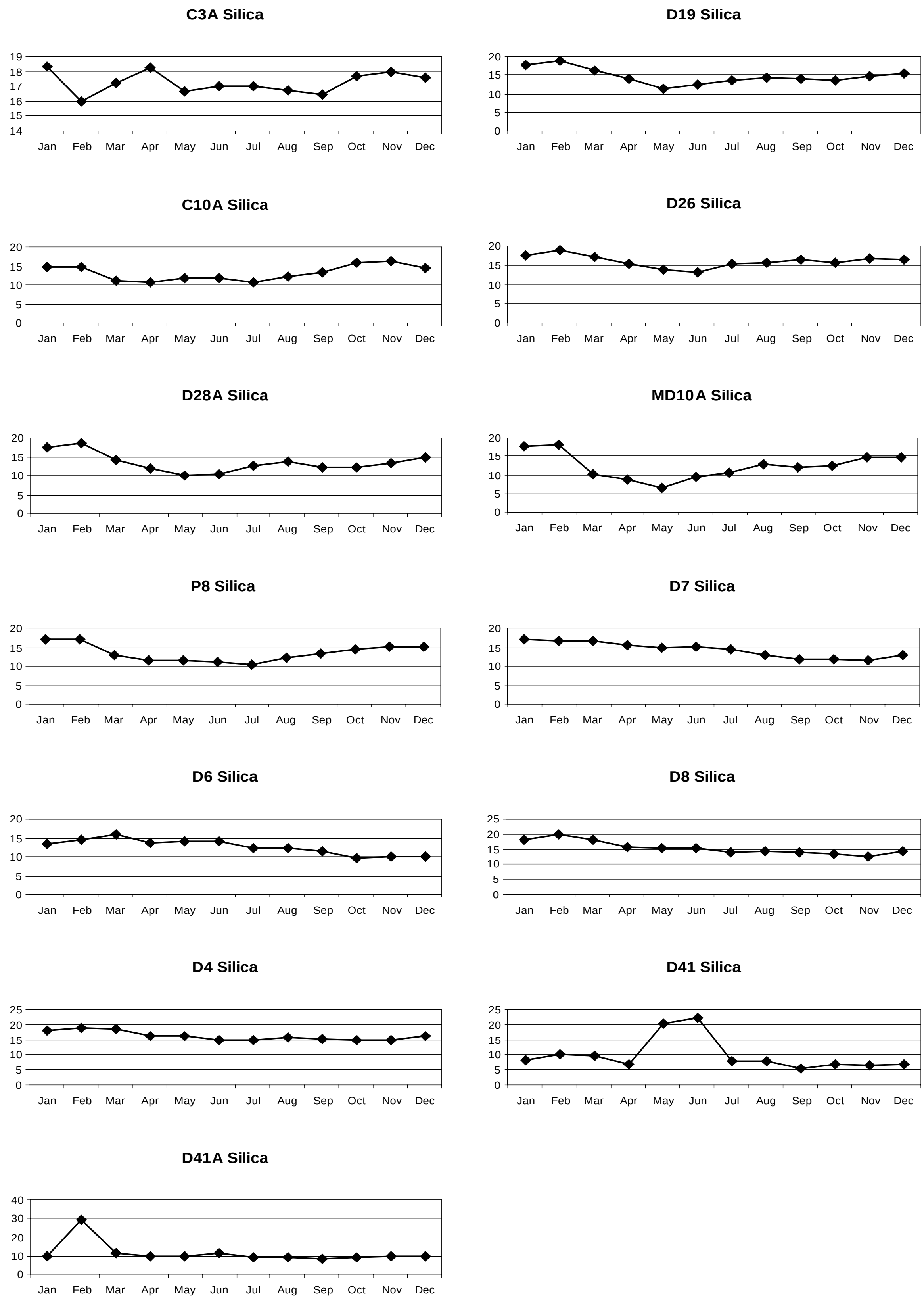


Figure 3-30 Chloride

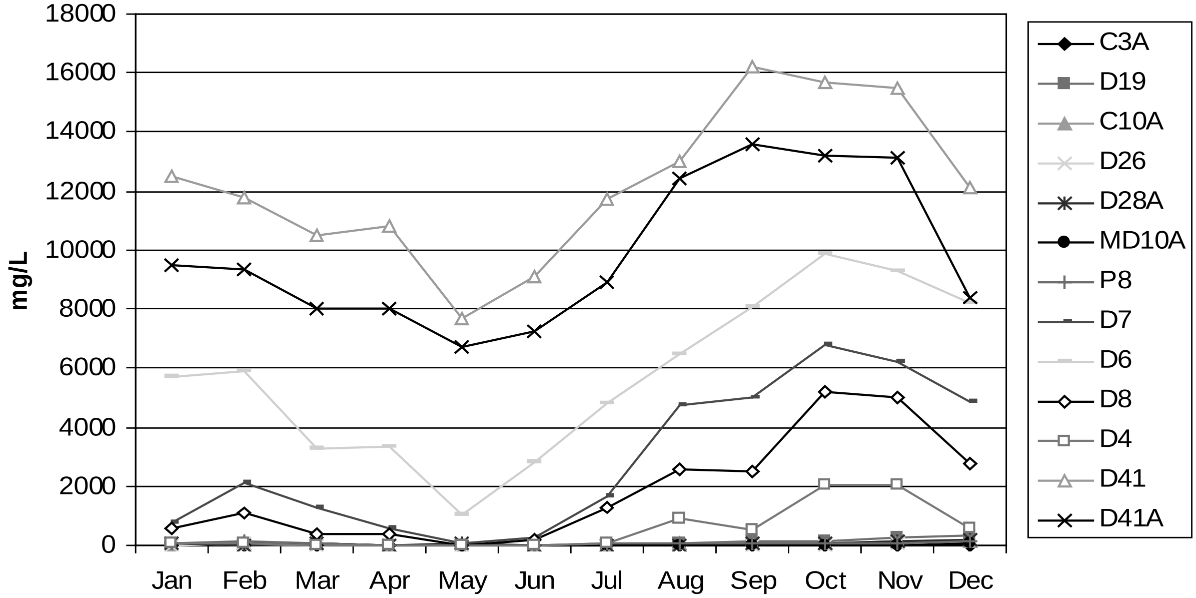
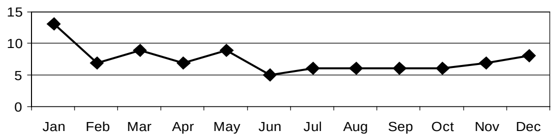
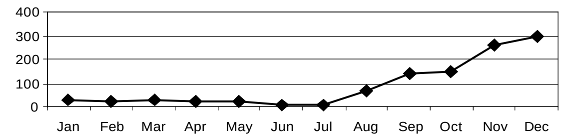


Figure 3-31 Chloride (mg/L)

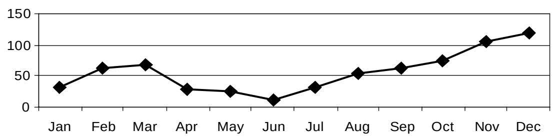
C3A Chloride



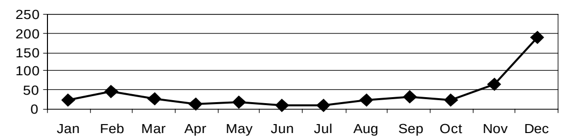
D19 Chloride



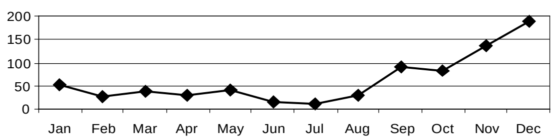
C10A Chloride



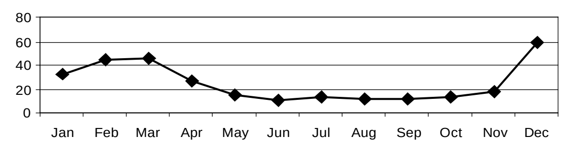
D26 Chloride



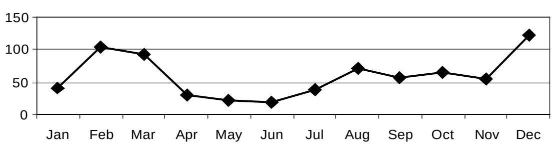
D28A Chloride



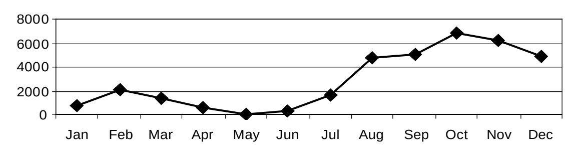
MD10A Chloride



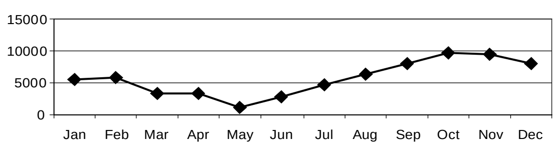
P8 Chloride



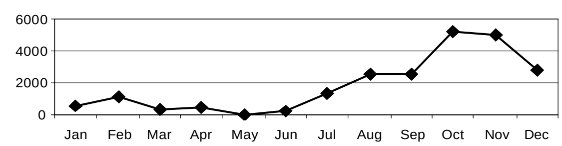
D7 Chloride



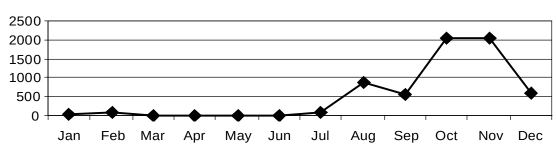
D6 Chloride



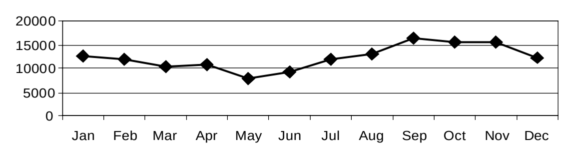
D8 Chloride



D4 Chloride



D41 Chloride



D41A Chloride

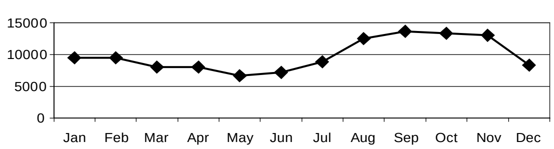


Table 3-1 Water quality parameters measured

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 and D19
North Delta	C3A
Central Delta	D28A
East Delta	MD10A
South Delta	C10A and P8
Suisun Bay	D6, D7 and D8
San Pablo Bay	D41 and D41A

Chapter 4. Phytoplankton and Chlorophyll

Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll *a* samples in order to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (Estuary). The thirteen 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 2005.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes which influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular, colonial or filamentous forms (Horne and Goldman 1994). 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). In freshwater, the blue-green algae (Cyanophyceae) are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al. 1995).

In addition to being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can be useful in assessing water quality (Gannon and Stemberger 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes; 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*. Conversely, when the phytoplankton have died and are decaying, levels of pheophytin *a* are expected to be high in relation to chlorophyll *a*.

Phytoplankton biomass and the resulting chlorophyll *a* concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced overbite clam, *Corbula amurensis* (Alpine and Cloern 1992). Well-established benthic populations of *C. amurensis* in 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 13 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using 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. Phytoplankton identification and enumeration were performed at DWR'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 twenty 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.

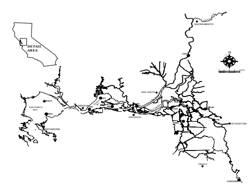


Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

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

Organisms = *(C x Ac) / (V x Af x 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))

The 10 most common genera were determined by summing the number of organisms per milliliter across all stations and months for each genus.

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1) using 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 the Standard Methods (APHA 1998) spectrophotometric procedure. 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).

Results

Phytoplankton Identification

Of the eight groups identified, Bacillariophyceae, Chlorophyceae, Cryptophyceae, and Cyanophyceae constituted 90.7% of the organisms collected (Figure 4-2).

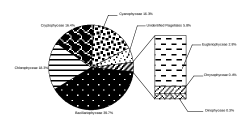


Figure 4-2 Percent phytoplankton composition by family for 2005

All organisms collected in 2005 fell into these eight categories:

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

Table 4-1 lists the genera found in each family in the upper Estuary.

Family	Genus
Bacillariophyceae	Achnanthes
	Amphiprora
	Asterionella
	Aulacoseira
	Centric Diatom
	Cocconeis
	Cyclotella
	Diatoma
	Entomoneis
	Fragilaria
	Gyrosigma
	Mastogloia
	Melosira
	Navicula
	Pennate Diatom
	Skeletonema
	Synedra
Chlorophyceae	Actinastrum
	Carteria
	Chlamydomonas
	Chlorella
	Chodatella
	Closterium
	Crucigenia
	Elakatothrix
	Eudorina
	Gloeocystis
	Gonyostomum
Chrysophyceae	Dinobryon
Cryptophyceae	Chroomonas
	Cryptomonas
	Rhodomonas
Cyanophyceae	Anabaena
	Aphanizomenon
	Chroococcus
	Merismopedia
	Microcystis
	Oscillatoria
	Phormidium
	Pseudanabaena
	Synechocystis
Dinophyceae	Glenodinium
	Gymnodinium
Euglenophyceae	Euglena
	Trachelomonas
Unknown	*Unidentified flagellates*

Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2005

The 10 most common genera collected in 2005 were:

- *Cyclotella* (Bacillariophyceae)
- *Skeletonema* (Bacillariophyceae)
- *Monoraphidium* (Chlorophyceae)
- *Cryptomonas* (Cryptophyceae)
- *Rhodomonas* (Cryptophyceae)
- *Aulacoseira* (Bacillariophyceae)
- Unidentified flagellates
- Unidentified centric diatoms (Bacillariophyceae)
- *Aphanizomenon* (Cyanophyceae)
- *Pseudanabaena* (Cyanophyceae)

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/phytoplankton_dictionary.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. Some stations had secondary peaks in chlorophyll *a* in late winter and early spring. Several stations had one or two high peaks in chlorophyll *a* which skewed the mean values higher than the median values (Table 4-2 and Figures 4-3 through 4-15).

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C10A	21.50	1.86	6.47	8.43	6.13
C3A	3.83	0.75	2.06	2.13	0.83
D19	3.20	0.56	1.36	1.47	0.70
D26	3.28	0.40	1.18	1.31	0.71
D28A	3.07	0.56	1.43	1.65	0.79
D4	3.74	0.61	1.63	1.59	0.88
D41	4.60	1.03	2.84	2.84	1.14
D41A	8.01	0.67	2.45	3.21	2.46
D6	3.97	0.62	1.29	1.70	1.12
D7	9.18	0.61	1.61	2.34	2.45
D8	5.11	0.42	1.47	1.72	1.32
MD10A	21.40	0.81	5.07	8.41	7.54
P8	20.20	1.51	6.09	8.42	6.66

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C10A	15.10	1.57	2.49	3.58	3.71
C3A	2.60	0.64	1.38	1.46	0.57
D19	2.26	0.36	0.67	0.80	0.54
D26	1.39	0.23	0.73	0.73	0.36
D28A	1.53	0.60	0.84	0.92	0.27
D4	1.36	0.38	0.88	0.88	0.34
D41	1.15	0.32	0.66	0.68	0.25
D41A	2.96	0.13	0.84	1.17	1.00
D6	1.84	0.32	0.57	0.72	0.48
D7	2.70	0.18	0.89	1.04	0.69
D8	4.43	0.25	0.71	1.04	1.15
MD10A	13.60	0.57	1.37	3.02	3.62
P8	10.50	1.39	2.92	3.86	2.56

Table 4-2 Chlorophyll *a* and Pheophytin *a* values

Monthly chlorophyll *a* concentrations throughout much of the Estuary were relatively low when compared to historical data. Of the 156 samples taken in 2005, 95.5% (149 samples) had chlorophyll *a* levels below 15 µg/L. Those samples with chlorophyll *a* levels above 15 µg/L were all taken from the east (MD10A) and south Delta (P8, C10A) in spring and summer. One hundred thirty-four samples, or 85.9% of all the samples, had chlorophyll *a* levels below 5 µg/L. Twenty-two samples, or 14.1% of all the samples, had chlorophyll *a* levels above 5 µg/L; of these, 18 were from east (MD10A) and south Delta (P8, C10A) in the spring and summer. The other four samples were from Suisun Bay (D7, D8) and San Pablo Bay (D41); three of these samples were recorded in spring and summer (D7, D8, D41), and another was recorded in early fall (D41).

The mean chlorophyll *a* concentration for all samples in 2005 was 3.48 µg/L, and the median value was 1.88 µg/L. The maximum chlorophyll *a* concentration in 2005 was 21.5 µg/L, recorded in August in the south Delta (C10). Chlorophyll *a* maxima were recorded in the spring or summer at all stations, except in the north Delta (C3A) where the maximum was recorded in February. The minimum chlorophyll *a* concentration was 0.40 µg/L, recorded in February in the lower San Joaquin River (D26). Chlorophyll *a* minima were recorded in fall or winter at all stations.

Pheophytin *a* concentrations varied among stations, with some stations remaining relatively constant, while others had peaks during one or more months. There was no apparent seasonality among stations, as maximum and minimum values occurred in all seasons. There did not appear to be consistent seasonality within embayments or regions, either; the exception was south Delta, where both stations (C10A, P8) had similar pheophytin *a* peaks in August. In addition, concentrations at both stations showed similar patterns with little variation, with the exception of a relatively minor peak in June at station P8.

The mean pheophytin *a* concentration for all samples in 2005 was 1.53 µg/L, and the median value was 0.97 µg/L. The maximum pheophytin *a* concentration was 15.10 µg/L, recorded at C10A (south Delta) in August. The minimum pheophytin *a* concentration was 0.13 µg/L, recorded at D41A (San Pablo Bay) in December. As with chlorophyll *a*, peaks in pheophytin *a* skewed the mean values higher than the median values at some stations (Table 4-2 and Figures 4-3 through 4-15).

Table 4-2 shows the maximum and minimum values for chlorophyll *a* and pheophytin *a* for each station, as well as the median, mean, and standard deviation. Figures 4-3 through 4-15 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

Site C3A: North Delta

At station C3A, the highest chlorophyll *a* concentration was recorded in February (3.83 µg/L), and the lowest was recorded in October (0.75 µg/L) (Figure 4-3). There was some minor seasonal fluctuation; after early peaks in late winter and early spring, concentrations dropped slightly in April. Chlorophyll *a* began slowly increasing through the summer months and declining again through the fall.

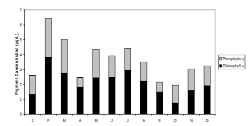


Figure 4-3 Chlorophyll *a* and pheophytin *a* concentrations at C3A in 2005

Pheophytin *a* did not show a clear seasonal pattern. Like chlorophyll *a*, it also peaked in February (2.60 µg/L), but by April, it had dropped to a minimum of 0.64 µg/L for the year. It increased threefold in May, but then remained relatively stable for the rest of the year.

Site C10A: South Delta

The maximum chlorophyll *a* concentration at C10A was recorded in August (15.10 µ/L), and the minimum was recorded in November (1.86 µg/L) (Figure 4-4). This station generally showed a slight seasonal trend, with higher values recorded in spring and summer, and lower values recorded in fall and winter (except in June and December).

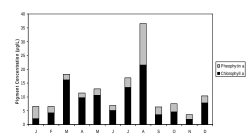


Figure 4-4 Chlorophyll *a* and Pheophytin *a* concentrations at C10A in 2005

Pheophytin *a* did not show a seasonal pattern; it remained relatively low and stable throughout the year, with concentrations under 5 µg/L. There was a large peak in August with a maximum concentration of 15.10 µg/L, which was nearly four times greater than the next highest concentration for the year. The minimum concentration was 1.57 µg/L, recorded in April.

Site P8: South Delta

Chlorophyll *a* concentrations showed a strong seasonal pattern at P8 (Figure 4-5), with the highest values recorded in spring and summer, and the lowest recorded in fall and winter. The maximum of 20.2 µg/L was recorded in June, and the minimum of 1.51 µg/L was recorded in January. After an initial spike in March, chlorophyll *a* concentrations remained relatively high through spring and summer before beginning a steady decline in the fall.

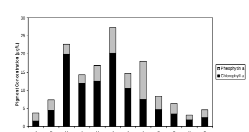


Figure 4-5 Chlorophyll *a* and Pheophytin *a* concentrations at P8 in 2005

Pheophytin *a* remained stable for most of the year, but had a peak in June and another peak in August. The maximum value was 10.5 µg/L in August; the minimum was 1.39 µg/L in November.

Site MD10A: East Delta

Chlorophyll *a* mostly showed a seasonal pattern at this site; except for a steep drop in June, concentrations were high in the spring and summer, and low in the fall and winter (Figure 4-6). The maximum was 21.4 µg/L in April and the minimum was 0.81 µg/L in January. Chlorophyll *a* peaked in late spring, and, after a sharp decrease in June, chlorophyll *a* jumped up again in late summer before starting a steady decline in the fall.

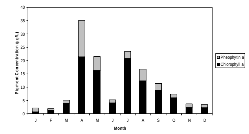


Figure 4-6 Chlorophyll *a* and Pheophytin *a* concentrations at MD10A in 2005

Pheophytin *a* remained stable, showing no seasonal pattern. Except for a sudden peak in April (13.6 µg/L), which was the maximum for the year, concentrations were mostly under 5 µg/L. The minimum was recorded in February (0.57 µg/L).

Site D26: Lower San Joaquin River

Although remaining stable for most of the year, chlorophyll *a* did show a slight seasonal pattern, with concentrations higher in spring and summer and lower in fall and winter (Figure 4-7). Chlorophyll *a* peaked in August at a maximum value of 3.28 µg/L. The minimum, recorded in February, was 0.40 µg/L.

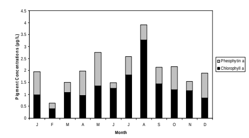


Figure 4-7 Chlorophyll *a* and Pheophytin *a* concentrations at D26 in 2005

Pheophytin *a* fluctuated throughout the year, particularly in the first six months. Decreases in late winter and early spring were followed by sharp increases in April and May. Values declined again in June and then increased in July, remaining relatively stable for the remainder of the year.

Site D19: Central Delta

Chlorophyll *a* concentrations showed a slight seasonal pattern, with generally minor changes throughout the year (Figure 4-8). The minimum concentration of 0.56 µg/L in February was followed by a sharp increase in March. Concentrations fluctuated little until peaking in August at 3.20 µg/L; they dropped by nearly half in September, and then remained stable through fall and winter.

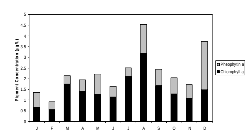


Figure 4-8 Chlorophyll *a* and Pheophytin *a* concentrations at D19 in 2005

Pheophytin *a* also remained stable throughout the year, excepting a secondary peak in August, and a primary peak in December reflecting the maximum value of 2.26 µg/L. The minimum value of 0.36 µg/L was recorded in February.

Site D28A: Central Delta

Chlorophyll *a* had two peak periods at this site: the first in spring and the second, larger peak in late summer (Figure 4-9). Concentrations indicated a seasonal pattern, except for June, which had the lowest value of the spring and summer months. The maximum of 3.07 µg/L was recorded in August; the minimum (0.56 µg/L) was recorded in January.

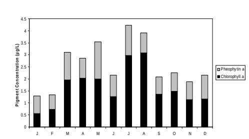


Figure 4-9 Chlorophyll *a* and Pheophytin *a* concentrations at D28A in 2005

Pheophytin *a* samples showed little fluctuation or seasonality, with concentrations staying fairly stable throughout the year. The maximum (1.53 µg/L) was recorded in May, and the minimum (0.60 µg/L) was recorded in February.

Site D4: Lower Sacramento River

Chlorophyll *a* at site D4 showed a clear seasonal pattern, with a steady increase in concentration through spring and summer followed by declining values in fall and winter (Figure 4-10). Chlorophyll *a* peaked in July (maximum of 3.74 µg/L); the lowest concentration of 0.61 µg/L was recorded in November.

Pheophytin *a* concentrations stayed fairly constant throughout the year, with little fluctuation. There were minor increases in early spring, but values remained stable until declining slightly in late fall. The maximum concentration was 1.36 µg/L in August; the minimum was 0.38 µg/L in November.

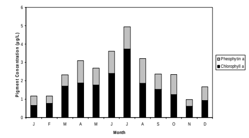


Figure 4-10 Chlorophyll *a* and Pheophytin a concentrations at D4 in 2005

Site D6: Suisun Bay

Chlorophyll *a* showed a slight seasonal pattern at site D6; the primary peak in late spring and early summer was followed by a steep decline in late summer and a secondary peak in early fall (Figure 4-11). Values for late fall and winter were lower than for rest of the year, excepting the late summer decline. The maximum concentration (3.97 µg/L) was recorded in May; the minimum (0.62 µg/L) was recorded in January.

Pheophytin *a* remained stable for most of the year, except for a peak in May and another peak in September. The maximum concentration was 1.84 µg/L and was recorded in May; the minimum (0.32 µg/L) was recorded in March.

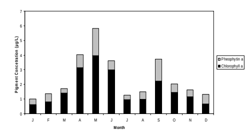


Figure 4-11 Chlorophyll *a* and Pheophytin *a* concentrations at D6 in 2005

Site D7: Suisun Bay

Chlorophyll *a* did show a seasonal pattern here, although it is difficult to distinguish due to the very high concentrations recorded in May and June. Overall, lower concentrations occurred in winter and higher concentrations in spring and summer (Figure 4-12). The maximum was 9.18 µg/L, recorded in May; the minimum was 0.61 µg/L, recorded in February.

Pheophytin *a* did not show a seasonal pattern; concentrations remained stable throughout the year, with a slight peak in May. The maximum (recorded in May) was 2.70 µg/L; the minimum (recorded in March) was 0.18 µg/L.

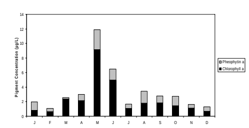


Figure 4-12 Chlorophyll *a* and Pheophytin *a* concentrations at D7 in 2005

Site D8: Suisun Bay

Chlorophyll *a* concentrations were generally higher in spring and summer, and lower in fall and winter, indicative of a seasonal trend (Figure 4-13). Slight increases in the spring were followed by a sharp peak in June, and then concentrations declined again. The maximum value of 5.11 µg/L was recorded in June; the minimum value was 0.42 µg/L and was recorded in January.

Pheophytin *a* had a sharp peak in spring, but otherwise fluctuated only slightly. No seasonal trend was apparent. The maximum value of 4.43 µg/L was recorded in May; the minimum of 0.25 µg/L was recorded in September.

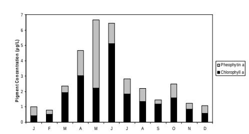


Figure 4-13 Chlorophyll *a* and Pheophytin *a* concentrations at D8 in 2005

Site D41: San Pablo Bay

Chlorophyll *a* did not show a strong seasonal trend at D41; concentrations were generally similar throughout the year, with little fluctuation between seasons (Figure 4-14). Chlorophyll *a* increased in the spring, and then dropped sharply in June before increasing again. Concentrations stayed

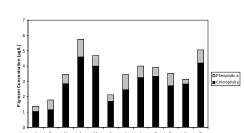


Figure 4-14 Chlorophyll *a* and Pheophytin *a* concentrations at D41 in 2005

relatively high through fall, and began increasing again in December, nearly reaching spring levels. The maximum value of 4.60 µg/L was recorded in April, and the minimum value of 1.03 µg/L was recorded in January.

Pheophytin *a* did not show a seasonal trend either; concentrations remained stable with only slight peaks in spring and summer. The maximum (1.15 µg/L) was recorded in April; the minimum (0.32 µg/L) was recorded in November.

Site D41A: San Pablo Bay

Chlorophyll *a* showed a clear seasonal trend, but also had a late peak in the fall (Figure 4-15). However, concentrations were generally higher in spring and summer and lower in fall and winter. The maximum value was recorded in April (8.01 µg/L), and the minimum was recorded in January (0.67 µg/L).

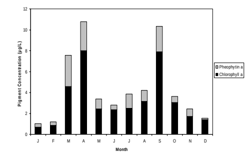


Figure 4-15 Chlorophyll *a* and Pheophytin *a* concentrations at D41A in 2005

Pheophytin *a* had an early spring peak and a late fall peak, parallel to the chlorophyll *a* peaks, but otherwise did not show a seasonal pattern. Excepting the peak values, concentrations changed little from season to season. The maximum of 2.96 µg/L was recorded in March; the minimum of 0.13 µg/L was recorded in December.

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2005. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following eight categories: diatoms, green algae, cryptomonads, blue-green algae, unidentified flagellates, euglenoids, yellow-brown algae, and dinoflagellates. The ten most common genera were *Cyclotella, Skeletonema, Monoraphidium, Cryptomonas, Rhodomonas, Aulacoseira,* unidentified flagellates, unidentified centric diatoms, *Aphanizomenon,* and *Pseudanabaena.* Chlorophyll *a* concentrations showed a distinct seasonal pattern; values ranged from 0.40 µg/L to 21.5 µg/L. Pheophytin *a* concentrations did not show a seasonal pattern; values ranged from 0.13 µg/L to 15.10 µg/L. Overall, chlorophyll *a* concentrations were relatively low when compared with the historical data.

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Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

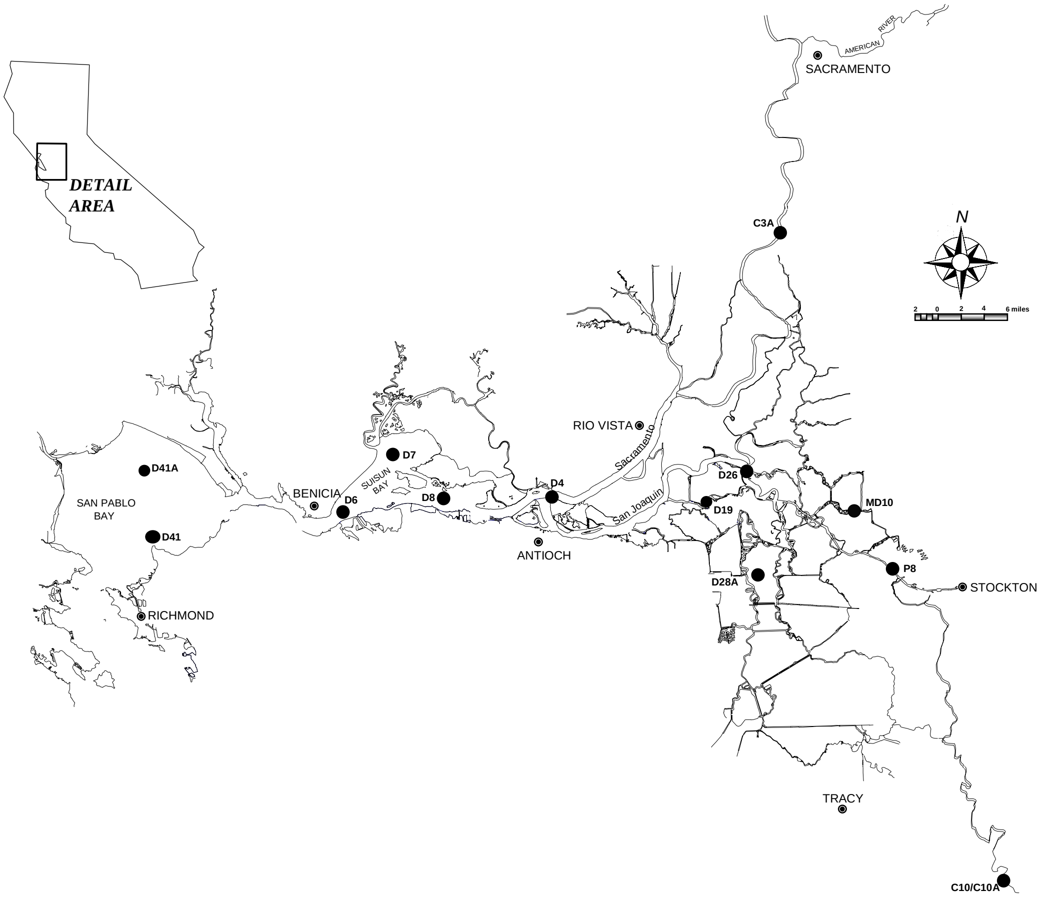


Figure 4-2 Percent phytoplankton composition by family for 2005

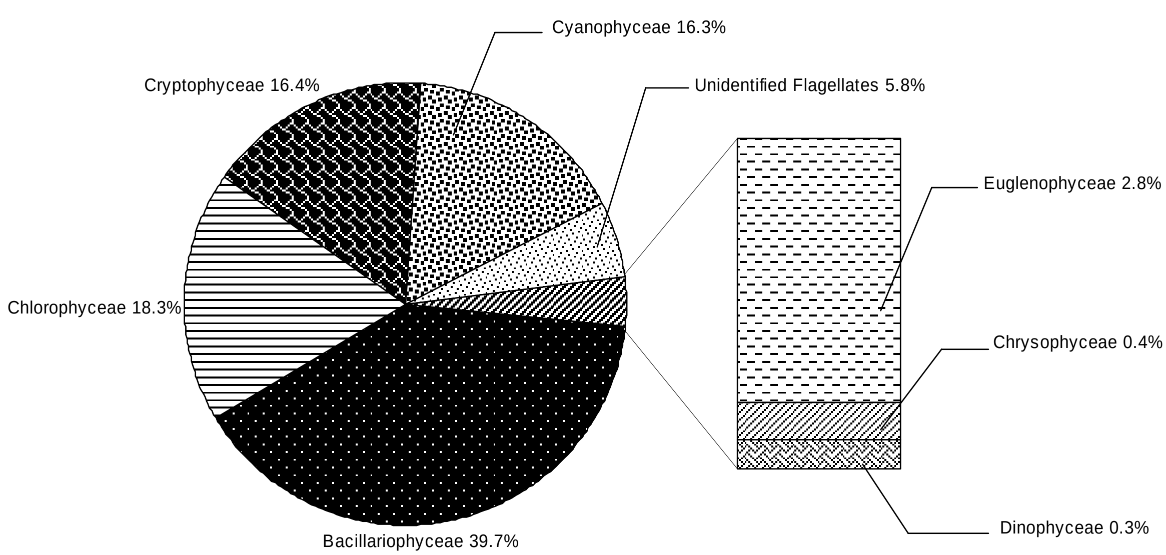


Figure 4-3 Chlorophyll *a* and pheophytin *a* concentrations at C3A in 2005

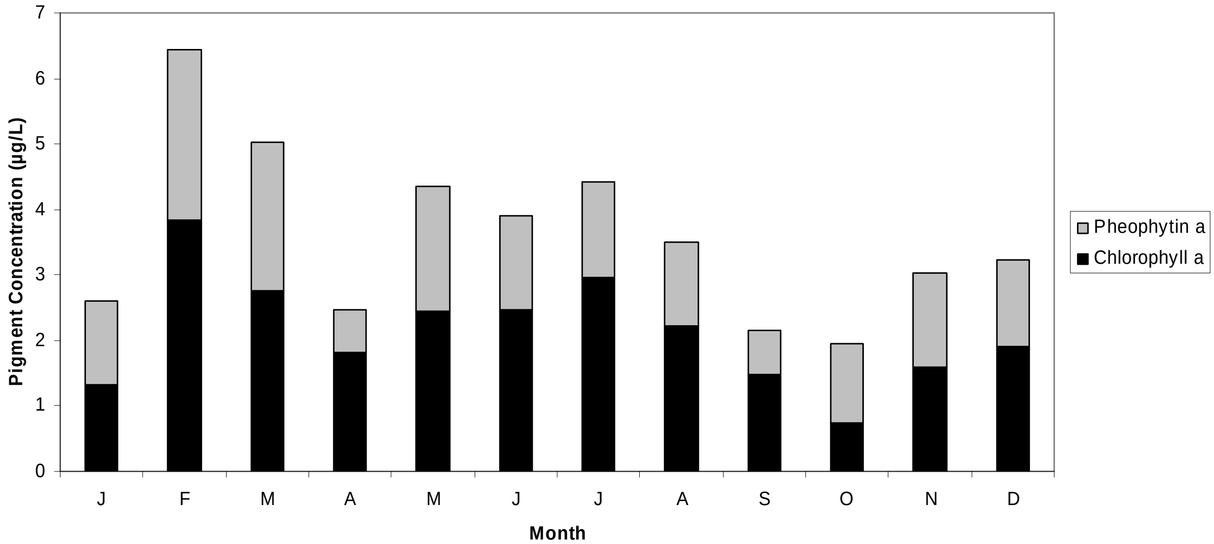
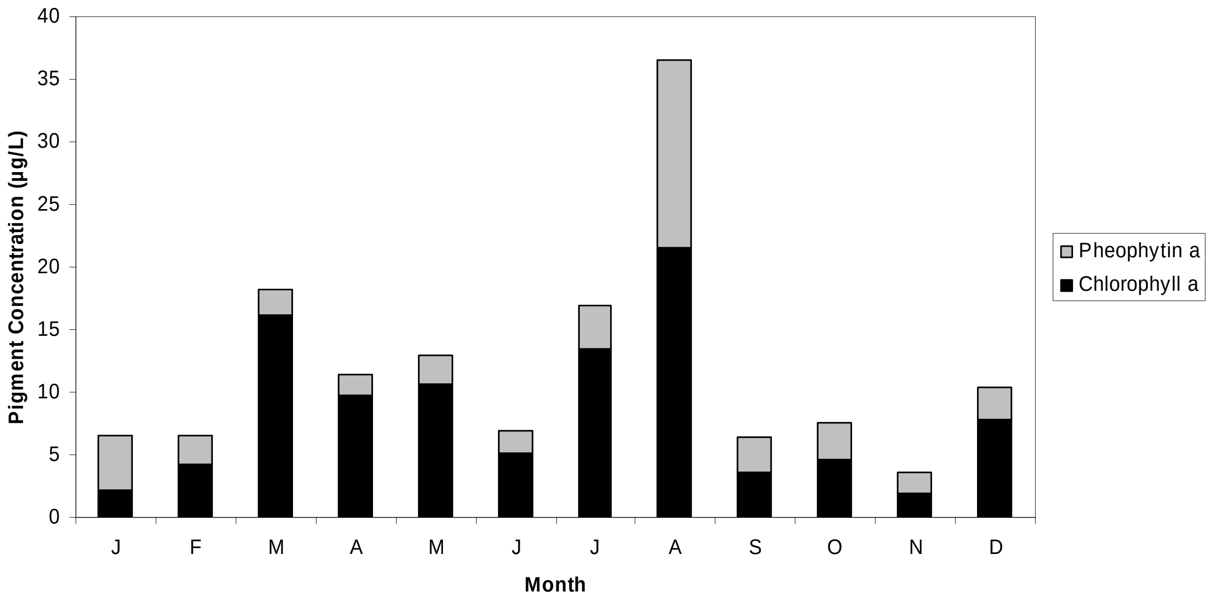


Figure 4-4 Chlorophyll *a* and Pheophytin *a* concentrations at C10A in 2005



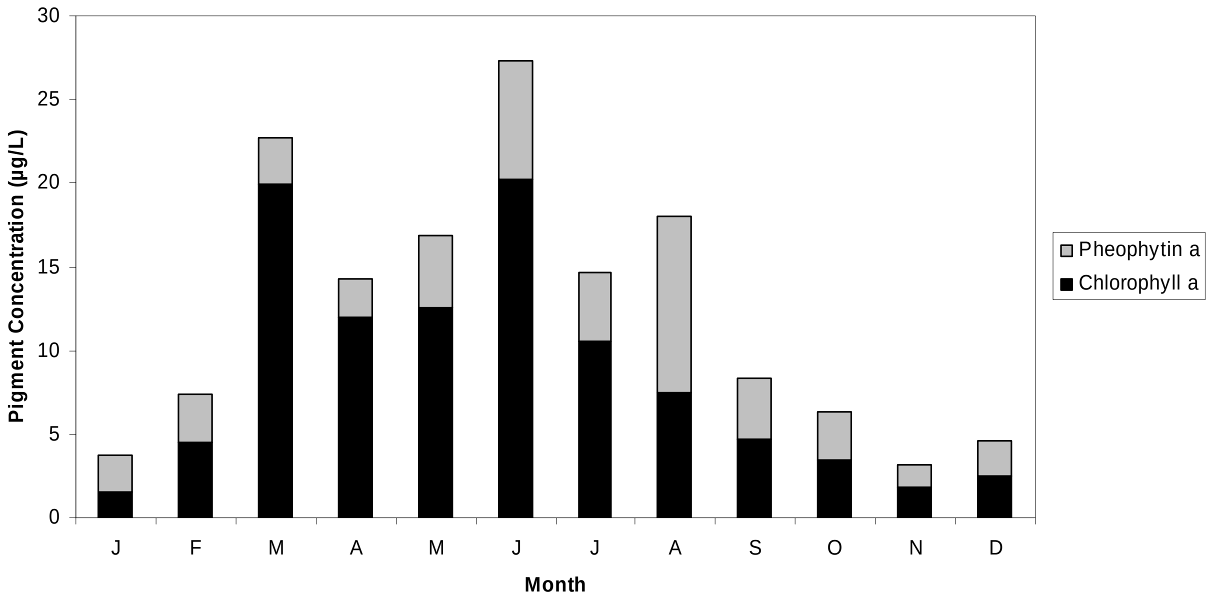


Figure 4-5 Chlorophyll *a* and Pheophytin *a* concentrations at P8 in 2005

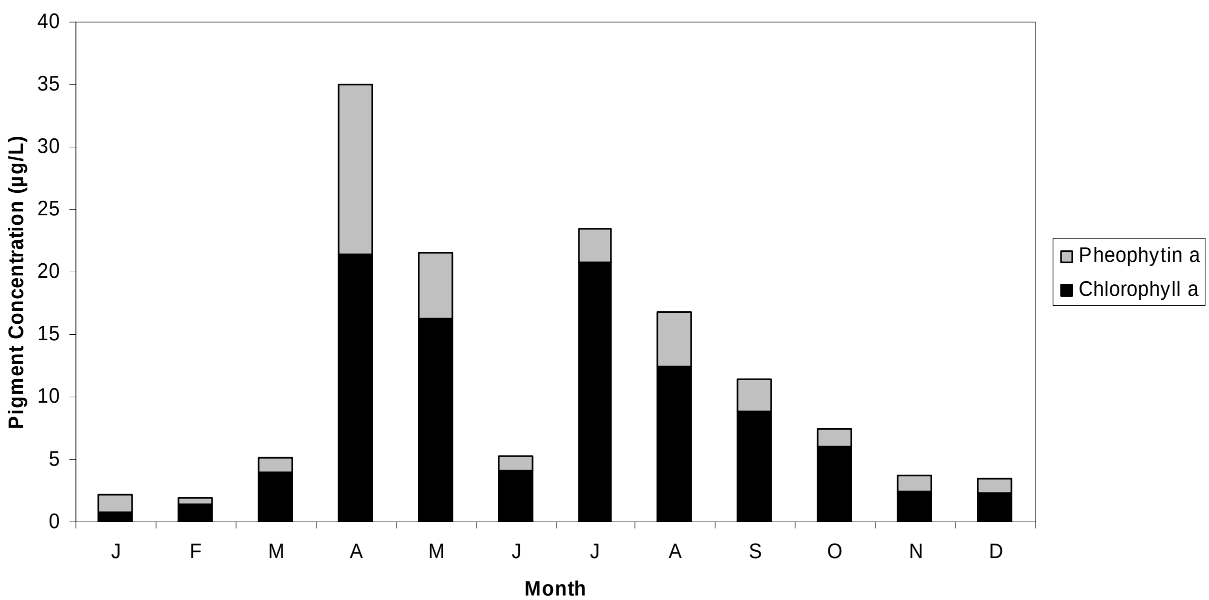


Figure 4-6 Chlorophyll *a* and Pheophytin *a* concentrations at MD10A in 2005

Figure 4-7 Chlorophyll *a* and Pheophytin *a* concentrations at D26 in 2005

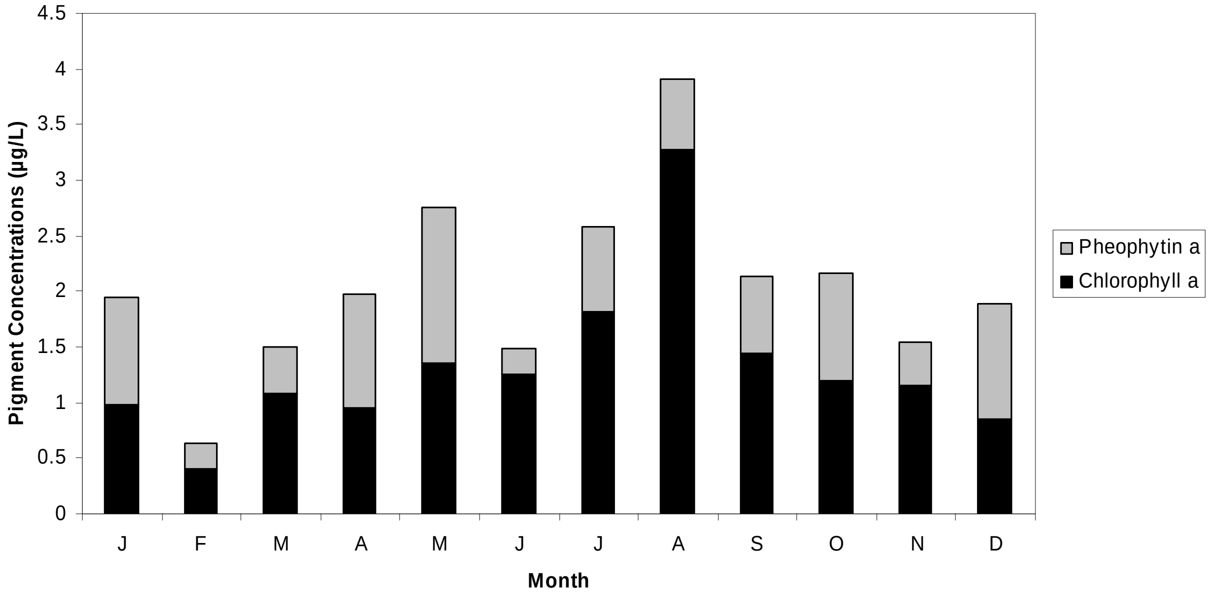


Figure 4-8 Chlorophyll *a* and Pheophytin *a* concentrations at D19 in 2005

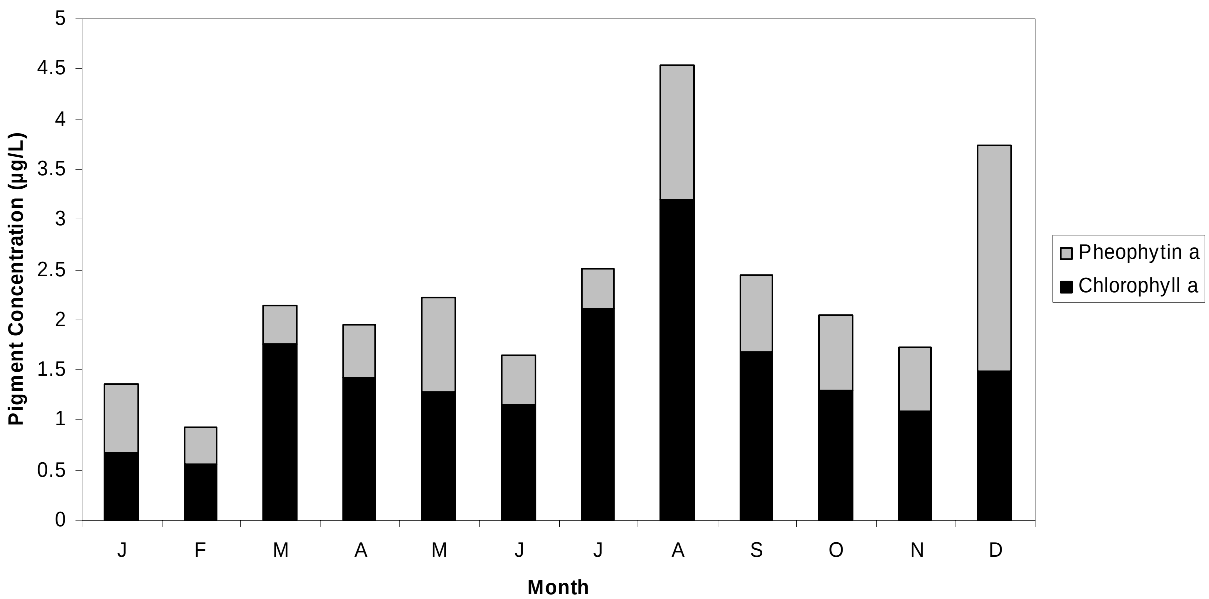


Figure 4-9 Chlorophyll *a* and Pheophytin *a* concentrations at D28A in 2005

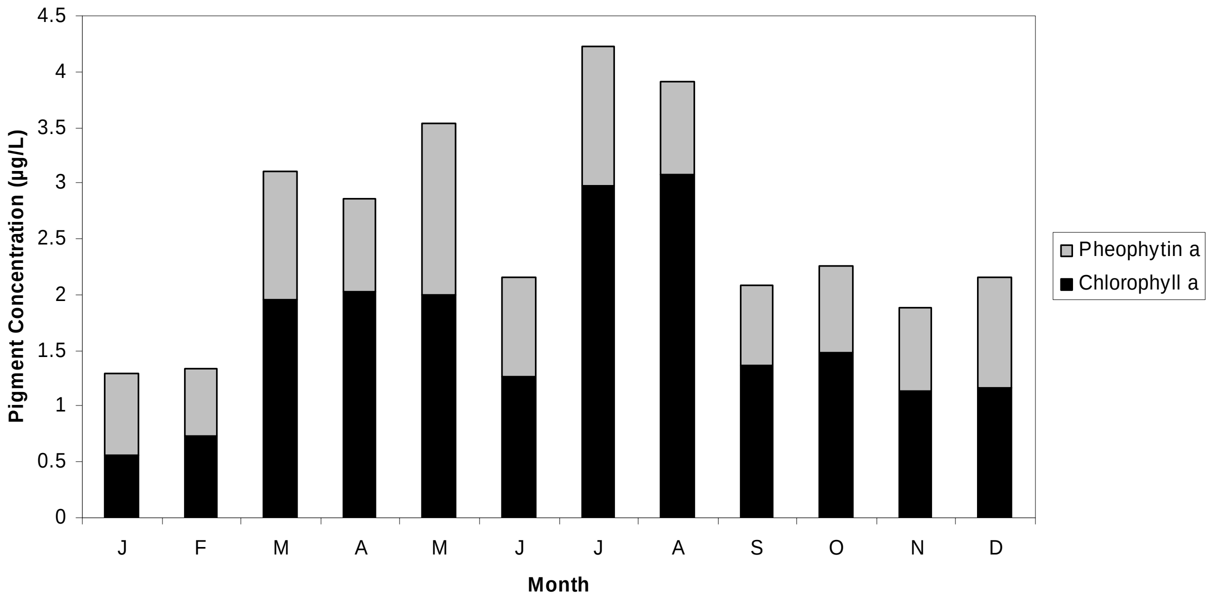


Figure 4-10 Chlorophyll *a* and Pheophytin *a* concentrations at D4 in 2005

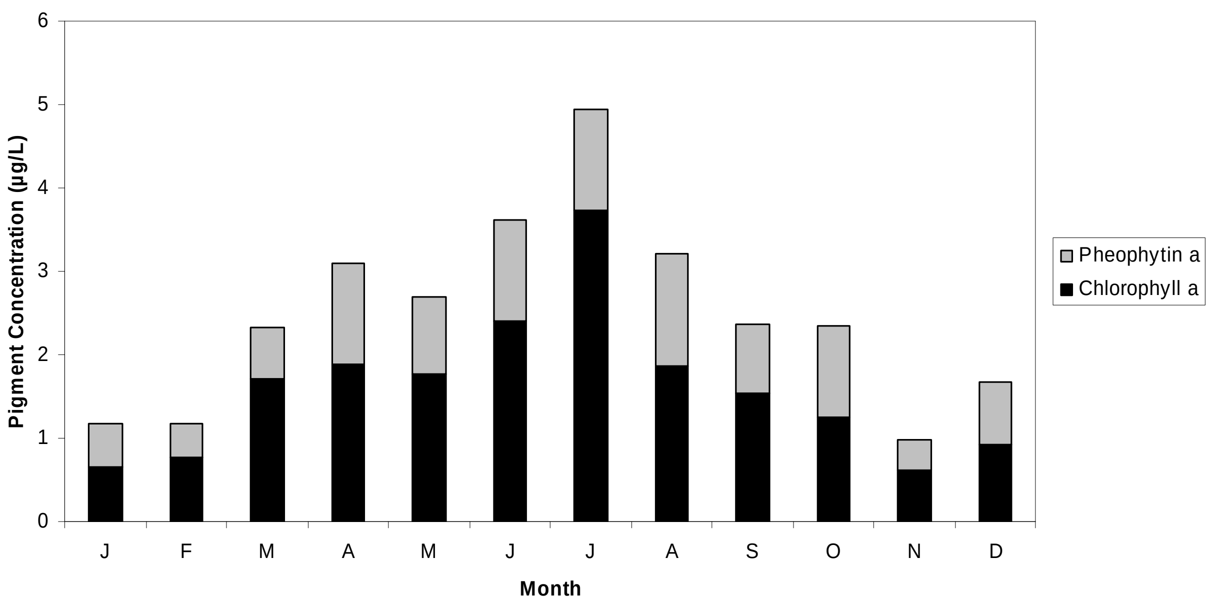


Figure 4-11 Chlorophyll *a* and Pheophytin *a* concentrations at D6 in 2005

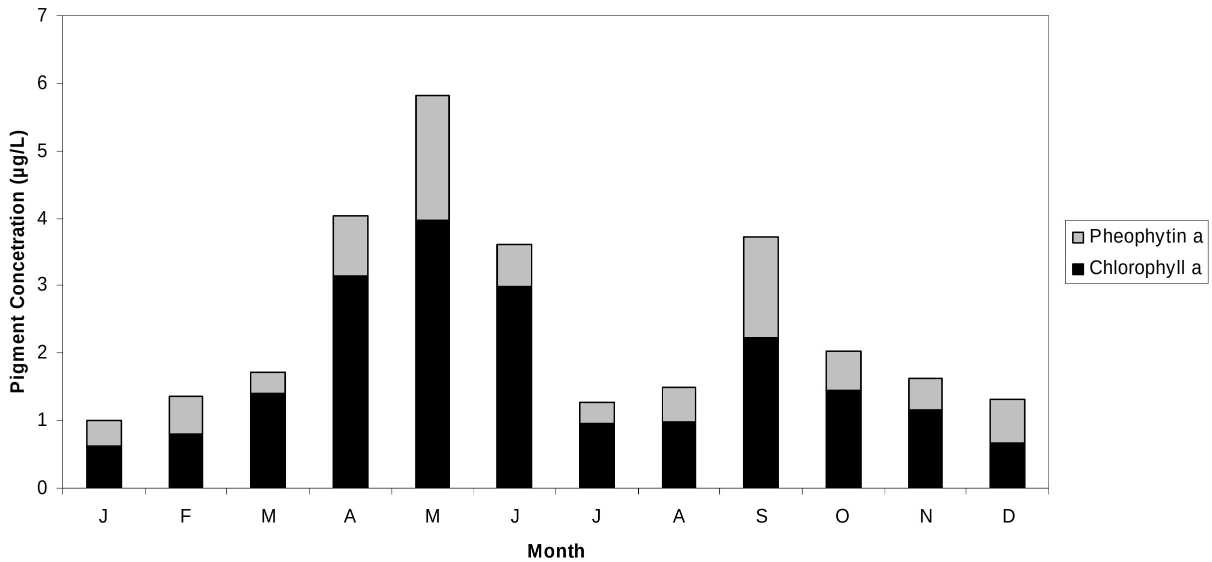


Figure 4-12 Chlorophyll *a* and Pheophytin *a* concentrations at D7 in 2005

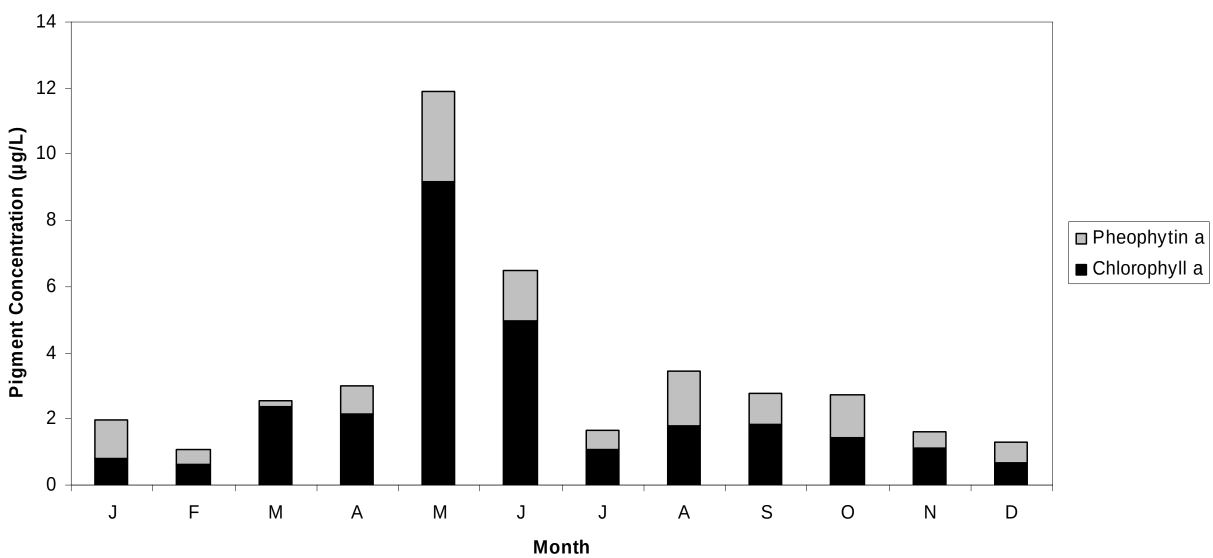


Figure 4-13 Chlorophyll *a* and Pheophytin *a* concentrations at D8 in 2005

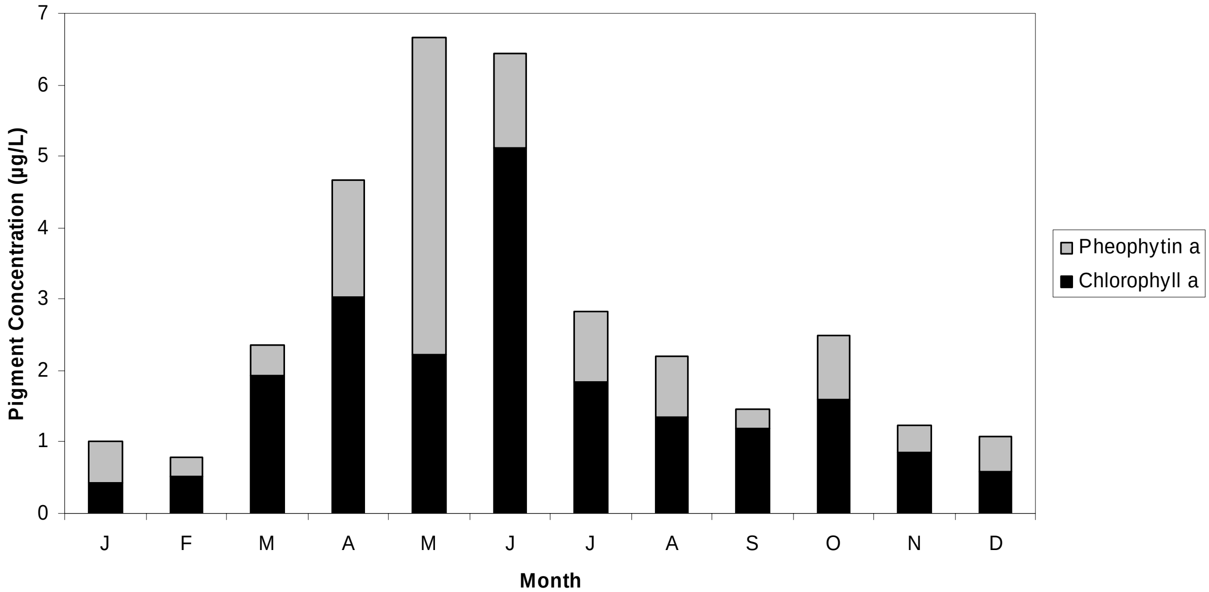


Figure 4-14 Chlorophyll *a* and Pheophytin *a* concentrations at D41 in 2005

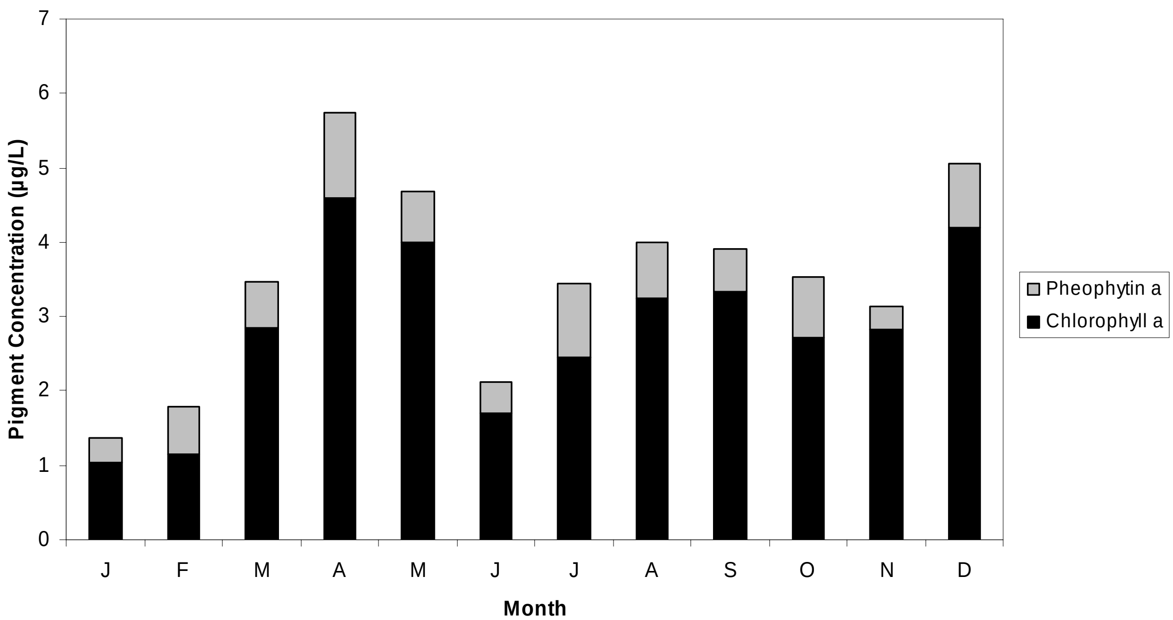


Figure 4-15 Chlorophyll *a* and Pheophytin *a* concentrations at D41A in 2005

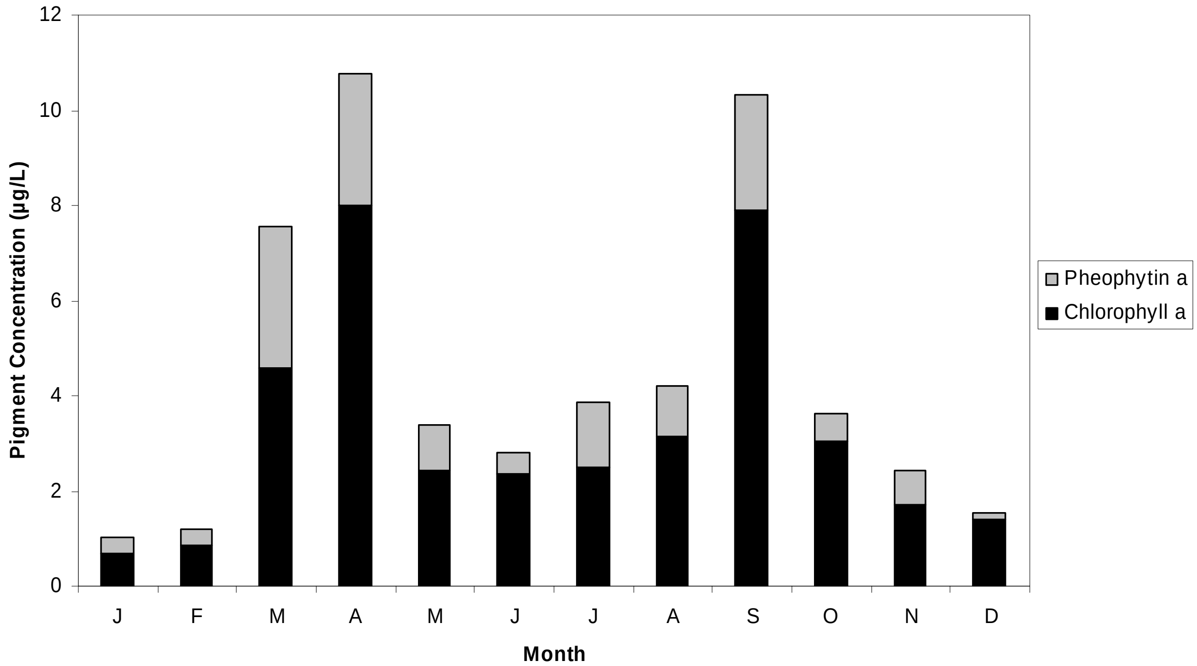


Table 4-1 All genera found in each family in the upper San Francisco Estuary in 2005

Family	Genus
Bacillariophyceae	*Achnanthes*
	Amphiprora
	Asterionella
	Aulacoseira
	Centric Diatom
	Cocconeis
	Cyclotella
	Diatoma
	Entomoneis
	Fragilaria
	Gyrosigma
	Mastogloia
	Melosira
	Navicula
	Pennate Diatom
	Skeletonema
	Synedra
Chlorophyceae	*Actinastrum*
	Carteria
	Chlamydomonas
	Chlorella
	Chodatella
	Closterium
	Crucigenia
	Elakatothrix
	Eudorina
	Gloeocystis
	Gonyostomum
	Kirchneriella
	Monoraphidium
	Monostroma
	Mougeotia
	Oocystis
	Planktosphaeria
	Scenedesmus
	Selenastrum
	Stichococcus
	Tetraedron
	Tetrastrum
Chrysophyceae	*Dinobryon*
Cryptophyceae	*Chroomonas*
	Cryptomonas
	Rhodomonas
Cyanophyceae	*Anabaena*
	Aphanizomenon
	Chroococcus
	Merismopedia
	Microcystis
	Oscillatoria
	Phormidium
	Pseudanabaena
	Synechocystis
Dinophyceae	*Glenodinium*
	Gymnodinium
Euglenophyceae	*Euglena*
	Trachelomonas
Unknown	Unidentified flagellates

Table 4-2 Chlorophyll *a* and Pheophytin *a* values

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C10A	21.50	1.86	6.47	8.43	6.13
C3A	3.83	0.75	2.06	2.13	0.83
D19	3.20	0.56	1.36	1.47	0.70
D26	3.28	0.40	1.18	1.31	0.71
D28A	3.07	0.56	1.43	1.65	0.79
D4	3.74	0.61	1.63	1.59	0.88
D41	4.60	1.03	2.84	2.84	1.14
D41A	8.01	0.67	2.45	3.21	2.46
D6	3.97	0.62	1.29	1.70	1.12
D7	9.18	0.61	1.61	2.34	2.45
D8	5.11	0.42	1.47	1.72	1.32
MD10A	21.40	0.81	5.07	8.41	7.54
P8	20.20	1.51	6.09	8.42	6.66

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C10A	15.10	1.57	2.49	3.58	3.71
C3A	2.60	0.64	1.38	1.46	0.57
D19	2.26	0.36	0.67	0.80	0.54
D26	1.39	0.23	0.73	0.73	0.36
D28A	1.53	0.60	0.84	0.92	0.27
D4	1.36	0.38	0.88	0.88	0.34
D41	1.15	0.32	0.66	0.68	0.25
D41A	2.96	0.13	0.84	1.17	1.00
D6	1.84	0.32	0.57	0.72	0.48
D7	2.70	0.18	0.89	1.04	0.69
D8	4.43	0.25	0.71	1.04	1.15
MD10A	13.60	0.57	1.37	3.02	3.62
P8	10.50	1.39	2.92	3.86	2.56

Chapter 5. Zooplankton and Mysid Shrimp

Introduction

Zooplankton are important food organisms for larval and juvenile salmon, for striped bass and splittail, and for planktivorous fishes (such as delta smelt) throughout their lives. The Department of Fish and Game's Neomysis-Zooplankton Study monitors the annual and seasonal abundance and distribution of the major zooplankton taxa (usually genus or species level) to assess the size and location of the fish food resources in the San Francisco Estuary (Estuary). This study also seeks to detect the presence of introduced species that have recently established themselves in the estuary, to monitor their distribution and abundance, and to determine their impacts on native species. The study began monitoring the native mysid *Neomysis mercedis* in June 1968 and was expanded in January 1972 to monitor copepods, cladocerans, and rotifers. Other mysid species were consistently identified and enumerated as of 1998, while newly introduced copepods, cladocerans, and rotifers were identified and enumerated as they were detected.

Methods

Zooplankton were sampled monthly at 17 to 22 stations in the Delta and Suisun Bay (Figure 5-1). Twenty of these stations were at fixed geographic locations. Two stations were "floating" stations located where bottom electrical conductance (EC) was 2,000 µS/cm and 6,000 µS/cm, +/-10%. Because they are not geographically fixed, the floating stations are not shown in Figure 5-1. One station in San Pablo Bay and two stations in Carquinez Strait were sampled only when their surface EC was less than 20 µS/cm. Monthly sampling was scheduled such that each station was sampled at high slack tide.

Figure 5-1 Zooplankton monitoring stations

At each station three types of gear were deployed: 1) a mysid net; 2) a Clarke-Bumpus (CB) net for mesozooplankton; and 3) a pump sampler for microzooplankton. The mysid net was 1.48 m long with a 28 cm interior mouth diameter and a mesh size of 505 µm. It was attached to a ski-mounted towing frame made of steel tubing, with a General Oceanics model 2030 flowmeter mounted at the center of the mouth. The CB net was 75 cm long with an interior mouth diameter of 12.4 cm and a mesh size of 154 µm. The CB frame used a 19.1 cm long, clear acrylic pipe with an inside diameter of 12.0 cm and had a General Oceanics flowmeter suspended in the center of the pipe. The entire CB apparatus was mounted on top of the mysid frame. The pump sampler consisted of a 15-liter/minute-capacity pump connected to a 15 m intake hose that was discharged into a 19-L carboy. The subsample returned to the laboratory was filtered through several sieves and zooplankton retained by the 43 µm mesh sieve was identified.

Gear deployment occurred simultaneously for the mysid and CB nets while the vessel was underway, whereas the vessel was stopped or moving with the prevailing current during pump deployment. At each station a towing frame holding the mysid and CB nets was lowered to the bottom and retrieved obliquely in several steps over a 10-minute period. Flowmeter readings from both nets were recorded before and after each tow to calculate the volume of water filtered. At the end of this tow, after forward momentum had ceased, the pump was turned on and the intake was lowered to the bottom and was raised slowly to the surface twice, while pumped water was discharged into the carboy. After sampling was completed, the carboy was shaken and a 1.5 to 1.9 liter sample decanted into a jar. All samples were fixed in buffered 10% formalin and returned to the laboratory for processing.

Before and after each mysid-CB tow, water temperature (± 0.1 ^{o}C) and specific electrical conductance (EC, µS/cm) measurements were taken from the top (1 meter below the surface) and bottom (1 meter above the substrate) of the water column using a Seabird 911+ CTD.

In past reports the abundance of copepods, rotifers, and cladocerans was the sum of a taxon's CB and pump sample abundance (number per m^3). In this report abundance is reported only for the gear that collects the taxon most efficiently: 1) the CB net for all the calanoid copepods, the cyclopoid copepod *Acanthocyclops vernalis*, and all the cladocerans; 2) the pump for all the rotifers; and 3) both the CB and pump for the cyclopoid copepods *Limnoithona tetraspina* and *Oithona davisae*. We report abundance for both gears for these latter two species because larger adults are retained by the CB mesh and smaller adults are more effectively sampled by the pump.

Zooplankton distribution within the estuary is determined more by salinity than geography. To account for this, the stations were categorized into three EC zones: 1) upstream of the entrapment zone (bottom EC < 1,800 µS/cm); 2) the entrapment zone (bottom EC range 1,800 µS/cm to 6,600 µS/cm); and 3) downstream of the entrapment zone (bottom EC > 6,600 µS/cm). However, four sampling events at three stations normally in the entrapment zone had EC values slightly higher than 6,600 µS/cm. The outlying events at these stations were grouped with the entrapment zone for two reasons: 1) the other sampling events at these stations were part of the entrapment zone during the rest of the year, and 2) the EC values of the outliers were within 10% of 6,600 µS/cm. Monthly and annual abundance for each taxon was calculated as the mean number per m^3 for each gear type and each EC zone. The number of stations in each zone varied by 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 abundance for each zone provided a common basis for comparisons.

To depict the seasonal changes in abundance, data were log transformed ($\log_{10}$ (abundance+1)) before plotting. Log transformation smoothed trend lines and allowed low abundance to be discerned when abundance ranged across several orders of magnitude.

For brevity, trends from only a subset of the taxa collected are discussed. Taxa were ranked based on mean annual abundance for all stations sampled. Monthly abundance trends are presented for the three, four, or five top ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Results

Mysids

Acanthomysis bowmani has been present in the estuary since 1993 and was the most abundant mysid across all zones (Table 5-1). Abundance was highest in the entrapment zone, with upstream and downstream abundance only 9% to 13% of the entrapment zone abundance. Seasonality was similar among zones, with peaks in spring and summer through early fall (Figure 5-2).

Taxonomists are attempting to determine if the sampling program is collecting the look-alike, introduced, *Neomysis japonica* in addition to the native *N. kadiakensis*. Until any distinction is confirmed, both species will be grouped as *N. kadiakensis/japonica.* This was the second most abundant mysid overall and was found mostly in and downstream of the entrapment zone (Table 5-1). Upstream of the entrapment zone, *Neomysis kadiakensis/japonica* was collected in only four months (Figure 5-3). Abundance peaked in spring within and downstream of the entrapment zone, with smaller peaks in fall in both zones.

Neomysis mercedis was the third most abundant mysid, but was collected only within and upstream of the entrapment zone (Table 5-1, Figure 5-4). Until the mid-1990s, this native species had been the most common mysid in the estuary. In 2005, abundance peaked in spring and summer in both zones where it was collected.

The native *Alienacanthomysis macropsis* prefers higher salinities, and was collected only downstream of the entrapment zone (Figure 5-5). Despite being the fourth most common mysid (Table 5-1), it was collected only from January through May and in the last two months of 2005.

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in 2005 (Table 5-2). Its abundance was highest within and upstream of the entrapment zone, with large seasonal peaks through spring and summer (Figure 5-6). Downstream of the entrapment zone, abundance peaked in summer and fall.

The genus *Acartia* consists of three native brackish water species and it was the second most common calanoid copepod (Table 5-2). It was by far the most common taxon collected downstream. Within and upstream of the entrapment zone, it appeared in only a few months of the year (Figure 5-7). Downstream, abundance peaked in early spring, with two smaller peaks in summer and fall.

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Acanthomysis bowmani	2.11	23.39	3.15	**6.60**
Neomysis kadiakensis/japonica	0.02	0.18	0.20	**0.11**
Neomysis mercedis	0.08	0.06	0.00	**0.05**
Alienacanthomysis macropsis	0.00	0.00	0.04	**0.01**

Table 5-1 Mysids: Catch per Unit Effort (CPUE)

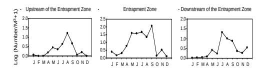


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone

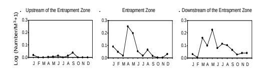


Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone

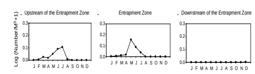


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone

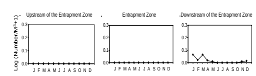


Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone

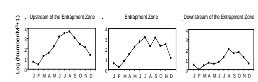


Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone

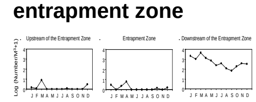


Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone

The introduced *Acartiella sinensis* was the third most abundant calanoid copepod, with highest abundance within and downstream of the entrapment zone (Table 5-2). Seasonal patterns were similar across all zones, with numbers steadily increasing throughout the year until finally peaking in the fall (Figure 5-8).

Eurytemora spp. was the fourth most common calanoid copepod in 2005 (Table 5-2); in 2004, the introduced *Sinocalanus doerrii* was fourth. *Eurytemora* spp. was most common upstream of the entrapment zone. Upstream and downstream showed similar seasonal trends, with bimodal peaks in spring and fall (Figure 5-9). In the entrapment zone, abundance peaked in spring and then declined sharply until fall.

Sinocalanus doerrii, the fourth most common calanoid copepod in 2004, was bumped down to fifth in 2005 (Table 5-2). It was most common in and upstream of the entrapment zone, with similar spring abundance peaks in both (Figure 5-10). Downstream of the entrapment zone, it was collected in only four months of the year.

Cyclopoid Copepods

Since it was first detected in 1993, *Limnoithona tetraspina* has become the most abundant cyclopoid copepod in the study area. It was abundant in all three zones, with the majority occurring in and downstream of the entrapment zone (Table 5-3). Within and upstream of the entrapment zone, abundance in the CB samples peaked in summer and fall (Figure 5-11). Downstream of the entrapment zone, CB sample abundance peaked in early spring and again in fall. Within and downstream of the entrapment zone, pump abundance increased steadily through the year before peaking in summer. Upstream of the entrapment zone, pump abundance was bimodal, with a peak in early spring and another in late summer.

Another introduced species, *Oithona davisae*, was the second most abundant cyclopoid copepod in 2005 (Table 5-3). It was most common downstream of the entrapment zone where abundance in the pump samples peaked in summer, and abundance in the CB samples peaked a few months later (Figure 5-12). In the entrapment zone, both gears showed similar bimodal abundance peaks in late winter-early spring, and late summer-early fall. Upstream of the entrapment zone, abundance for both gear types peaked in August.

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod in 2005, and was the most common in the entrapment zone (Table 5-3). In and upstream of the entrapment zone, seasonal patterns were similar, with higher abundance in spring and summer followed by a fall decline (Figure 5-13). Downstream of the entrapment zone, abundance fluctuated slightly during the year, but rose sharply in late fall and early winter.

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Pseudodiaptomus forbesi	897.09	395.08	24.67	**508.49**
Acartia *spp.*	0.79	0.85	811.95	**271.19**
Acartiella sinensis	26.66	278.71	148.15	**116.26**
Eurytemora *spp.*	74.27	56.76	21.66	**53.32**
Sinocalanus doerrii	70.91	52.58	0.68	**43.93**

Table 5-2 Calanoid copepods: CPUE

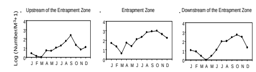


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone

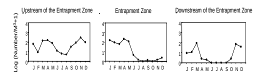


Figure 5-9 Monthly *Eurytemora* spp. abundance upstream, in, and downstream of the entrapment zone

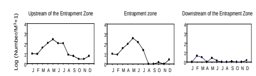


Figure 5-10 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone

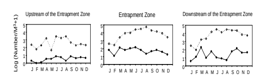


Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone

Clarke-Bumpus Net

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Limnoithona tetraspina	**3.02**	**67.34**	**54.41**	32.68
Oithona davisae	**0.41**	**7.42**	**412.77**	139.23
Acanthocyclops vernalis	**14.40**	**53.76**	**5.59**	19.13

Pump

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Limnoithona tetraspina	**990.71**	**14880.78**	**13771.04**	7986.52
Oithona davisae	**242.47**	**258.78**	**810.84**	434.35

Table 5-3 Cyclopoid copepods: CPUE

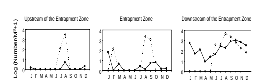


Figure 5-12 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone

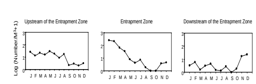


Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone

Cladocerans

The most common cladocerans collected by this study are mainly freshwater, and the majority of them are found upstream of the entrapment zone. *Bosmina* spp., the most abundant cladoceran (Table 5-4), had high numbers throughout the year upstream (Figure 5-14). Within the entrapment zone, abundance was stable for the first half of the year, and then declined in summer. Downstream, abundance was low most of the year. All three zones showed increasing abundance in December.

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Bosmina *spp.*	409.35	7.79	1.69	**195.24**
Diaphanosoma *spp.*	181.67	1.23	0.02	**85.97**
Daphnia *spp.*	90.22	3.48	0.91	**43.55**

Table 5-4 Cladocerans: CPUE

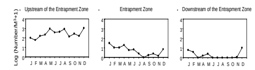


Figure 5-14 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone

Diaphanosoma spp. was the second most abundant cladoceran in 2005 (Table 5-4). The summer peaks of seasonal abundance were similar within and upstream of the entrapment zone; the upstream peak, however, lasted into the fall (Figure 5-15). Downstream of the entrapment zone, *Diaphanosoma* spp. appeared only in July.

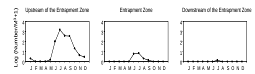


Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone

The third most abundant cladoceran was *Daphnia* spp. (Table 5-4). Abundance upstream of the entrapment zone fluctuated throughout the year; the peak was in May (Figure 5-16). Conversely, the other two zones showed a winter peak that declined to very low numbers for most of the year.

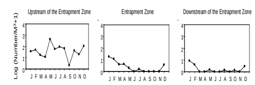


Figure 5-16 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone

Rotifers

In 2005, the common rotifer taxa switched ranks from 2004. Like cladocerans, rotifers are primarily freshwater organisms. The most common rotifer in 2005 was *Synchaeta* spp. (Table 5-5), which had been second in 2004. It was most common downstream of the entrapment zone, but its numbers were relatively high in the other zones as well. *Synchaeta* spp. abundance remained fairly stable throughout the year, with the exception of November in the entrapment zone (Figure 5-17).

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Synchaeta *spp.*	4308.38	3689.86	8255.01	**5495.61**
Keratella *spp.*	4389.51	855.15	186.75	**2293.85**
Polyarthra *spp.*	3651.12	511.40	73.23	**1841.10**

Table 5-5 Rotifers: CPUE

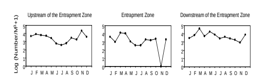


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone

Keratella spp. was the second most abundant rotifer in 2005 (Table 5-5); it had been third in 2004. Abundance trends varied among zones; it was relatively stable upstream, but within the entrapment zone, it showed a steep decline in the fall (Figure 5-18). Downstream of the entrapment zone abundance fluctuated greatly, with multiple peaks and declines.

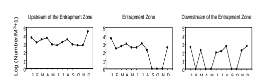


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone

Polyarthra spp., which had been the most common in 2004, was third most common in 2005 (Table 5-5). Like the other two species, abundance was stable upstream of the entrapment zone (Figure 5-19). Within the entrapment zone, abundance was stable during the first part of the year, but fluctuated greatly after July. Downstream, abundance showed an opposite pattern, with large fluctuation early in the year before numbers leveled off in late summer through fall.

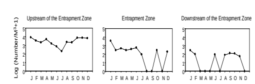


Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone

Summary

In 2005, the annual rankings of the most common zooplankton were the same as for 2004, with a few exceptions. Monthly abundance patterns between 2004 and 2005 were also similar. The introduced *Acanthomysis bowmani* and the *Neomysis kadiakensis/japonica* complex remained the two most abundant mysids, followed by the native *Neomysis mercedis* and *Alienacanthomysis macropsis*. *Pseudodiaptomus forbesi*, ranked first in 2004, was again the most common calanoid copepod. The native *Acartia* spp. was second, and the introduced *Acartiella sinensis* was third. The three most common cyclopoid copepods remained the introduced *Limnoithona tetraspina* and *Oithona davisae,* followed by the native *Acanthocyclops vernalis.* The top three cladocerans also did not change from 2004, with *Bosmina* spp., *Diaphanosoma* spp., and *Daphnia* spp. most commonly collected. The rotifers switched ranks in 2005, with *Synchaeta* spp. most common, followed by *Keratella* spp. and *Polyarthra* spp. In 2004, *Polyarthra* spp. had been the most common.

Figure 5-1 Zooplankton monitoring stations

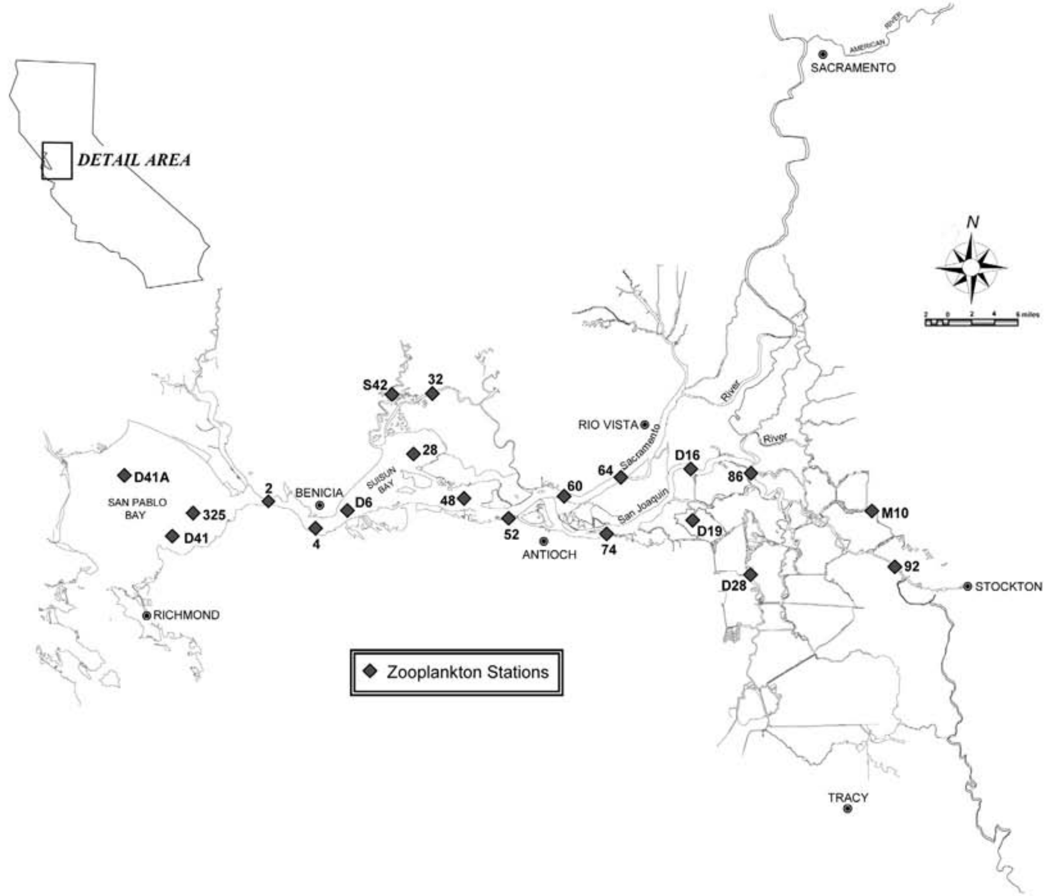


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone for 2005

Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone for 2005

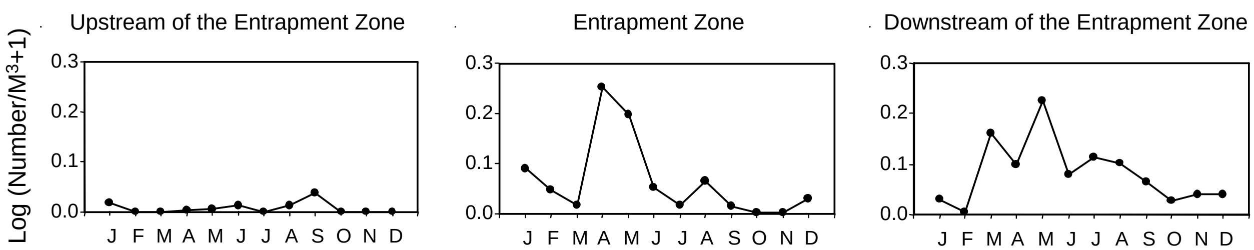


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone for 2005

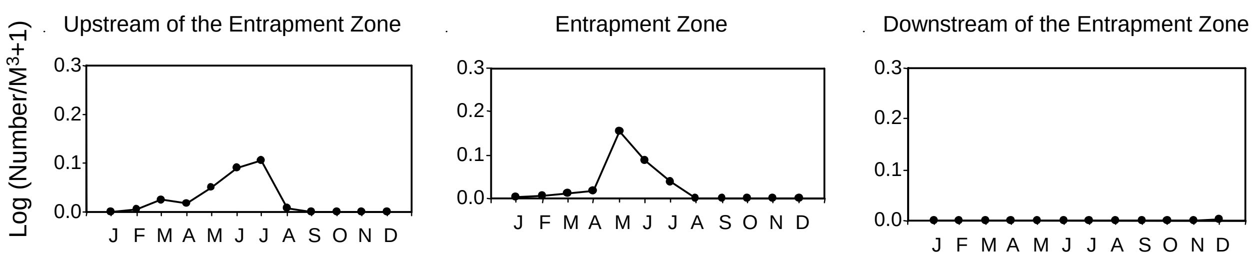


Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone for 2005

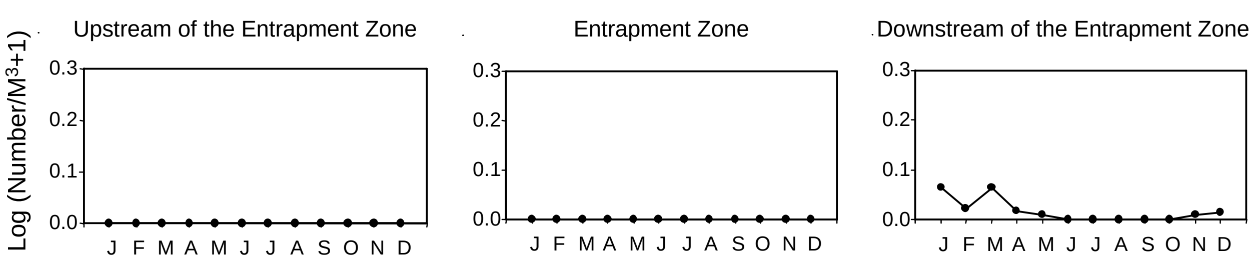


Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone for 2005

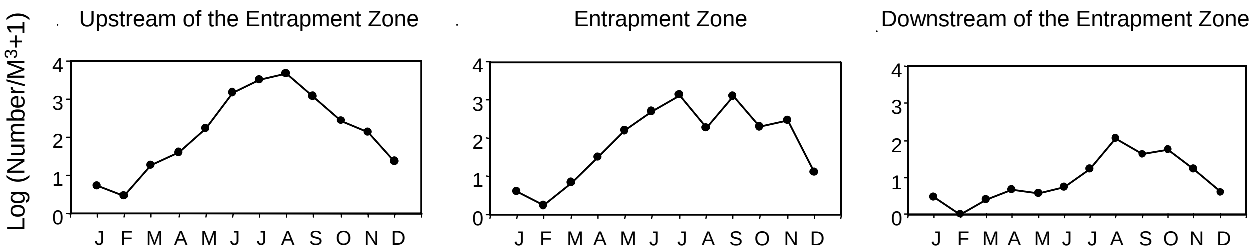


Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

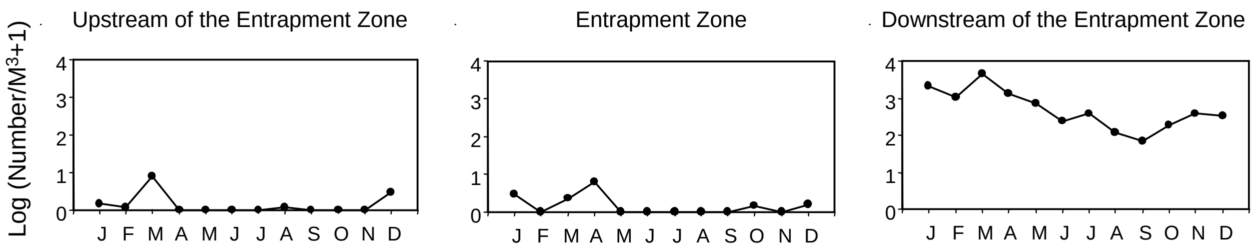


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone for 2005

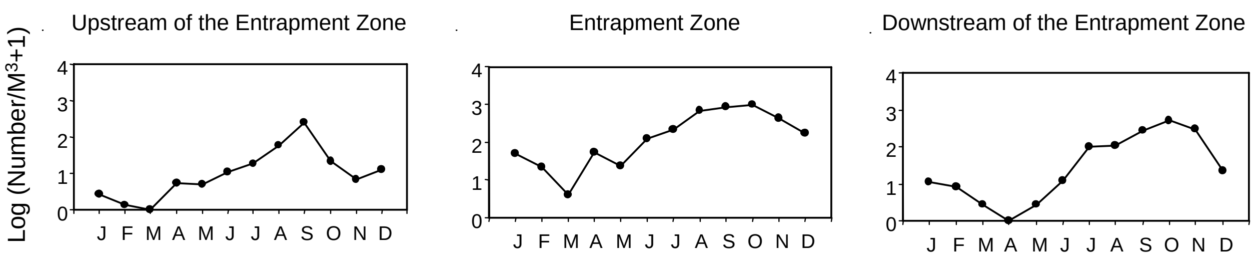


Figure 5-9 Monthly *Eurytemora* spp. abundance upstream, in, and downstream of the entrapment zone

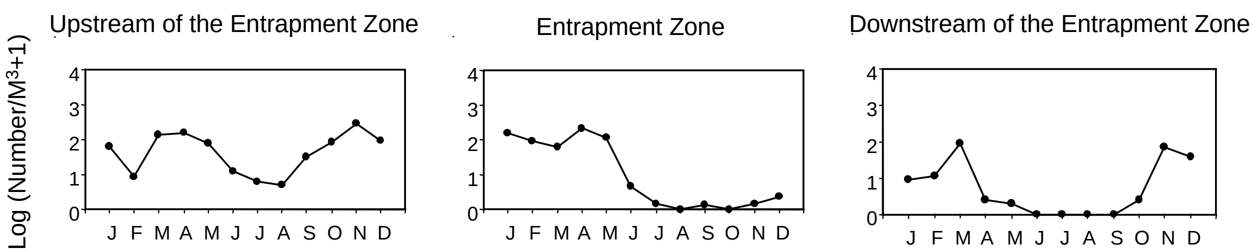


Figure 5-10 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone for 2005

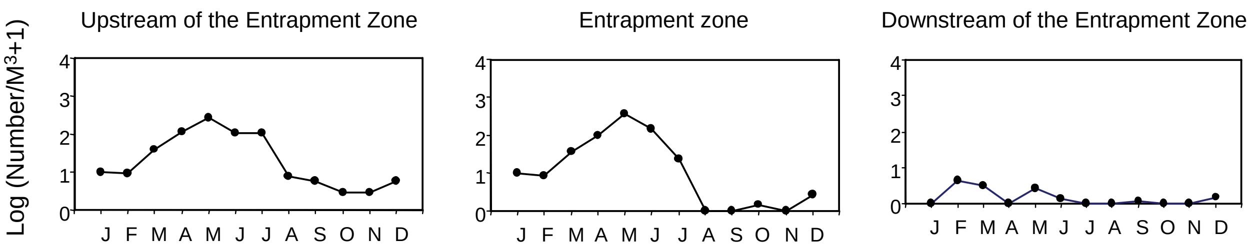


Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone for 2005

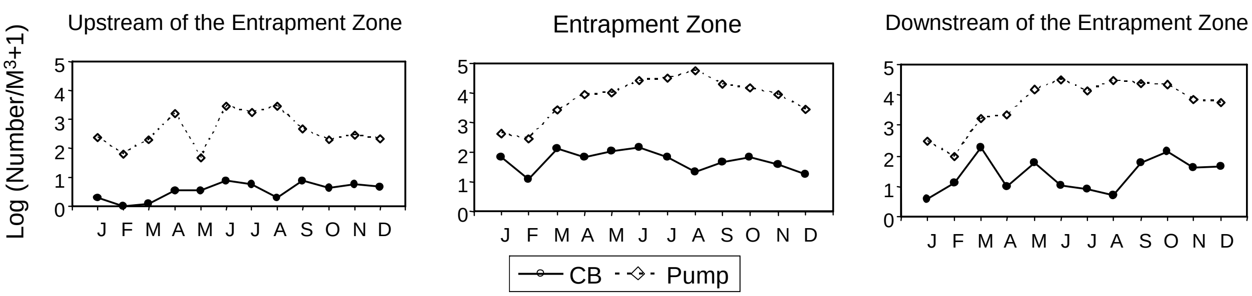


Figure 5-12 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone for 2005

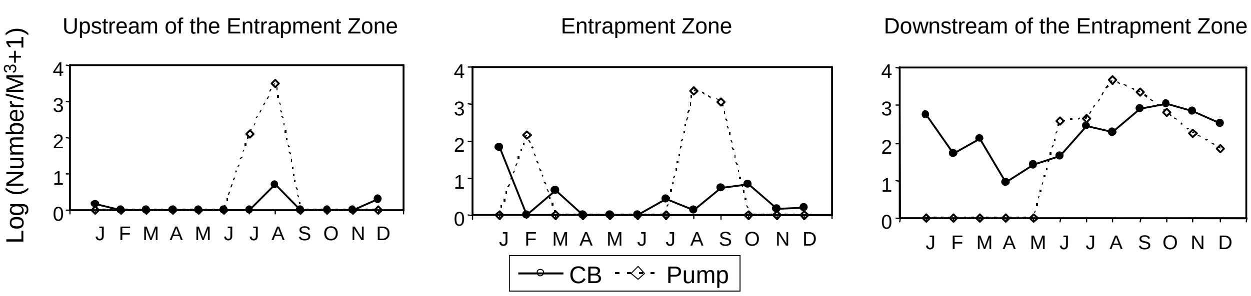


Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone for 2005

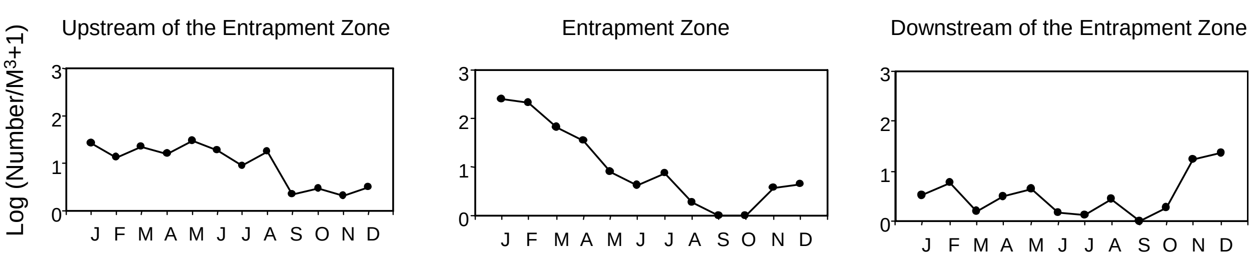


Figure 5-14 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

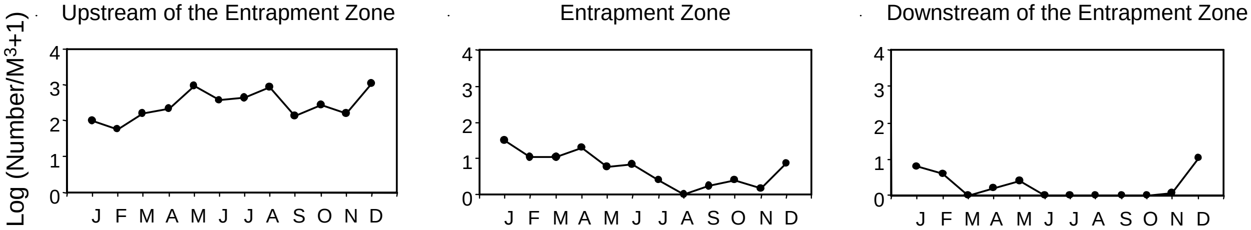


Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

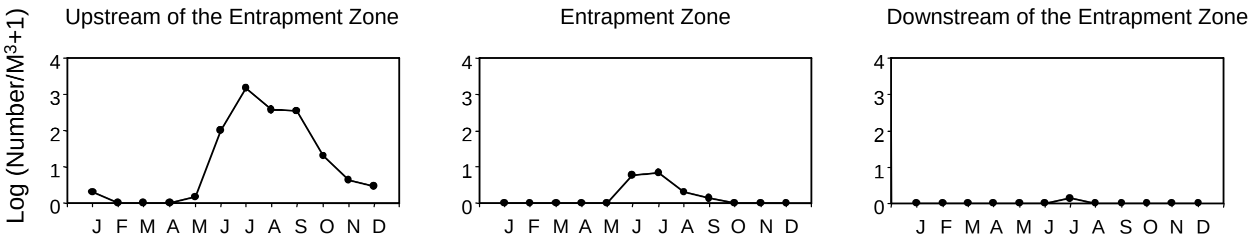


Figure 5-16 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

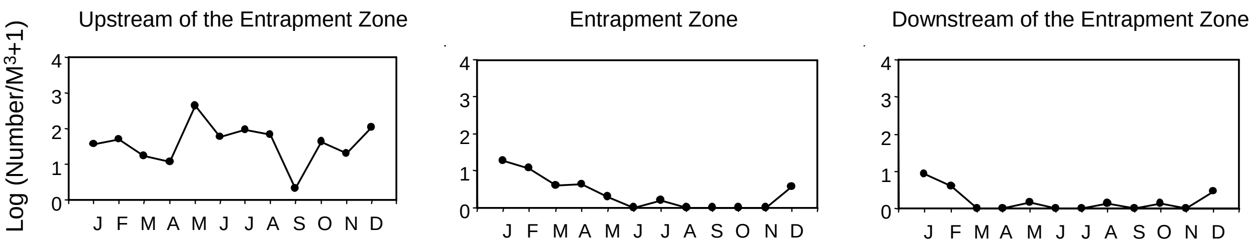


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone for 2005

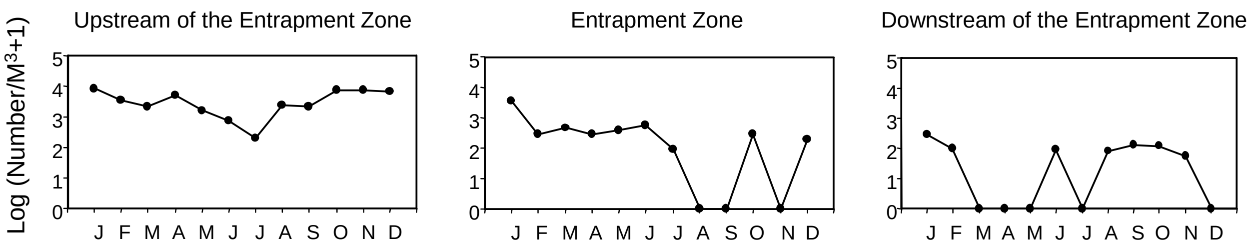


Table 5-1 Mysids: Catch per Unit Effort (CPUE)

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Acanthomysis bowmani	2.11	23.39	3.15	**6.60**
Neomysis kadiakensis/japonica	0.02	0.18	0.20	**0.11**
Neomysis mercedis	0.08	0.06	0.00	**0.05**
Alienacanthomysis macropsis	0.00	0.00	0.04	**0.01**

Table 5-2 Calanoid copepods: CPUE

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Pseudodiaptomus forbesi	897.09	395.08	24.67	**508.49**
Acartia spp.	0.79	0.85	811.95	**271.19**
Acartiella sinensis	26.66	278.71	148.15	**116.26**
Eurytemora spp.	74.27	56.76	21.66	**53.32**
Sinocalanus doerrii	70.91	52.58	0.68	**43.93**

Table 5-3 Cyclopoid copepods: CPUE

Clarke-Bumpus Net

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Limnoithona tetraspina	3.02	67.34	54.41	**32.68**
Oithona davisae	0.41	7.42	412.77	**139.23**
Acanthocyclops vernalis	14.40	53.76	5.59	**19.13**

Pump

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Limnoithona tetraspina	990.71	14880.78	13771.04	**7986.52**
Oithona davisae	242.47	258.78	810.84	**434.35**

Table 5-4 Cladocerans: CPUE

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Bosmina spp.	409.35	7.79	1.69	**195.24**
Diaphanosoma spp.	181.67	1.23	0.02	**85.97**
Daphnia spp.	90.22	3.48	0.91	**43.55**

Table 5-5 Rotifers: CPUE

Species	Upstream	Entrapment Zone	Downstream	Grand Total
Synchaeta spp.	4308.38	3689.86	8255.01	**5495.61**
Keratella spp.	4389.51	855.15	186.75	**2293.85**
Polyarthra spp.	3651.12	511.40	73.23	**1841.10**

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 contains 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). The EMP periodically undergoes review, and as part of the current assessment we agreed to carry out special studies to determine how best to modify our benthic monitoring program. In an effort to free up the necessary resources to conduct recommended special studies, and with SWRCB approval, the benthic monitoring program temporarily changed to quarterly sampling for two years. This change coincided with the beginning of the 2003-2004 water year. The program returned to monthly sampling at the beginning of the 2005-2006 water year. Recommendations for modifying the benthic monitoring element, based on the results of special studies conducted over the two year quarterly sampling period, will be presented to the SWRCB in early 2007.

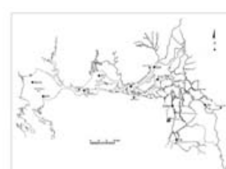


Figure 6-1 Benthic monitoring stations, 2005

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 6-1 Macrobenthic monitoring station characteristics

Methods

Benthic Organisms

Field sampling was conducted at ten sites quarterly until October 2005, when the sampling returned to a monthly regime. 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 *Endeavor*, 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 was 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 (70X-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 *Endeavor* 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 were performed for each sediment sample. 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). The 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 Composition and Abundance

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 152 species collected, ten represented 88 percent of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods

Americorophium stimpsoni
Corophium alienense
Ampelisca abdita
Gammarus daiberi

Sabellidae Polychaete

Laonome sp. *A*
Manayunkia speciosa

Tubificid Worm

Limnodrilus hoffmeisteri

Aquatic Oligocheate

Varichaetadrilus angustipenis

Asian Clams

Corbula amurensis
Corbicula fluminea

Of the 10 dominant species, *Ampelisca abdita* and *Corbula amurensis* represent macrofauna that inhabit a typically high saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *Corophium alienense*, *Americorophium stimpsoni*, *Limnodrilus hoffmeisteri*, and *Laonome* sp. *A* tolerate a wider range of salinity. They were collected both in the higher saline western sites and the more brackish water to freshwater eastern sites, such as the San Joaquin River at Twitchell Island and the Sacramento River above Point Sacramento. The remaining four species—*Gammarus daiberi*, *Varichaetadrilus angustipenis*, *Manayunkia speciosa* 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. All data is available at http://www.baydelta.ca.gov.

All organisms collected during 2005 fell into nine phyla:

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

Of the eight phyla identified, Annelida, Arthropoda, and Mollusca constituted 98.7% 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.

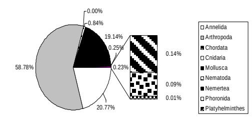


Figure 6-2 Total contribution by phyla for all stations during 2005

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 and dominant species) 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 2005 occurred in July with a total of 14,635 organisms per meter squared (Figure 6-3). *Americorophium stimpsoni* (2,822 org/m^2), *Limnodrilus hoffmeisteri* (2,969 org/m^2), and *Varichaetadrilus angustipenis* (4,109 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in January with a total of 542 organisms per meter squared. *Limnodrilus hoffmeisteri* (352 org/m^2) was the dominant species.

Site P8: Benthic Abundance

Maximum abundance in 2005 occurred in July with a total of 4,475 organisms per meter squared (Figure 6-3). The dominant species were *Llyodrilus frantzi* (708 org/m^2), and *Limnodrilus hoffmeisteri* (1,876 org/m^2). The minimum abundance in 2005 occurred in October with a total of 3,415 organisms per meter squared. The dominant species were *Limnodrilus hoffmeisteri* (812 org/m^2) and *Laonome* sp. *A* (1,221 org/m^2).

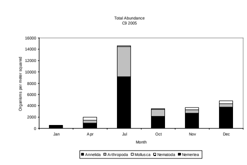


Figure 6-3 Benthic abundance at stations C9 and P8, 2005

Site D28A: Benthic Abundance

Maximum abundance in 2005 occurred in December with a total of 12,046 organisms per meter squared (Figure 6-4). *Varichaetadrilus angustipenis* (1,501 org/m^2), *Manayunkia speciosa* (2,655 org/m^2), and *Cyprideis* sp. *A*

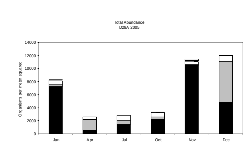


Figure 6-4 Benthic abundance at stations D28A and D16, 2005

(5,672 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in October with a total of 3,344 organisms per meter squared. *Limnodrilus hoffmeisteri* (960 org/m^2) was the dominant species.

Site D16: Benthic Abundance

Maximum abundance in 2005 occurred in October with a total of 223 organisms per meter squared (Figure 6-4). *Corbicula fluminea* (33 org/m^2) and *Gammarus daiberi* (147 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in January with a total of 67 organisms per meter squared. *Corbicula fluminea* (33 org/m^2) was the dominant species.

Site D24: Benthic Abundance

Maximum abundance in 2005 occurred in July with a total of 10,469 organisms per meter squared (Figure 6-5). *Varichaetadrilus angustipenis* (2,033 org/m^2), *Corbicula fluminea* (2,052 org/m^2), and *Americorophium stimpsoni* (5,197 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in January with a total of 4,470 organisms per meter squared. *Americorophium stimpsoni* (1,278 org/m^2) and *Varichaetadrilus angustipenis* (1,430 org/m^2) were the dominant species.

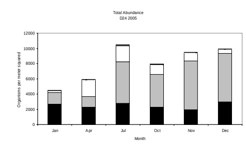


Figure 6-5 Benthic abundance at stations D24 and D4, 2005

Site D4: Benthic Abundance

Maximum abundance in 2005 occurred in November with a total of 11,471 organisms per meter squared (Figure 6-5). *Varichaetadrilus angustipenis* (2,242 org/m^2) and *Gammarus daiberi* (4,361 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in January with a total of 6,683 organisms per meter squared. C*orbula amurensis* (1,202 org/m^2), *Varichaetadrilus angustipenis* (1,492 org/m^2) and *Laonome* sp. *A* (1,577 org/m^2) were the dominant species.

Site D6: Benthic Abundance

Maximum abundance in 2005 occurred in December with a total of 16,692 organisms per meter squared (Figure 6-6). *Corbula amurensis* (15,708 org/m^2) was the dominant species. The minimum abundance in 2005 occurred in April with a total of 3,401 organisms per meter squared. C*orbula amurensis* (3,130 org/m^2) was the dominant species.

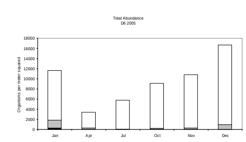


Figure 6-6 Benthic abundance at stations D6 and D7, 2005

Site D7: Benthic Abundance

Maximum abundance in 2005 occurred in October with a total of 10,094 organisms per meter squared (Figure 6-6). *Corophium alienense* (4,270 org/m^2) and *Corbula amurensis* (5,757 org/m^2) were the dominant species. The minimum abundance in 2005 occurred in April with a total of 3,083 organisms per meter squared. C*orbula amurensis* (884 org/m^2) and *Corophium alienense* (1,838 org/m^2) were the dominant species.

Site D41: Benthic Abundance

Maximum abundance in 2005 occurred in November with a total of 32,861 organisms per meter squared (Figure 6-7). *Ampelisca abdita* (31,507 org/m^2) was the dominant species. The minimum abundance in 2005 occurred in April with a total of 6,289 organisms per meter squared. *Ampelisca abdita* (1,786 org/m^2) and *Diadumene* sp. *A* (2,009 org/m^2) were the dominant species.

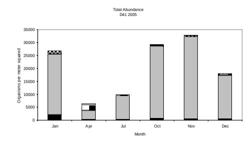


Figure 6-7 Benthic abundance at stations D41 and D41A, 2005

Site D41A: Benthic Abundance

Maximum abundance in 2005 occurred in October with a total of 26,149 organisms per meter squared (Figure 6-7). *Ampelisca abdita* (23,489 org/m^2) was the dominant species. The minimum abundance in 2005 occurred in July with a total of 11,851 organisms per meter squared. *Ampelisca abdita* (10,075 org/m^2) was the dominant species.

Sediment Analysis

Site C9: Sediment Composition

Fine sediment was the dominant type at site C9 for 2005 (Figure 6-8). The percentage of organic content ranged from 0.4% to 4.4%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

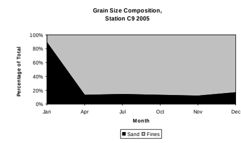


Figure 6-8 Sediment organic content and grain size at station C9 during 2005

Site P8: Sediment Composition

Sand dominated the sediment at site P8 for most of 2005 (Figure 6-9). The organic matter ranged from 1.9% to 3.7%, with the higher values typically coinciding with an influx of finer sediments.

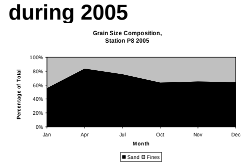


Figure 6-9 Sediment organic content and grain size at station P8 during 2005

Site D28A: Sediment Composition

Sandy sediment dominated the sediment at D28A (Figure 6-10). The organic matter ranged from 1.4% to 10.6%. Higher percentages of organic matter occurred during the months with the highest percentages of fines.

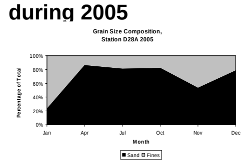


Figure 6-10 Sediment organic content and grain size at station D28A during 2005

Site D16: Sediment Composition

Sand dominated the sediment type at D16 (Figure 6-11). The percent of organic matter at this site remained low and fairly stable during 2005 (ranging between 0.3% and 0.5%).

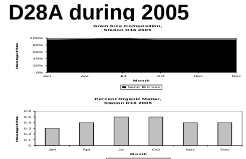


Figure 6-11 Sediment organic content and grain size at station D16 during 2005

Site D24: Sediment Composition

Fine sediment dominated the winter months while a mixture of fine and sand dominated during the rest of the year (Figure 6-12). The organic matter ranged from 1.4% to 3.5%.

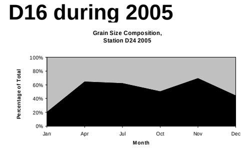


Figure 6-12 Sediment organic content and grain size at station D24 during 2005

Site D4: Sediment Composition

Sand dominated the sediment at D4 during 2005, with the exception of the April and July sampling events during which fines dominated (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 (ranged from 6.4% to 46.4 %).

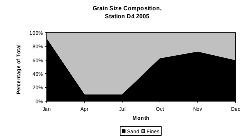


Figure 6-13 Sediment organic content and grain size at station D4 during 2005

Site D6: Sediment Composition

Finer sediments were the dominant sediment at D6 (Figure 6-14). Organic matter at this site was stable during 2005: it ranged from 3.9% to 4.9%.

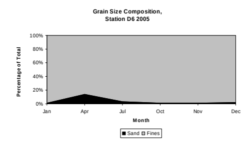


Figure 6-14 Sediment organic content and grain size at station D6 during 2005

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: it ranged from 3.1% to 4.5%.

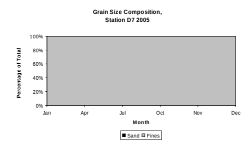


Figure 6-15 Sediment organic content and grain size at station D7 during 2005

Site D41: Sediment Composition

Finer sediments dominated the sediment at D41 (Figure 6-16). The organic matter at this site was relatively stable: it ranged from 2.7% to 4.5%.

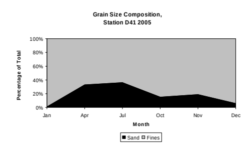


Figure 6-16 Sediment organic content and grain size at station D41 during 2005

Site D41A: Sediment Composition

Finer sediments dominated the sediment at D41A (Figure 6-17). The percent organic matter at this site was stable: it ranged 2.9% to 4.4%.

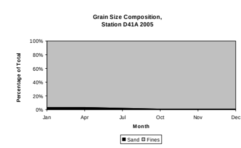


Figure 6-17 Sediment organic content and grain size at station D41A during 2005

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 2005 fell into nine phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida and Platyhelminthes. Of these nine phyla, Annelida, Arthropoda and Mollusca constituted 98.7% of the organisms collected during the study period. Ten species represent 88% of all organisms collected during this period. These species are: (1) the amphipods, *Americorophium stimpsoni*, *Corophium alienense*, *Gammarus daiberi* and *Ampelisca abdita*; (2) the tubificid worm, *Limnodrilus hoffmeisteri*; (3) the aquatic oligocheate, *Varichaetadrilus angustipenis*; (4) the Sabellidae polychaetes, *Laonome* sp. *A* and *Manayunkia speciosa*; and (5) the Asian clams, *Corbula amurensis* and *Corbicula fluminea*.

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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] Department of Water Resources, 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta During 1996. A report to the State Water Resources Control Board in Accordance with Water Right Decision 1485, Order 4(f)*. Department of Water Resources, Sacramento, California.

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*. Department of Water Resources.

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Thompson, J, 2005. "*Potamocorbula amurensis* Is, For Now, *Corbula amurensis"*. *Interagency Ecological Program Newsletter.* Volume 18; Number 2. Spring 2005. Department of Water Resources.

Figure 6-1 Benthic monitoring stations, 2005

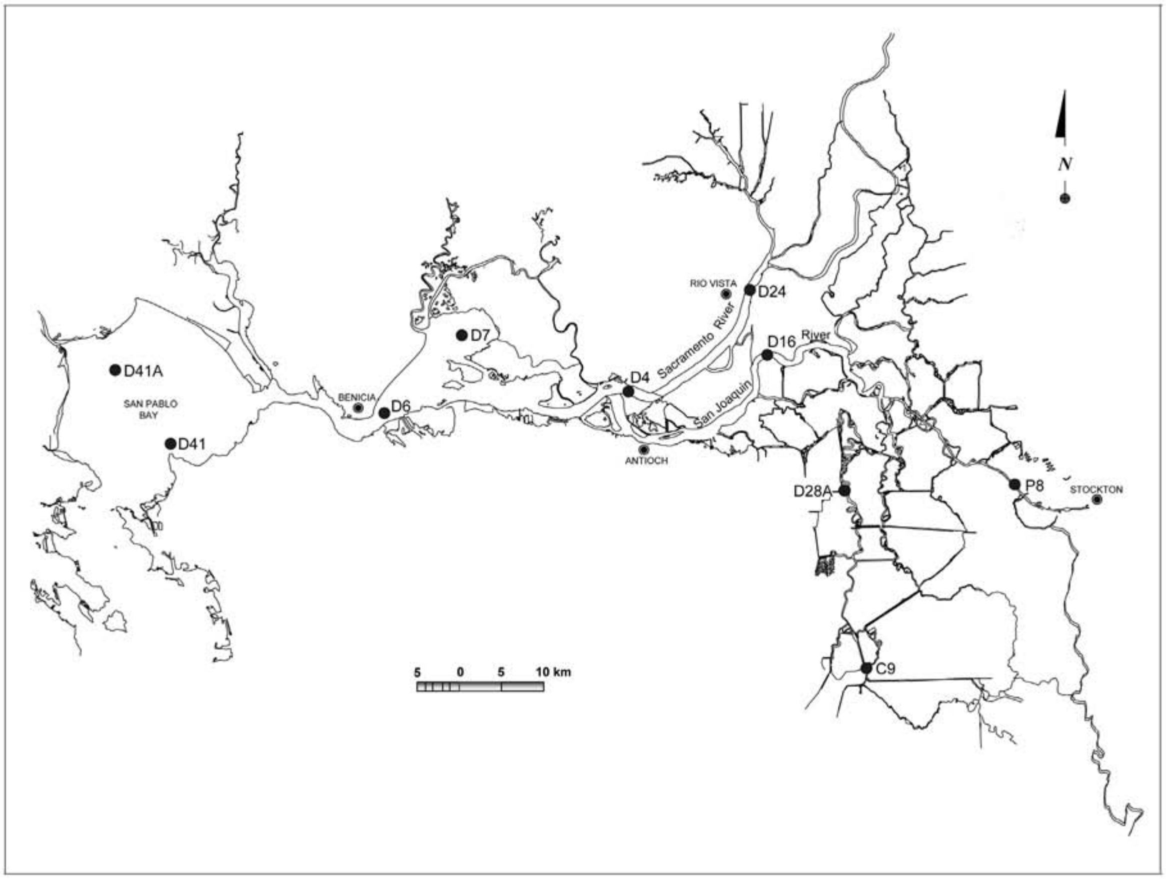


Figure 6-2 Total contribution by phyla for all stations during 2005

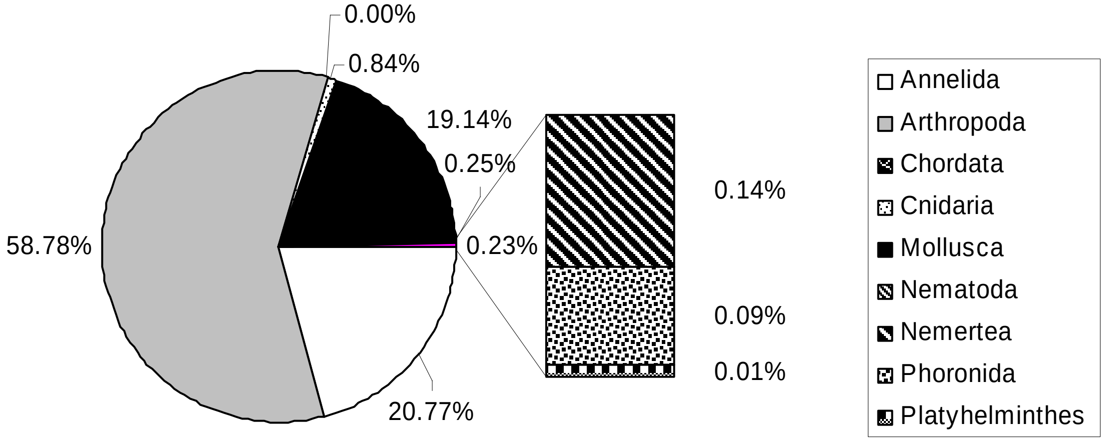
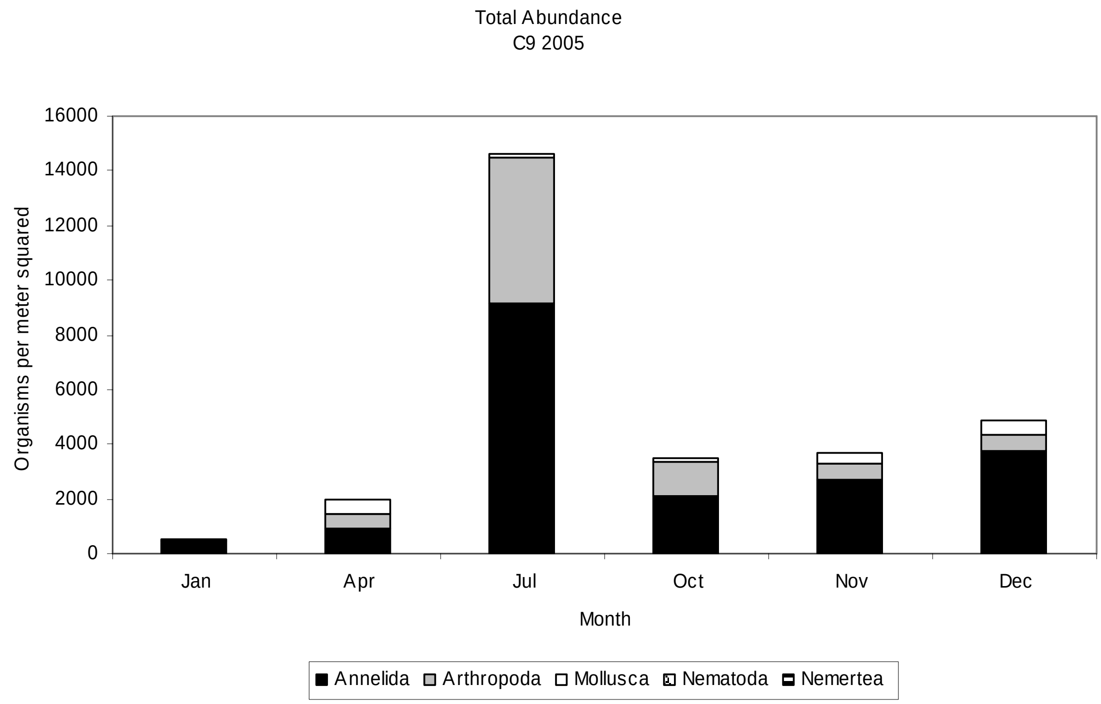
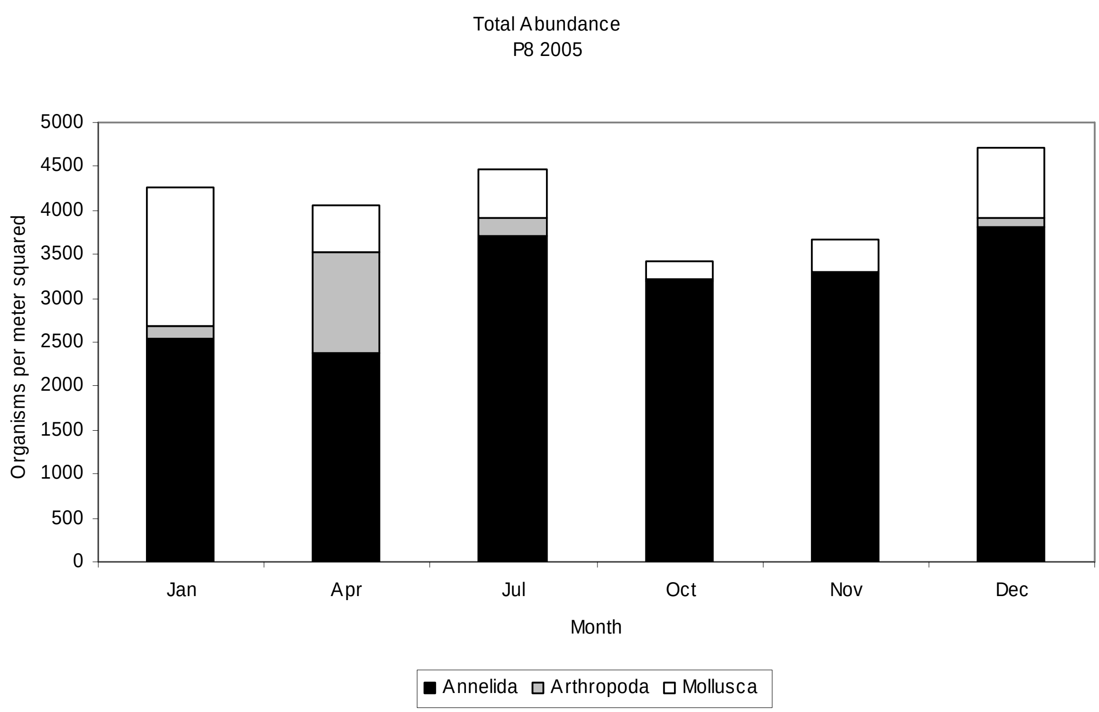


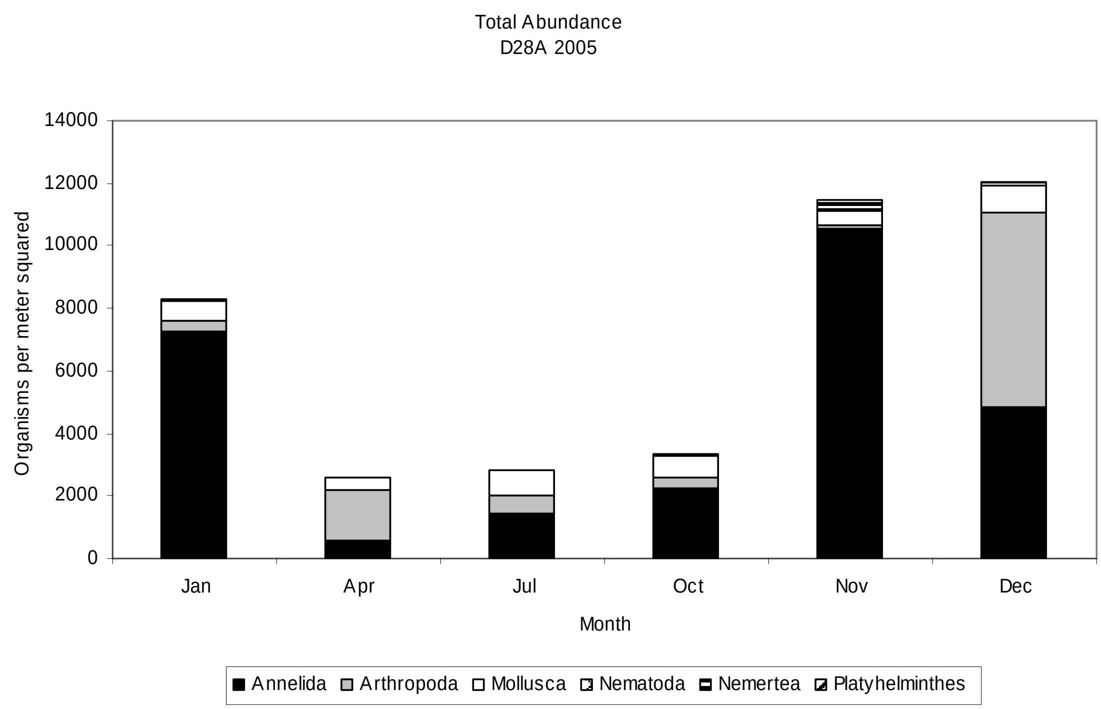
Figure 6-3 Benthic abundance at stations C9 and P8, 2005

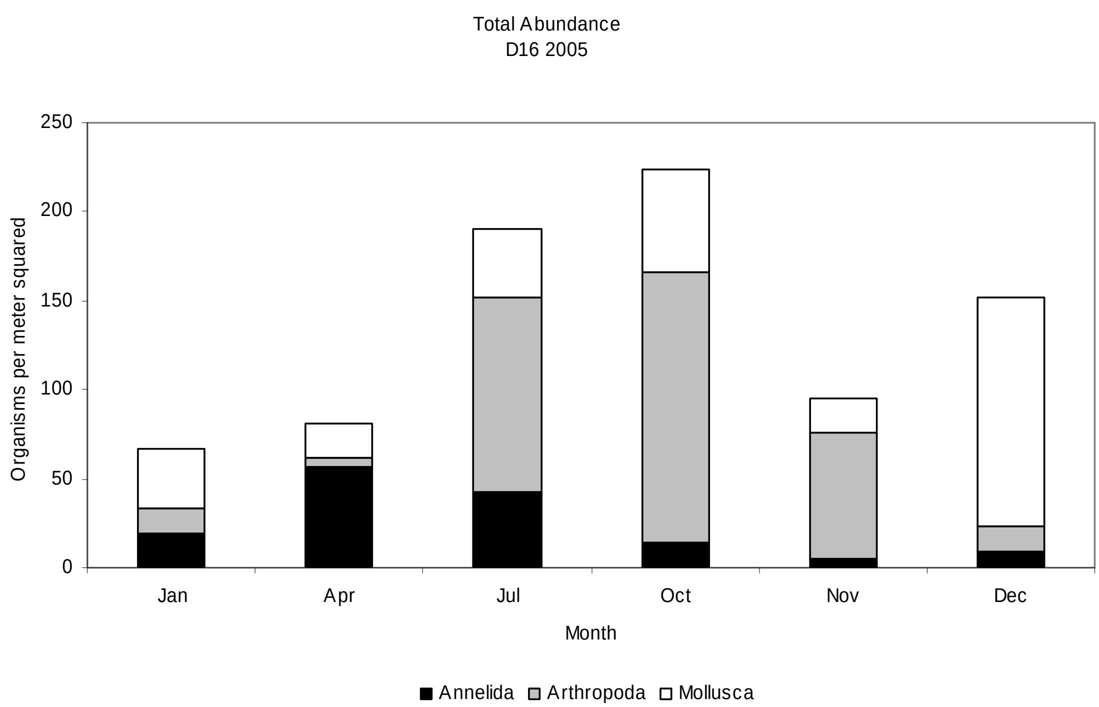




Note differences in scale

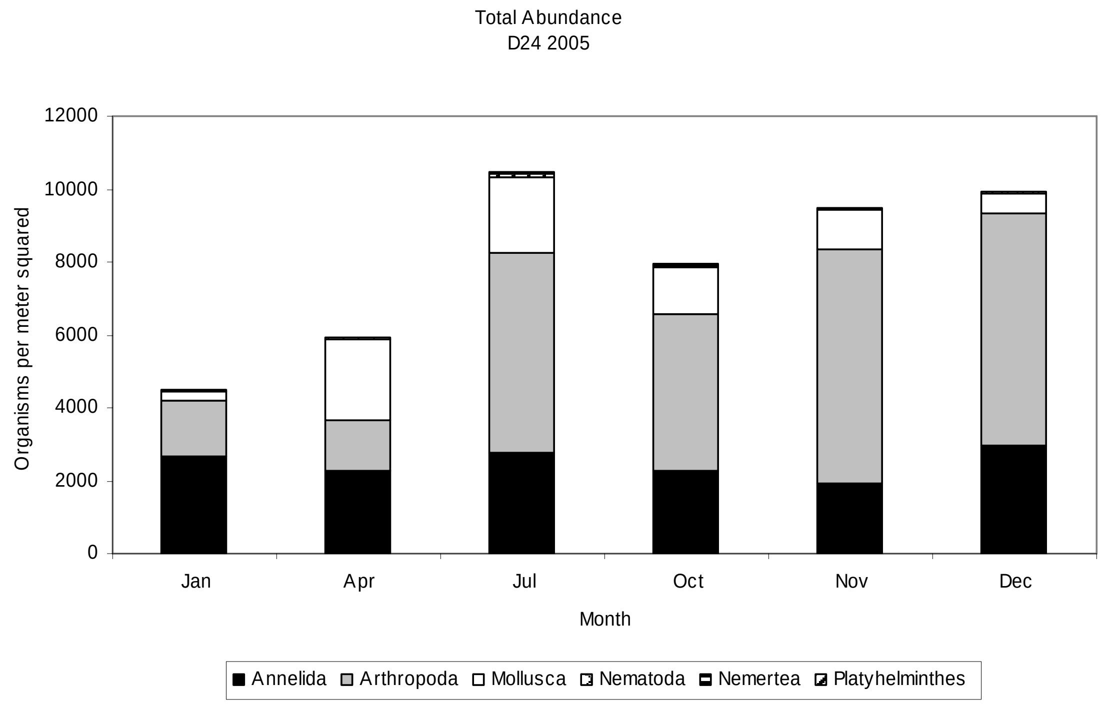
Figure 6-4 Benthic abundance at stations D28A and D16, 2005

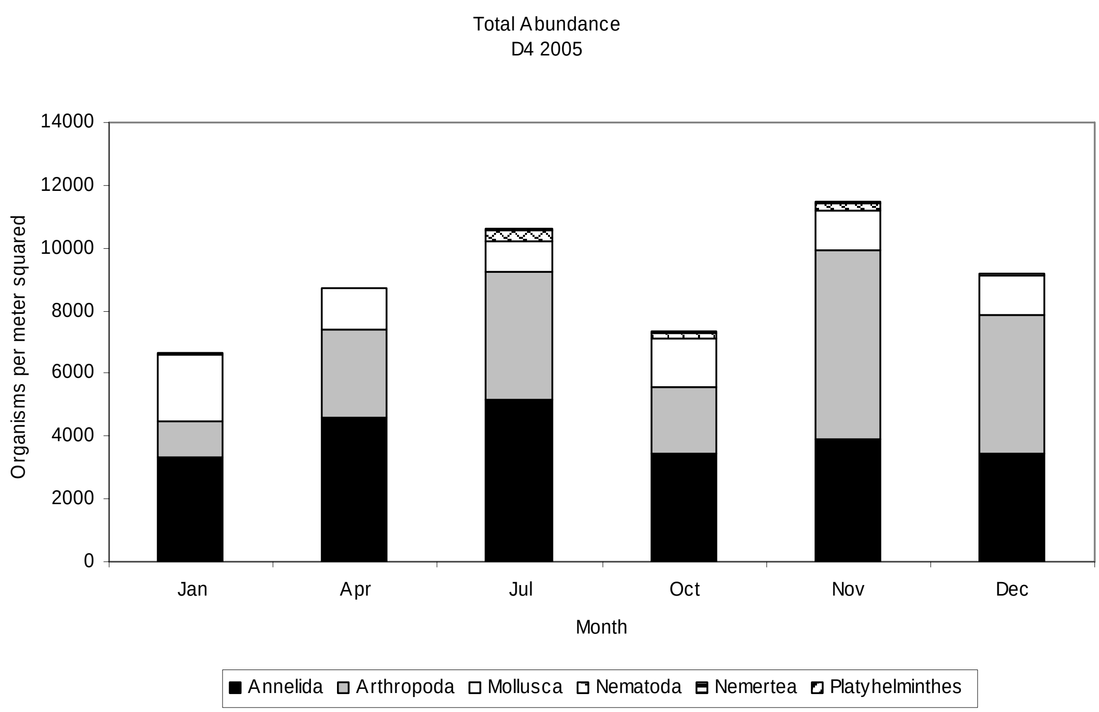




Note differences in scale

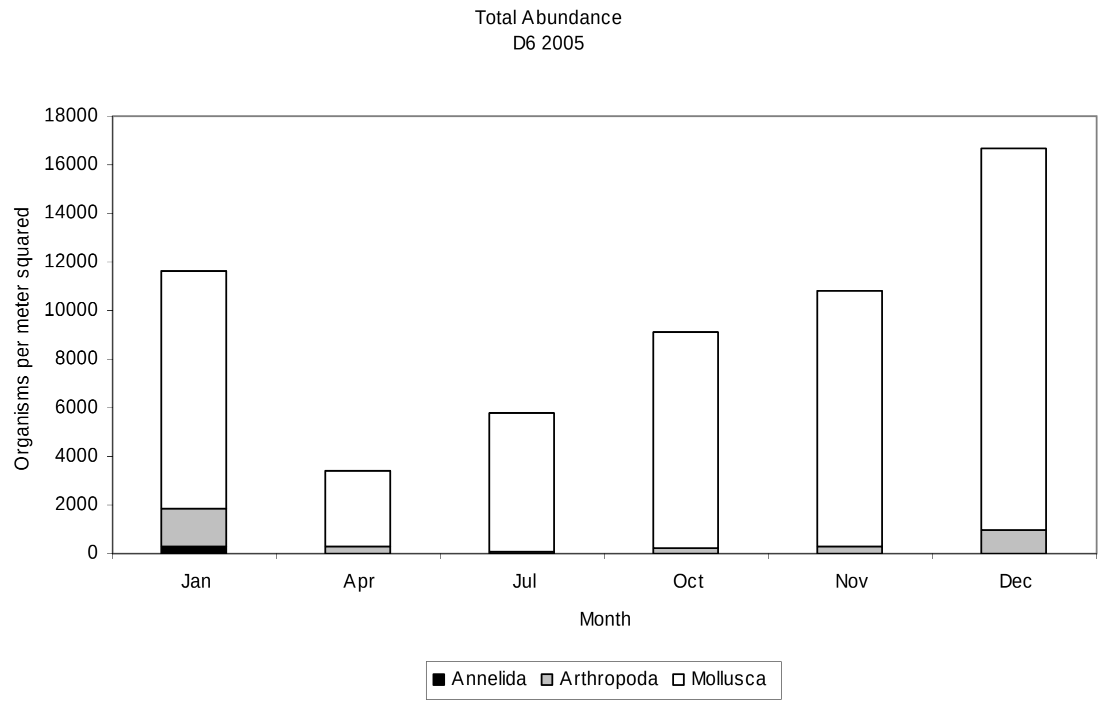
Figure 6-5 Benthic abundance at stations D24 and D4, 2005

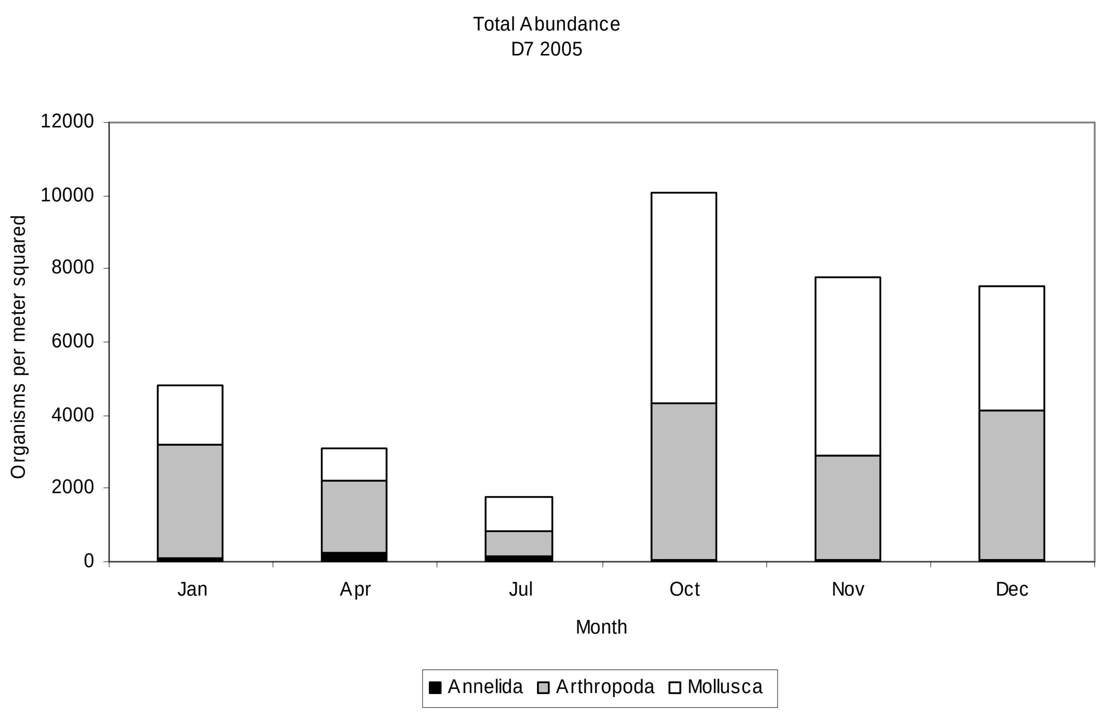




Note differences in scale

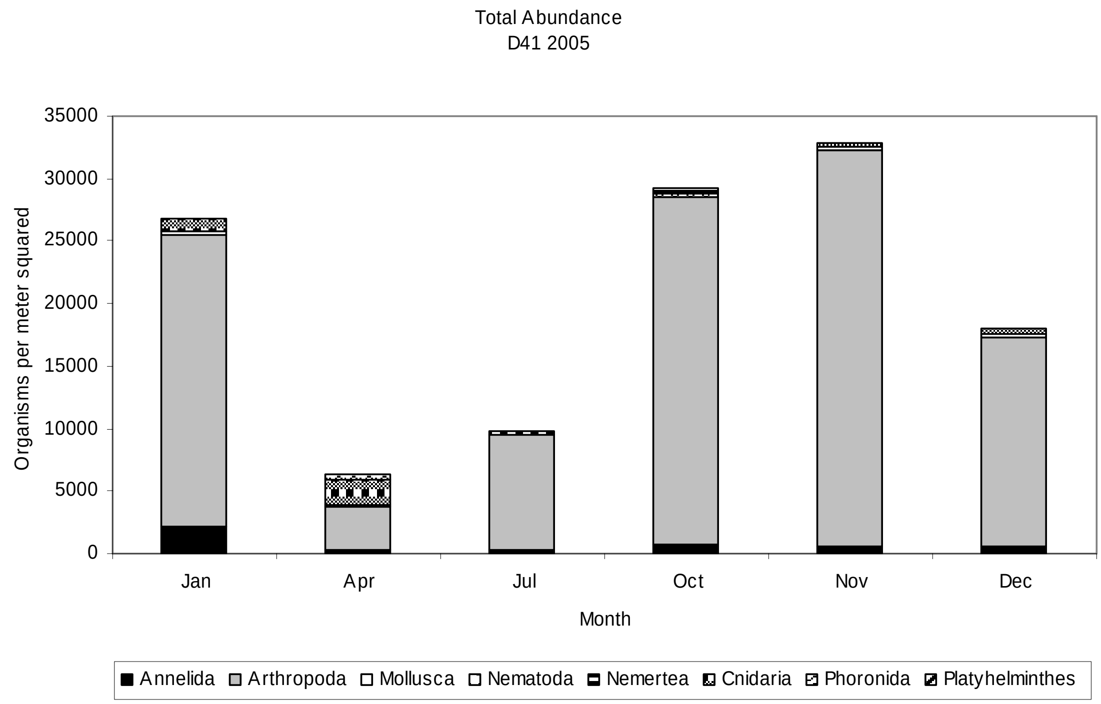
Figure 6-6 Benthic abundance at stations D6 and D7, 2005

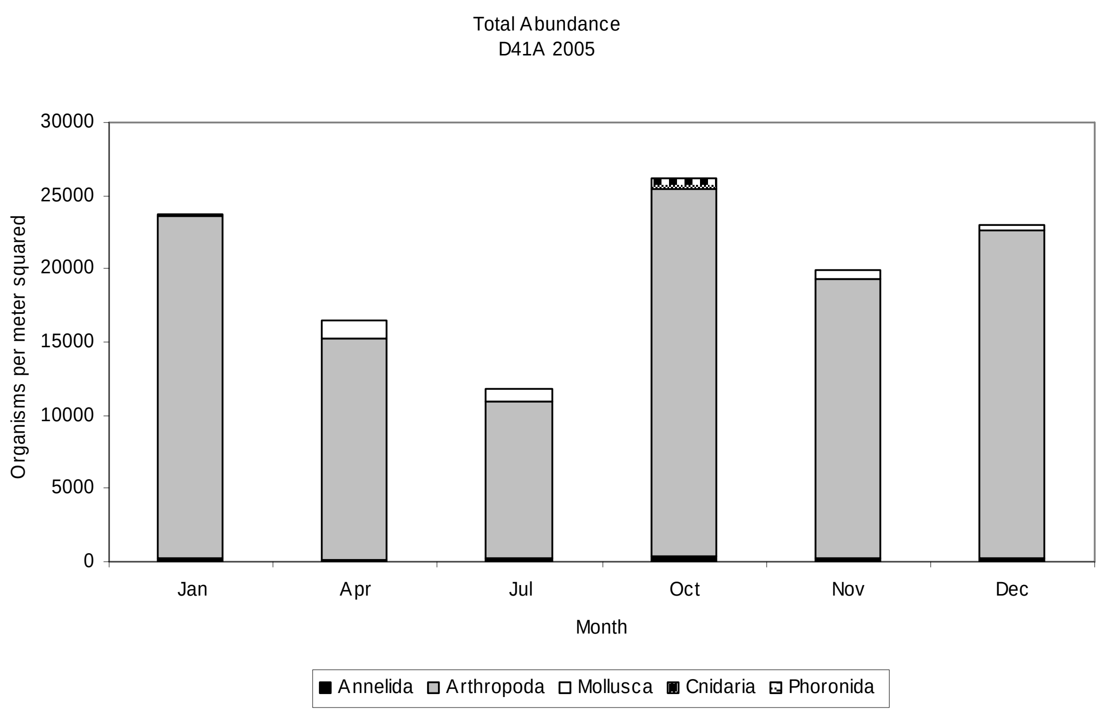




Note differences in scale

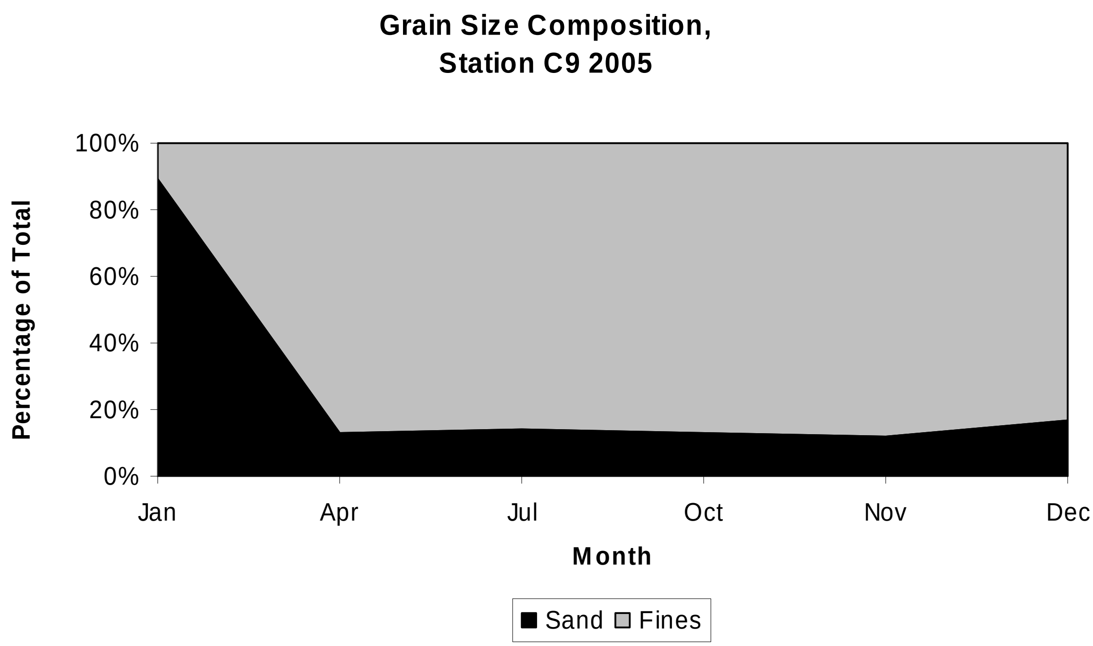
Figure 6-7 Benthic abundance at stations D41 and D41A, 2005





Note differences in scale

Figure 6-8 Sediment organic content and grain size at station C9 during 2005



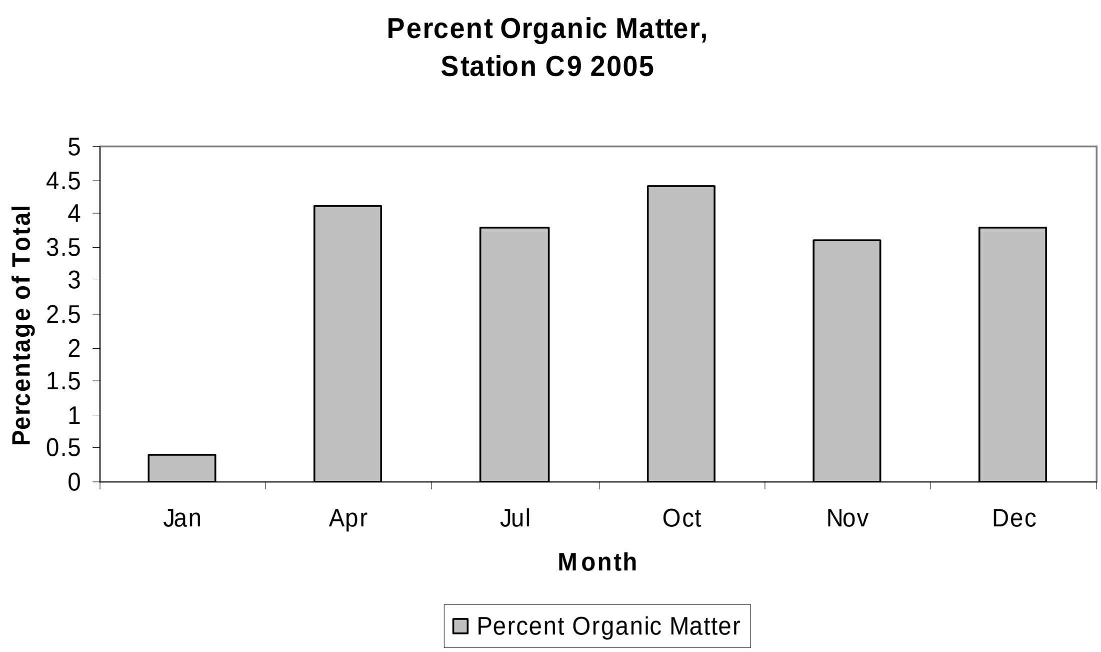
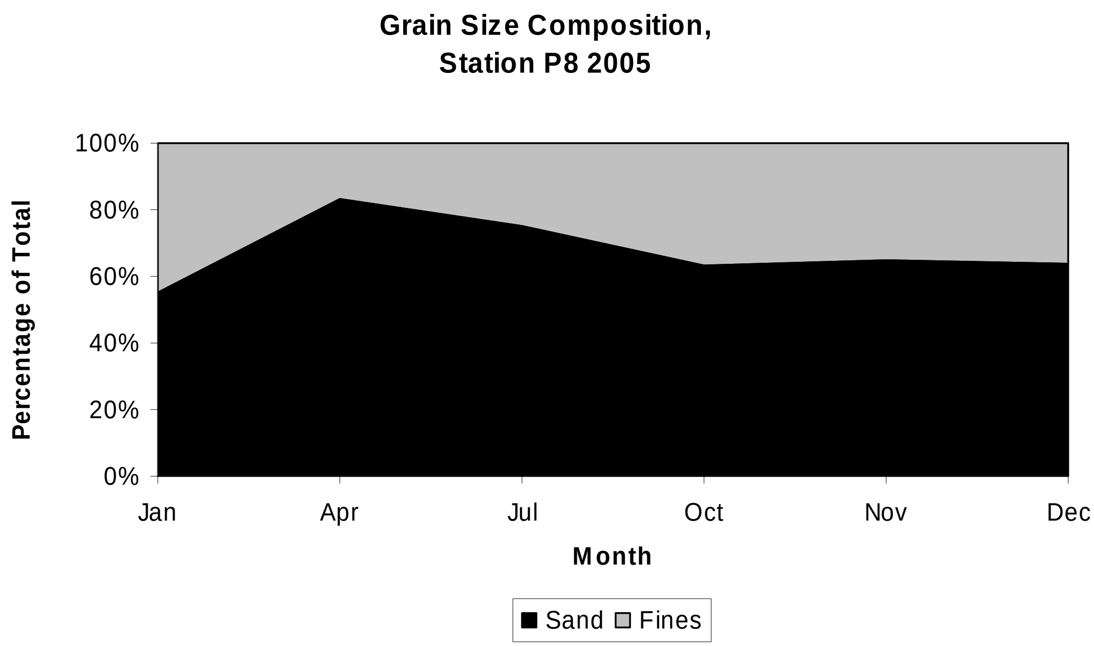


Figure 6-9 Sediment organic content and grain size at station P8 during 2005



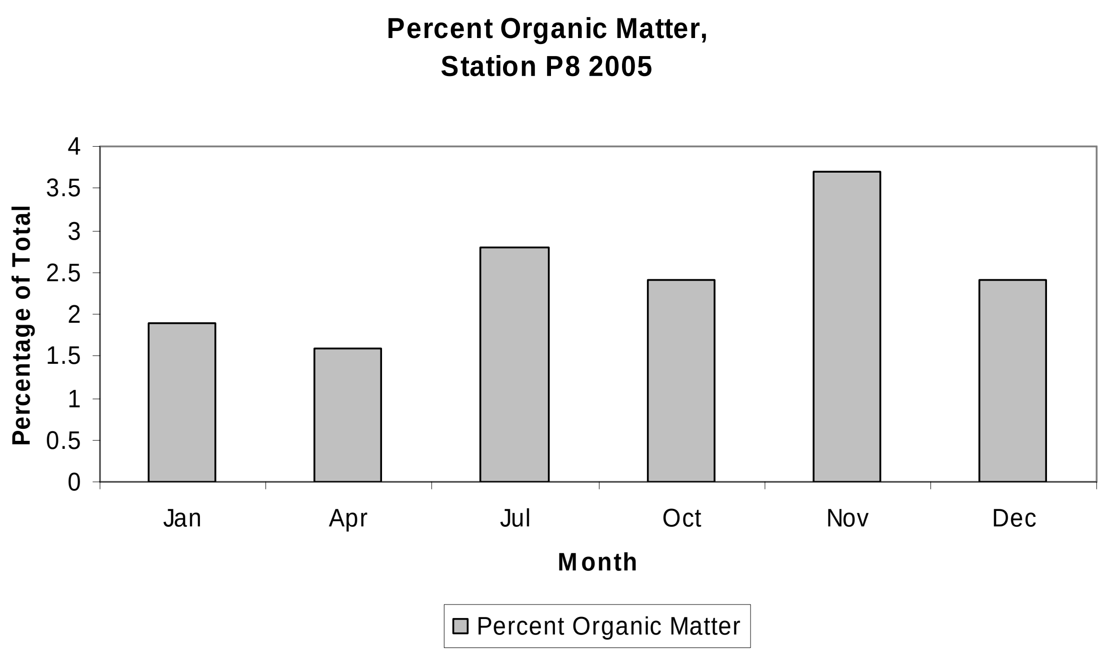
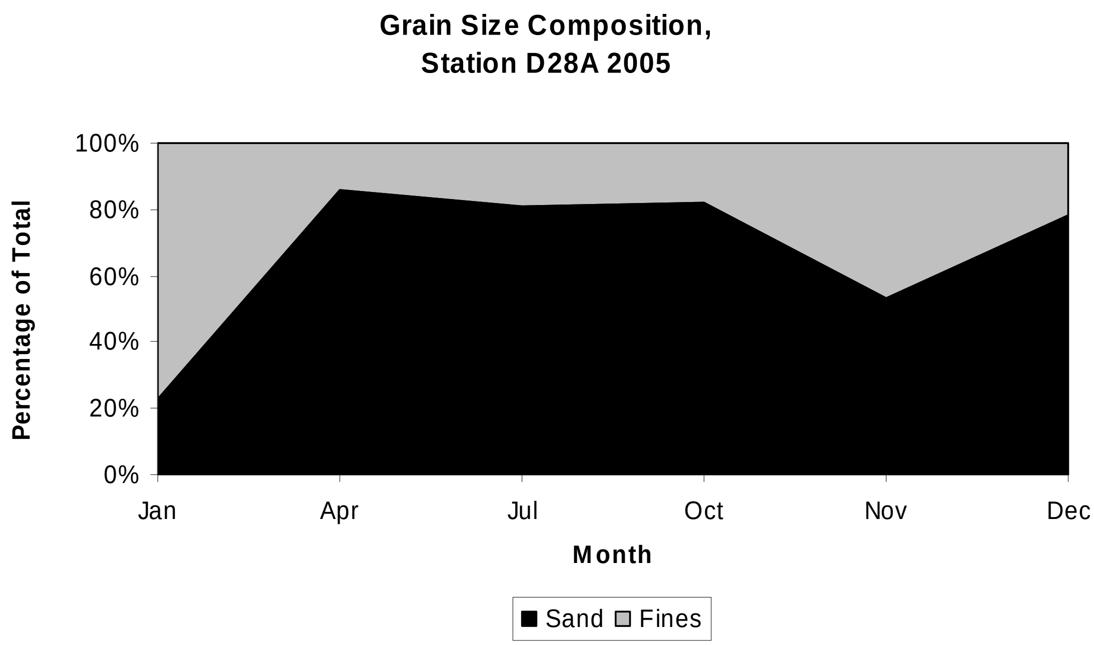


Figure 6-10 Sediment organic content and grain size at station D28A during 2005



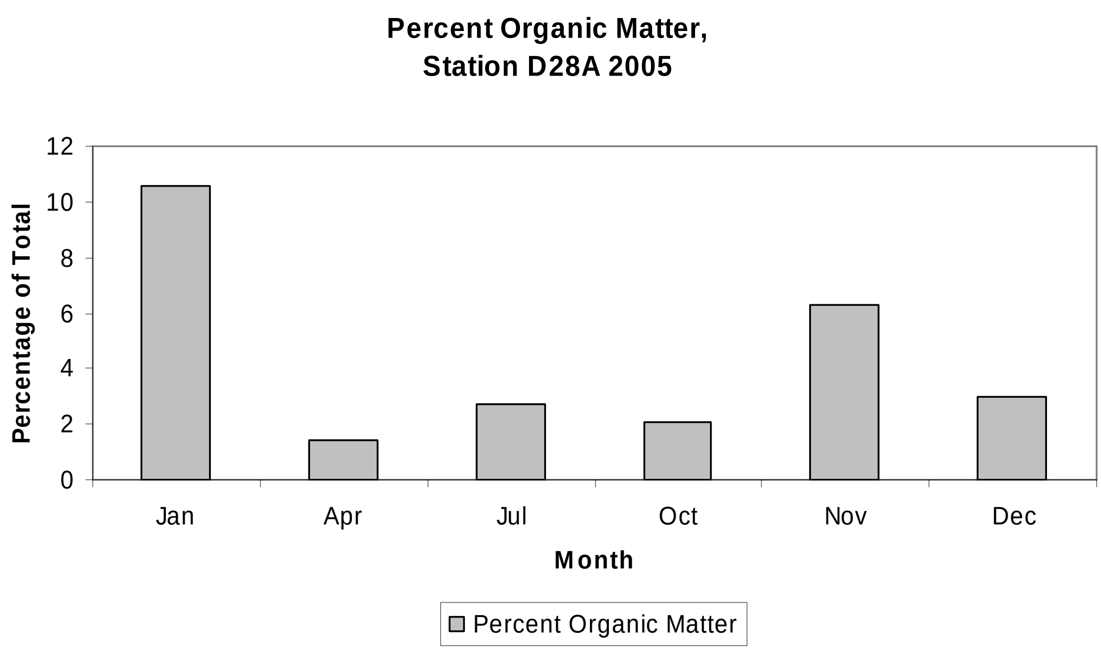
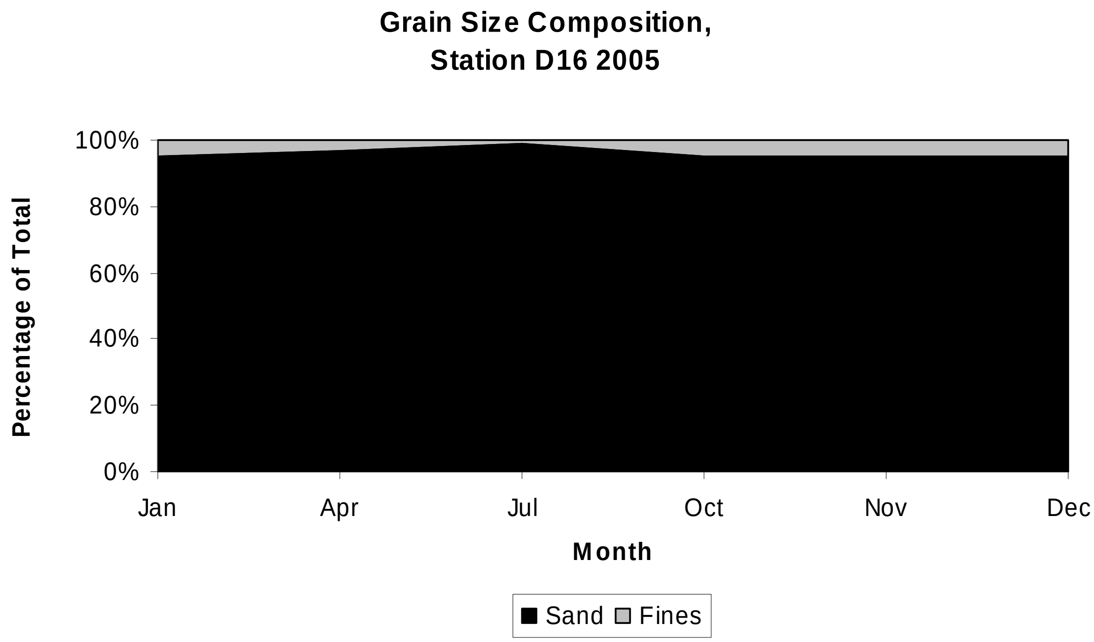


Figure 6-11 Sediment organic content and grain size at station D16 during 2005



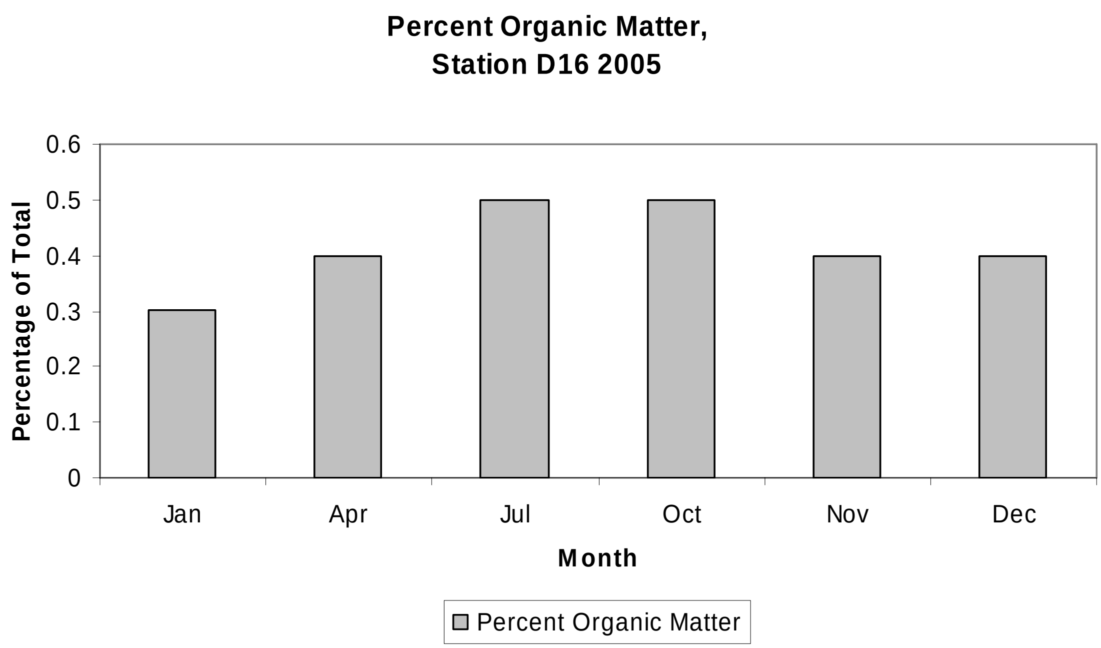
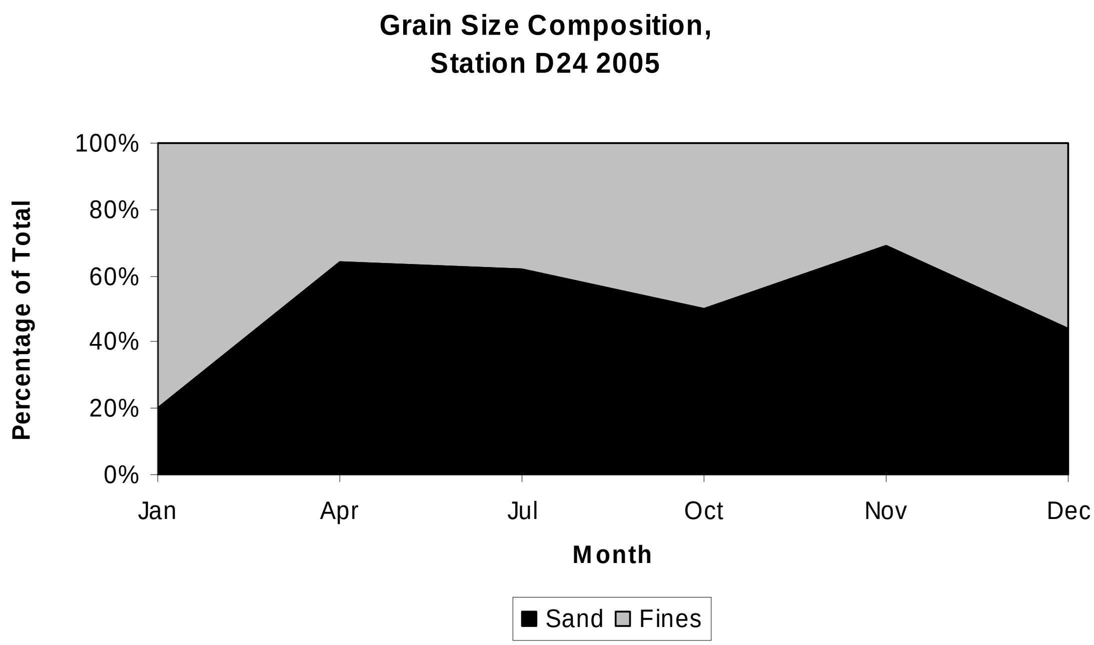


Figure 6-12 Sediment organic content and grain size at station D24 during 2005



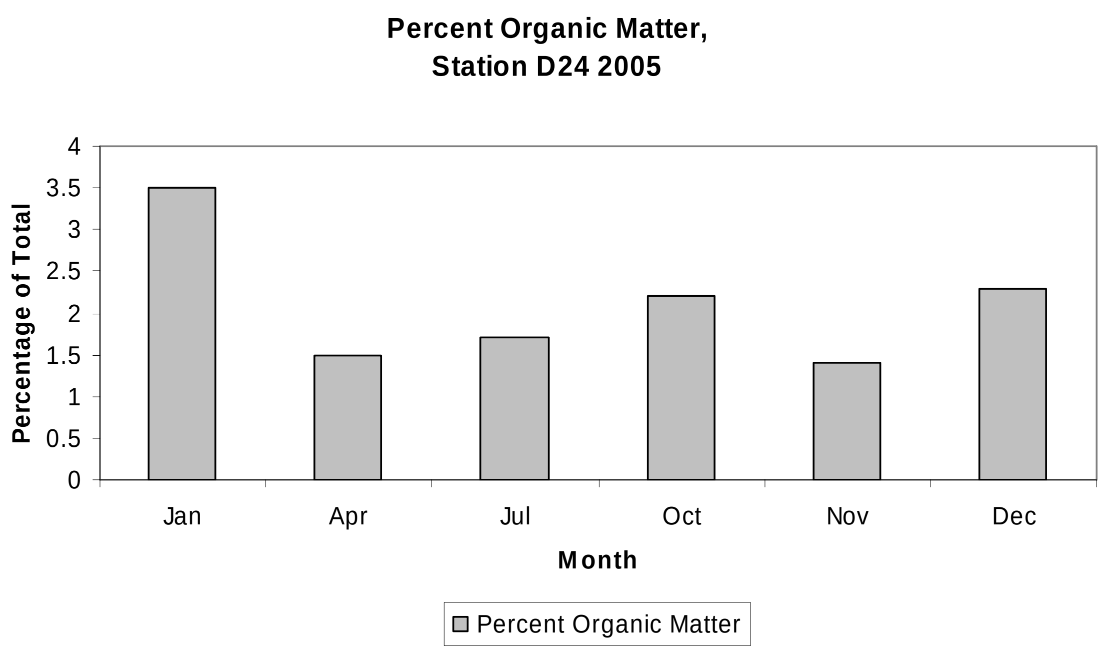
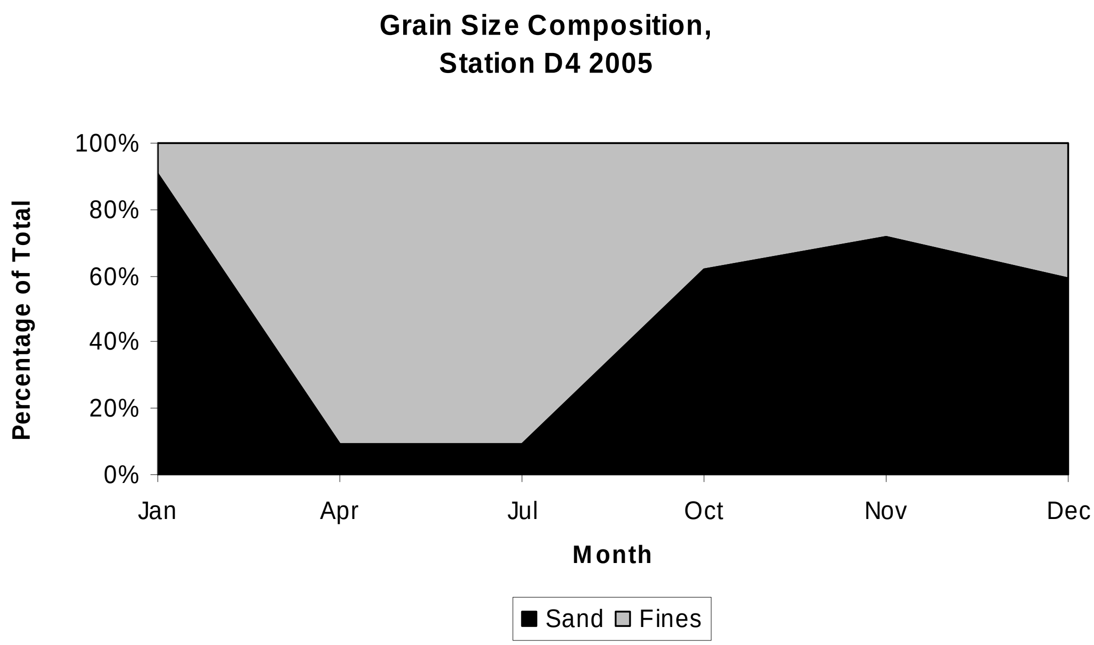


Figure 6-13 Sediment organic content and grain size at station D4 during 2005



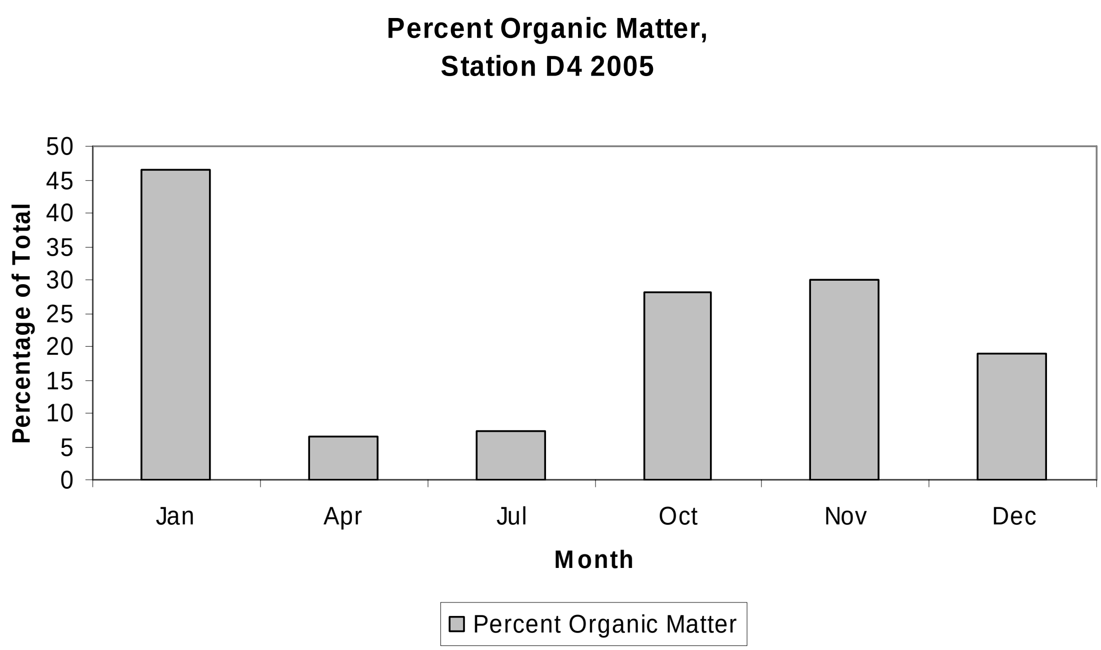
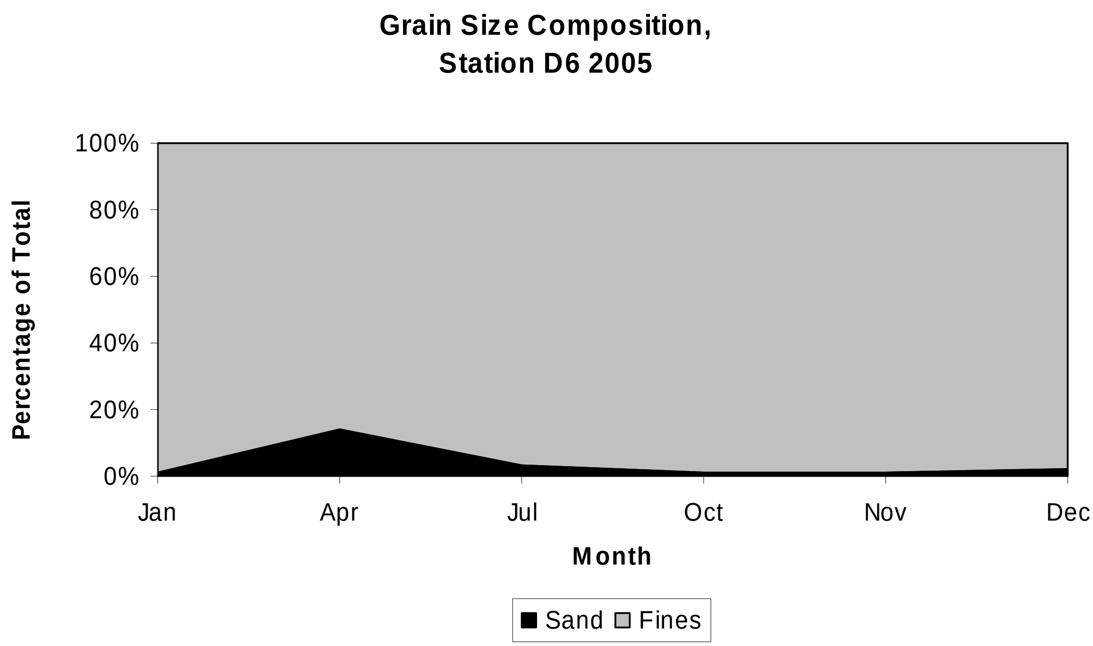


Figure 6-14 Sediment organic content and grain size at station D6 during 2005



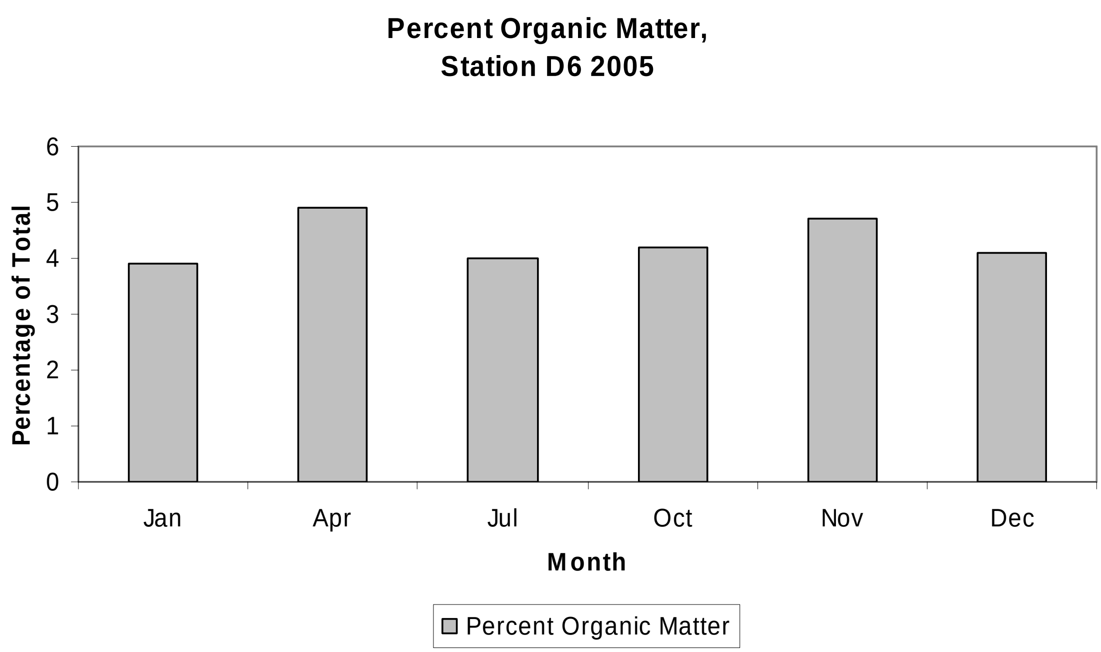
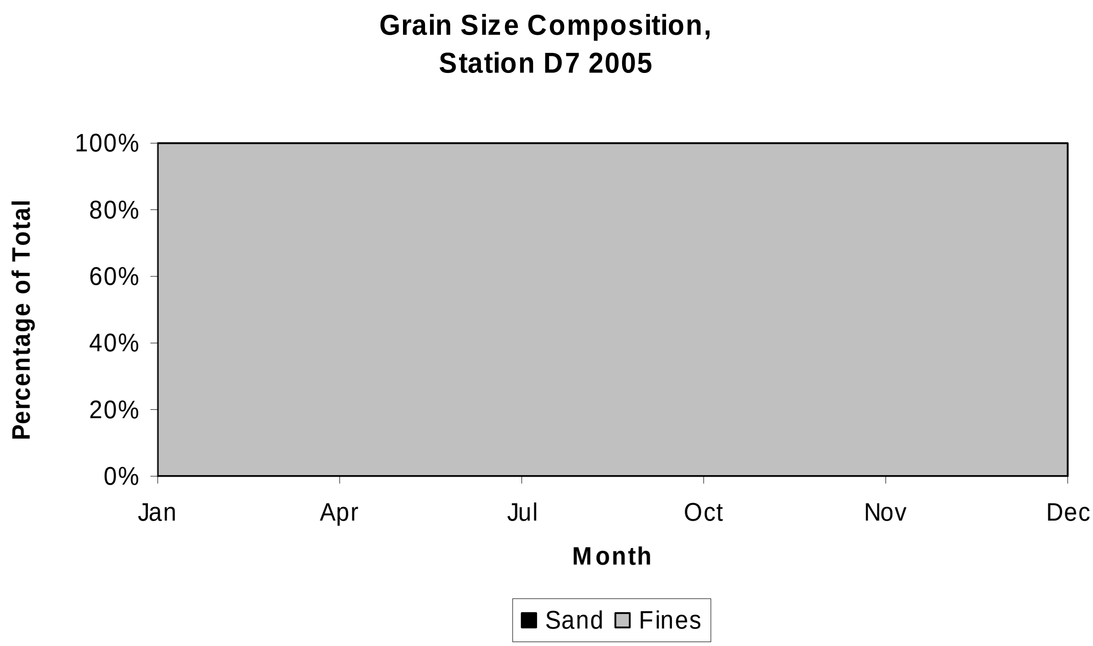


Figure 6-15 Sediment organic content and grain size at station D7 during 2005



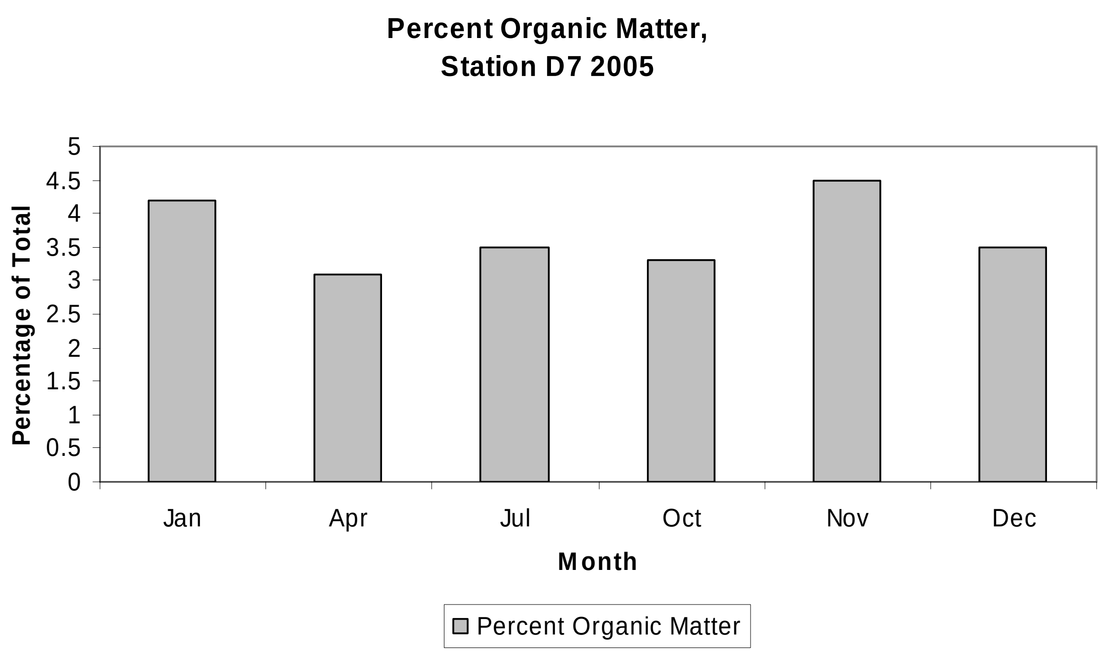
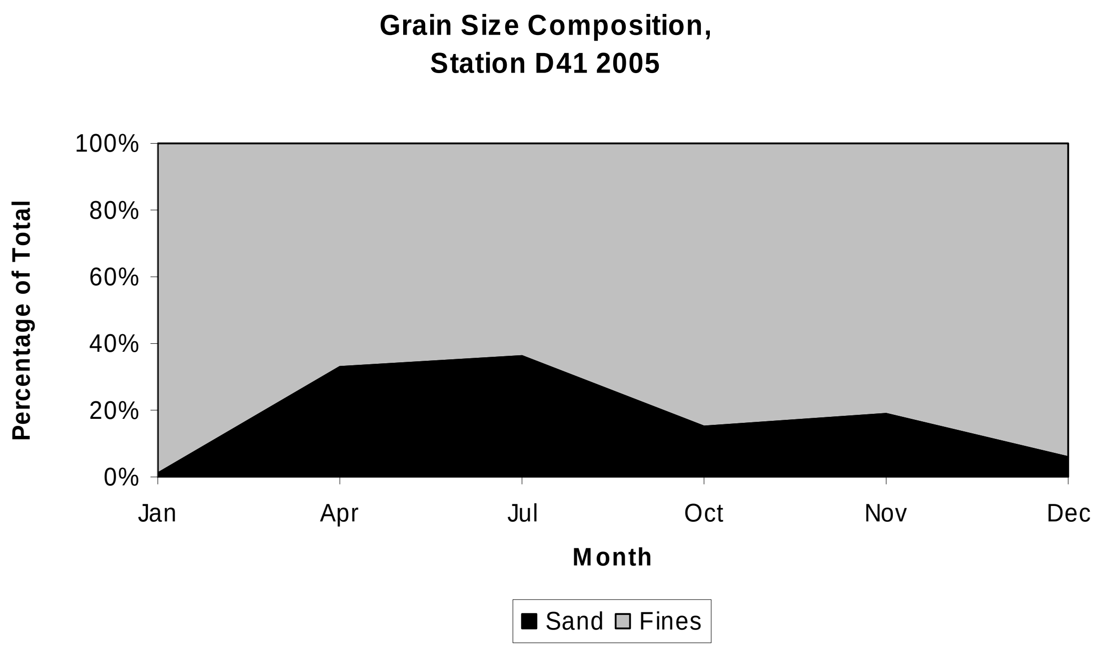


Figure 6-16 Sediment organic content and grain size at station D41 during 2005



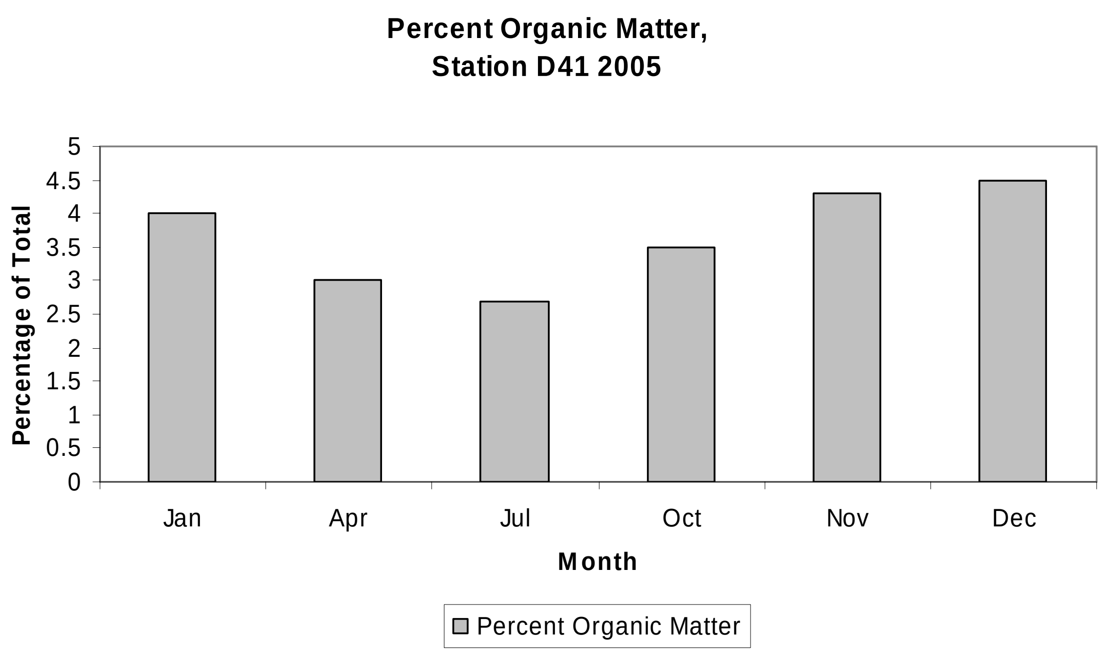
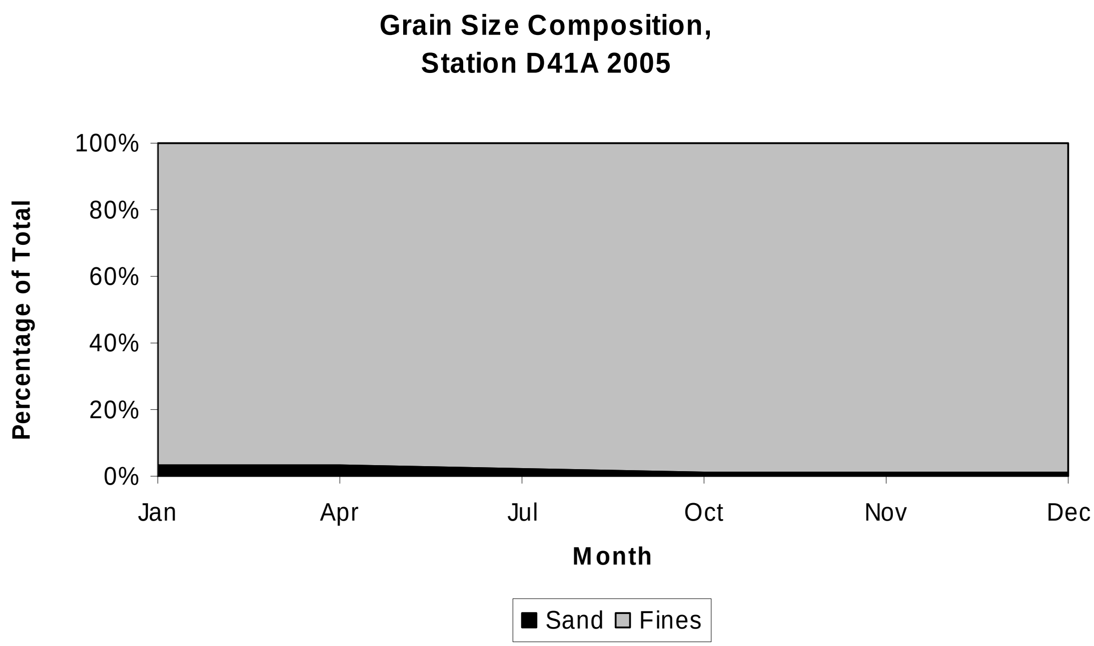


Figure 6-17 Sediment organic content and grain size at station D41A during 2005



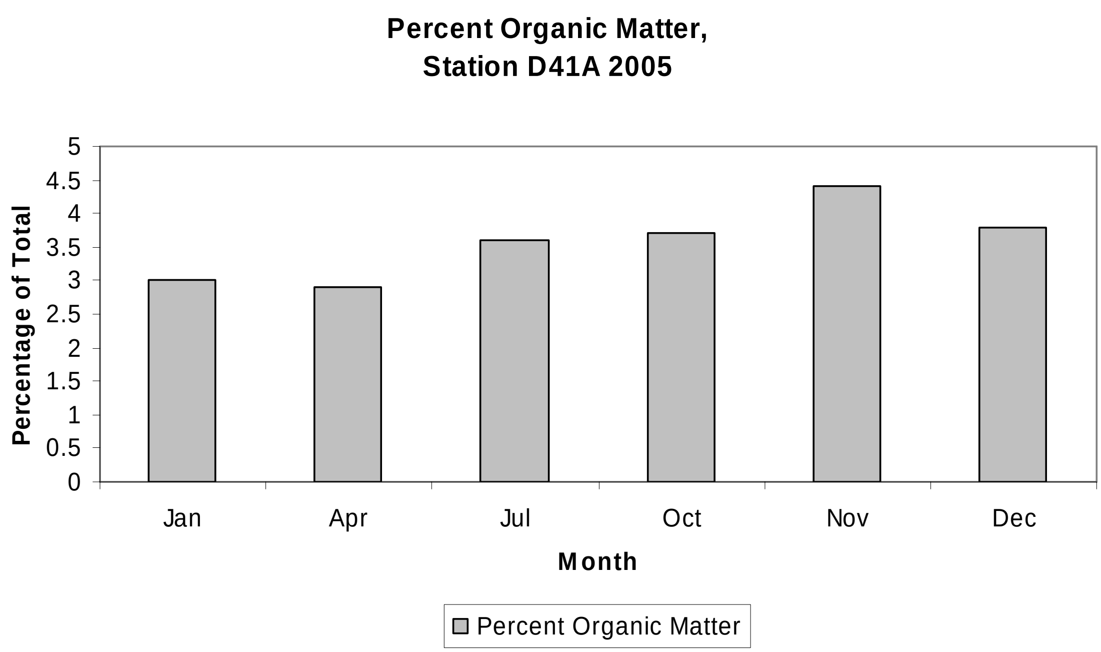


Table 6-1 Macrobenthic monitoring station characteristics

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

Chapter 7. Dissolved Oxygen Monitoring in the Stockton Ship Channel

Dissolved oxygen (DO) 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, DO 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 at Stockton.

Because low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the State has established specific water quality objectives to protect these uses. Within the channel, two separate DO 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 protect migrating fall-run Chinook salmon (SWRCB 1995).

As part of a 1969 Memorandum of Understanding between DWR, the US Fish and Wildlife Service, USBR, and the Department of Fish and Game, DWR has installed a rock barrier across the head of Old River during periods of projected low fall San Joaquin River outflow. This barrier increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving DO levels. The barrier is usually installed in the fall and spring when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

Due to high San Joaquin River flows in 2005, the barrier was not installed this spring. Fall construction of the barrier began on September 19, and was completed on September 30. Removal of the barrier began on November 7, and was completed by November 15.

Methods

Monitoring of DO concentrations in the Stockton Ship Channel was conducted by vessel on eight monitoring runs from August 3 to November 15, 2005[1]. During each of the monitoring runs, fourteen sites were sampled at low water slack, beginning at Prisoner's Point (Station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the ship channel (Station 14). For geographic reference and simplicity of reporting,

[1] Funding for these special studies was provided by DWR's Division of Operations and Maintenance.

the sampling stations are keyed to Channel Light Markers[2] as shown in Figure 7-1.


Figure 7-1 Monitoring sites in the Stockton Ship Channel

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 7-1. The western channel begins at Prisoner's 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; however, the findings are displayed graphically together with the other 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 were analyzed for DO concentrations and temperature. Top DO samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were obtained using a Seabird submersible sampler and measured using a YSI 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 with a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data recorded at the Vernalis monitoring station, operated jointly by the US Geological Survey and DWR[4]. Average daily flows past Vernalis were obtained by averaging 15-minute data. Tidal cycles of ebb and flood are not seen in flows at Vernalis and flow proceeds downstream (positive flow) throughout the year.

The flow data for the San Joaquin River past Stockton used in this report were recorded by the 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. Due to low inflows, upstream agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse

[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 DO levels are typically: high and stable (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.

[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 which represents net river flow exclusive of tidal cycles.

direction. From August through November 2005, net flows at Stockton occasionally approached zero. No net reverse flows were recorded during this period.

Results

During the August 3 to November 15 study period, DO levels varied from 4.1 to 8.9 mg/L between regions within the channel (not including the turning basin). In the western channel, DO concentrations were relatively high and stable, ranging from 6.5 to 8.9 mg/L. The robustness of DO concentrations in this portion of the channel, in comparison with the central and eastern portions of the channel, is apparently due to greater tidal mixing, less biochemical oxygen demand from sources in the water, and shorter hydrological residence time. In the central portion of the channel, DO concentrations were more variable than the concentrations observed in the western channel, ranging from 4.1 to 8.2 mg/L. In the eastern channel, the DO levels were the most variable and stratified, ranging from 4.5 to 8.7 mg/L.

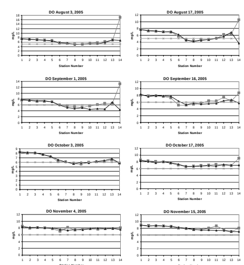


Figure 7-2 Fall 2005 dissolved oxygen concentrations at 14 stations in the Stockton Ship Channel

Inflows from the San Joaquin River past Stockton were variable during the study period. Net daily flow from July through December 2005, exclusive of tidal pulses, ranged from +4,112 cfs to -218 cfs. The positive flow indicates net downstream flow, while negative flows indicate net upstream flow.

The findings for the late summer and fall of 2005 are briefly summarized by month as follows.

August

Monitoring during cruises on August 3 and 17 showed surface DO levels ranging from 4.3 mg/L at Station 8 in the central channel to 7.7 mg/L at Station 1 in the west channel (Figure 7-2). Bottom DO levels ranged from 4.1 mg/L at Station 8 in the central channel to 7.7 mg/L at Station 1.

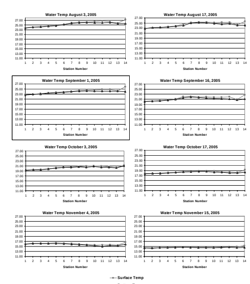


Figure 7-3 Fall 2005 water temperatures (°C) at 14 stations in the Stockton Ship Channel

A DO sag[7] (<6.0 mg/L) was observed at the surface and bottom in both the central and eastern channel stations. On August 3, the DO sag extended from Stations 6 to 12. On August 17, DO conditions had slightly worsened; however, the extent of the DO sag remained unchanged. DO conditions in the western channel remained relatively high throughout August and all stations reported DO levels well above the state's objective.

August water temperature values ranged from surface values of 22.8 °C in the western channel to 26.7 °C in the east channel, and bottom values of 22.7 °C in the west to 26.0 °C in the central channel (Figure 7-3).

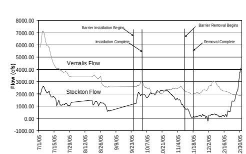


Figure 7-4 San Joaquin River average net daily flow: Fall 2005

Average daily flows in the San Joaquin River past Vernalis ranged from 1,990 to 3,554 cfs. Net flow in the San Joaquin River past Stockton ranged from 851 to 1,482 cfs (Figure 7-4).

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7 In this report, we define a DO "sag" as a region within the channel where DO levels do not meet the SWRCB objective of 6.0 mg/L.

September

Monitoring during cruises on September 1 and 16 showed surface DO levels ranging from 5.1 mg/L at Station 6 in the central channel to 8.0 mg/L at Station 1 in the west channel (Figure 7-2). Bottom DO levels ranged from 4.5 mg/L at Station 10 to 8.3 mg/L at Station 1. The west channel exhibited the highest DO and all stations there maintained DO levels above the state's objective.

During the September 1 cruise, a DO sag was observed beginning at Station 6 (bottom DO) and extending to Station 12 (bottom DO). Monitoring on September 16 showed the extent of the sag from Station 6 (surface DO) to Station 11 (bottom DO).

September surface water temperatures ranged from 20.2 °C at Station 1 in the west channel to 24.8 °C at stations 11 and 12 in the east channel. Bottom temperatures ranged from 20.0°C at Station 1 to 24.2 °C at Station 9 (Figure 7-3). Similar to the pattern observed in August, September water temperatures declined in a roughly linear gradient from east to west across the channel.

Major in-water work for the barrier installation at the head of Old River began on September 19, and was completed on September 30. Flow rates past Vernalis during September ranged from 2,005 to 2,611 cfs. Flows at Stockton during September increased from a low of 588 cfs prior to barrier construction to a high of 2,141 cfs upon completion of the barrier (Figure 7-4).

October

Surface DO levels ranged from 5.6 mg/L at Station 9 in the central channel to 8.5 mg/L at Station 1 in the west channel. Bottom DO levels ranged from 5.7 mg/L at Station 8 to 8.4 mg/L at Station 1 (Figure 7-2). A slight DO sag was observed at Stations 8 and 9 on the October 3 cruise, but by the next sampling cruise on October 17, all stations had DO levels above the state's objective.

Surface water temperatures ranged from 17.6 °C at Station 1 in the west channel to 21.0 °C at Station 10 in the east channel (Figure 7-3). Bottom water temperatures were similar, ranging from 17.7 °C at Station 1 to 20.8 °C at Station 10.

Average daily flows of the San Joaquin River at Vernalis ranged from 1,957 to 3,050 cfs during October (Figure 7-4). Net daily flows at Stockton were similar, ranging from 1,702 to 2,319 cfs. 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.

November

Due to acceptable DO readings throughout October, efforts to begin the removal of the barrier at Old River began on November 7, and barrier removal was effectively completed by November 15. DWR conducted two monitoring cruises in November, the first on the November 4, prior to removal of the barrier, and the second on November 15, at completion of the barrier removal. Both surface and bottom DO levels for the month ranged from 7.0 to 8.9 mg/L. All DO levels measured during the month were well above objectives.

Surface and bottom water temperature ranges were similar for the month, ranging from 14.4 to 16.4 °C and 14.3 to 16.2 °C, respectively (Figure 7-3). Surface and bottom water temperatures on November 15 were uniform throughout the channel, with a difference of only 0.4 °C.

San Joaquin River flows at Vernalis ranged from 1,860 to 2,405 cfs. Net daily flows past Stockton ranged from 1,676 cfs on November 3 to 17 cfs by November 29 (Figure 7-4). The reduced flows seen at Stockton coincided with the removal of the barrier, which allowed a significant diversion of flow from the San Joaquin River to the Old River.

Stockton Turning Basin

DO levels in the Stockton turning basin were below state's objective, at either the surface or bottom, for the monitoring cruises from August 17 through October 3. Surface DO levels in August were supersaturated, while bottom levels reached a low of 3.6 mg/L (Figure 7-2). September DO levels at the surface and bottom ranged from 13.2 to 4.3 mg/L. DO levels showed improvement at the end of October, with surface levels at 9.0 mg/L and bottom levels at 7.0 mg/L. November DO readings were well above the state's objective, ranging from 8.0 mg/L at the surface to 7.0 mg/L at the bottom.

Summary

DO concentrations in the Stockton Ship Channel fell below both the CVRWQCB's 5.0 mg/L and the SWRCB's 6.0 mg/L objectives in August, September, October, and November 2004, a period which coincided with generally low net flows in the San Joaquin River past Stockton. A temporary barrier across the head of Old River was installed and fully operational on September 30, 2005, to increase flows down the San Joaquin River into the Stockton Ship Channel. The installation of the barrier coincided with increased net flows at Vernalis and Stockton. Subsequent sampling after the barrier installation, occurring during high inflows in October, showed a marked improvement of DO conditions. In October all stations showed levels above the 6.0 mg/L objective, except bottom DO levels in the turning basin that were only slightly below the objective.

DO levels remained high through the first half of November, and the barrier was removed on November 15. The removal of the barrier coincided with a reduction in net flows at Vernalis and Stockton.

Further monitoring operations for the fall 2005 special study were suspended after November 15, 2005.

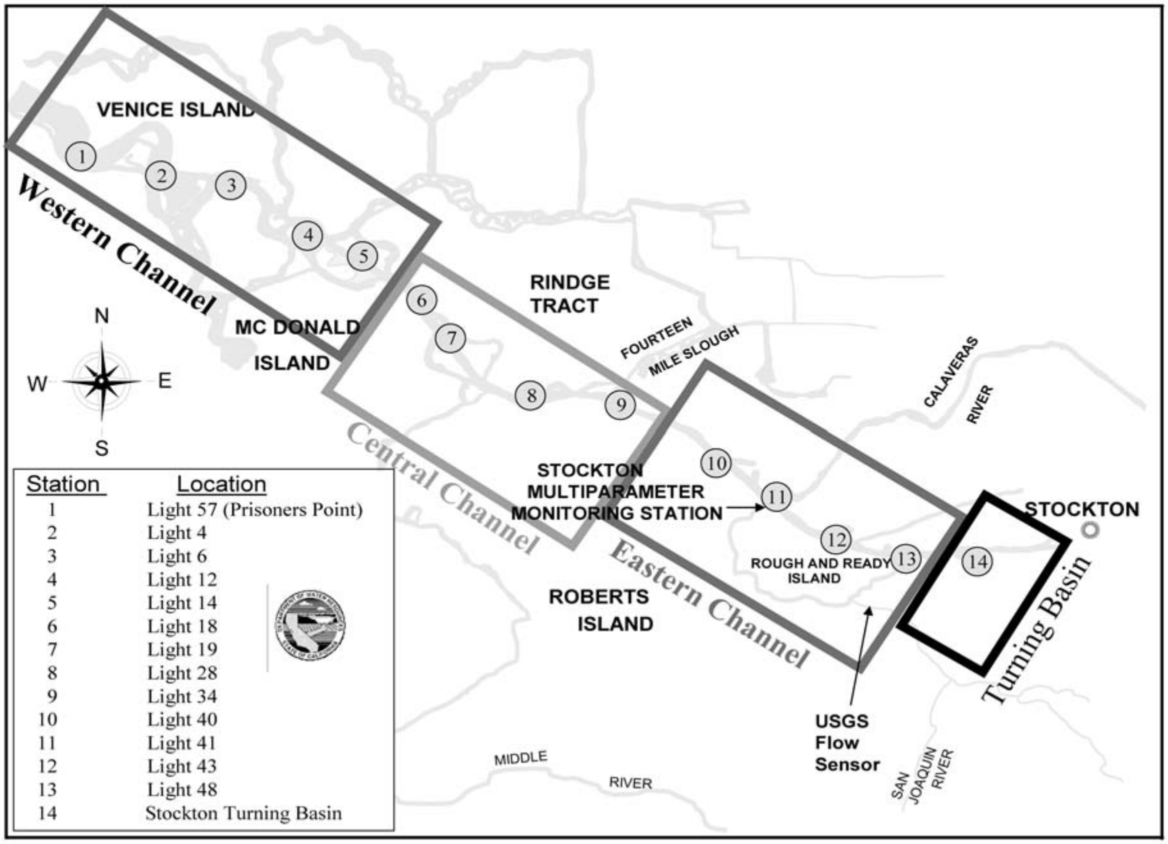
References

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

[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 7-1 Monitoring sites in the Stockton Ship Channel



Station	Location
1	Light 57 (Prisoners Point)
2	Light 4
3	Light 6
4	Light 12
5	Light 14
6	Light 18
7	Light 19
8	Light 28
9	Light 34
10	Light 40
11	Light 41
12	Light 43
13	Light 48
14	Stockton Turning Basin

Figure 7-2 Fall 2005 dissolved oxygen concentrations at 14 stations in the Stockton Ship Channel

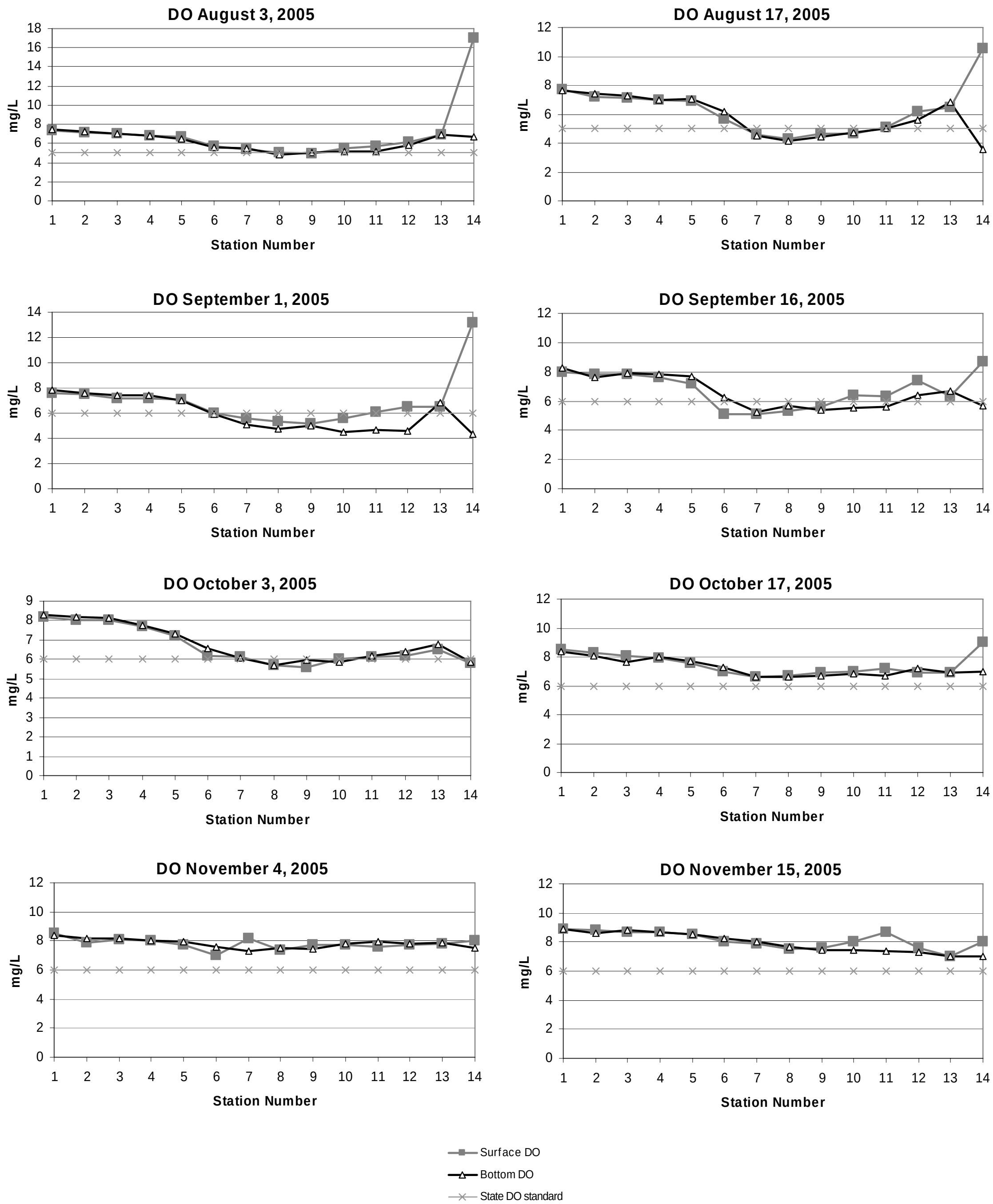


Figure 7-3 Fall 2005 water temperatures (°C) at 14 stations in the Stockton Ship Channel

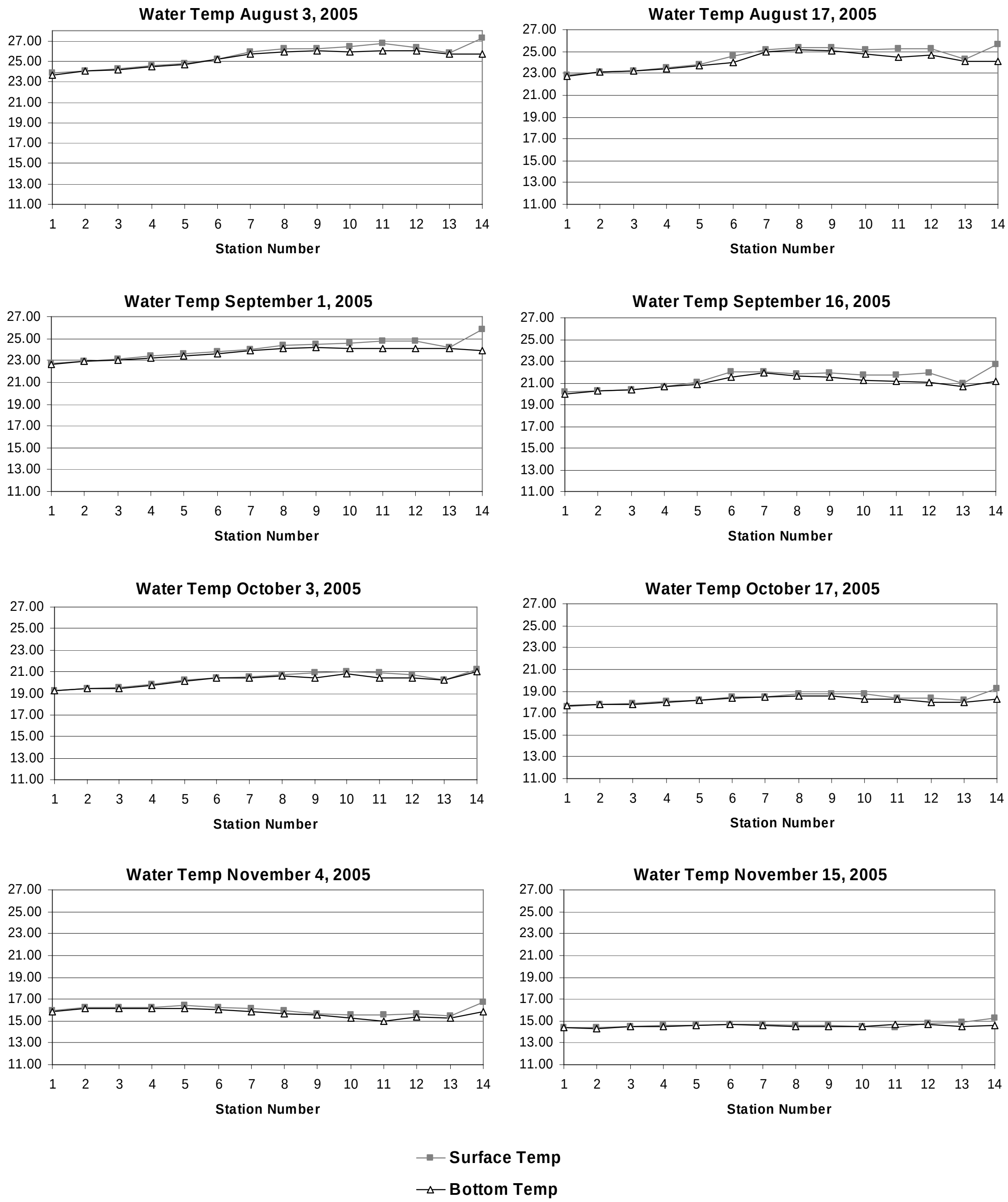
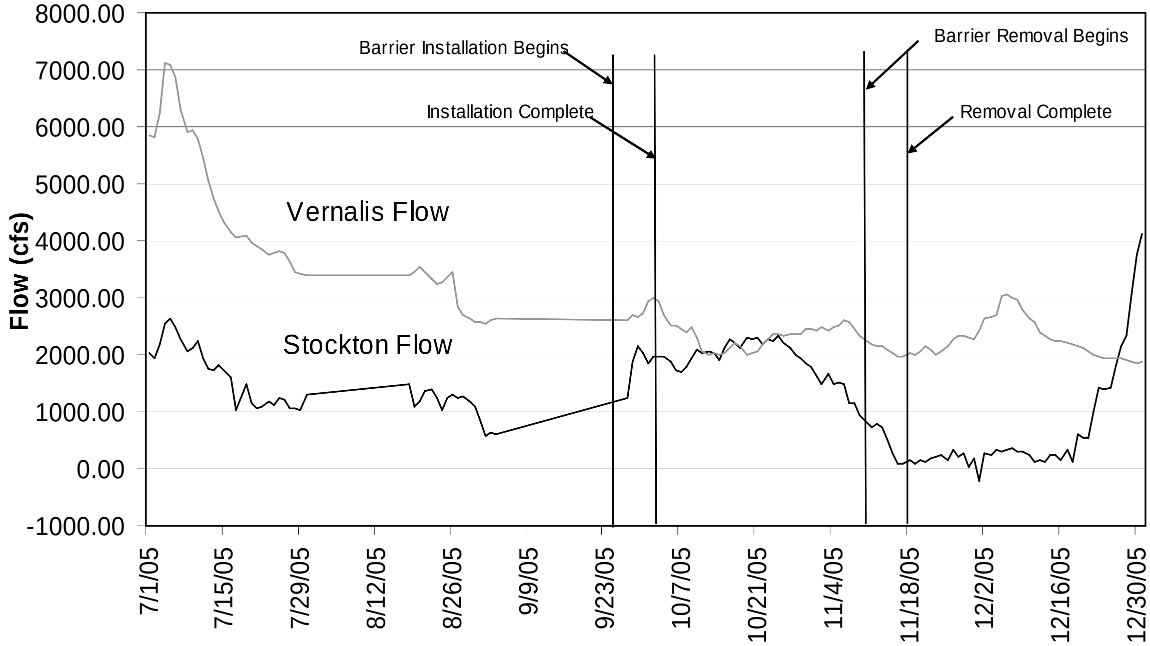


Figure 7-4 San Joaquin River average net daily flow: Fall 2005



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 Sacramento-San Joaquin Estuary's watershed. The EMP water quality, benthic and phytoplankton data stored in this database are available 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 Interagency Ecological Program (IEP) website at: http://www.iep.water.ca.gov/emp/Metadata/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' (DWR) 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 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 against paper datasheet records for accuracy, completeness, and consistency. 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." At 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 website, but may be obtained from EMP staff upon request.

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

A subset of the data from automated continuous water quality monitoring stations is send by telemetry in near real-time to DWR's California Data Exchange Center (CDEC). **These real time data are unchecked and may include data that are the result of malfunctioning instruments.** They are available for viewing and download at: http://cdec.water.ca.gov/

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. From October 2003 to October 2005, they were sampled quarterly. Monthly sampling was resumed after October 2005. Laboratory identification and enumeration of macrobenthic 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 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's 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 each quarter.

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 are 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 is underway of a zooplankton database able to export data to BDAT.

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 the 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 in the upper San Francisco Estuary (Figure 9-1). These stations provide continuous measurements of seven water quality parameters and four environmental parameters. These measurements 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 2005, with two new additional stations on the San Joaquin River at Prisoner's Point and Vernalis. The stations were divided into three regions to allow for detail in the plots:

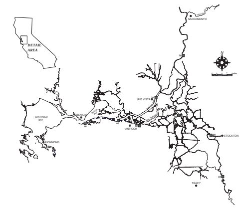


Figure 9-1 Station locations

Sacramento River stations:	Hood and Rio Vista
San Joaquin River stations:	Mossdale, Prisoner's Point, Vernalis 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. At seven of the monitoring stations, continuous data are collected for water temperature, pH, dissolved oxygen, surface specific conductance, chlorophyll fluorescence, and turbidity. Additional sensors are installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom specific conductance, 1.5 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 Water Right Decision 1641 (SWRCB 1999). Environmental measurements of air temperature, solar radiation, wind speed, and direction—are taken at all stations except the Mossdale (only air temperature) and Hood stations (none). The Prisoner's Point station also monitors only water temperature and specific conductance to meet SWRCB Water Right Decision 1641 requirements (SWRCB 1999).

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*	*10 minute instantaneous*
Turbidity	*NTU*	*10 minute instantaneous*
Surface Specific Conductance	*µS/cm*	*Hourly average*
Bottom Specific Conductance	*µS/cm*	*15 minute instantaneous*
River Stage	*feet (from mean sea level) (NGVD 1929)*	*15 minute instantaneous*

Table 9-1 Parameters measured by the Continuous Monitoring Program

Except for bottom specific conductance and data collected at Prisoner's Point station, all water samples are collected at 1 meter below the water surface using a float-mounted pump and distributed to the water quality sensors. A data acquisition system scans the output from the sensors once per second and records the hourly average of these approximately 3,600 readings on the hour. Bottom specific conductance, Prisoner's Point and Vernalis data, 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, chlorophyll florescence, turbidity, wind velocity, wind direction, solar radiation intensity and river stage are available on the Bay Delta and Tributaries (BDAT) Project database http://bdat/index.html unless otherwise noted. All other inquiries 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 2005 are shown in Figures 9-2 to 9-10.

Water Temperature

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

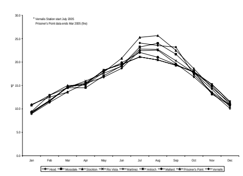


Figure 9-2 Average monthly water temperature at nine stations, 2005

Average monthly water temperatures in the upper San Francisco Estuary (Estuary) ranged from 8.9 °C in January 2005 at the Hood station on the Sacramento River to 25.9 °C in August 2005 at the Stockton station on the San Joaquin River (Figure 9-2). These values are lower than the same time period in 2004.

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.

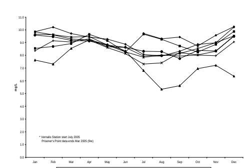


Figure 9-3 Average monthly dissolved oxygen at eight stations, 2005

Average monthly dissolved oxygen values for the seven monitoring stations ranged from 5.3 mg/L to 10.2 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 5.3 mg/L was calculated for the Stockton station in August 2005, and a value of 10.2 mg/L was calculated for the Hood station for February 2005. All other stations showed monthly averages between 7.3 mg/L and 10.2 mg/L with the Stockton station recording lower values starting in July 2005. 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

[1] For specific questions regarding availability of continuous monitoring data, contact Mr. Darrell Kaff, 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, telephone: (916) 651-0175, or by e-mail at dkaff@water.ca.gov.

and ranged from 5.3 mg/L to 9.2 mg/L. The Stockton station, located in the Stockton Deep Water Ship Channel, showed a small DO sag of 7.3 mg/L in February 2005. This pattern of winter sag was first identified in 2000. The 2005 sag was significantly less than the same time period in 2004 and showed an improvement of 2 mg/L from the same period in 2004.

During summer and fall 2005, monthly average dissolved oxygen values at the Mossdale and Vernalis stations showed a familiar pattern of increase for July and August. Monthly average dissolved oxygen values in previous years showed a similar pattern from June to September. The July increase to 9.7 mg/L at the Mossdale station in 2005 was much smaller than the 2004 increase to 12.1 mg/L. The high average summer DO levels seen at the Mossdale station coincided with high chlorophyll fluorescence during the same period (Figure 9-9).

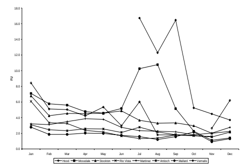


Figure 9-9 Average monthly chlorophyll at eight stations, 2005

Specific Conductance

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

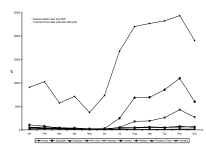


Figure 9-4 Average monthly specific conductance at nine stations, 2005

Monthly average surface specific conductance for the Estuary ranged from 130 µS/cm to 24,322 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). The 2005 data is very similar to the 2004 data range. 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 Hood and Rio Vista stations on the Sacramento River (Figure 9-4a).

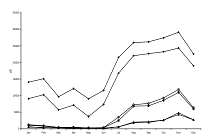


Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2005

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).

pH

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

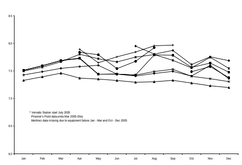


Figure 9-6 Average monthly pH at eight stations, 2005

Monthly average pH levels for the Estuary for all stations ranged from 7.2 to 8.0 pH units (Figure 9-6). Unlike 2004—where the Mossdale station on the San Joaquin River showed an increase in pH values in June, July, and August—there was a decrease in pH from 7.7 to 7.4 during the same time period in 2005.

Air Temperature

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

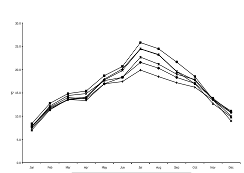


Figure 9-7 Monthly average air temperature at six stations, 2005

Monthly average air temperatures in the Estuary ranged from 7.0 °C in January 2005 at the Stockton station on the San Joaquin River to 25.8 °C July 2005 at the Mossdale station on the San Joaquin River (Figure 9-7).

Chlorophyll Fluorescence

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

Monthly average chlorophyll fluorescence recorded at the stations in the Estuary ranged from minima of 0.9 fluorescence units (FU) in November 2005 at the Mallard station on the Sacramento River to maxima of 10.8 FU in August 2005 at the Mossdale station on the San Joaquin River (Figure 9-9, a-c).

Turbidity

Turbidity was measured using a Turner Designs SCUFA® Fluorometer.

Monthly average turbidity was recorded at the stations in the Estuary ranged from minima of 4 Nephelometric Turbidity Units (NTU) at the Hood station on the Sacramento River in September 2005 to maxima of 78 NTU at the Mossdale station on the San Joaquin River in January 2005 (Figure 9-10, a-c).

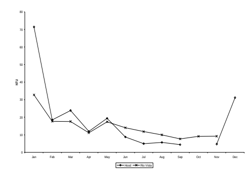


Figure 9-10a Average monthly turbidity at two Sacramento River stations, 2005

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 in the ship channel (Stockton Station P8a) 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). 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 also been established for September through November by the State Water Resources Control Board (SWRCB 1995).

For 2005, average monthly DO values at the Stockton station fell below the 6.0 mg/L standard during September 2005 and remained above the standards all other months (Figure 9-8).

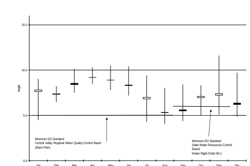


Figure 9-8 Range of monthly dissolved oxygen values at San Joaquin River at Rough and Ready Island, 2005

Monthly average DO values in 2005 ranged from 5.3 to 9.2 mg/L. The lowest DO value occurred in August 2005 while the highest value of 9.2 mg/L occurred in April 2005. Monthly average DO values only dropped below the state-mandated standards in September. In 2005, hourly values ranged from 4.1 to 11.6 mg/L. The minimum value of 4.1 mg/L was recorded in August 2005. 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 2005, but remained above the 5.0 mg/L standard.

The box plots (Figure 9-8) 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 averages. Open boxes indicate that the monthly median is greater than the monthly average, with the top of the box indicating the median, and the bottom of the box indicating the average. Filled boxes indicate that the monthly average is greater than the median, with the top of the box indicating the average and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the average are equal.

Summary

Water quality conditions in the upper San Francisco Estuary for calendar year 2005 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 continue to be found on the San Joaquin River.

The upper San Joaquin River stations at Mossdale and Vernalis showed higher dissolved oxygen and chlorophyll *a* fluorescence values in July, August, and September than any other station in the Estuary. Unlike 2004, the pH values remained near or lower than pH values measured at the other Estuary stations. The dissolved oxygen ranged from 8.7 mg/L to 9.7 mg/L. The chlorophyll *a* fluorescence values ranged from 5.3 FU to 16.7 FU.

The San Joaquin River station at Stockton remained above the 5.0 mg/L standard, which was set by the CVRWQCB (1998), for the entire period. This includes the winter dissolved oxygen sag that was first noticed in 2000. With an average monthly value of 5.6 mg/L, the dissolved oxygen levels were below the 6.0 mg/L standard (SWRCB 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.

[SWRCB] State Water Resources Control Board. 1999. *Water Right Decision 1641*. Adopted December 29, 1999, Revised in Accordance with order WR2000-02 March 15, 2000, Sacramento, CA. 211pp.

Figure 9-1 Station locations

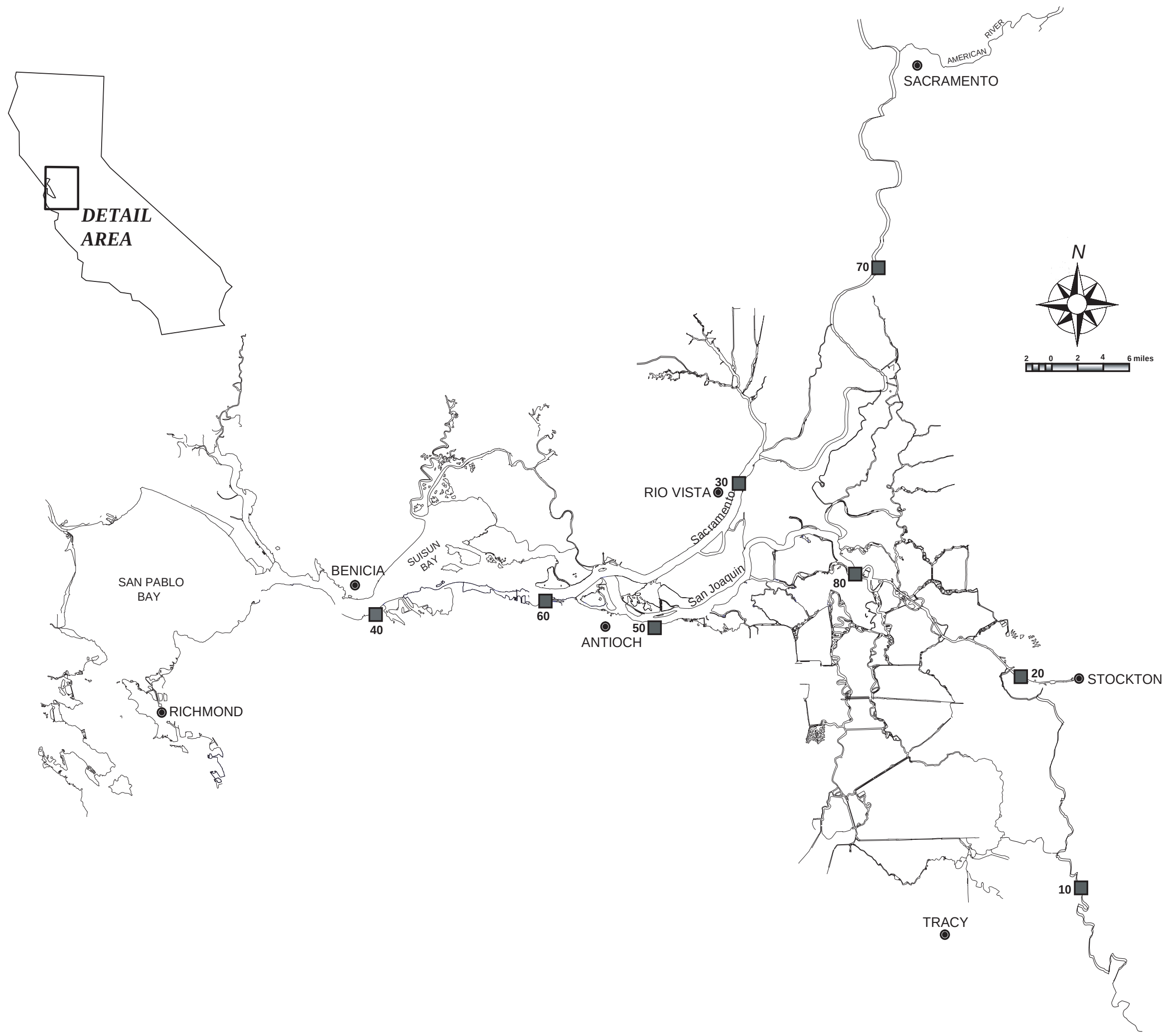


Figure 9-2 Average monthly water temperature at nine stations, 2005

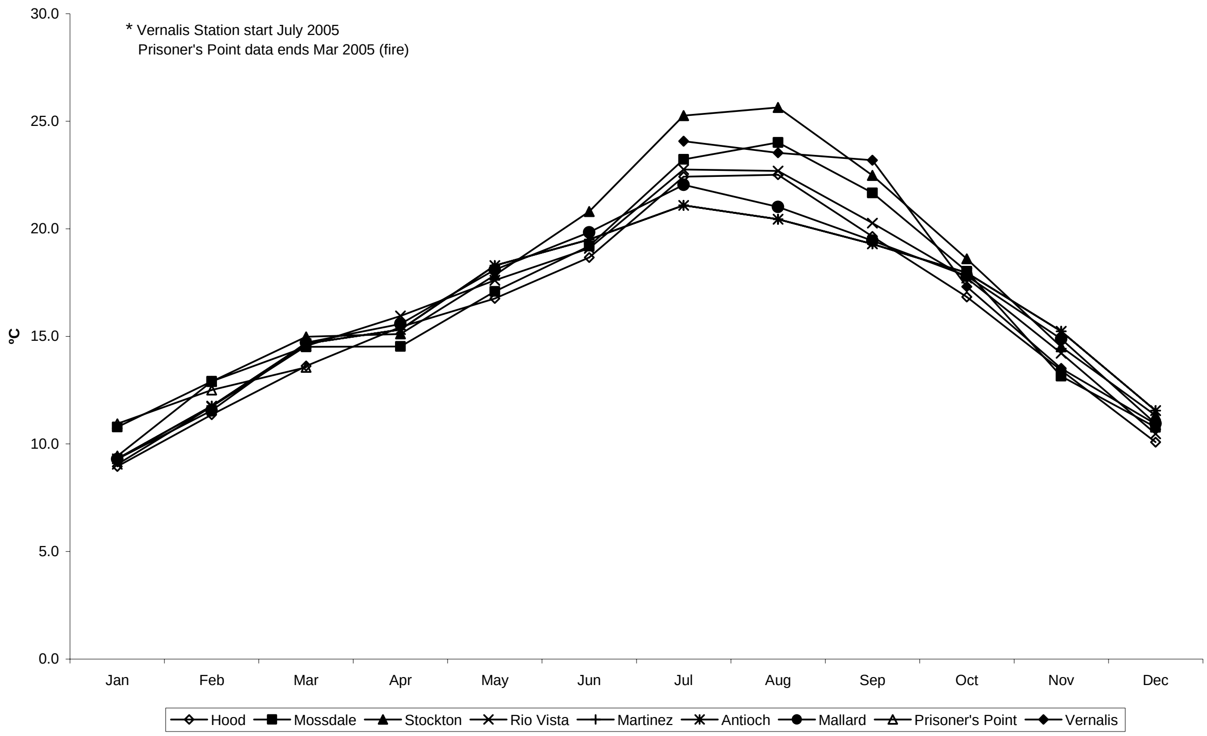


Figure 9-3 Average monthly dissolved oxygen at eight stations, 2005

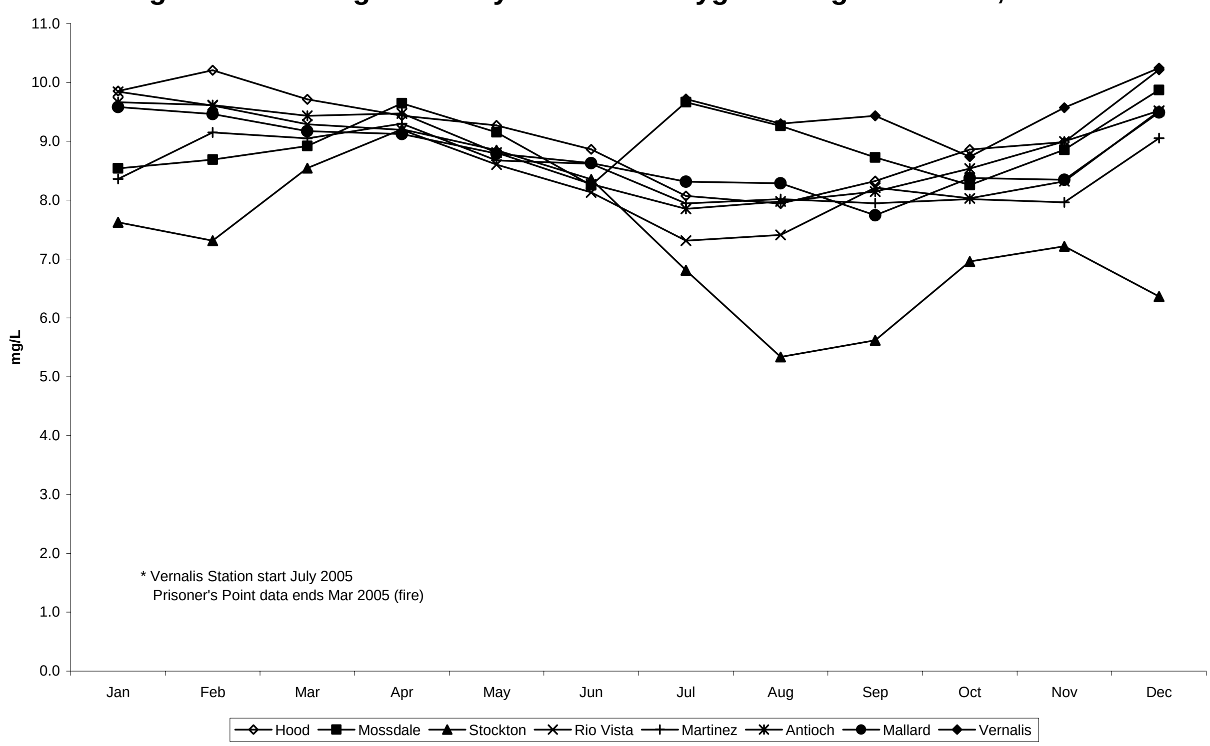


Figure 9-4 Average monthly specific conductance at nine stations, 2005

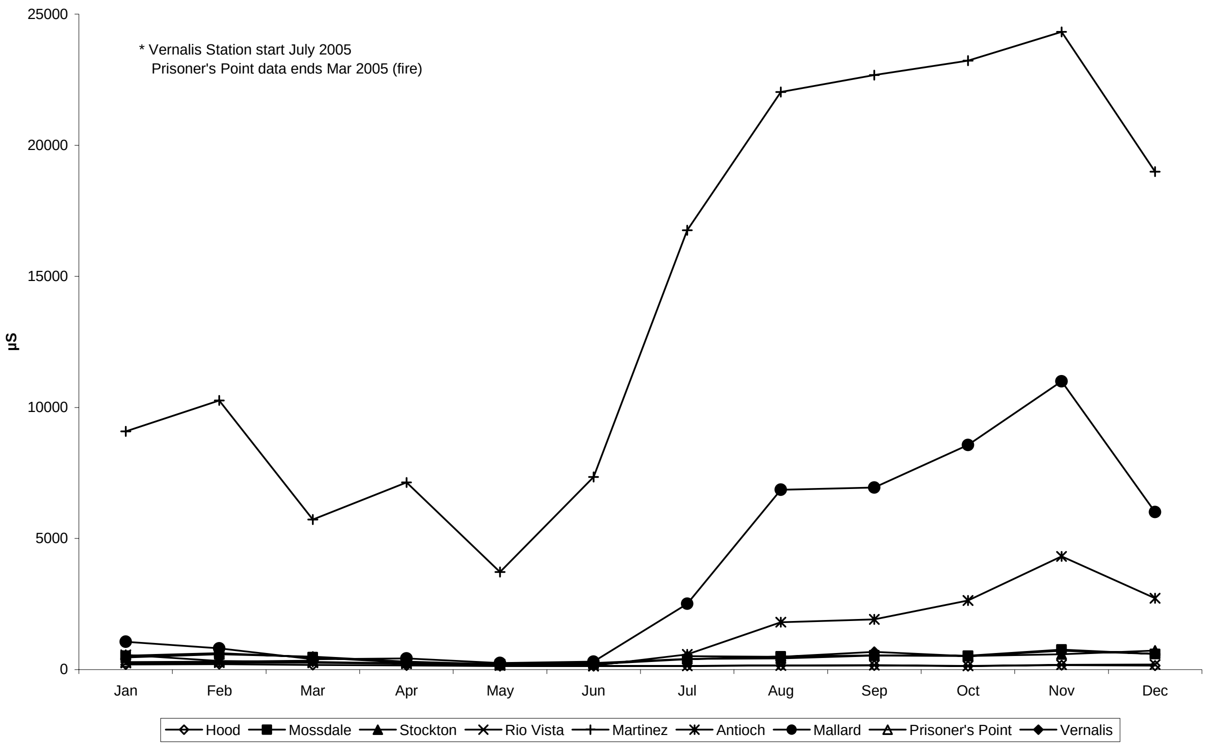


Figure 9-4a Average monthly specific conductance at six stations, 2005

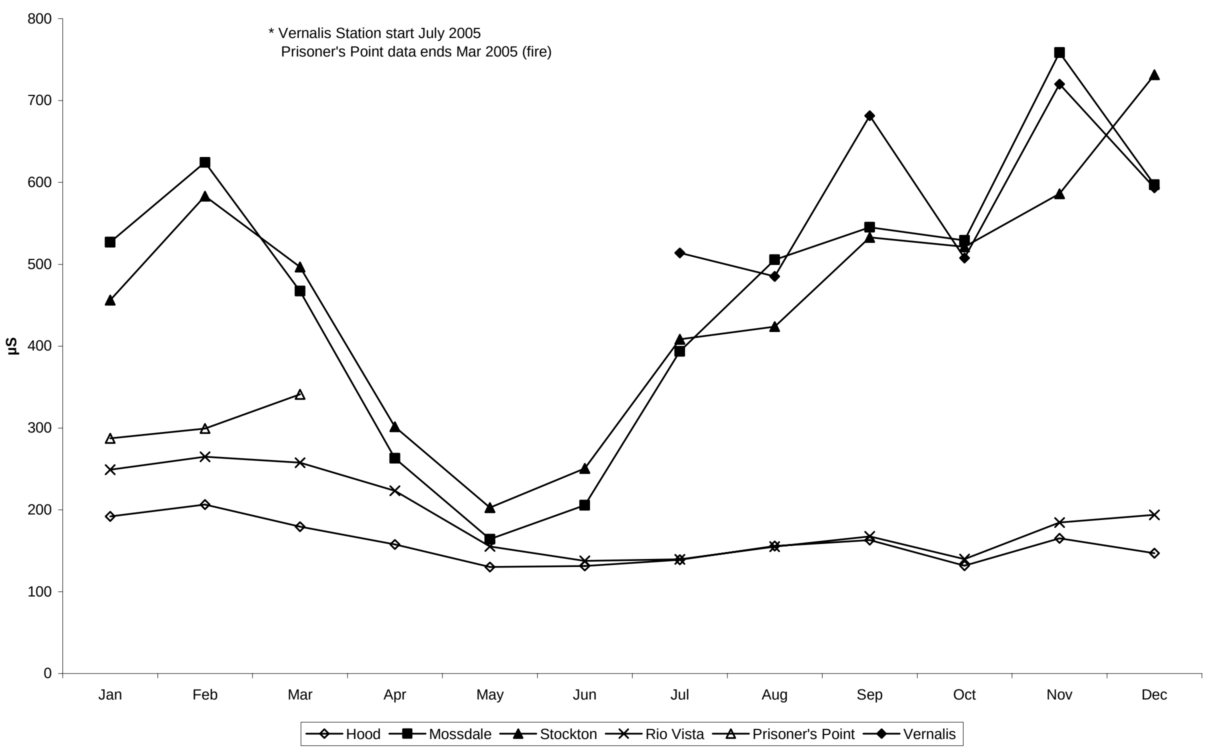


Figure 9-5 Average monthly surface and bottom specific conductance at three tidally influenced stations, 2005

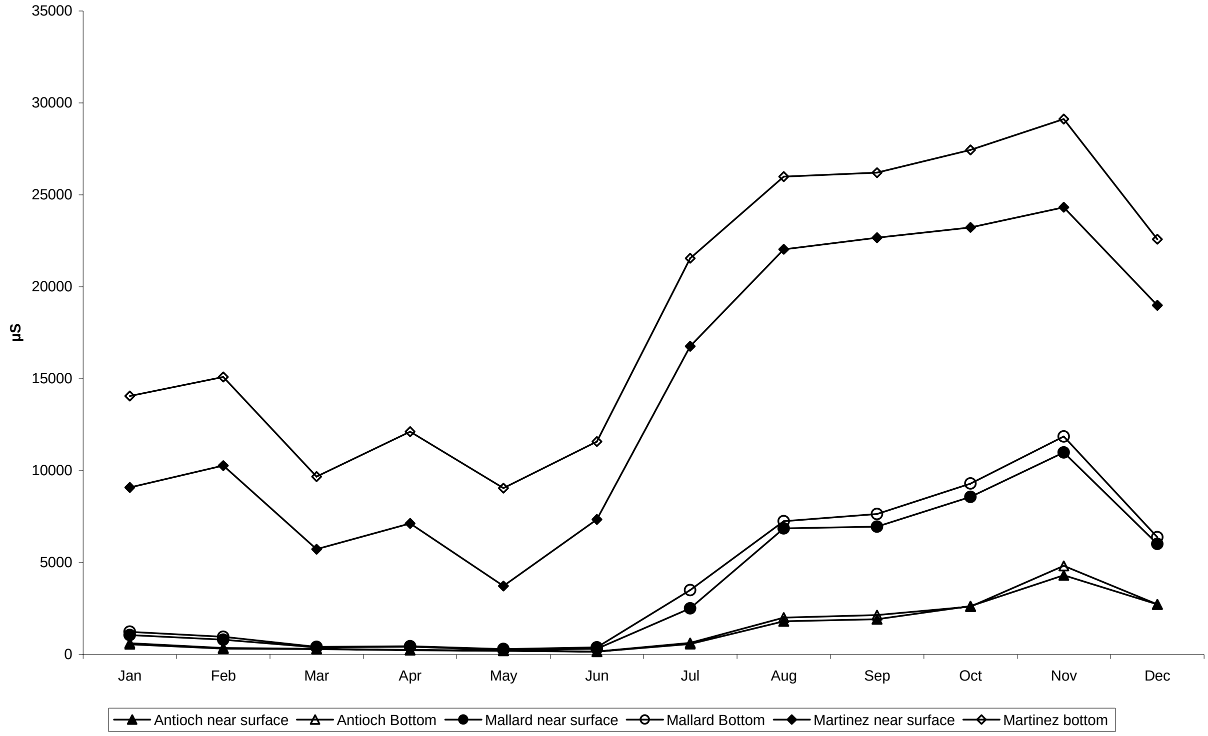


Figure 9-6 Average monthly pH at eight stations, 2005

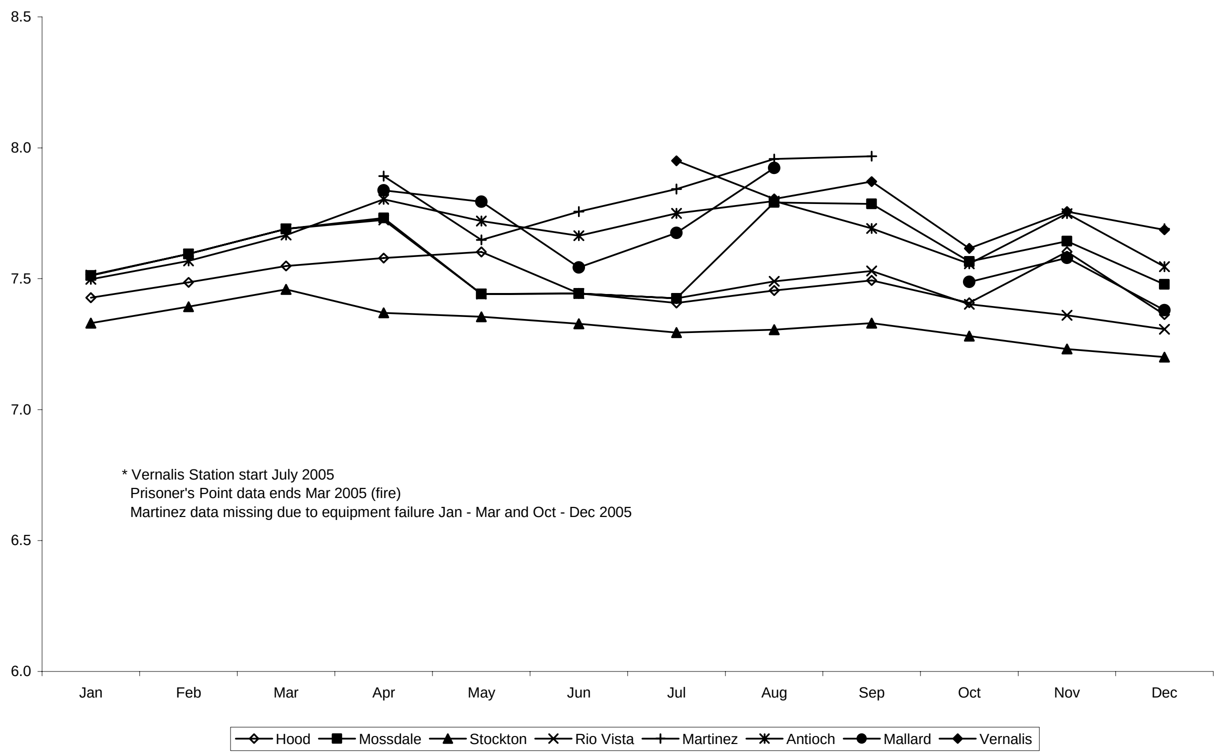


Figure 9-7 Monthly average air temperature at six stations, 2005

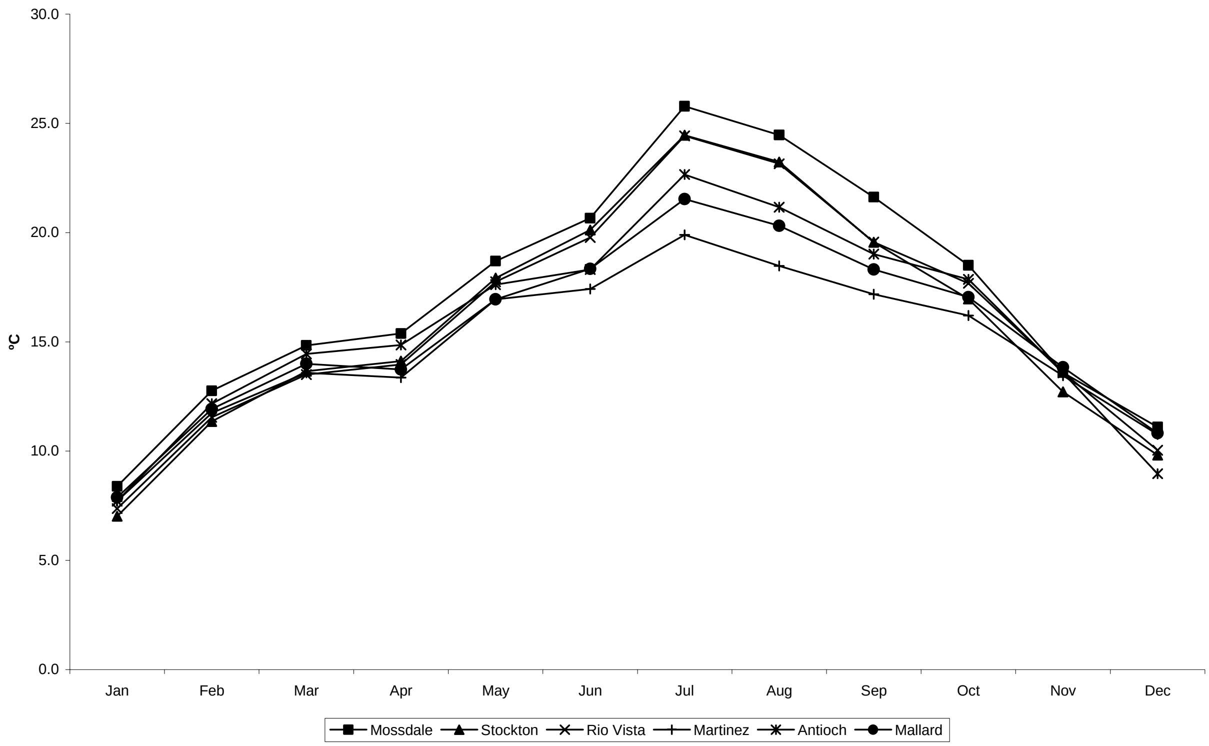


Figure 9-8 Range of monthly dissolved oxygen values at San Joaquin River at Rough and Ready Island, 2005

* Solid boxes when monthly average higher than monthly median

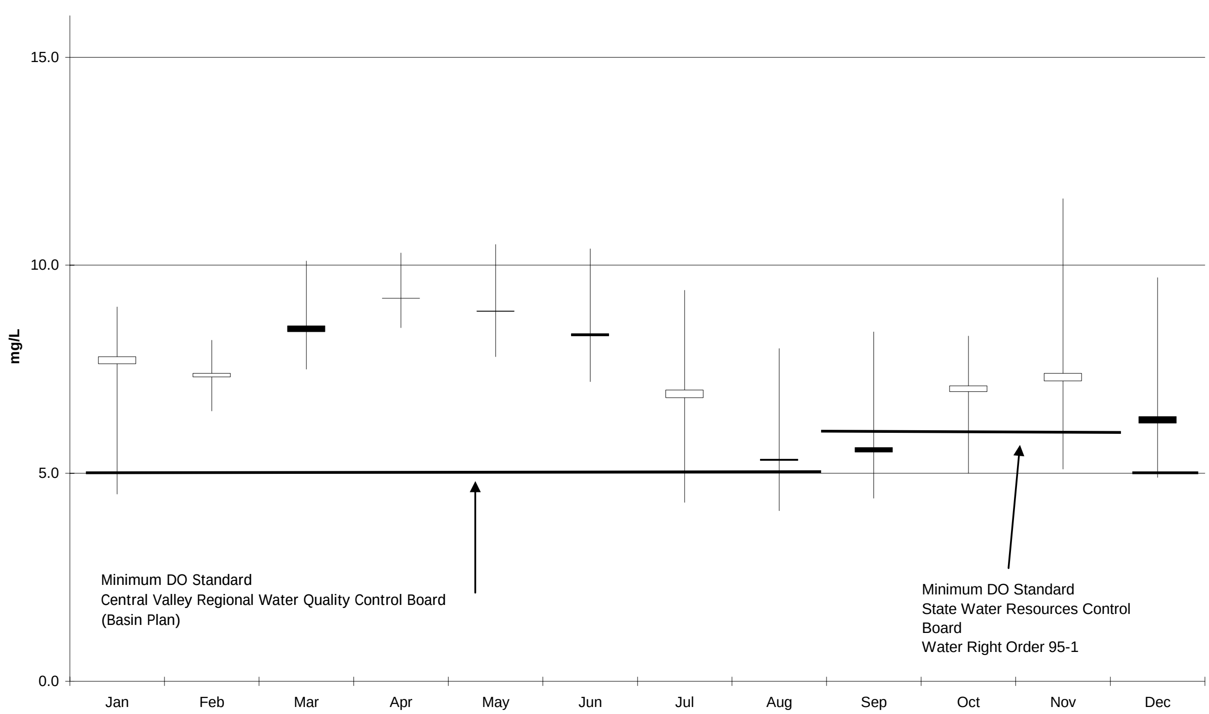


Figure 9-9 Average monthly chlorophyll at eight stations, 2005

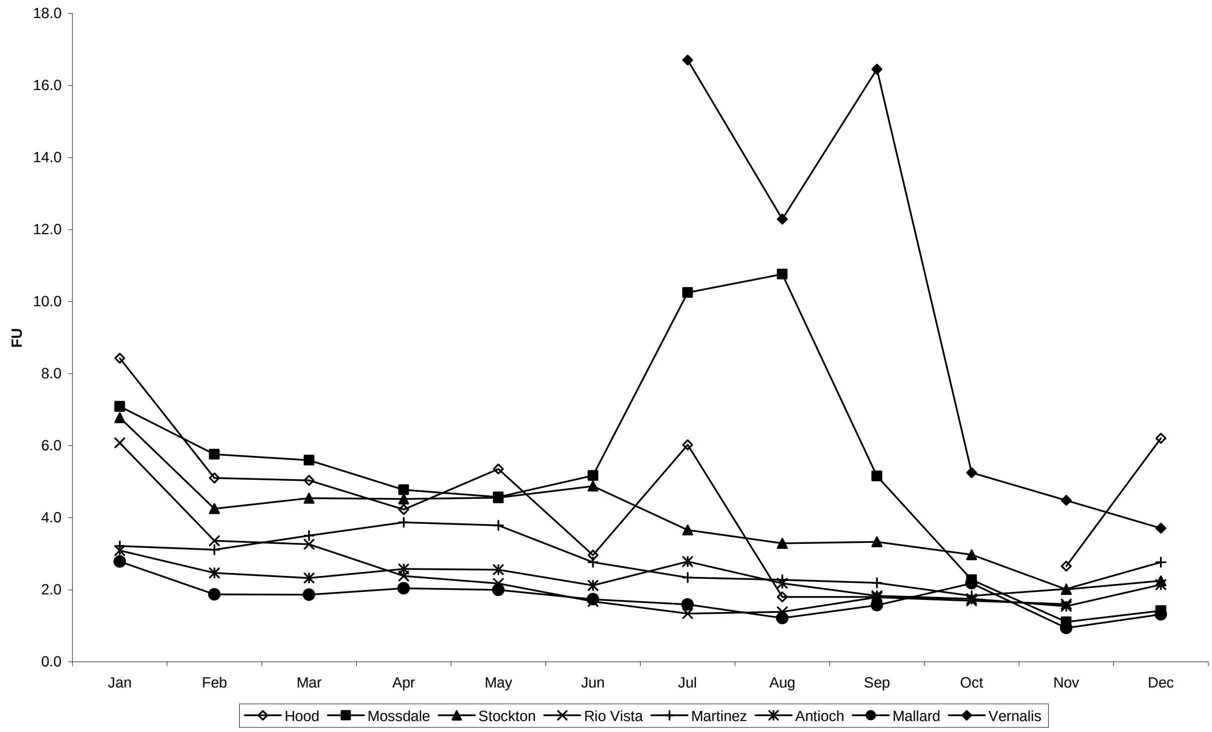


Figure 9-9a Average monthly chlorophyll at two Sacramento River stations, 2005

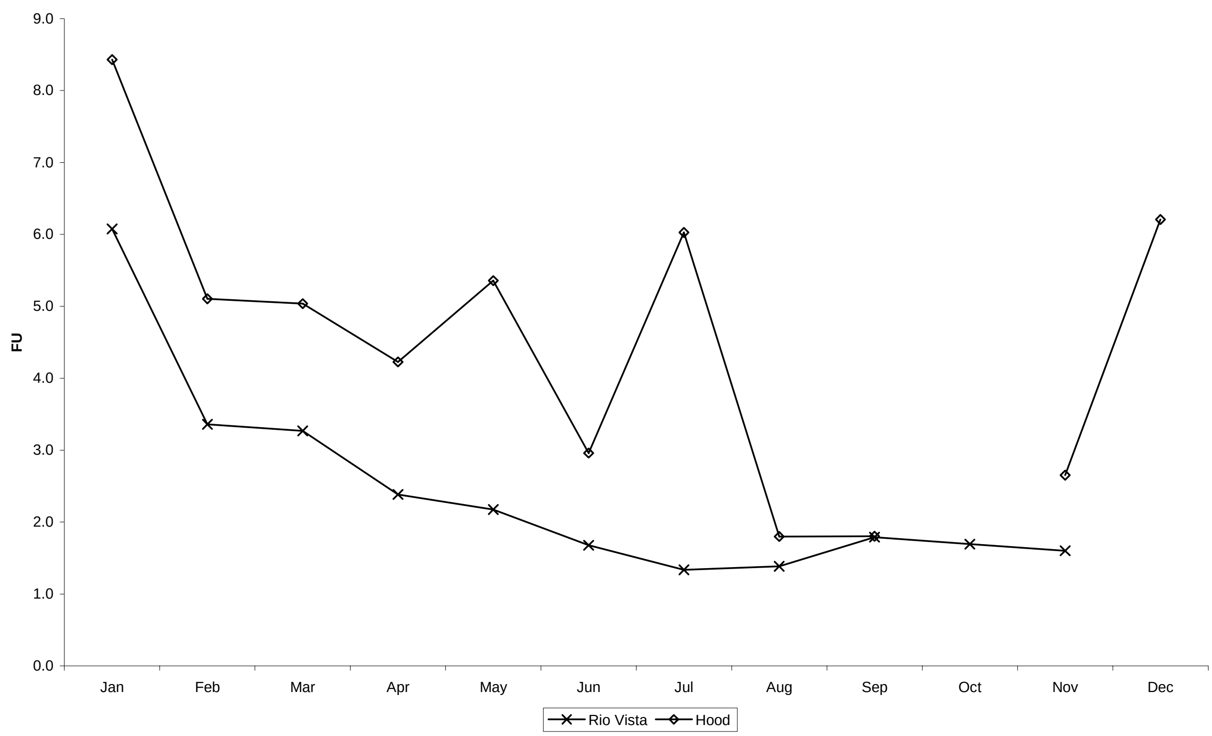


Figure 9-9b Average monthly chlorophyll at three San Joaquin River stations, 2005

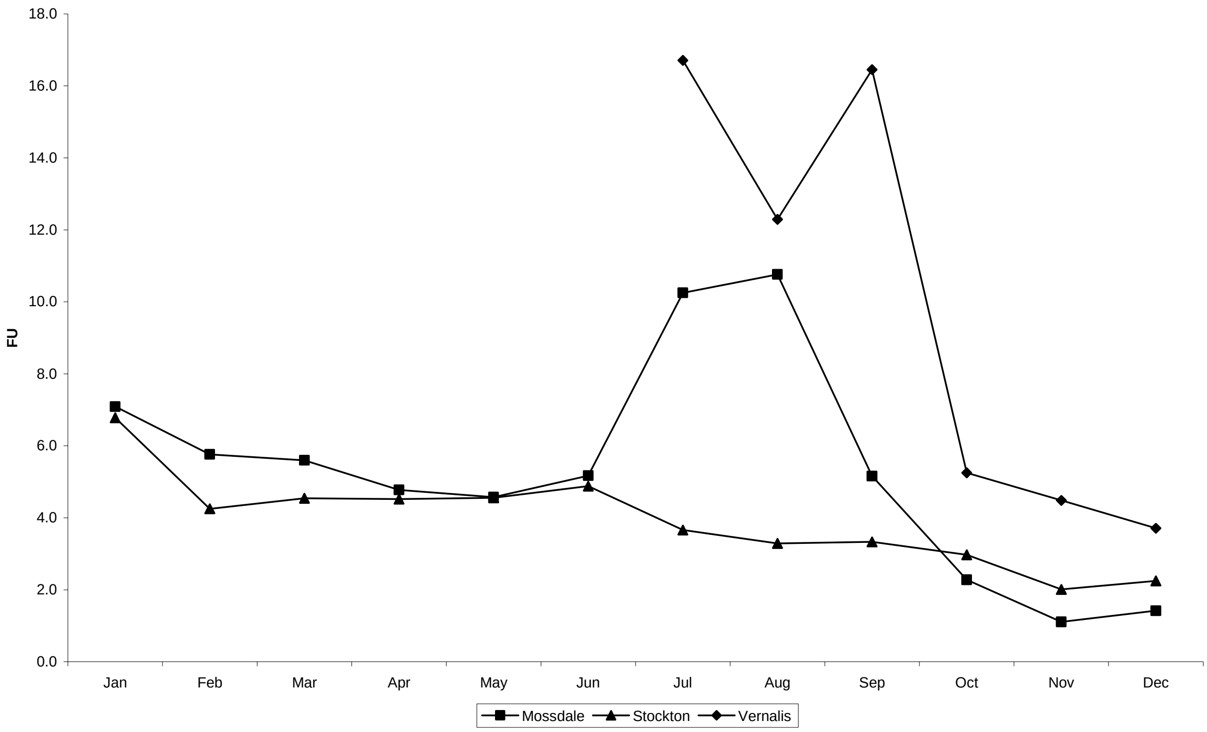


Figure 9-9c Average monthly chlorophyll at three tidally influenced stations, 2005

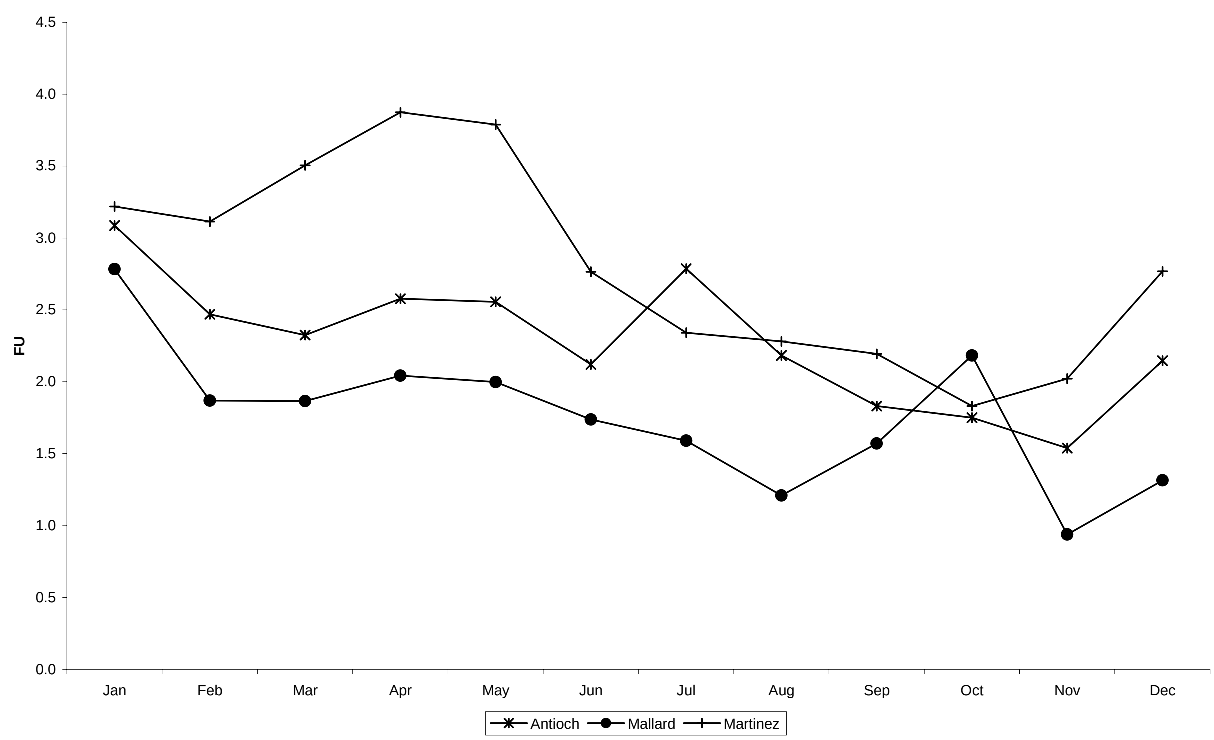


Figure 9-10a Average monthly turbidity at two Sacramento River stations, 2005

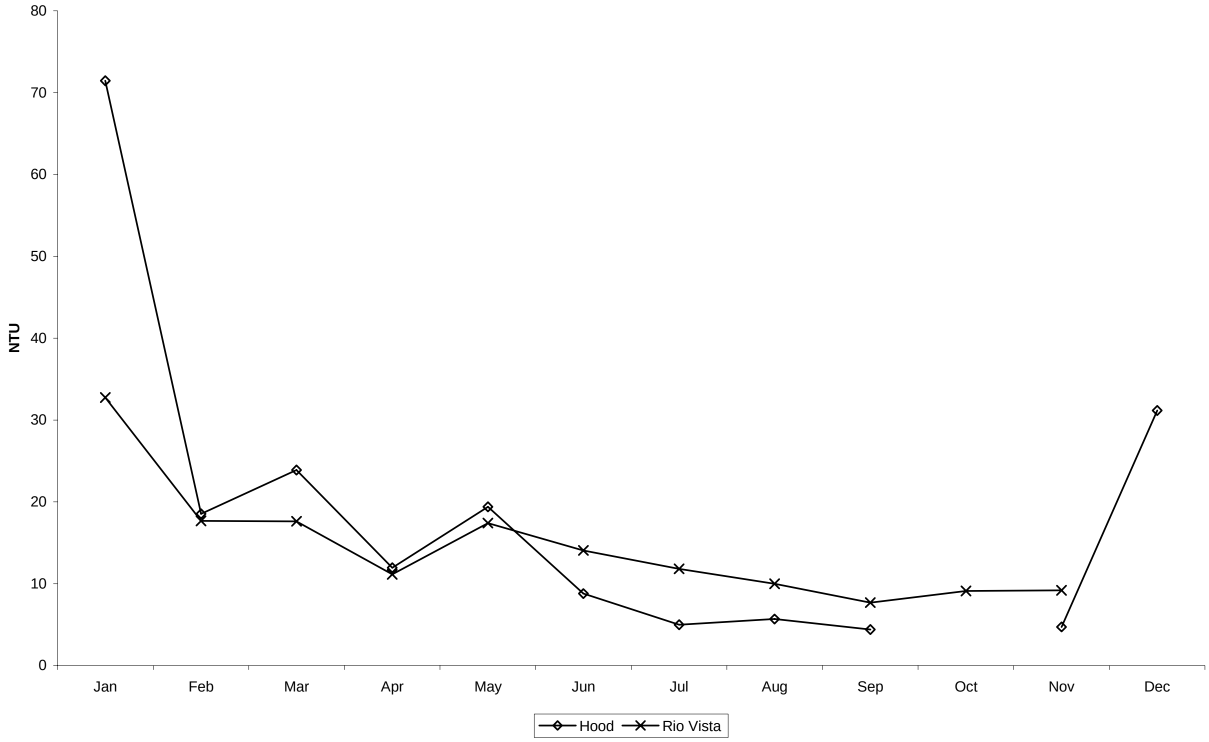


Figure 9-10b Average monthly turbidity at three San Joaquin River stations, 2005

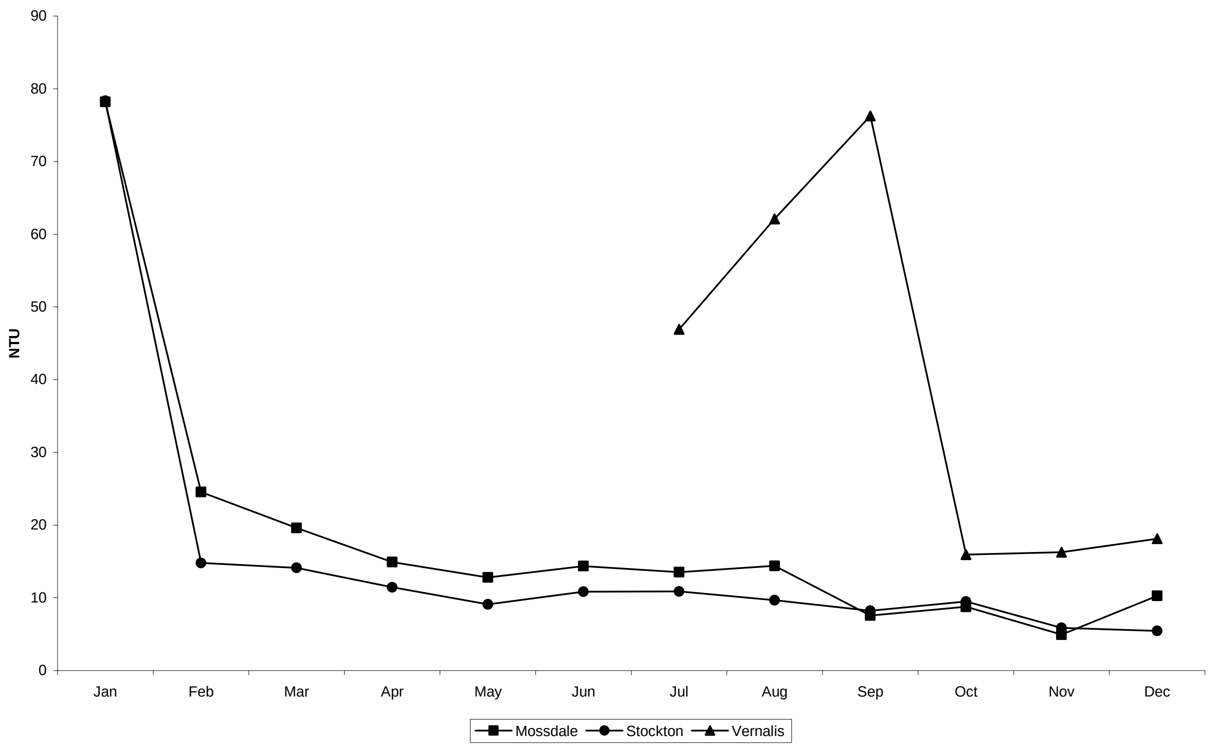


Figure 9-10c Average monthly turbidity at three tidally influenced stations, 2005

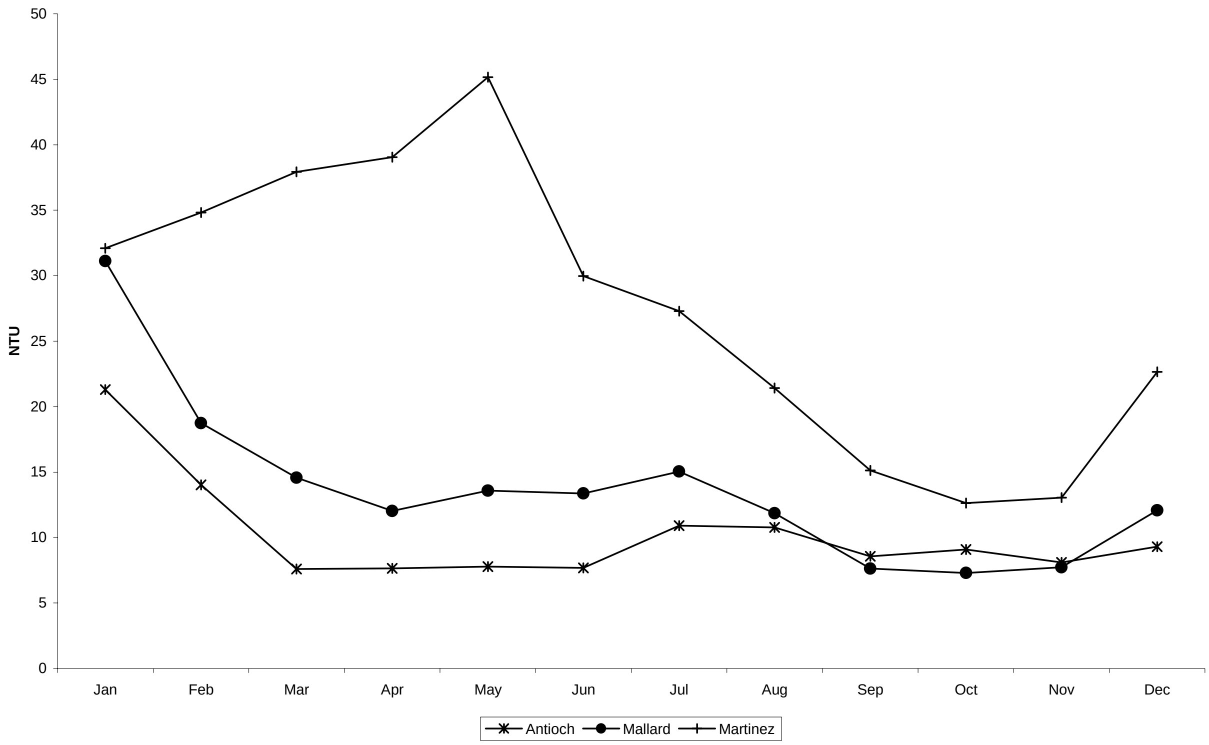


Table 9-1 Parameters measured by the Continuous Monitoring Program

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	10 minute instantaneous
Turbidity	NTU	10 minute instantaneous
Surface Specific Conductance	µS/cm	Hourly average
Bottom Specific Conductance	µS/cm	15 minute instantaneous
River Stage	feet (from mean sea level)	15 minute instantaneous
Wind Speed	knots/hr	15 minute instantaneous
Wind Direction	degrees	15 minute instantaneous
Solar Radiation	$cal/min/cm^2$	15 minute instantaneous