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 2006

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

January 2008

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

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Executive Summary 2006

This report summarizes the results of water quality monitoring and special studies conducted by the Environmental Monitoring Program (EMP) within the Sacramento-San Joaquin Delta and Suisun and San Pablo bays (the upper San Francisco Estuary) during calendar year 2006. 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.

EMP monitored water quality using a protocol implemented in 1996. Under this monitoring protocol, 13 sampling sites—2 of which were added after 1996—representing 8 regions of the upper San Francisco Estuary (Estuary) were monitored for 15 physical and chemical water quality parameters. The results gathered from the sampling of these 15 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.

Chlorophyll *a* is the principal photosynthetic pigment and is common to all phytoplankton. Chlorophyll *a* is thus used as a measure of phytoplankton biomass. Samples for chlorophyll *a* and phytoplankton were taken at 13 sampling sites in the Estuary. Chlorophyll *a* concentrations for 2006 showed typical seasonal patterns and were generally below 10 µg/L for most regions and concentrations ranged between 0.52 µg/L and 32.9 µg/L throughout the Estuary. Phytoplankton samples were collected using a submersible pump from 1 meter below the water's surface. All organisms collected in 2006 fell into eight categories: centric diatoms, unidentified flagellates, green algae, blue-green algae, pennate diatoms, cryptomonads, euglenoids, and dinoflagellates. Of the eight groups identified, centric diatoms, unidentified flagellates, green algae, and blue-green algae constituted 91.7% of the organisms collected.

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 *Eurytemora* spp. 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.

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 99.3% of the organisms collected during the study period. Ten species in these phyla represent 84.4% of all organisms collected during this period.

EMP 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 2006. The studies were conducted to determine if DO levels dropped below Central Valley Regional Water Quality Control Board and State Water Resources Control Board water quality objectives (5.0 mg/L and 6.0 mg/L, respectively) established for the channel. Monitoring was conducted biweekly from July 24 to November 20 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 did not vary much between regions within the channel (not including the turning basin), with an overall range of 4.7 to 9.5 mg/L at the surface and 4.9 to 9.7 mg/L at the bottom.

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Acronyms and Abbreviations

BDAT	Bay Delta and Tributaries Database
CB	Clarke-Bumpus
CDEC	California Data Exchange Center
cfs	cubic feet per second
cm	centimeter
CPUE	catch per unit of effort
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
DFG	California Department of Fish and Game
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
DON	dissolved organic nitrogen
DWR	California Department of Water Resources
EC	electrical conductance
EMP	Environmental Monitoring Program
EPA	US Environmental Protection Agency
FLIMS	Field and Laboratory Information Management System
IEP	Interagency Ecological Program
L	liter
m	meter
mg/L	milligrams per liter
mL	milliliters
NH_3	total ammonia
NO_3	nitrate
NO_2	nitrite
NTU	nephelometric turbidity units
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TSS	total suspended solids
µm	micrometer
µS	microSiemens
USBR	US Bureau of Reclamation
USGS	US Geological Survey
VSS	volatile suspended solids

Metric Conversion Table

Quantity	*To Convert from Metric Unit*	*To Customary Unit*	*Multiply Metric Unit By*	*To Convert to Metric Unit Multiply Customary Unit By*
Length	millimeters (mm)	inches (in)	0.03937	25.4
	centimeters (cm) for snow depth	inches (in)	0.3937	2.54
	meters (m)	feet (ft)	3.2808	0.3048
	kilometers (km)	miles (mi)	0.62139	1.6093
Area	square millimeters (mm^2)	square inches (in^2)	0.00155	645.16
	square meters (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometers (km^2)	square miles (mi^2)	0.3861	2.590
Volume	liters (L)	gallons (gal)	0.26417	3.7854
	megaliters (ML)	million gallons (10*)	0.26417	3.7854
	cubic meters (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic meters (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekameters (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic meters per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	liters per minute (L/mn)	gallons per minute (gal/mn)	0.26417	3.7854
	liters per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megaliters per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekameters per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lbs)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb.)	1.1023	0.90718
Velocity	meters per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.32456	2.989
Specific capacity	liters per minute per meter drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per liter (mg/L)	parts per million (ppm)	1.0	1.0
Electrical conductivity	microsiemens per centimeter (µS/cm)	micromhos per centimeter (µmhos/cm)	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8X°C)+32	0.56(°F-32)

Chapter 1 Introduction

The State Water Resources Control Board (SWRCB) establishes water quality objectives and monitoring plans to protect the variety of beneficial uses of the 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).

SWRCB = State Water Resources Control Board

DWR = California Department of Water Resources

USBR = US Bureau of Reclamation

SWP = State Water Project

CVP = Central Valley Project

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

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 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]

EMP = Environmental Monitoring Program

DFG = California Department of Fish and Game

BDAT = Bay Delta and Tributaries Database

This report, titled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2006*, summarizes the findings of the EMP for calendar year 2006. 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.

[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

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Chapter 2 Hydrologic Conditions

Introduction

Hydrologic conditions are typically discussed using water years. The 2006 water year covered by this report comprises the period October 1, 2005, to September 30, 2006. Some data also cover calendar year 2006 where noted. All other chapters of this report cover data collected during calendar year 2006.

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 majority of California's precipitation falls within the northern half of the state and flows down the Sacramento River through the upper San Francisco Estuary (referred to as Estuary; includes San Pablo Bay, Suisun Bay, and the Delta). This index is also used because the Sacramento River watershed provides the majority of water to the SWP and CVP (SWRCB 1999). The San Joaquin Valley Index is used to characterize water conditions within the San Joaquin Valley. The Net Delta Outflow Index[5] (Figure 2-1) 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.

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

SWP = State Water Project

CVP = Central Valley Project

Figure 2-1 Net Delta Outflow Indices for 2006

[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] 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).

Summary

Water year 2006 was considered a wet year for precipitation, seasonal runoff, reservoir storage, and snow water content. Statewide figures for May 1 are summarized in Table 2-1 and include the previous 4 years for reference.

Table 2-1 Summary of statewide major hydrologic characteristics of water years 2002–2006

Accounting for precipitation, runoff, reservoir storage, and snowpack water content, the unimpaired runoffs for the Sacramento River and the San Joaquin River were high for 2006. Table 2-2 summarizes these conditions and includes the previous 4 years for reference. Figure 2-2 demonstrates these flow periods and includes the previous 10 years for reference.

Table 2-2 Average unimpaired runoff for water years 2002–2006

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, 1996–2006

Using the Sacramento Valley Index[6], water year 2006 was classified as "wet." Under the San Joaquin Valley Index[7], water year 2006 was also classified as "wet." Figures 2-3 and 2-4 summarize these findings and include the previous 10 years for reference.

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, 1996–2006

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, 1996–2006

Water year 2006 had maximum Delta outflow indices exceeding 5,349,000 acre-feet in April and minimum outflow indices approaching 148,600 acre-feet in October.

References

[CDEC] California Data Exchange Center. Homepage. 2006. Accessed April 2007 <http://cdec.water.ca.gov>.

[DWR] California Department of Water Resources. 2005-2006. *Water Conditions California. California Cooperative Snow Surveys Bulletin 120*. Report 1-4. Sacramento: California Department of Water Resources.

Hinojosa, Tracy, DWR, Chief of Compliance and Modeling Section, Division of Operations and Maintenance. 2007. WY 2006 totals. Personal communication to Sabrina Bell, Scientific Aide, DWR.

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

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

[7] 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).

Figure 2-1 Net Delta Outflow Indices for 2006

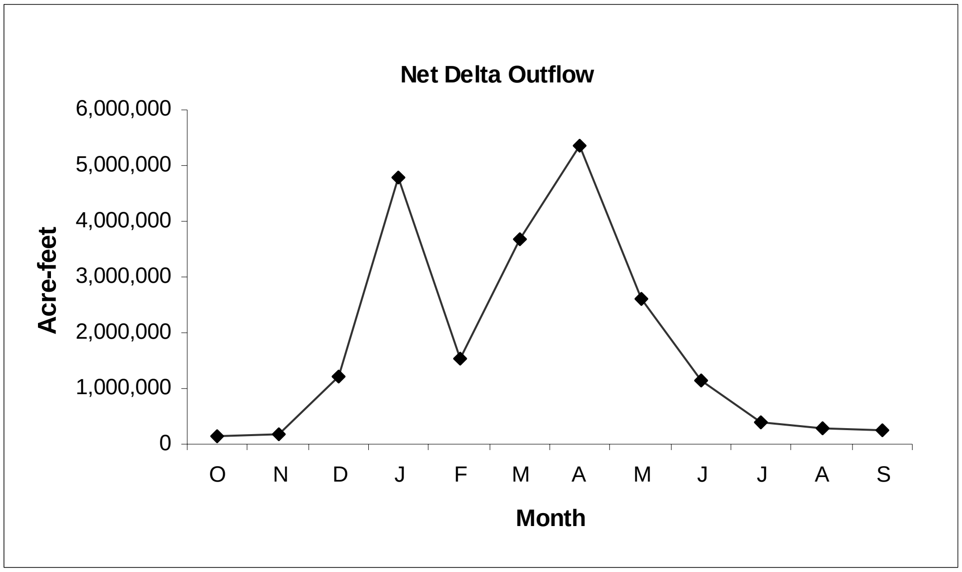

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, 1996–2006

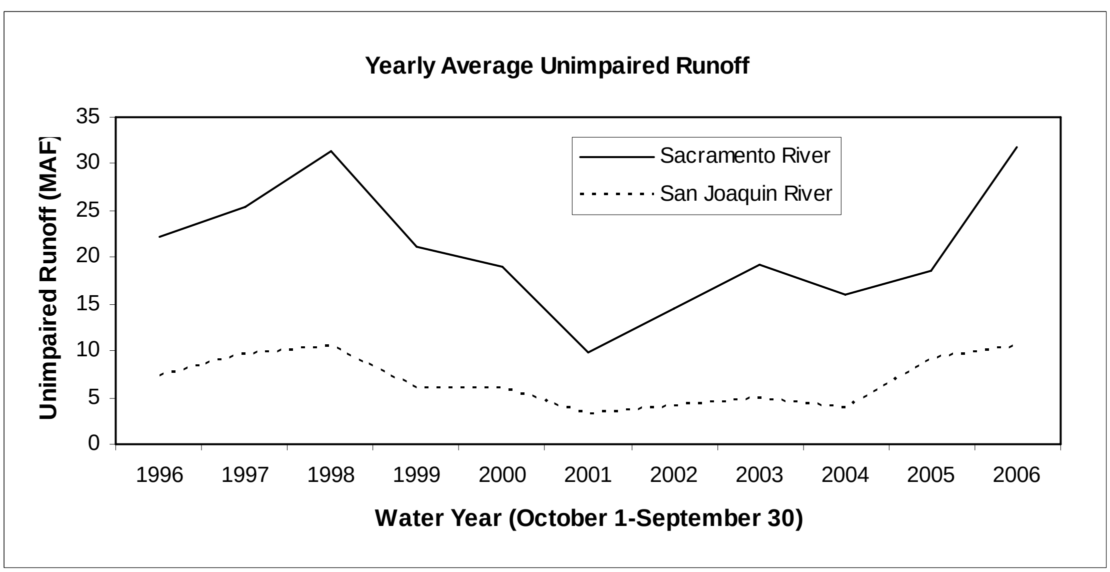

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, 1996–2006

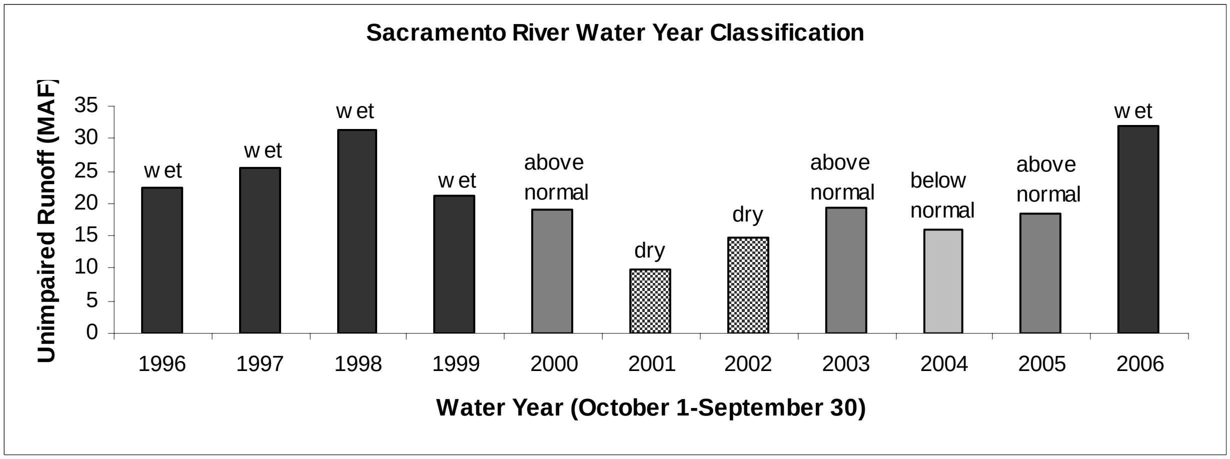

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, 1996–2006

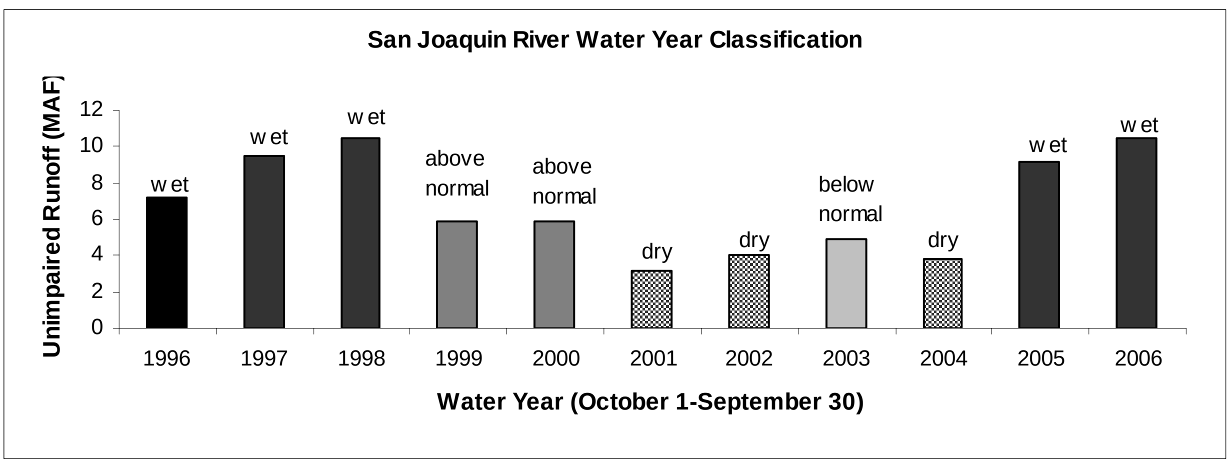

Table 2-1 Summary of statewide major hydrologic characteristics for water years 2002–2006

Water year	Precipitation (% of normal)	Seasonal runoff (% of normal)	Reservoir storage (% of normal)	Snow water content (% of normal)
2002	80	80	100	60
2003	110	100	105	105
2004	90	90	100	50
2005	135	80	105	150
2006	140	170	115	185

Table 2-2 Unimpaired runoff for water years 2002–2006

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)
2002	9.32	4.57	14.60	2002	1.27	2.75	4.06
2003	10.71	7.74	19.31	2003	1.25	3.49	4.87
2004	10.95	4.40	16.04	2004	1.51	2.25	3.81
2005	8.40	9.28	18.55	2005	2.73	6.28	9.21
2006	18.04	12.93	31.88	2006	2.87	7.37	10.45

Chapter 3 Water Quality Monitoring

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Chapter 3 Water Quality Monitoring

Introduction

Water quality monitoring in 2006 continued according to the amended protocol implemented by DWR in 1996, with the incorporation of several changes recommended by the 2001–2002 EMP review (www.baydelta.water.ca.gov/emp/EMP_Review_Final.html).

Lehman, P., S. Hayes, G. Marsh, C. Messer, C. Ralston, K. Gehrts, and J. Lee. 2001. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1996*. DWR.

Discrete samples were taken monthly at 13 of the 22 sampling locations (Figure 3-1). Data were recorded within 1 hour of high slack tide, and the time of each sample was recorded to the nearest 5 minutes of Pacific Standard Time. A qualitative statement of weather conditions (wind conditions and cloud cover) was recorded for each cruise. Samples were analyzed in terms of 15 physical and chemical parameters shown in Table 3-1. The complete database is available online at www.baydelta.water.ca.gov.

Figure 3-1 EMP's discrete water quality sampling stations

Table 3-1 Water quality parameters measured

As shown in Table 3-2, 13 of the 22 sampling sites were used in this study to represent 8 regions of the Bay-Delta system. Data results in this report are shown for each sample site.

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 USBR research vessel *Endeavor* or 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) that are inaccessible to the research vessels. Secchi disk depth is not measured at site C10A due to safety concerns of the sample site, which requires sampling equipment to be deployed from 50 feet above the water's surface. 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.

Water Temperature

Water temperature was measured in degrees Celsius (°C) with a YSI thermistor. For all sites except for C3A and C10A, temperatures were measured from water collected from a through-hull pump at a depth of 1 meter. At C3A and C10A, temperatures were measured from water collected at the continuous monitoring station through a float-mounted pump that draws water at 1 meter in depth.

Figure 3-2 Water temperature comparisons, 2006

Figure 3-3 Water temperature (°C) by station, 2006

A water temperature minimum of 9.3 °C was recorded in December 2006 at station C3A in the north Delta (Figures 3-2 and 3-3). This minimum temperature represents an increase of 0.8 °C from the previously recorded minimum in 2005 (Brown et al. 2006).

Brown, T., R. Barnett, M. Dempsey, K. Gehrts, P. Giovannini, K. Hieb, B. Noble and M. Vayssieres. 2006. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2005*. DWR.

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

A water temperature maximum of 26.7 °C was recorded in July at station MD10A, in the east Delta. This maximum is a 0.1 °C increase over the temperature maximum reported for 2005 (Brown et al. 2006). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

DO = dissolved oxygen

mL = milliliters

mg/L = milligrams per liter

Dissolved Oxygen

Dissolved oxygen (DO) was measured using the modified Winkler iodometric method described in Standard Methods (APHA 1992). A sample aliquot was collected from a through-hull pump or from a float-mounted pump at continuous monitoring stations (sites C3A and C10A) at a depth of 1 meter. The samples were collected in 300-mL glass-stoppered bottles and immediately analyzed.

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

During 2006, DO concentrations ranged from 5.4 mg/L at site P8 in July, to 12.0 mg/L at site MD10A in February (Figures 3-4 and 3-5). Seasonal trends were evident in most regions, with DO concentrations decreasing during the summer and rising in the winter. Reduced summer DO levels coincided with warmer water temperatures. This suggests that DO levels at many sites may be influenced primarily by physical processes (temperature, saturation capacity) rather than biological processes such as respiration and primary production.

Figure 3-4 Dissolved oxygen comparisons, 2006

Figure 3-5 Dissolved oxygen (mg/L) by station, 2006

Specific Conductance

Specific conductance, an estimate of salinity, was determined from samples collected from a through-hull pump or from a float-mounted pump at continuous monitoring stations (sites C3A and C10A) at a 1-meter depth. The samples were analyzed for specific conductance using a Seabird model CTD 911+ data logger, or a YSI 85 (sites C3A and C10A) with temperature compensation to 25 °C.

µS = microSiemens per centimeter

Specific conductance varied greatly between sites monitored, ranging from 100.4 µS/cm at site C3A in April to 42,233 µS/cm at site D41 in November (Figures 3-6 and 3-7). This range of specific conductance was similar to the range of 127 to 43,303 µS/cm reported for 2005 (Brown et al 2006).

Figure 3-6 Specific conductance comparisons, 2006

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

Figure 3-7 Specific conductance (µS/cm) by station, 2006

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 April and May to highs in October, November, and December. At sites with lower specific conductance, this seasonal trend was less apparent.

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,

m = meter

and the depth of its visual perception as it was raised. All measurements were made from the shaded side of the vessel.

A Secchi depth minimum of 20 cm was recorded at 2 sampling sites in June; D41A in the San Pablo Bay and D7 in Suisun Bay (Figures 3-8 and 3-9). A Secchi depth maximum of 196 cm was recorded at sampling site D28A (central Delta) in December. Secchi values during 2005 were similar, ranging from 20 to 192 cm (Brown et al 2006).

Figure 3-8 Secchi disk depth comparisons, 2006

Figure 3-9 Secchi disk depth (cm) by stations, 2006

Secchi disk depth varied considerably at all sites, with little apparent seasonal correlation. Average Secchi depth was lowest at site D7 and was the highest at site D28A.

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 from a through-hull pump at a 1-meter depth. 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 samples collected via float-mounted pump at the continuous monitoring station using a Hawk 2100P Turbidimeter, due to their inaccessibility by vessel.

NTU = nephelometric turbidity units

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 1.5 NTU at site D8 (Suisun Bay) in February to 64.7 NTU at site D41A (San Pablo Bay) in April. This range of turbidity was less than the 1.5 to 127 NTU range reported for 2005 (Brown et al 2006).

Figure 3-10 Turbidity comparisons, 2006

Figure 3-11 Turbidity (NTU) by station, 2006

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

Orthophosphate

Orthophosphate is soluble inorganic phosphate, the phosphorus compound most immediately available for assimilation by phytoplankton. Orthophosphate concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory[1] for analysis according to the U.S. Environmental Protection Agency (EPA 1983) colorimetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate is 0.01 mg/L.

EPA = U.S. Environmental Protection Agency

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

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest orthophosphate values of

Figure 3-13 Orthophosphate (mg/L) by station, 2006

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

0.02 mg/L occurred at 2 sites: station MD10A in February, August, September, and October; and station C3A from February through May. The 2005 study period showed the lowest values (0.02 mg/L) of orthophosphate occurring at site MD10A (Brown et al. 2006).

The highest value of orthophosphate, 0.18 mg/L, was recorded at site MD10A in January. During 2005, site P8 had the highest orthophosphate concentration (0.29 mg/L) in February (Brown et al. 2006).

Total Phosphorus

Total phosphorus is the sum of all phosphorus compounds in a 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 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 immediately frozen and later transported to Bryte Laboratory for analysis according to the EPA (1983) colorimetric semi-automated method 365.4. The minimum reporting limit for total phosphorus is 0.01 mg/L.

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 0.02 mg/L was recorded at site C3A during February, March, and April. This value is slightly lower than the minimum value of 0.04 mg/L recorded during 2005 at sites C3A in June and D28A in November (Brown et al 2006). A maximum value of 0.27 mg/L was recorded at site D7 in August. This value is lower than the maximum value of 0.54 mg/L recorded during 2005 at site C10A in January (Brown et al 2006).

Figure 3-14 Total phosphorus (mg/L) comparisons, 2006

Figure 3-15 Total phosphorus (mg/L) by station, 2006

Sites D7 and MD10A were the only sites to exceed 0.19 mg/L of total phosphorus during 2006. This is in contrast to the 2005 results, where sites D4, D6, P8, MD10A, and C10A exceeded 0.19 mg/L of total phosphorus (Brown et al 2006).

Kjeldahl Nitrogen

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

Kjeldahl nitrogen concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the EPA (1983) colorimetric semi-automated method 352.1. The minimum reporting limit for Kjeldahl nitrogen is 0.01 mg/L.

Kjeldahl nitrogen concentrations ranged from levels below the minimum reporting limit at sites D7 and C10A in January to 1.0 mg/L at site P8 in

September and December (Figures 3-16 and 3-17). Kjeldahl nitrogen levels during 2005 also peaked at site P8 with a high of 2.4 mg/L (Brown et al 2006). Minimum levels recorded during 2006 were less than those recorded during 2005, which had a low of 0.01 mg/L. (Brown et al 2006).

Figure 3-16 Kjeldahl nitrogen comparisons, 2006

Figure 3-17 Kjeldahl nitrogen (mg/L) by station, 2006

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

Dissolved Inorganic Nitrogen

DIN = dissolved inorganic nitrogen
NH_3 = total ammonia
NO_3 = nitrate
NO_2 = nitrite

Dissolved inorganic nitrogen (DIN) is a measure of total ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2), the nitrogen forms immediately available for assimilation by phytoplankton. DIN was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis for total ammonia according to the EPA (1983) colorimetric, automated, phenate method 350.1; and for nitrate and nitrite according to the colorimetric automated cadmium reduction method 353.2 (EPA 1983). DIN was calculated as the sum of total ammonia plus nitrate and nitrite. The minimum reporting limit for inorganic nitrogen is 0.01 mg/L.

DIN concentrations ranged from a minimum of 0.02 mg/L at site MD10A in July to a maximum of 2.72 mg/L at site P8 in December (Figures 3-18 and 3-19). This range is similar to the values observed during 2005, which recorded a minimum value of 0.01 mg/L at station MD10A and a maximum of 2.8 mg/L at station P8 (Brown et al. 2006).

Figure 3-18 Dissolved inorganic nitrogen comparisons, 2006

Figure 3-19 Dissolved inorganic nitrogen (mg/L) by station, 2006

DIN values were consistently high at south Delta stations C10A and P8. 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.

Concentrations in the south Delta also showed the greatest degree of seasonal variability. The other sites did not show any apparent seasonal trends.

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 the plant communities in aquatic and terrestrial environments. It does not include all organic nitrogen compounds, but does include proteins, peptides, nucleic acids, urea, and numerous synthetic organic compounds (APHA 1992).

DON = 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 immediately frozen and later transported to Bryte Laboratory for analysis according to the EPA (1983) colorimetric, semi-automated method 351.2. The minimum reporting limit for DON is 0.1 mg/L.

DON concentrations were below the minimum reporting limit at stations C3A, C10A, and D7 in January; stations C3A, D28A, D4, and D8 in August; and at station D4 in July. A maximum concentration of 0.6 mg/L was recorded at station MD10A in January (Figures 3-20 and 3-21). Peak DON levels during 2005 were higher, reaching 1.3 mg/L at station C10A in January (Brown et al. 2006).

Figure 3-20 Dissolved organic nitrogen comparisons, 2006

Figure 3-21 Dissolved organic nitrogen (mg/L) by station, 2006

DON concentrations at all sites showed no clear seasonal or intra-annual pattern of variation.

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).

TDS = total dissolved solids

TDS were measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately refrigerated at 4 °C and later transported to Bryte Laboratory for analysis, using EPA (1983) method 160.1.

Figure 3-22 Total dissolved solids comparisons, 2006

Figure 3-23 Total dissolved solids (mg/L) by station, 2006

TDS in the Bay-Delta varied over a wide range, from 57 mg/L at site C3A in April to 27,420 mg/L at site D41 in August (Figures 3-22 and 3-23). The values covered a similar range during 2005, which had a range of 71 mg/L to 27, 200 mg/L (Brown et al. 2006). The high values seen in San Pablo Bay are likely due to tidal influences of seawater with high TDS entering the Delta. The lower TDS values seen at site C3A are likely due to spring flows of low TDS fresh water entering the Delta from the Sacramento Valley basin.

All sites subject to significant tidal exchange (sites D41, D41A, D6, D7, D8, and D4) show TDS concentrations in proportion to their proximity to the coast. These sites also showed high seasonal variability in TDS concentrations. For these sites, low TDS values occurred in April or 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.

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 periods.

TSS = total suspended solids

Water samples for TSS analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory using EPA (1983) method 160.2.

TSS in the Delta varied over a wide range, from below the minimum reporting limit (<1.0 mg/L) at site D28A in September to 228 mg/L at site D7 in August (Figures 3-24 and 3-25). These results are in contrast to the 2005 study period, where the highest TSS value was recorded at site C10A (132 mg/L) and the lowest TSS value was 1.0 mg/L at site D28A (Brown et al 2006).

Figure 3-24 Total suspended solids comparisons, 2006

Figure 3-25 Total suspended solids (mg/L) by station, 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.

Volatile Suspended Solids

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

VSS = volatile suspended solids

VSS levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions and reached a high of 26.0 mg/L at site D7 in August (Figures 3-26 and 3-27). These results were different than those observed in 2005, which had a maximum value of 14.0 mg/L at site C10A in the south Delta (Brown et al. 2006). Most sites showed a high degree of variability, with no apparent seasonal trends.

Figure 3-26 Volatile suspended solids comparisons, 2006

Figure 3-27 Volatile suspended solids (mg/L) by station, 2006

Silica

Silica concentrations are used to determine habitat suitability for diatoms, one of the most abundant types of phytoplankton in the Estuary. When silica is limiting, the relative abundance of diatoms is low. Water samples for silica analysis were taken from aliquots collected from a depth of 1 meter into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size 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 a low of 5.4 mg/L at site D41 in November to a high of 19.5 mg/L at site D4 in January (Figures 3-28 and 3-29). By comparison, values during 2005 ranged from 5.6 mg/L at site D41 in September to 29.1 mg/L at site D41A in February (Brown et al. 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, excluding those in the Suisun and San Pablo bays. The sites in Suisun Bay and San Pablo Bay showed a slight trend of increasing silica

Figure 3-28 Silica comparisons, 2006

Figure 3-29 Silica (mg/L) by station, 2006

concentrations in the early spring, with concentrations decreasing at the beginning of summer.

Chloride

Water samples for chloride analysis were taken from aliquots collected from a depth of 1 meter into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45-micron pore size and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for chloride according to EPA Method 300.0 (EPA 1983).

Figure 3-30 Chloride comparisons, 2006

Figure 3-31 Chloride (mg/L) by station, 2006

Chloride concentrations in the Bay-Delta varied over a wide range from 2 mg/L at site C3A in April to 14,800 mg/L at site D41 in November (Figures 3-30 and 3-31). These results are very similar to those observed during 2005, which recorded a low of 5 mg/L at site C3A in June and a high of 16,200 mg/L at site D41 in September (Brown et al. 2006). The high values seen in San Pablo Bay are likely due to tidal influences of seawater entering the Delta, and the low values seen at site C3A are likely due to spring flows of fresh water down the Sacramento River. Values of chloride concentrations are closely correlated to values of specific conductance and TDS reported earlier in this chapter.

Summary

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

DWR = California Department of Water Resources

SWP = State Water Project

CVP = Central Valley Proejct

References

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

Brown, T., R. Barnett, M. Dempsey, K. Gehrts, P. Giovannini, K. Hieb, B. Noble and M. Vayssieres. 2006. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2005*. Sacramento: California Department of Water Resources.

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

Figure 3-1 EMP's discrete water quality sampling stations

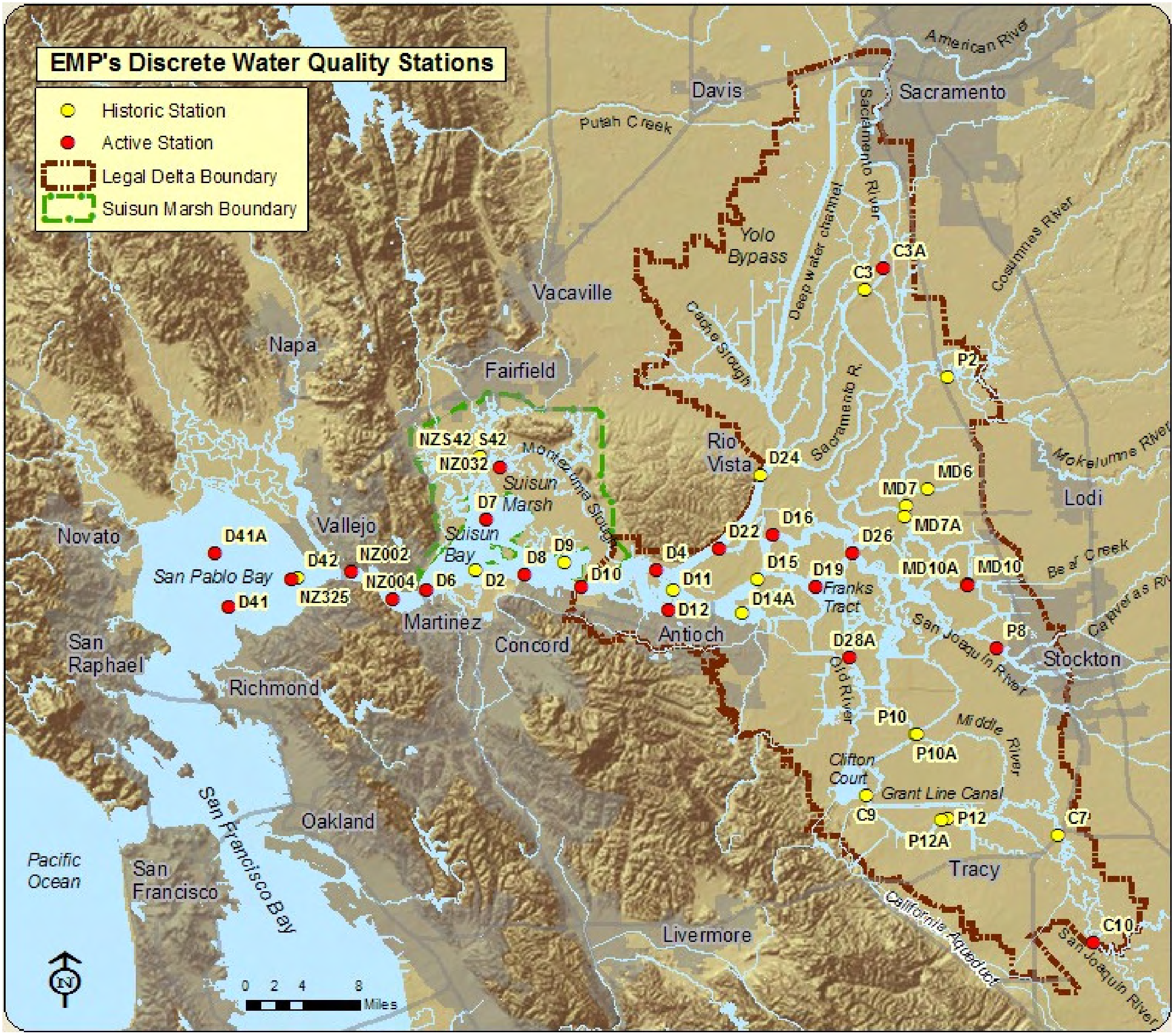

Figure 3-2 Water temperature comparisons, 2006

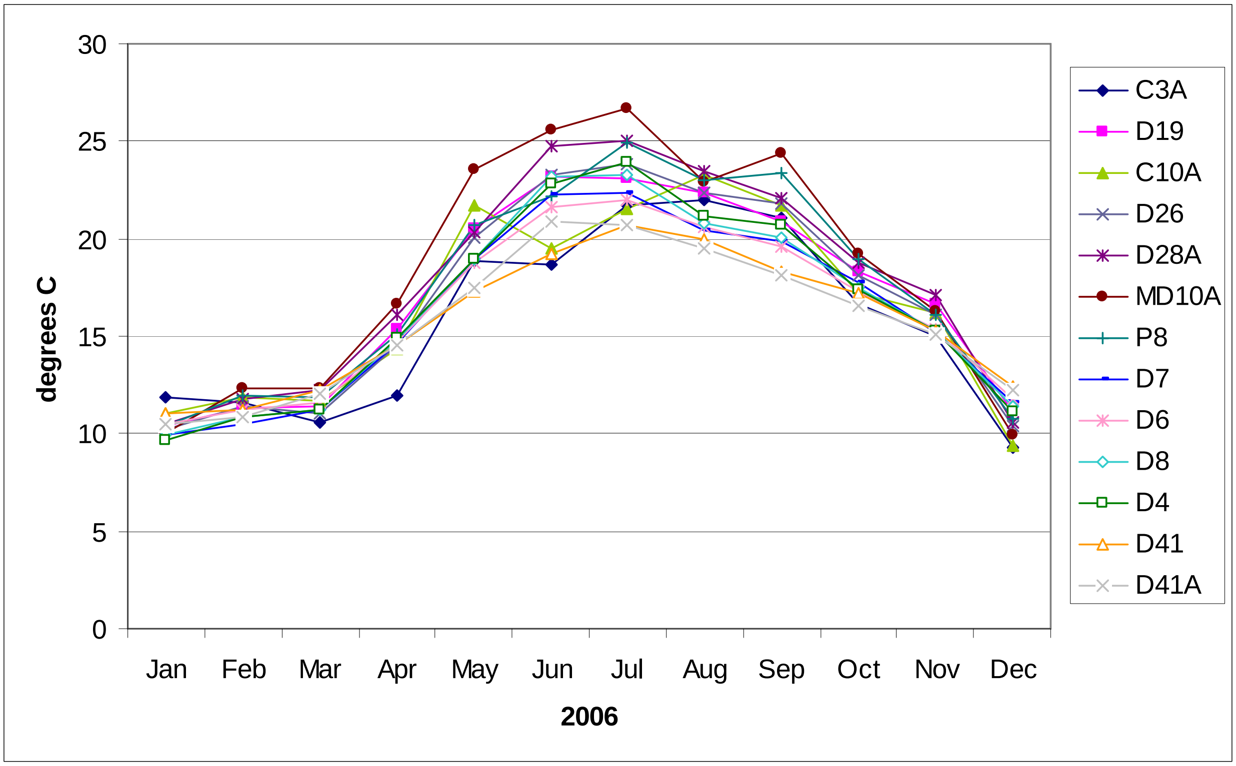

Figure 3-3 Water temperature (°C) by station, 2006

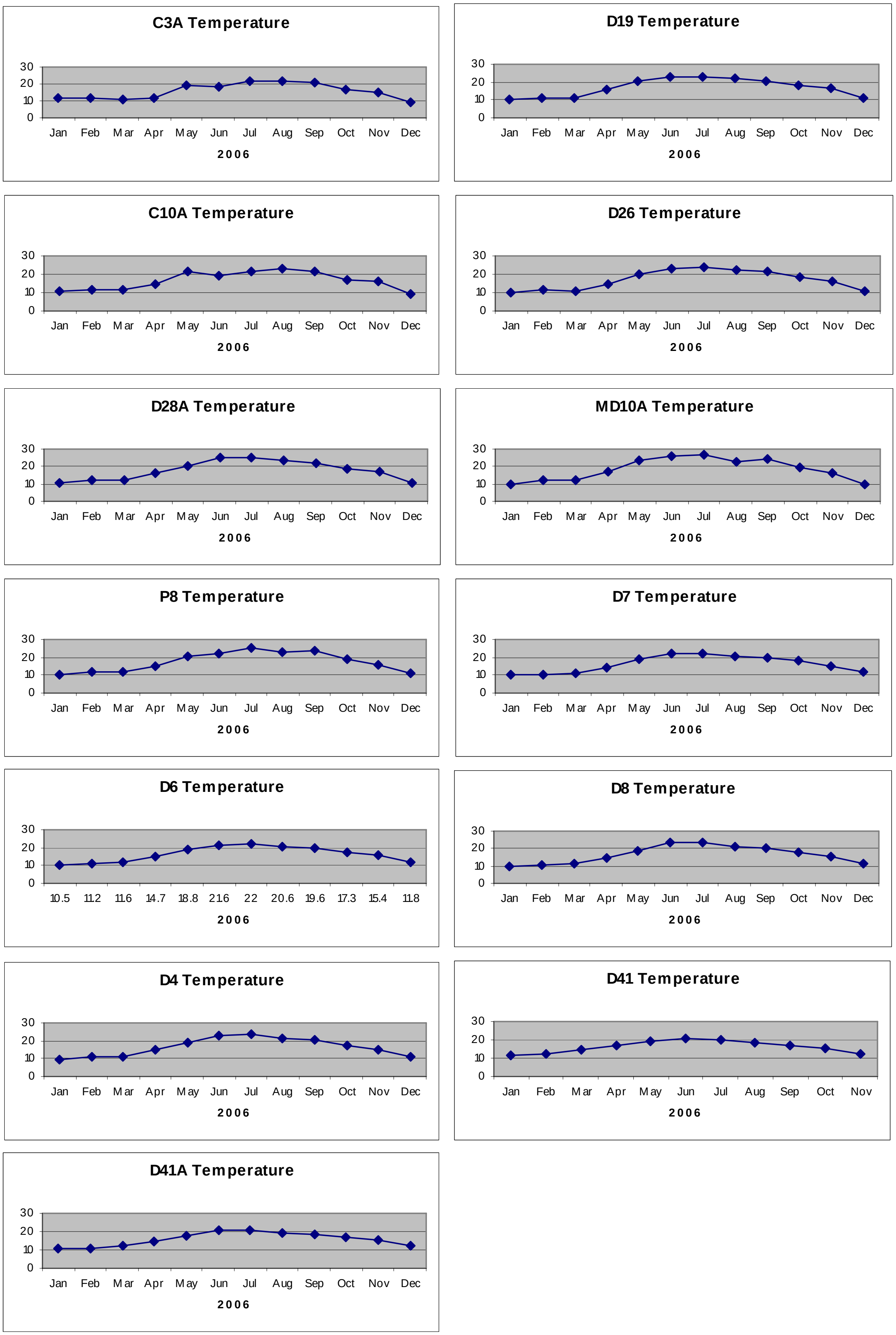

Figure 3-4 Dissolved oxygen comparisons, 2006

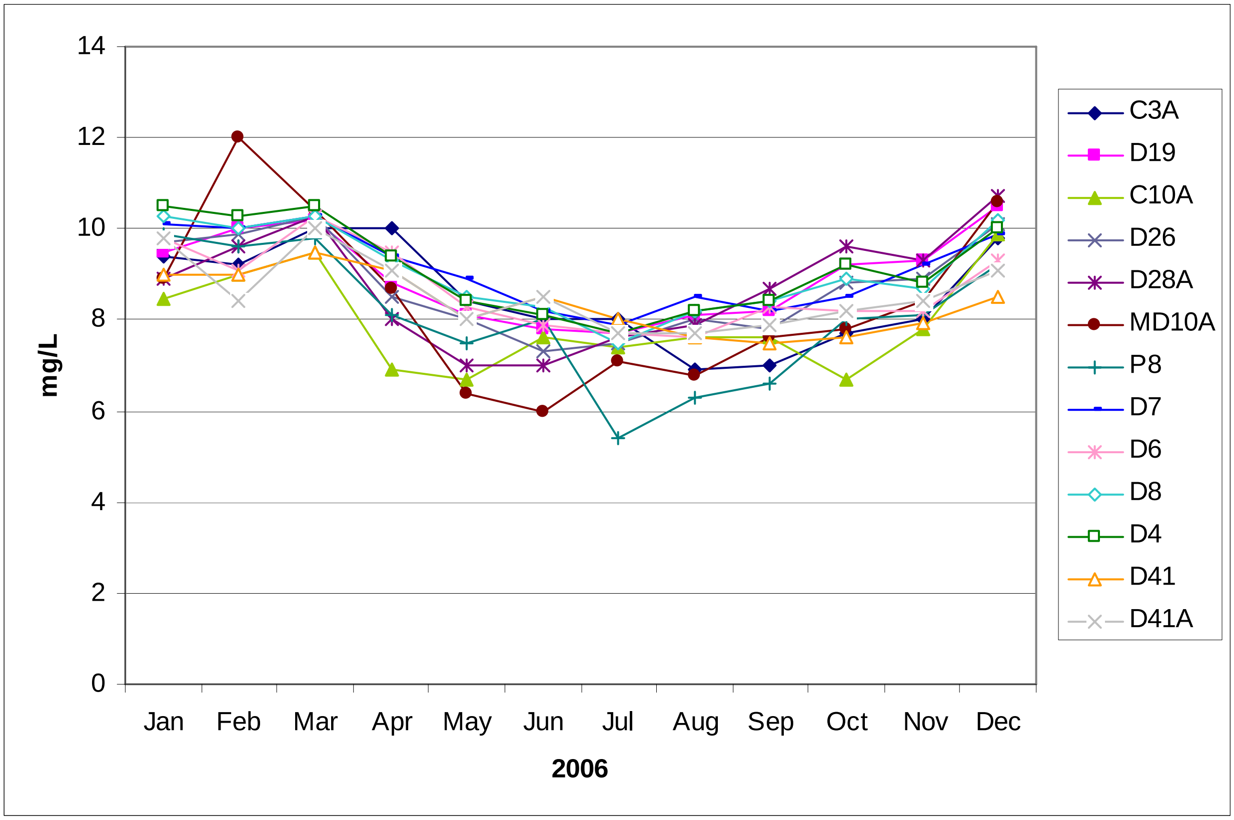

Figure 3-5 Dissolved oxygen (mg/L) by station, 2006

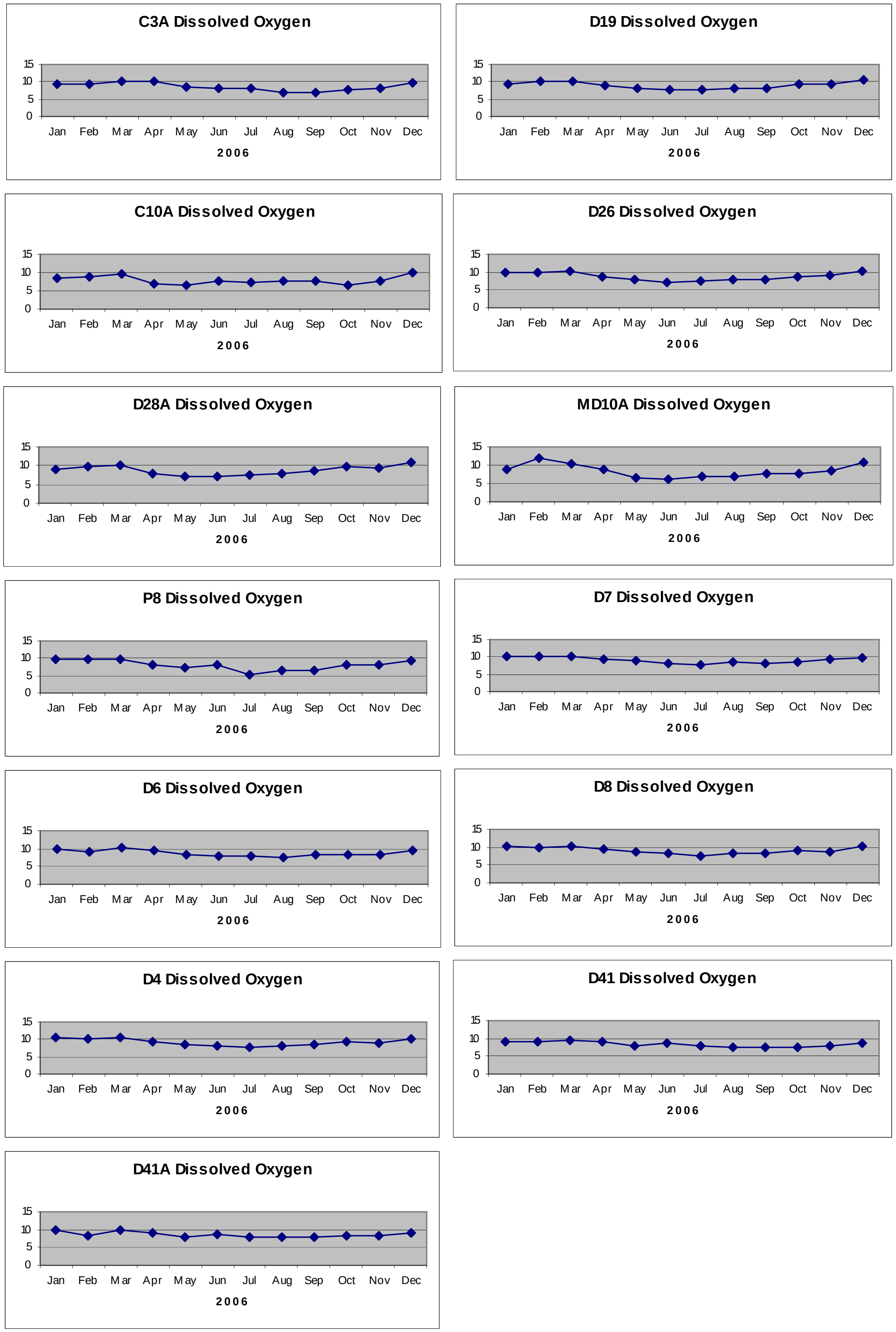

Figure 3-6 Specific conductance comparisons, 2006

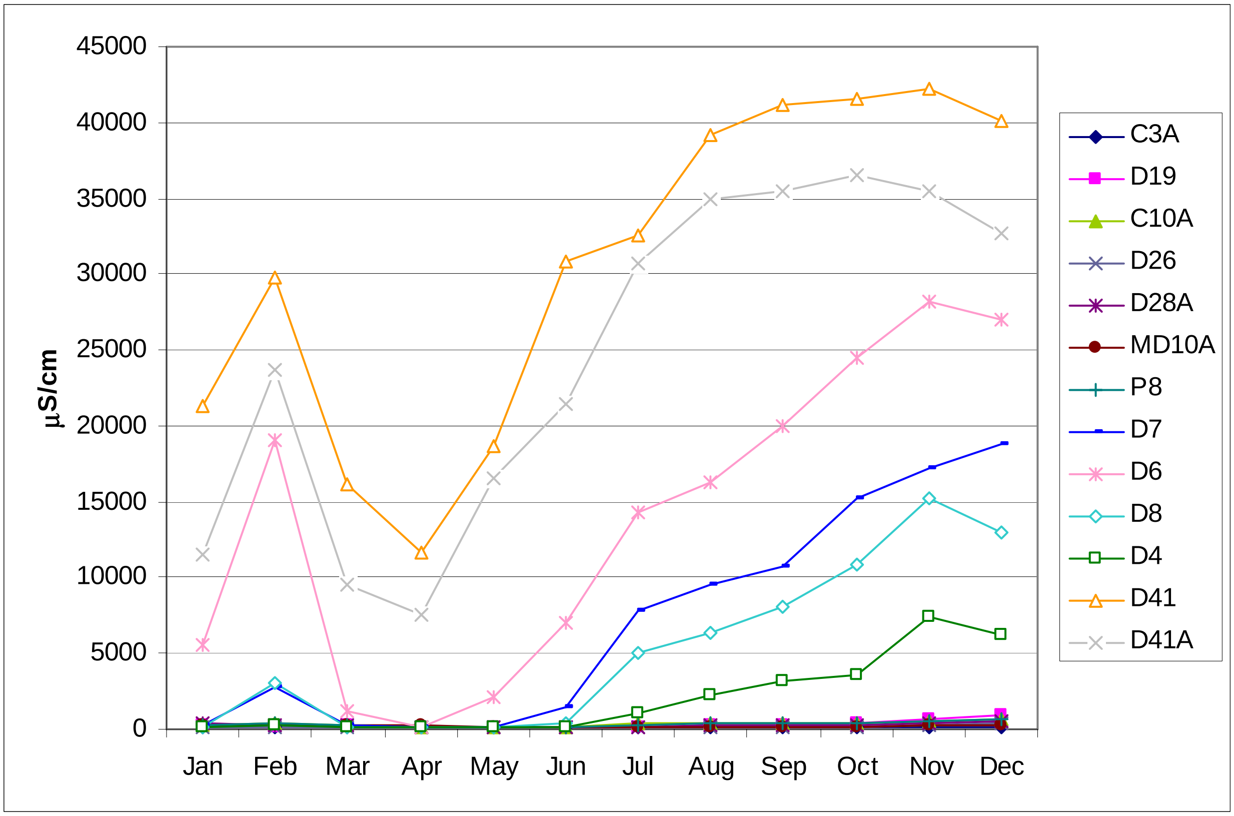

Figure 3-7 Specific conductance (µS/cm) by station, 2006

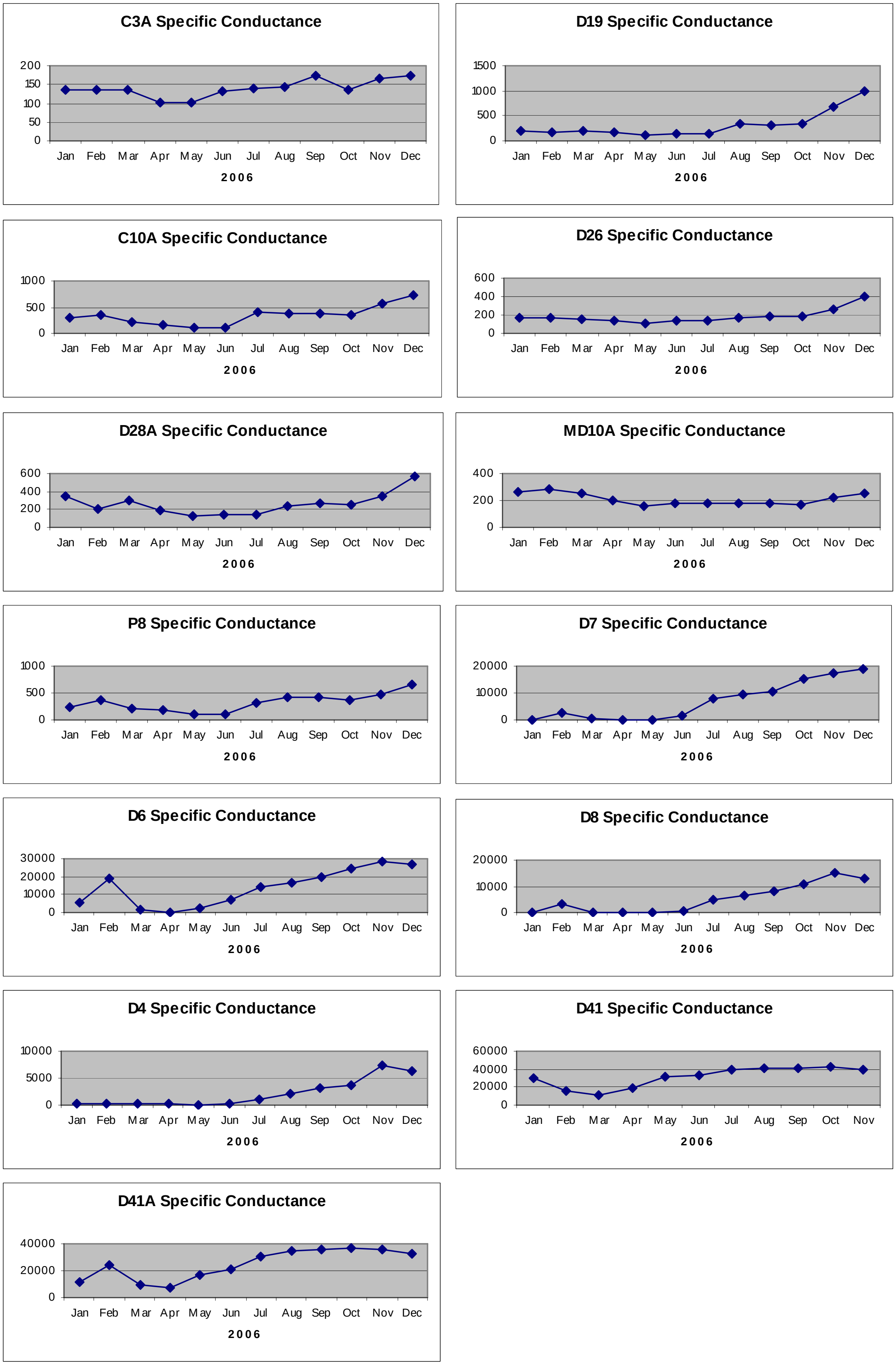

Figure 3-8 Secchi disk depth comparisons, 2006

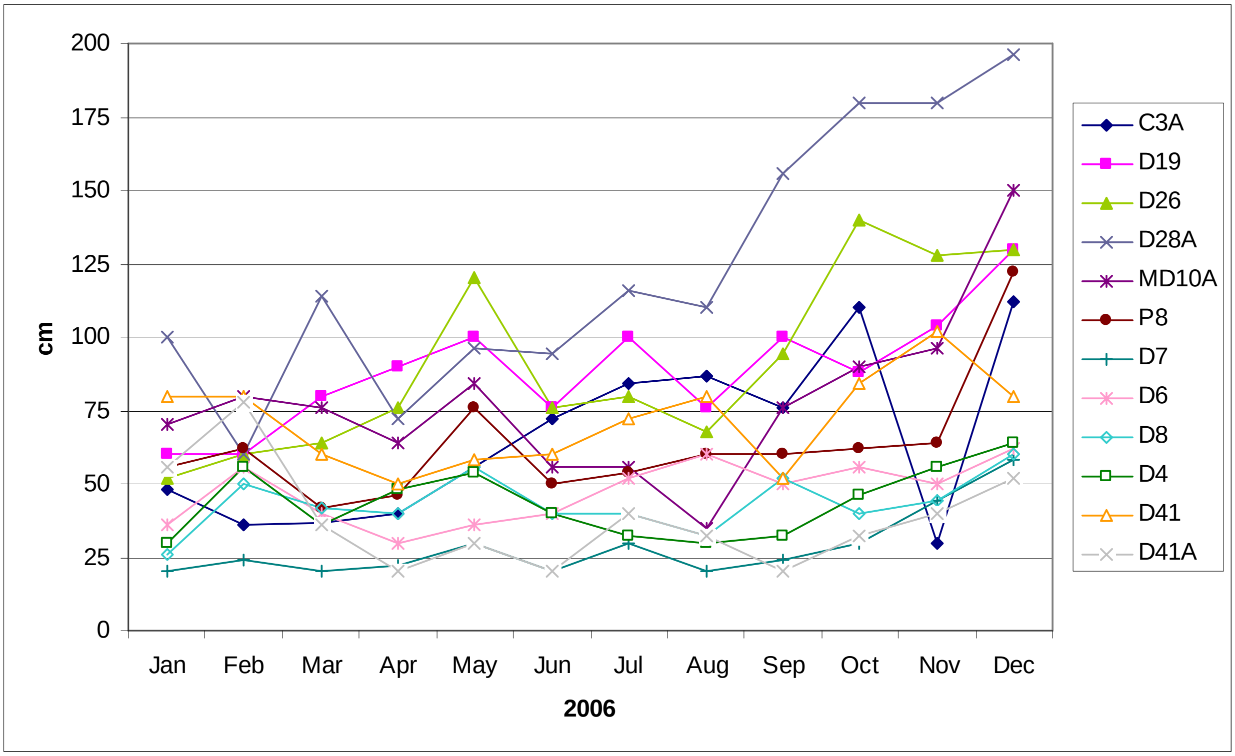

Figure 3-9 Secchi disk depth (cm) by station, 2006

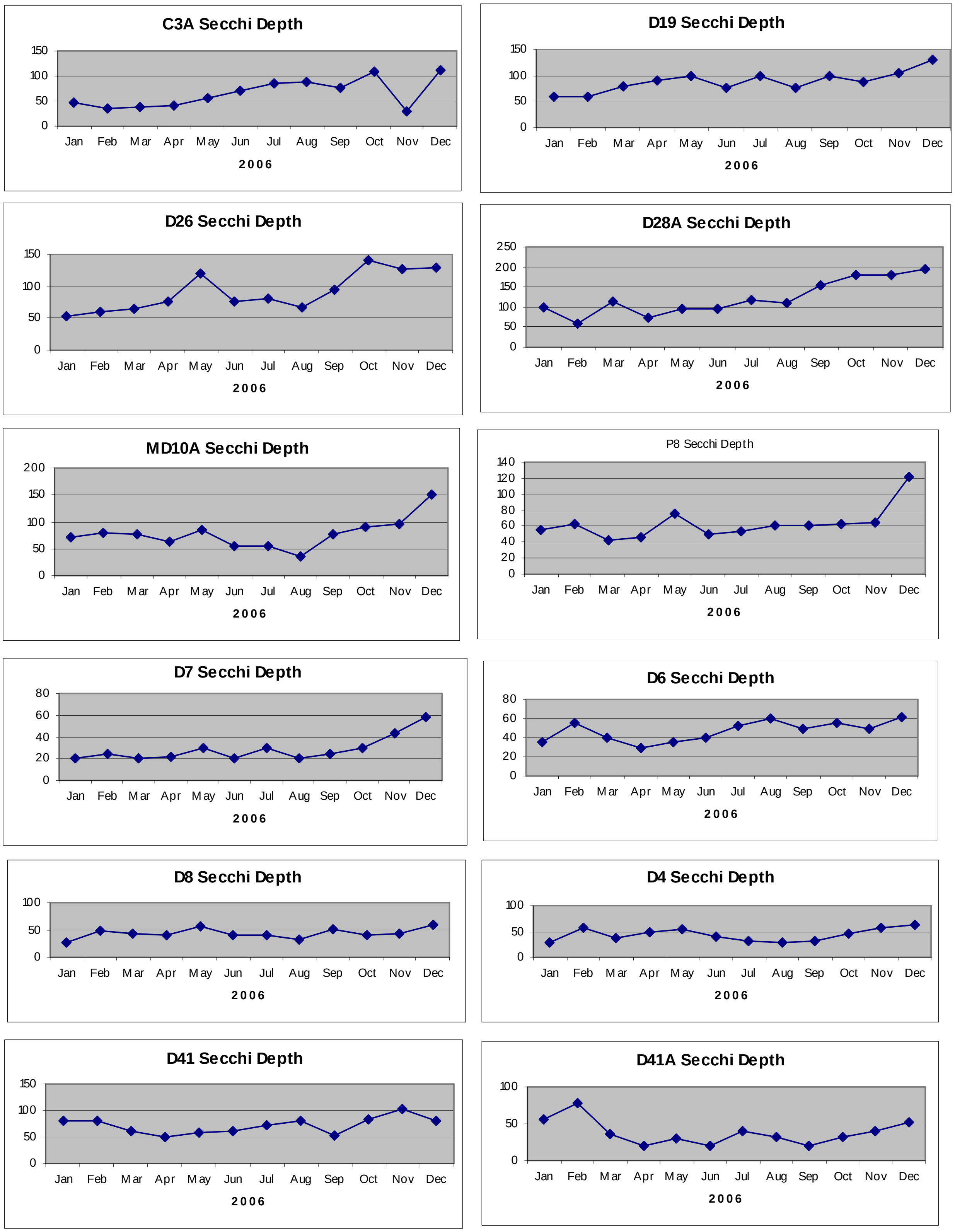

Figure 3-10 Turbidity comparisons, 2006

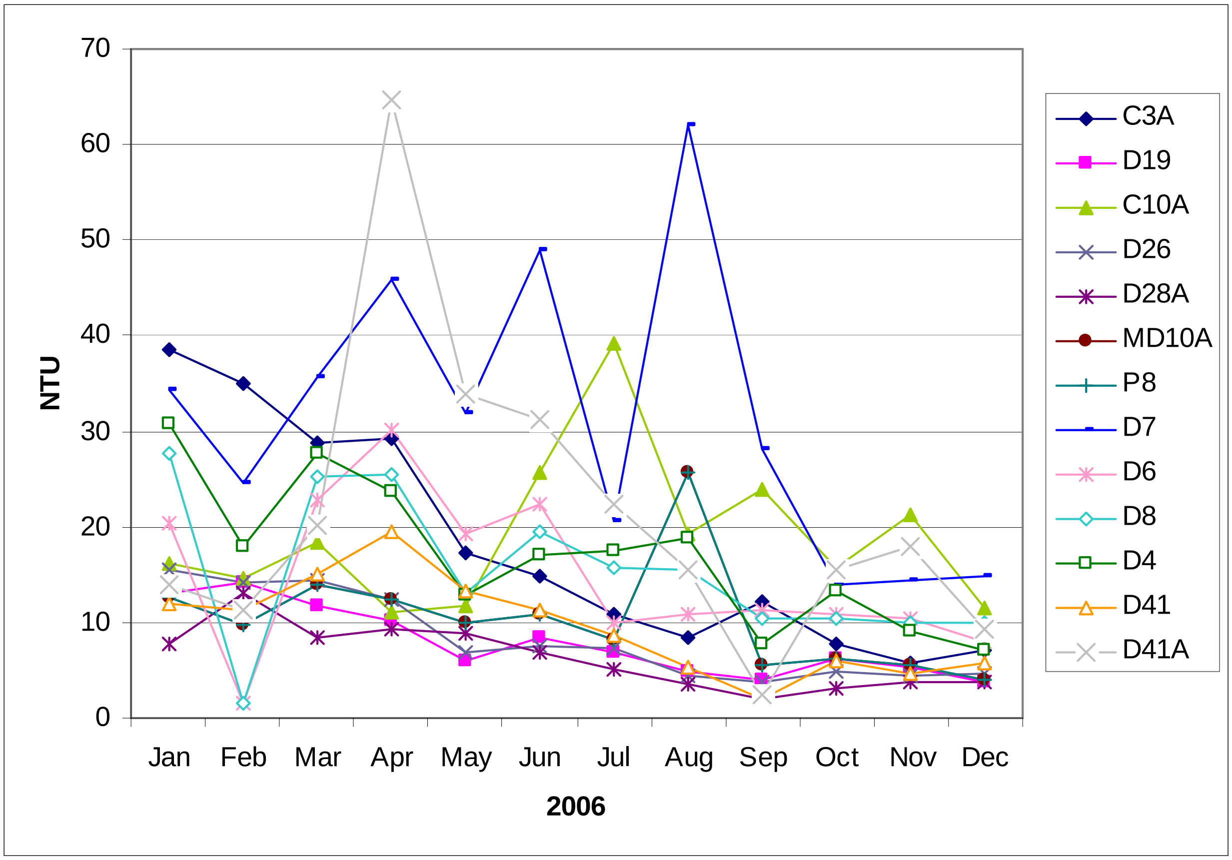

Figure 3-11 Turbidity (NTU) by station, 2006

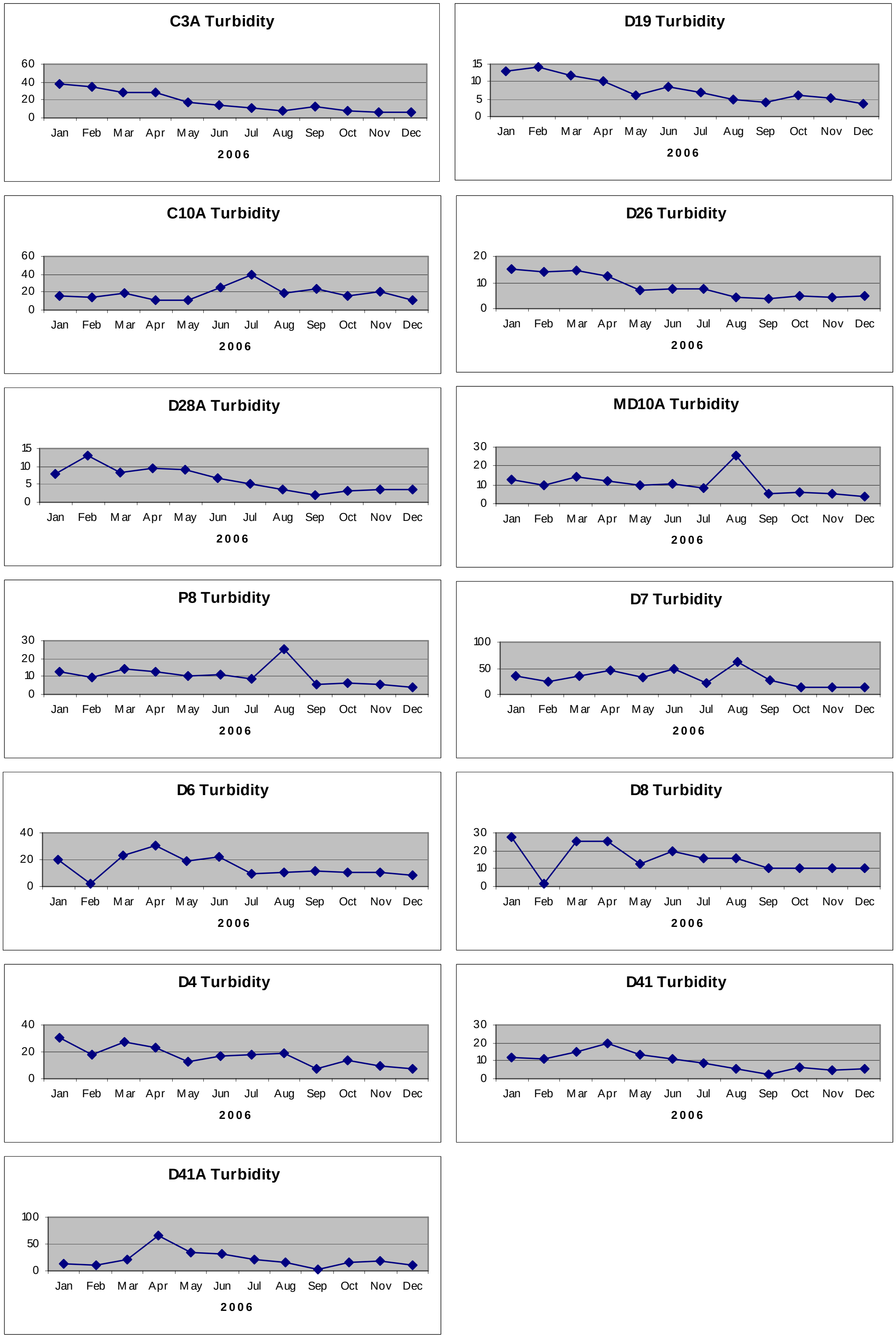

Figure 3-12 Orthophosphate comparisons, 2006

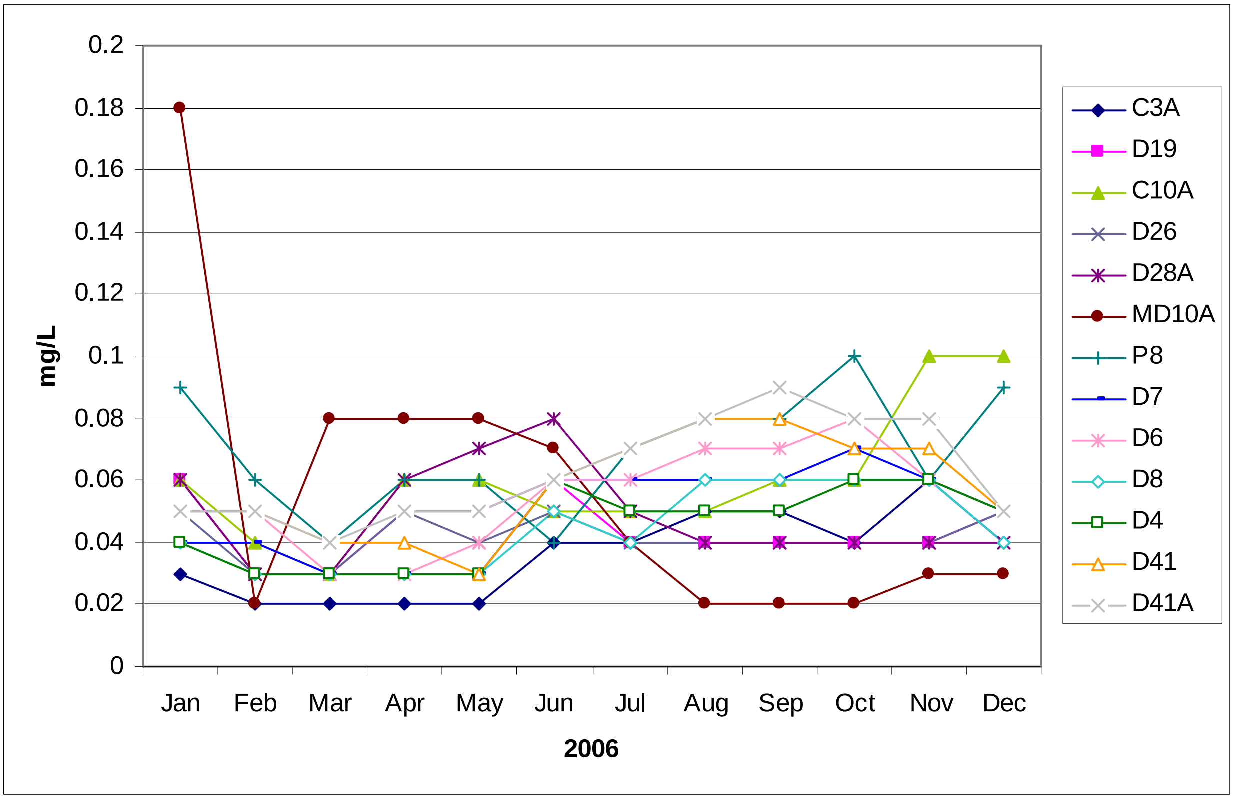

Figure 3-13 Orthophosphate (mg/L) by station, 2006

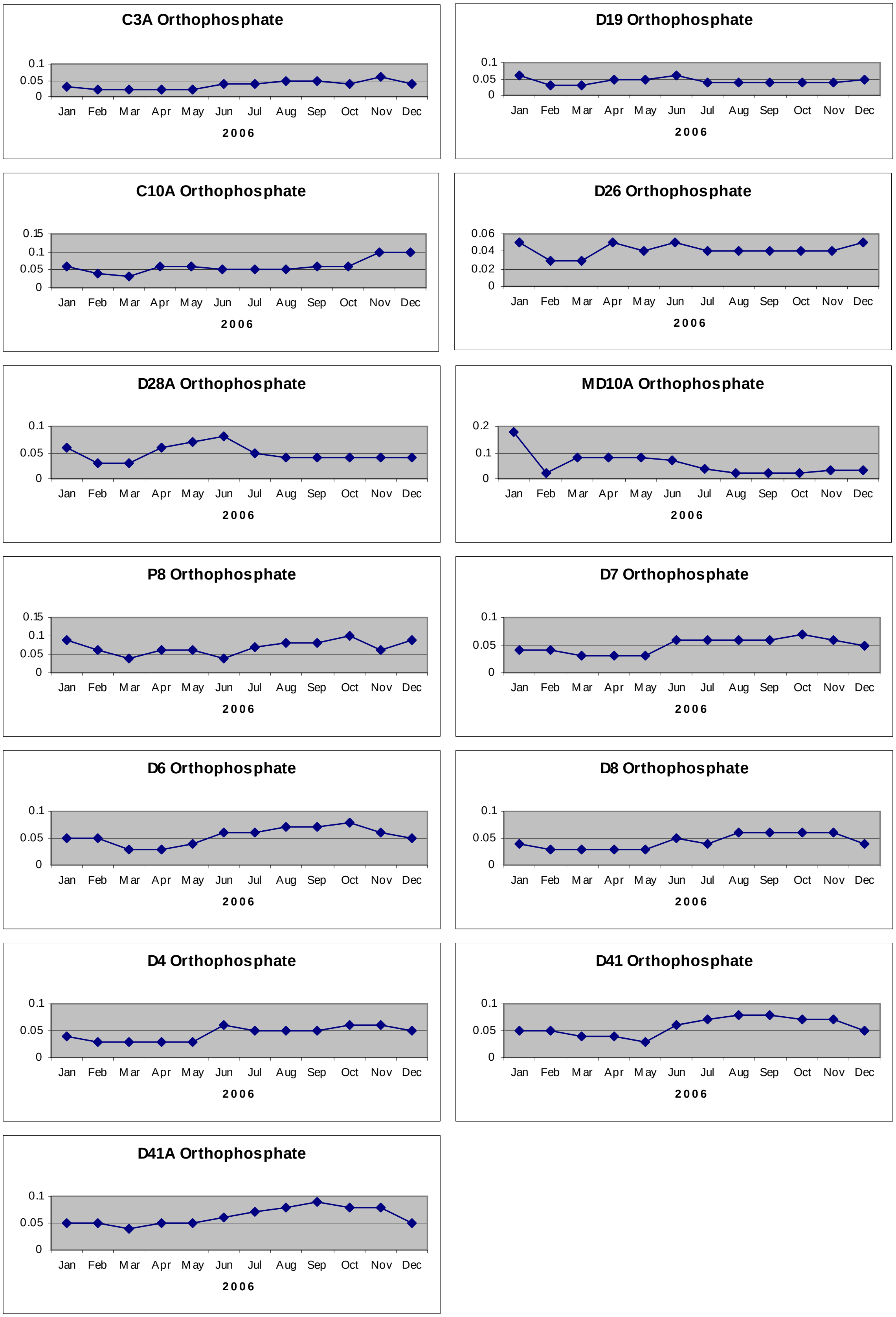

Figure 3-14 Total phosphorus (mg/L) comparisons, 2006

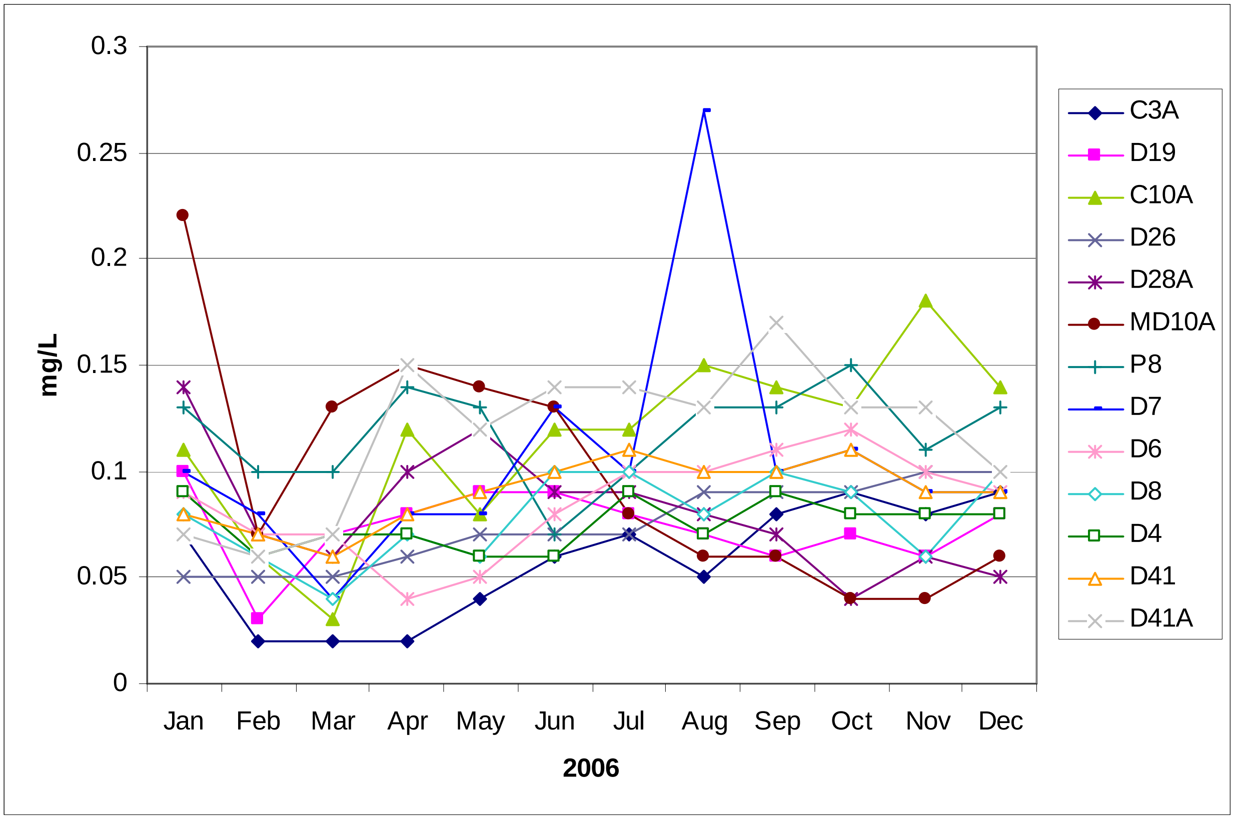

Figure 3-15 Total phosphorus (mg/L) by station, 2006

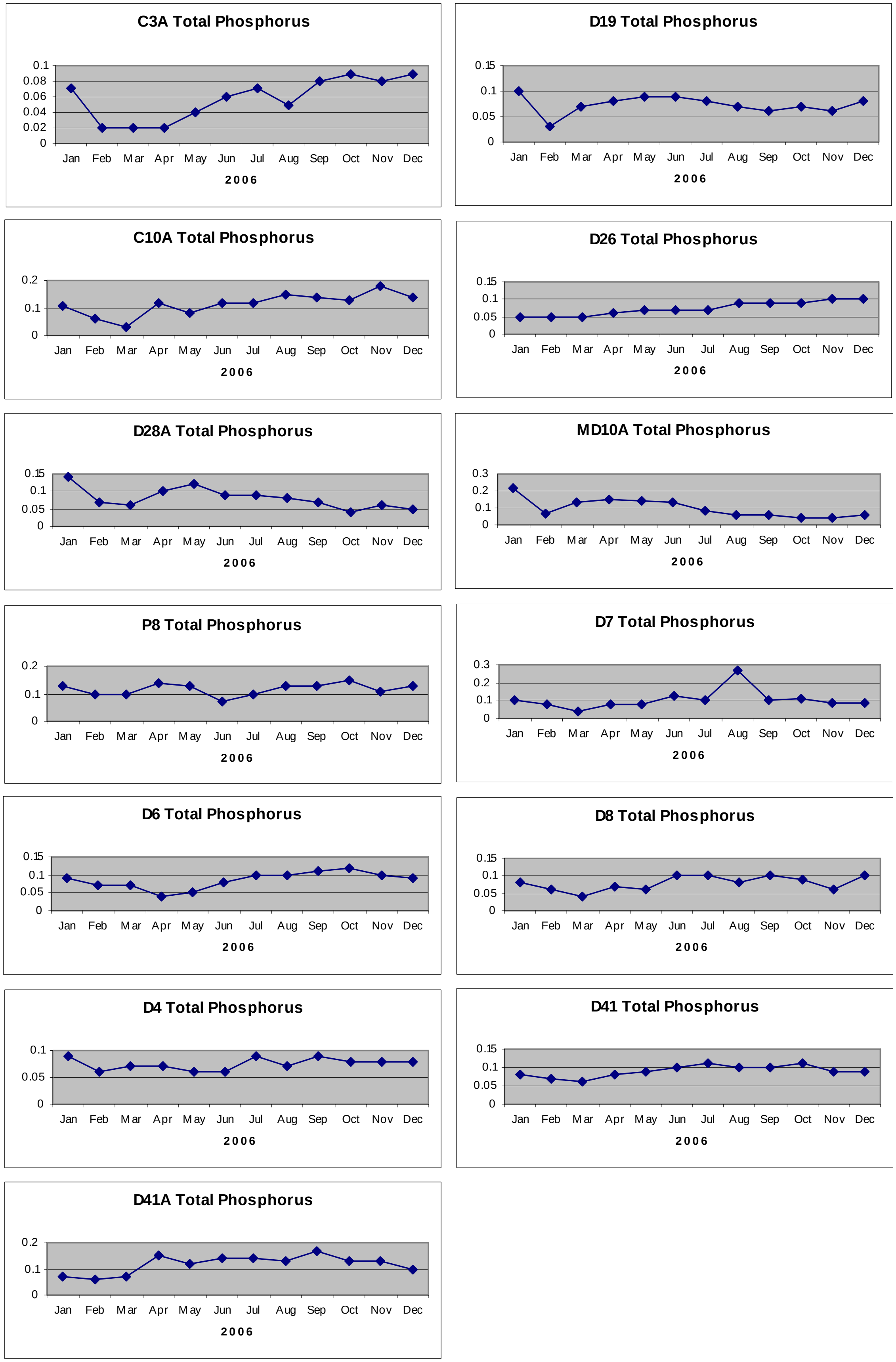

Figure 3-16 Kjeldahl nitrogen comparisons, 2006

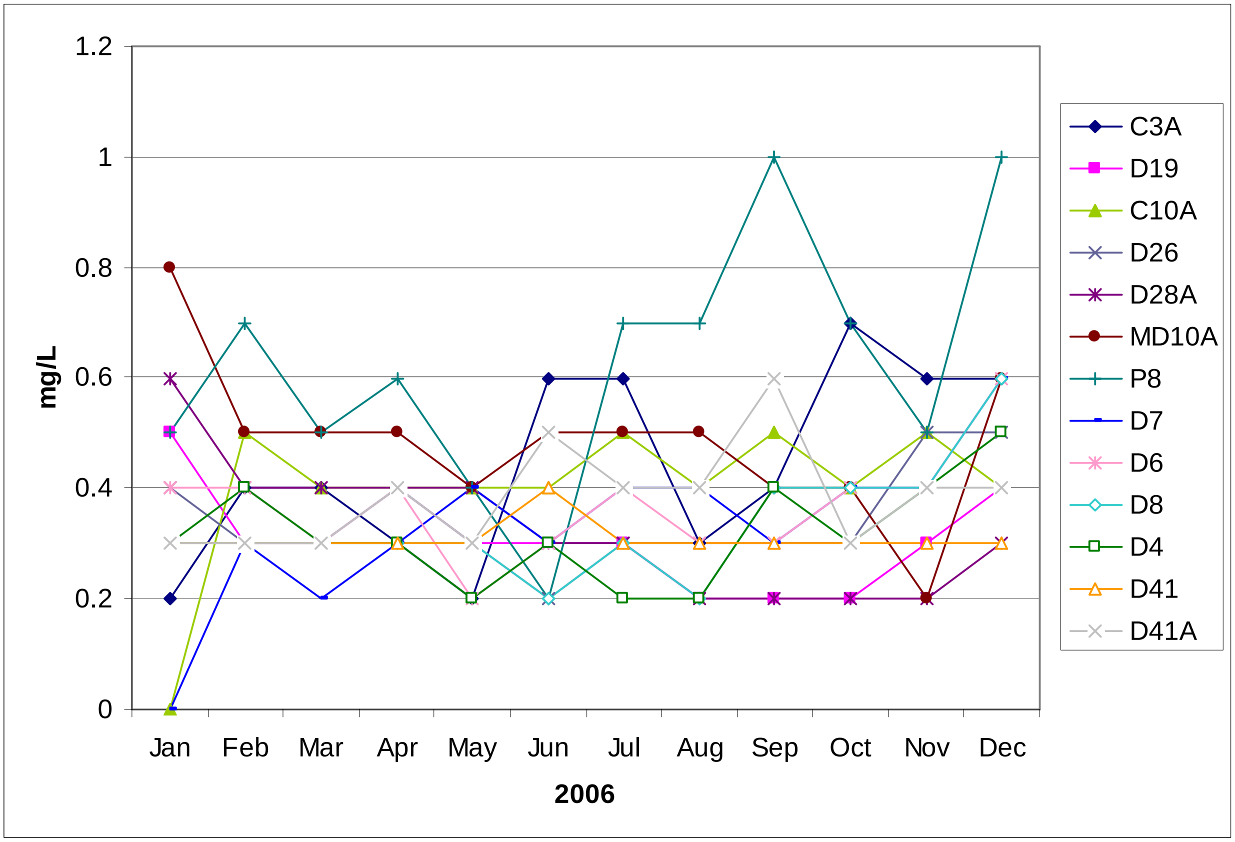

Figure 3-17 Kjeldahl nitrogen (mg/L) by station, 2006

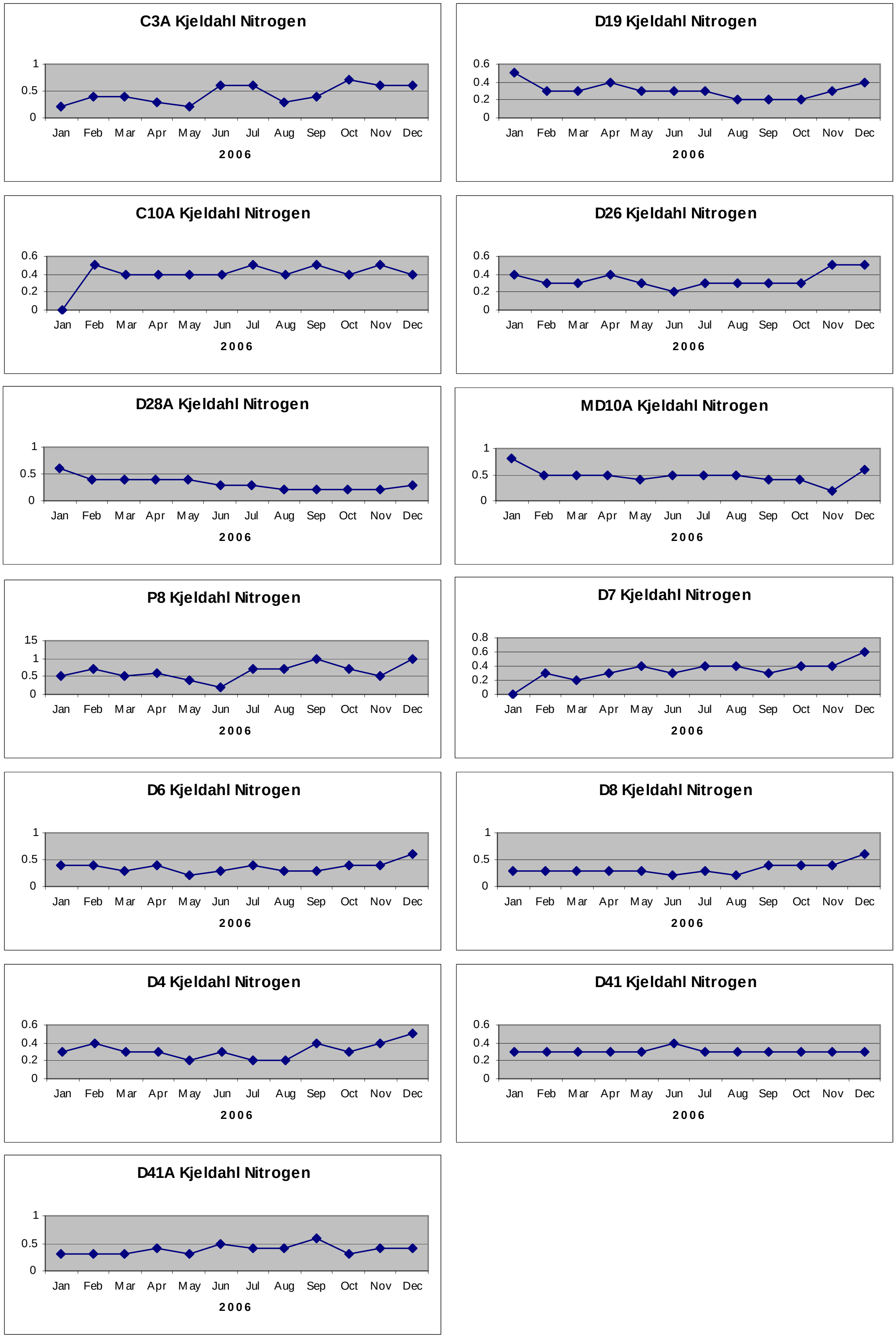

Figure 3-18 Dissolved inorganic nitrogen comparisons, 2006

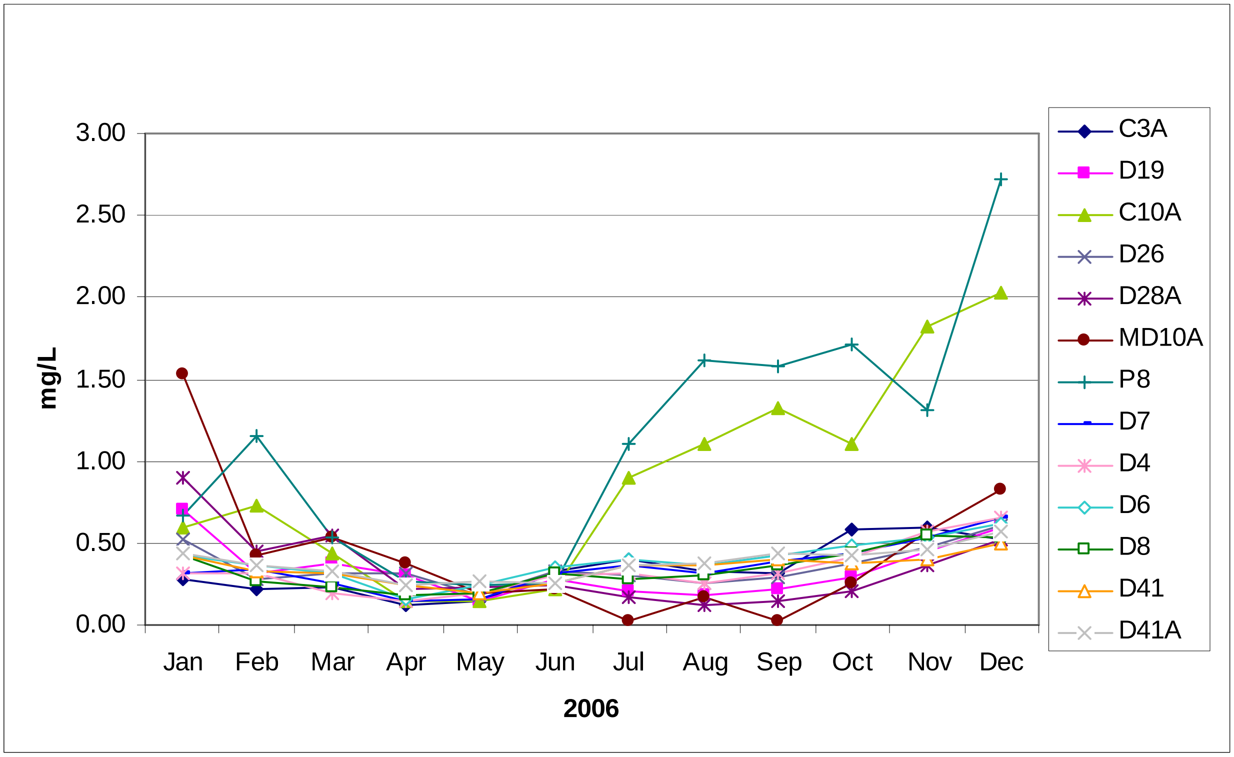

Figure 3-19 Dissolved inorganic nitrogen (mg/L) by station, 2006

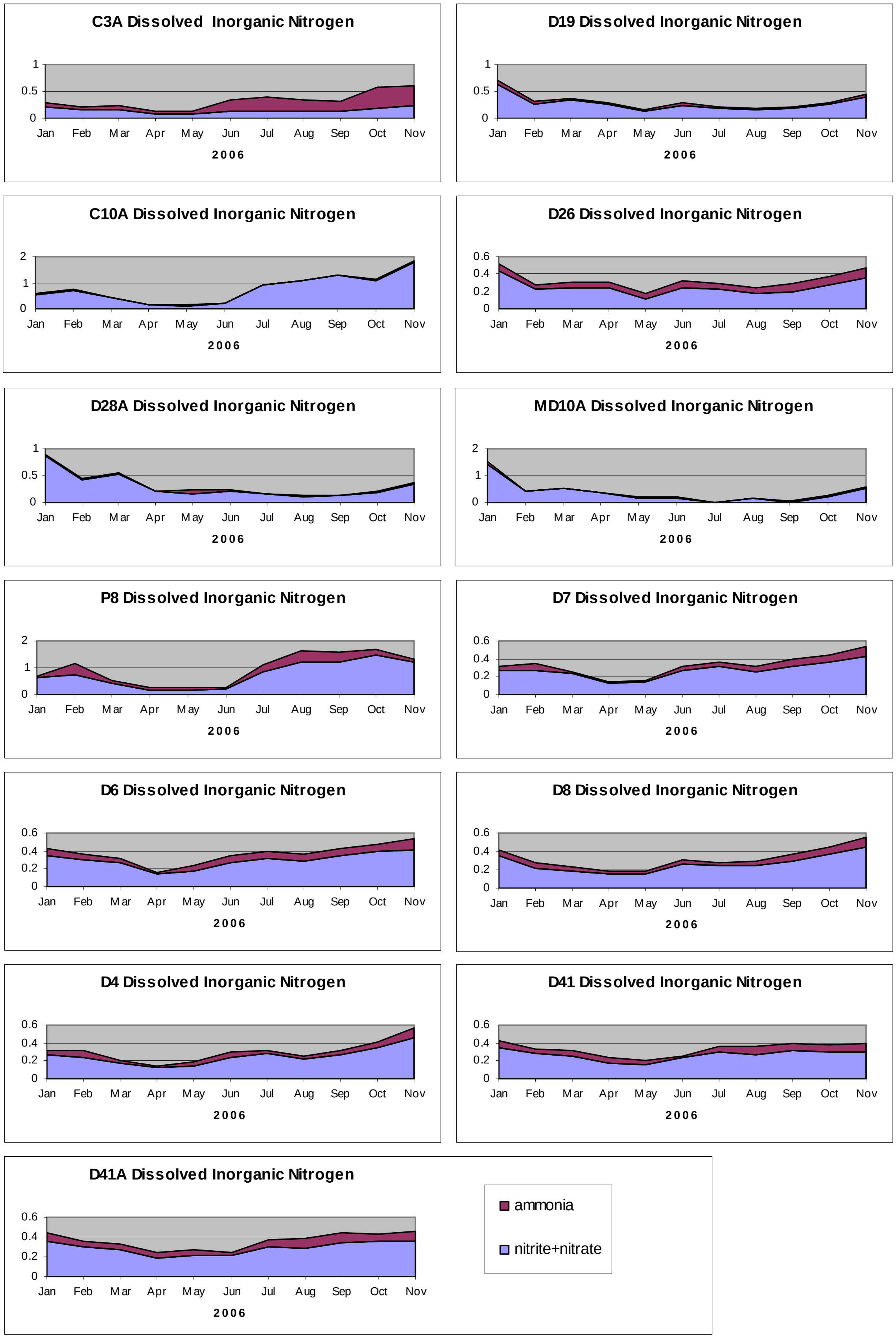

Figure 3-20 Dissolved organic nitrogen comparisons, 2006

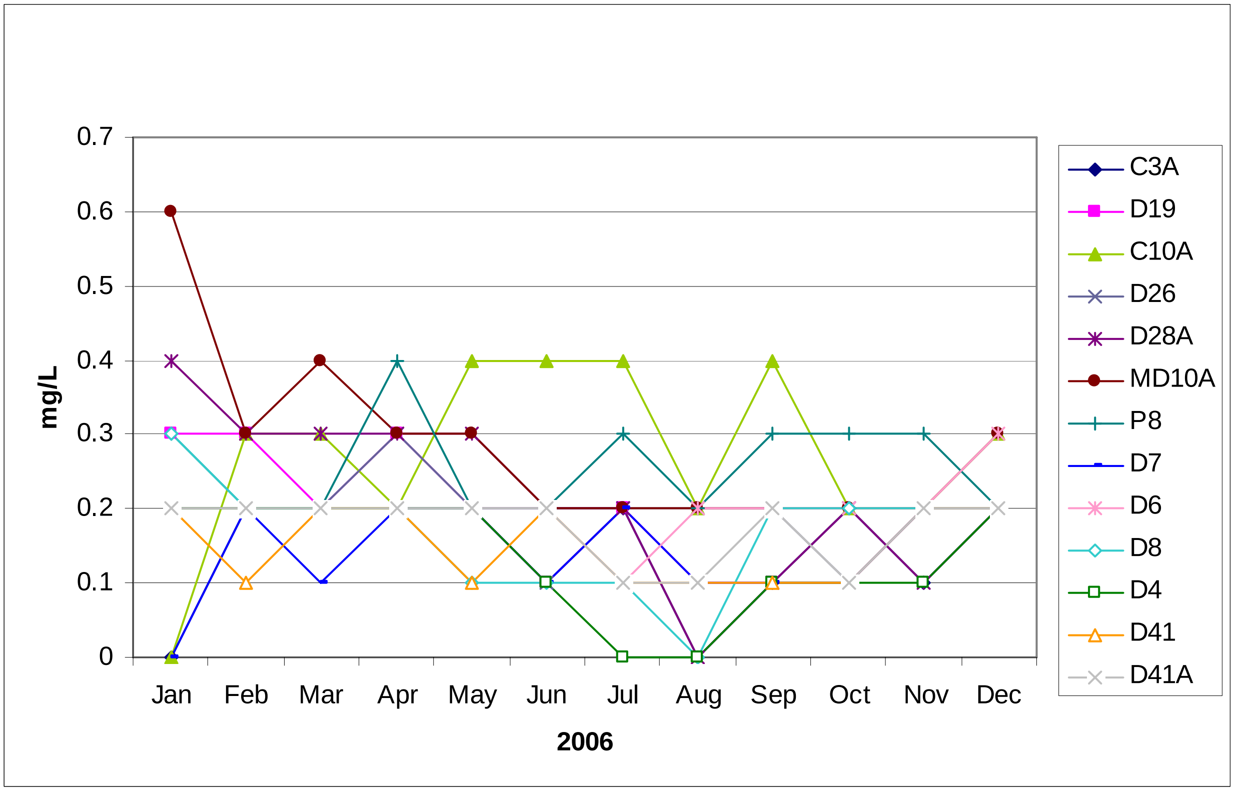

Figure 3-21 Dissolved organic nitrogen (mg/L) by station, 2006

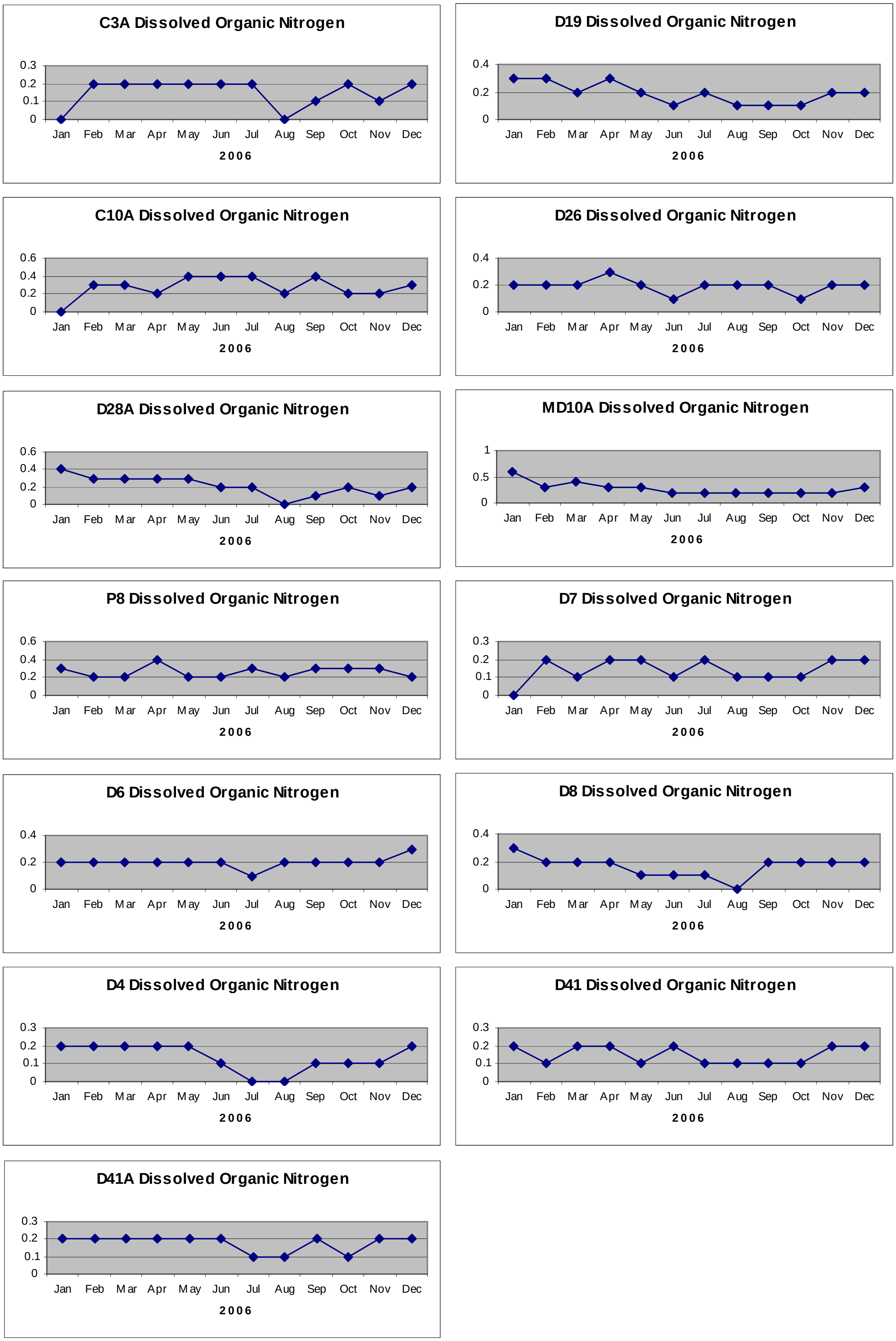

Figure 3-22 Total dissolved solids comparisons, 2006

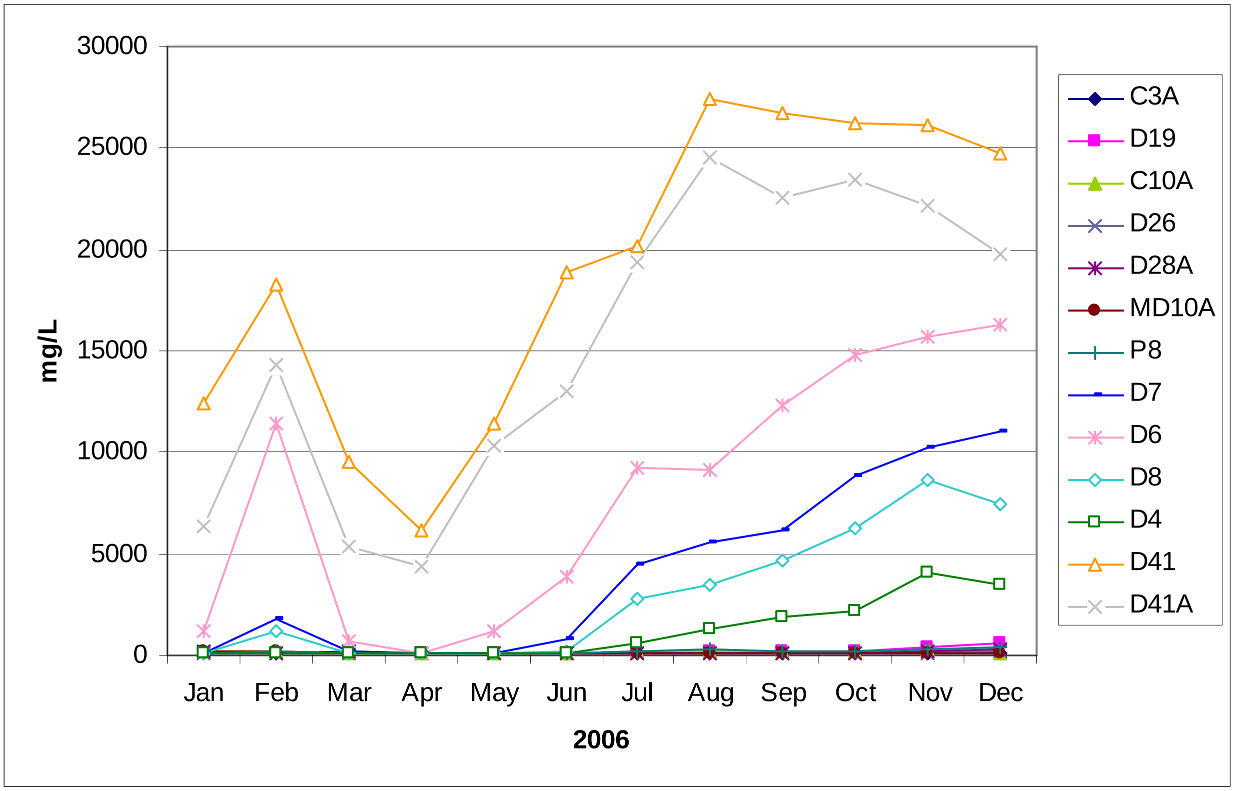

Figure 3-23 Total dissolved solids (mg/L) by station, 2006

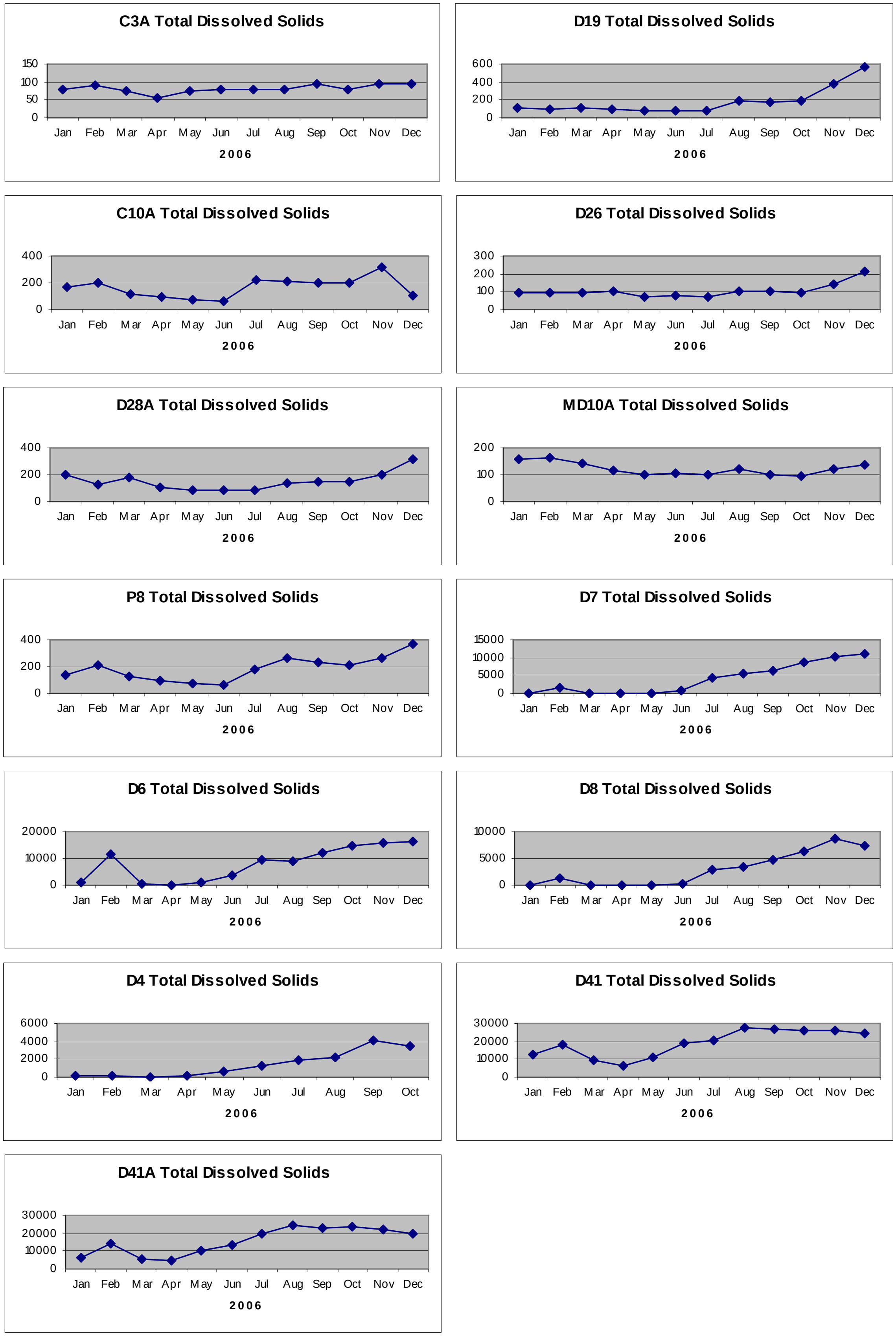

Figure 3-24 Total suspended solids comparisons, 2006

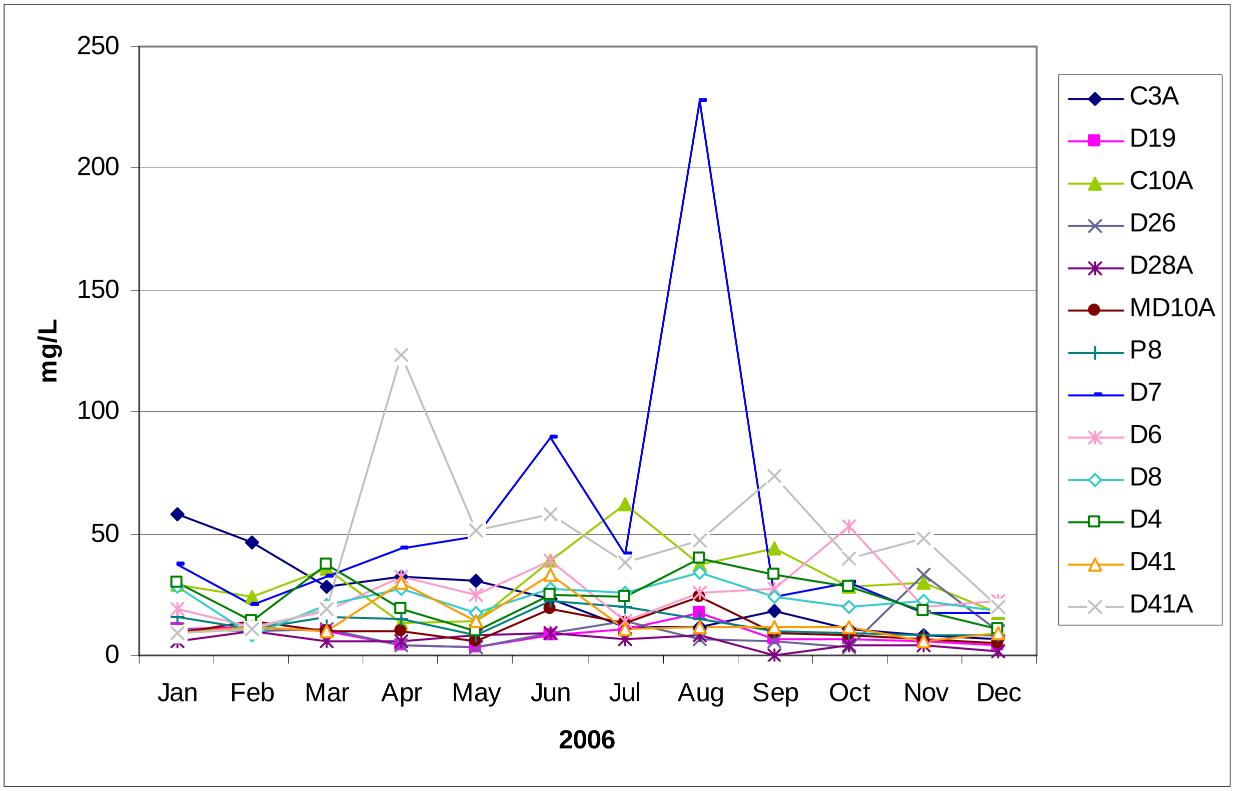

Figure 3-25 Total suspended solids (mg/L) by station, 2006

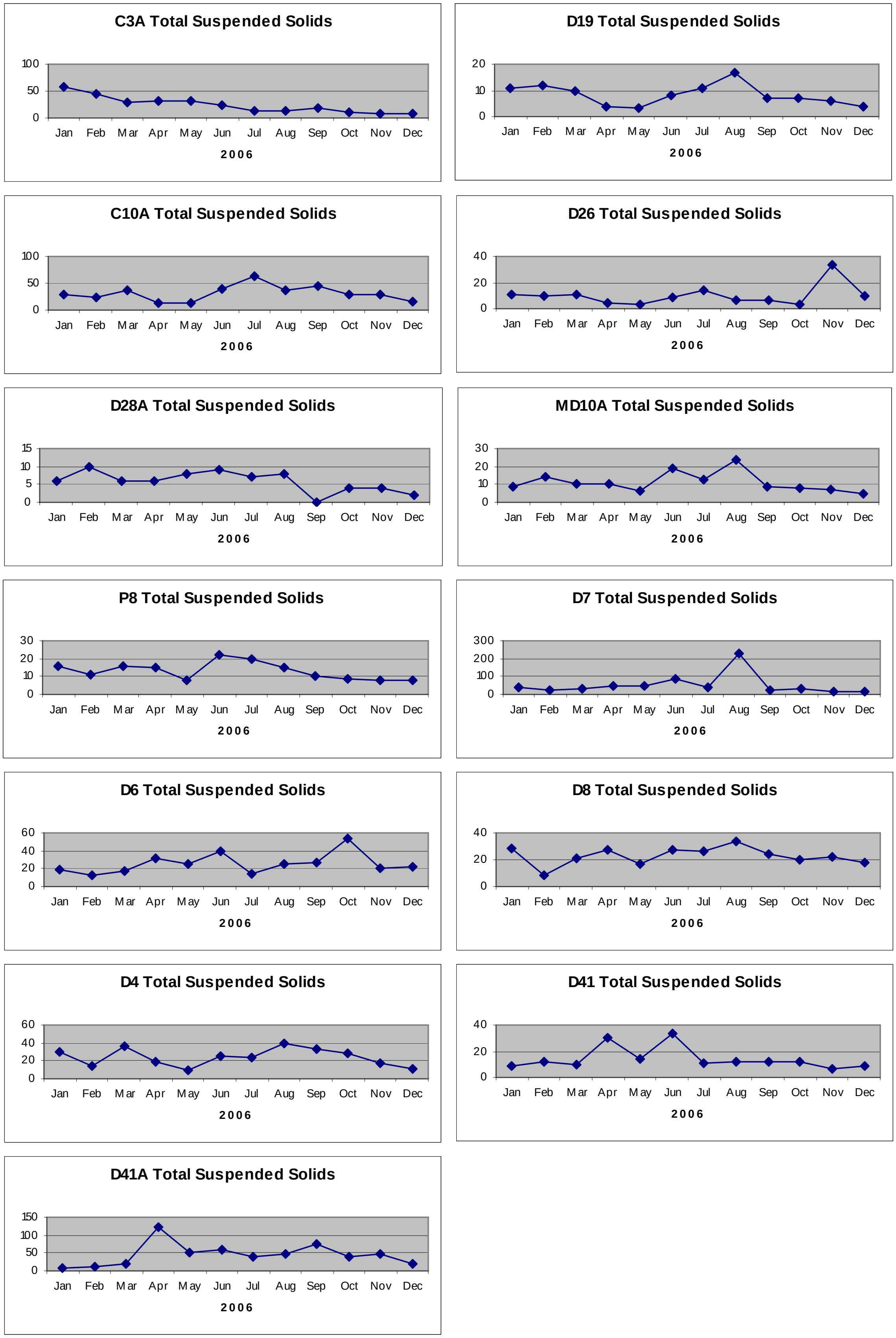

Figure 3-26 Volatile suspended solids comparisons, 2006

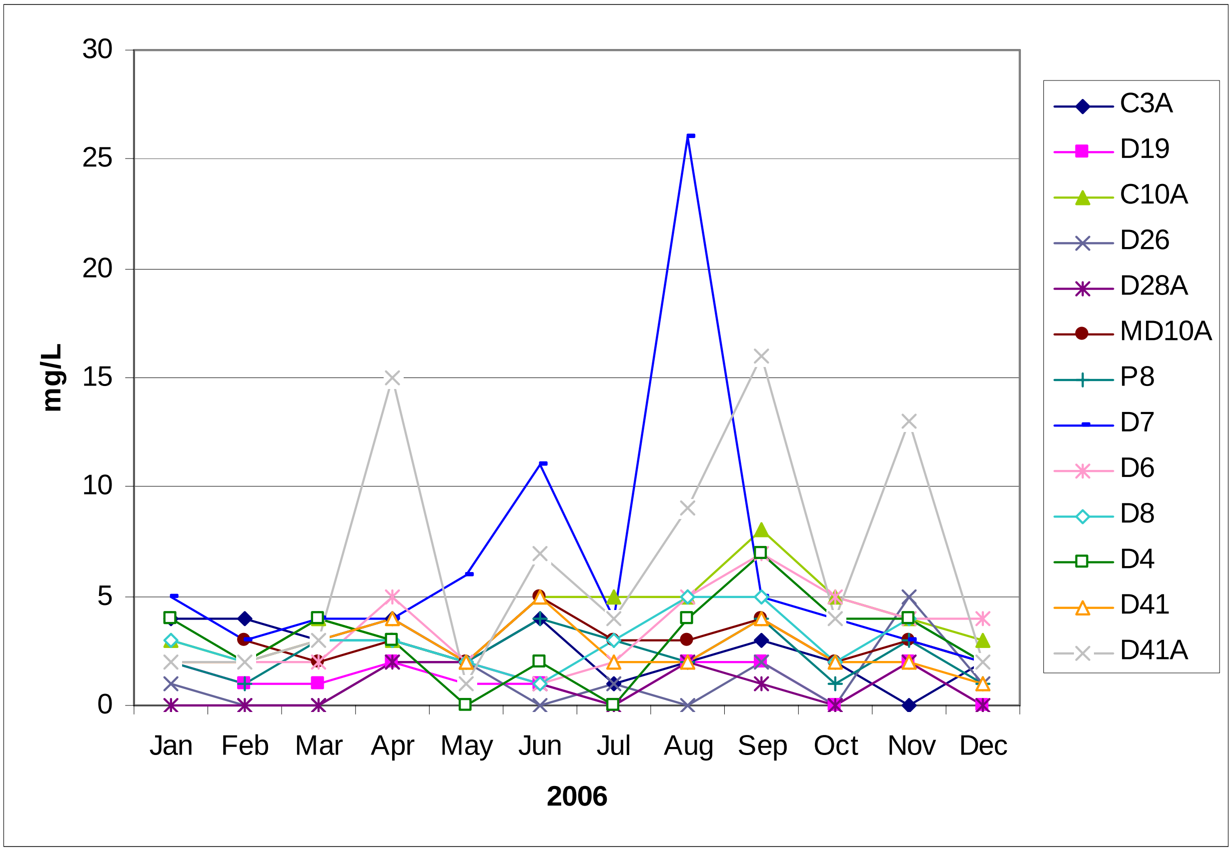

Figure 3-27 Volatile suspended solids (mg/L) by station, 2006

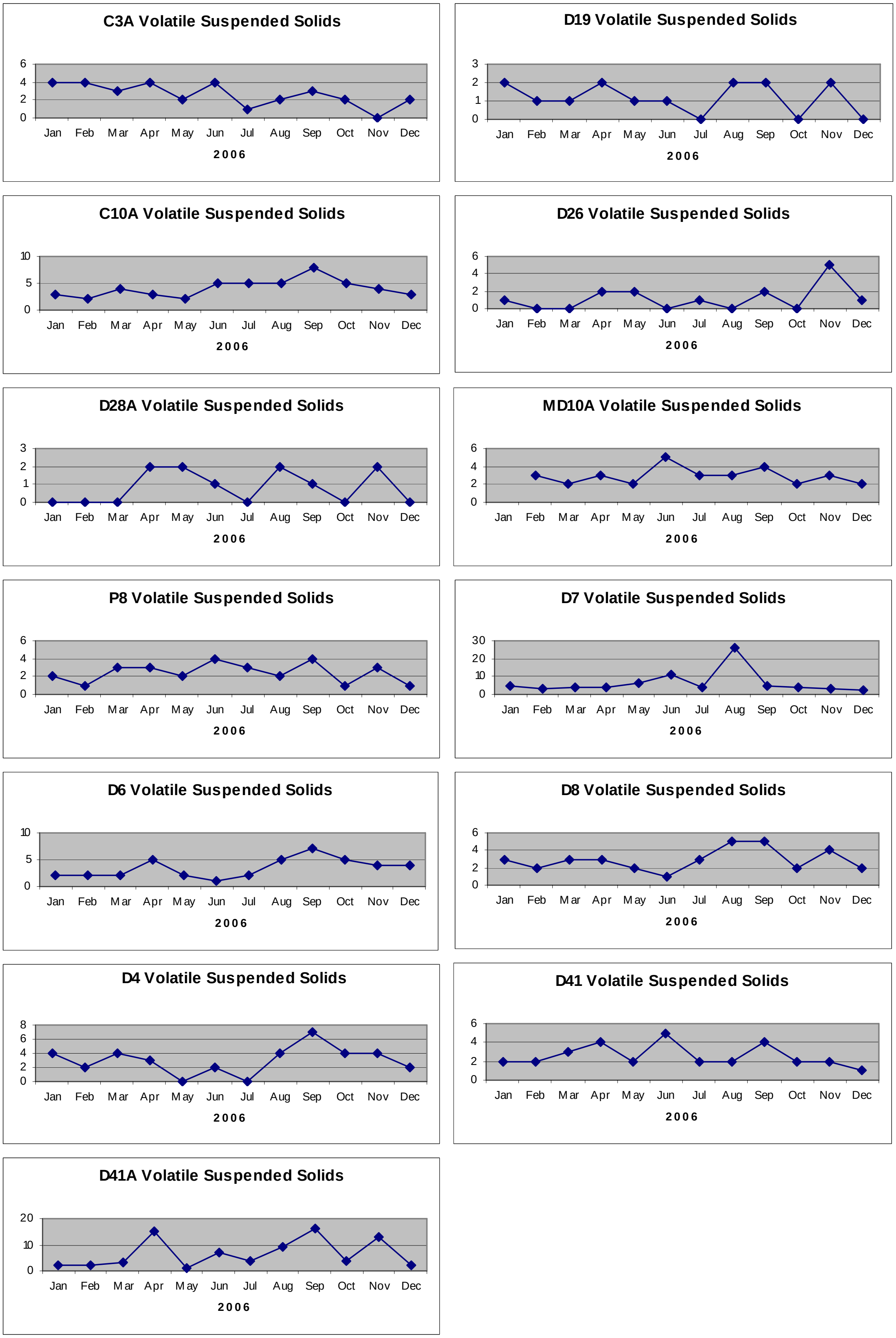

Figure 3-28 Silica comparisons, 2006

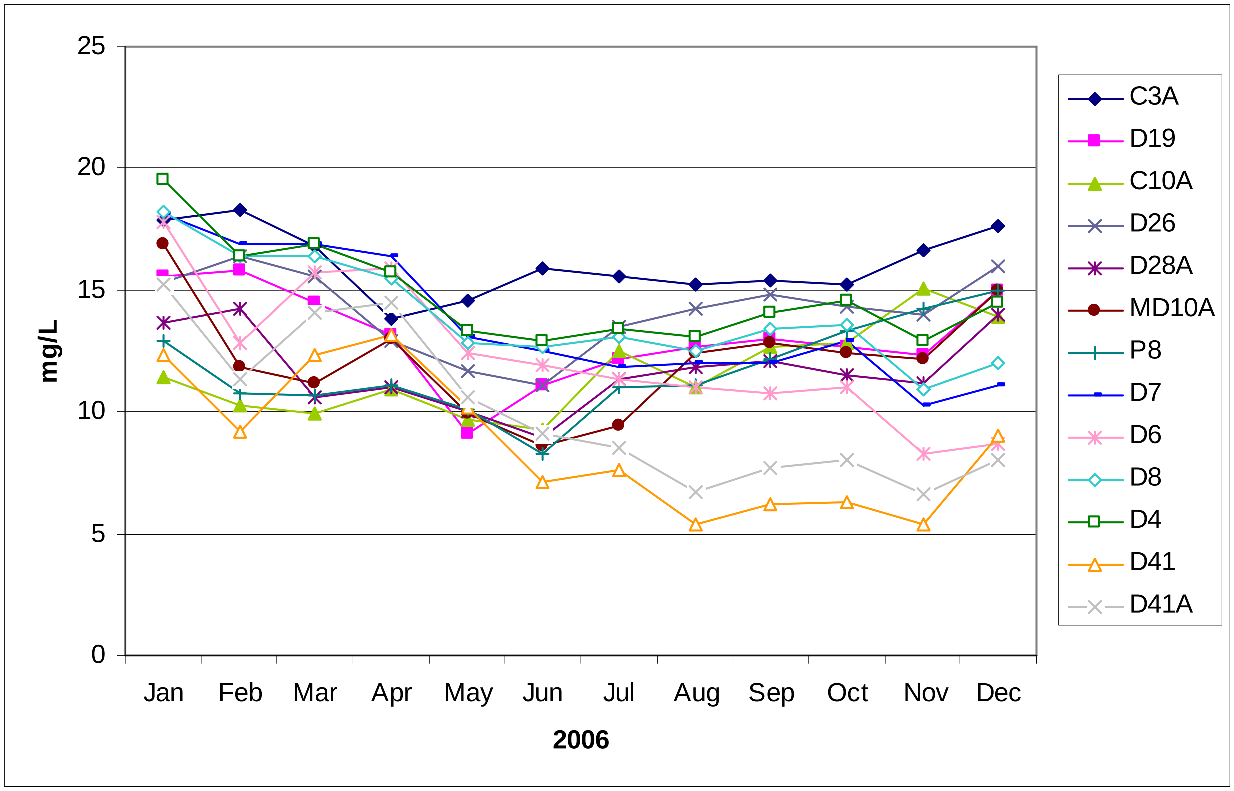

Figure 3-29 Silica (mg/L) by station, 2006

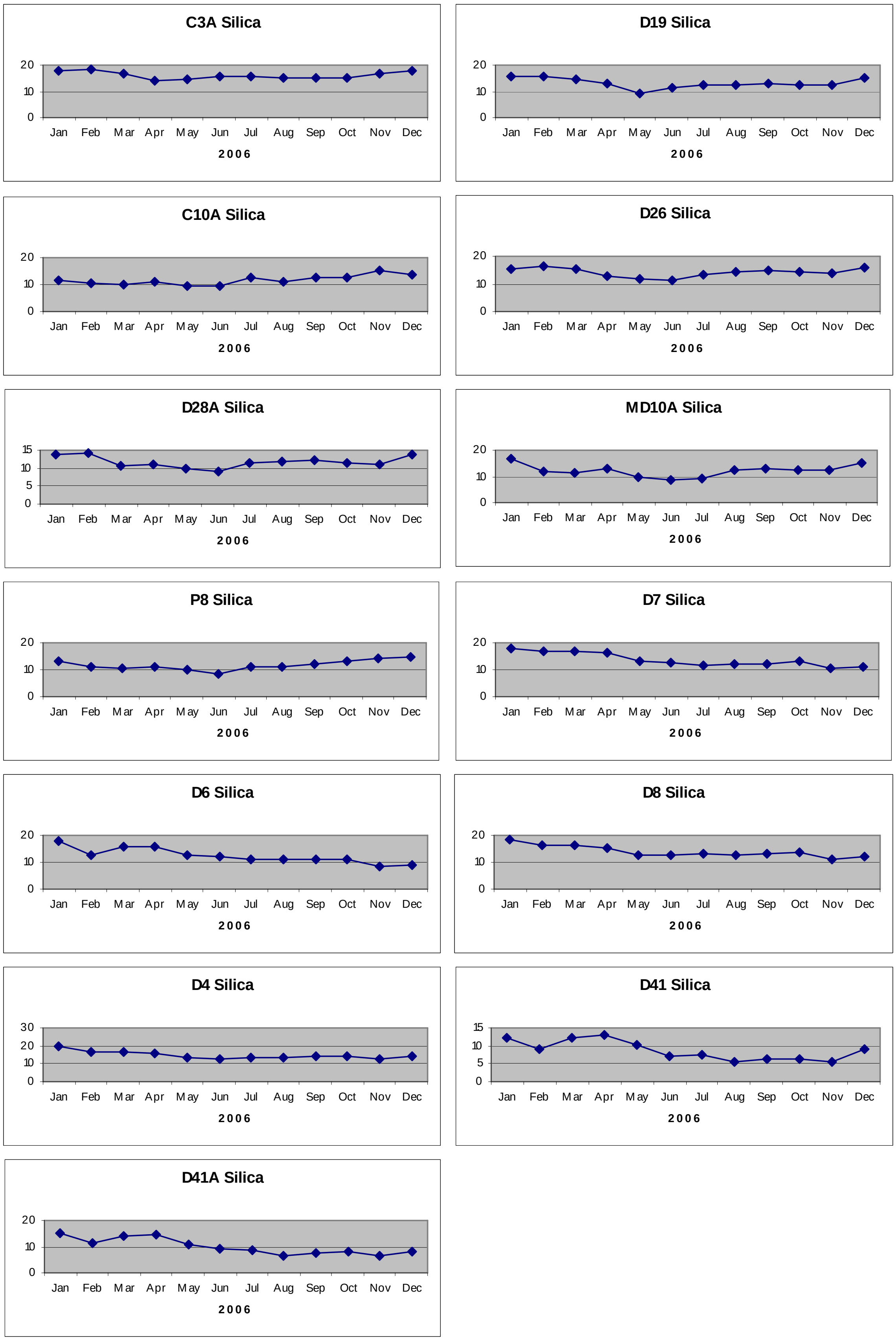

Figure 3-30 Chloride comparisons, 2006

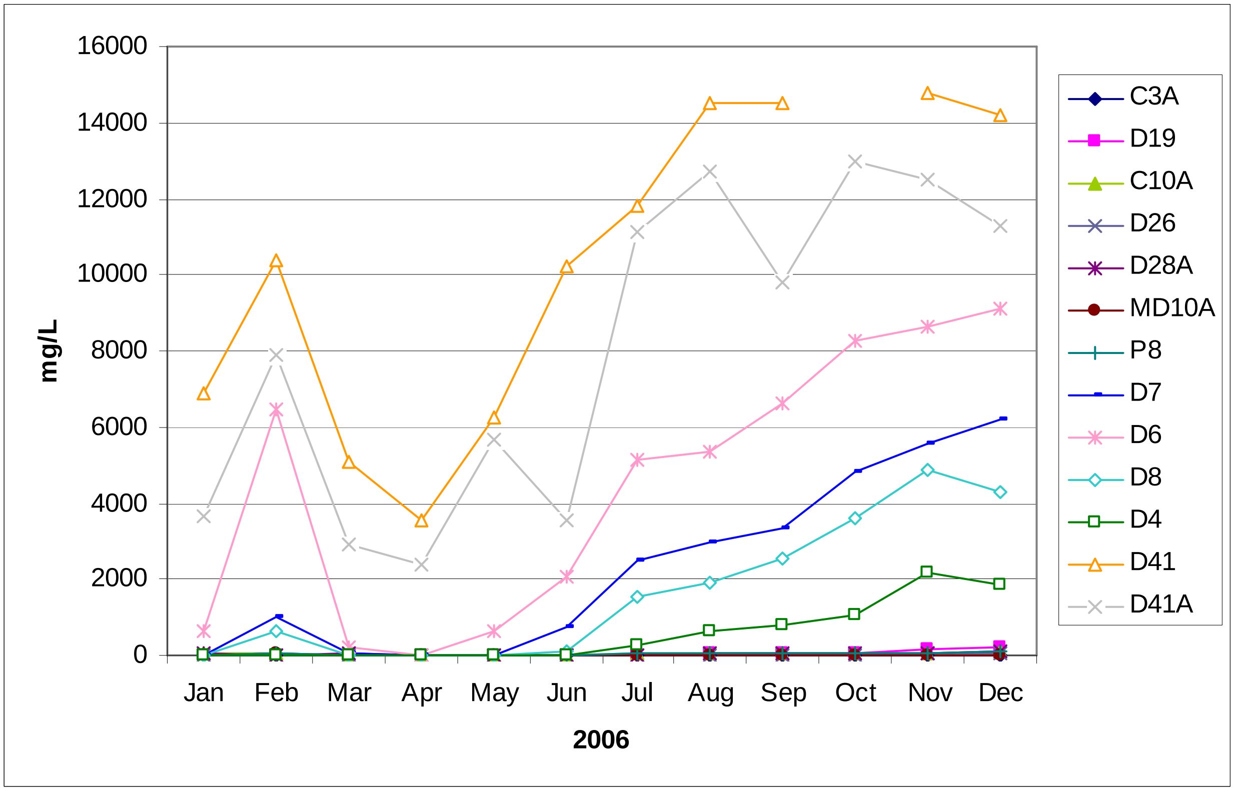

Figure 3-31 Chloride (mg/L) by station, 2006

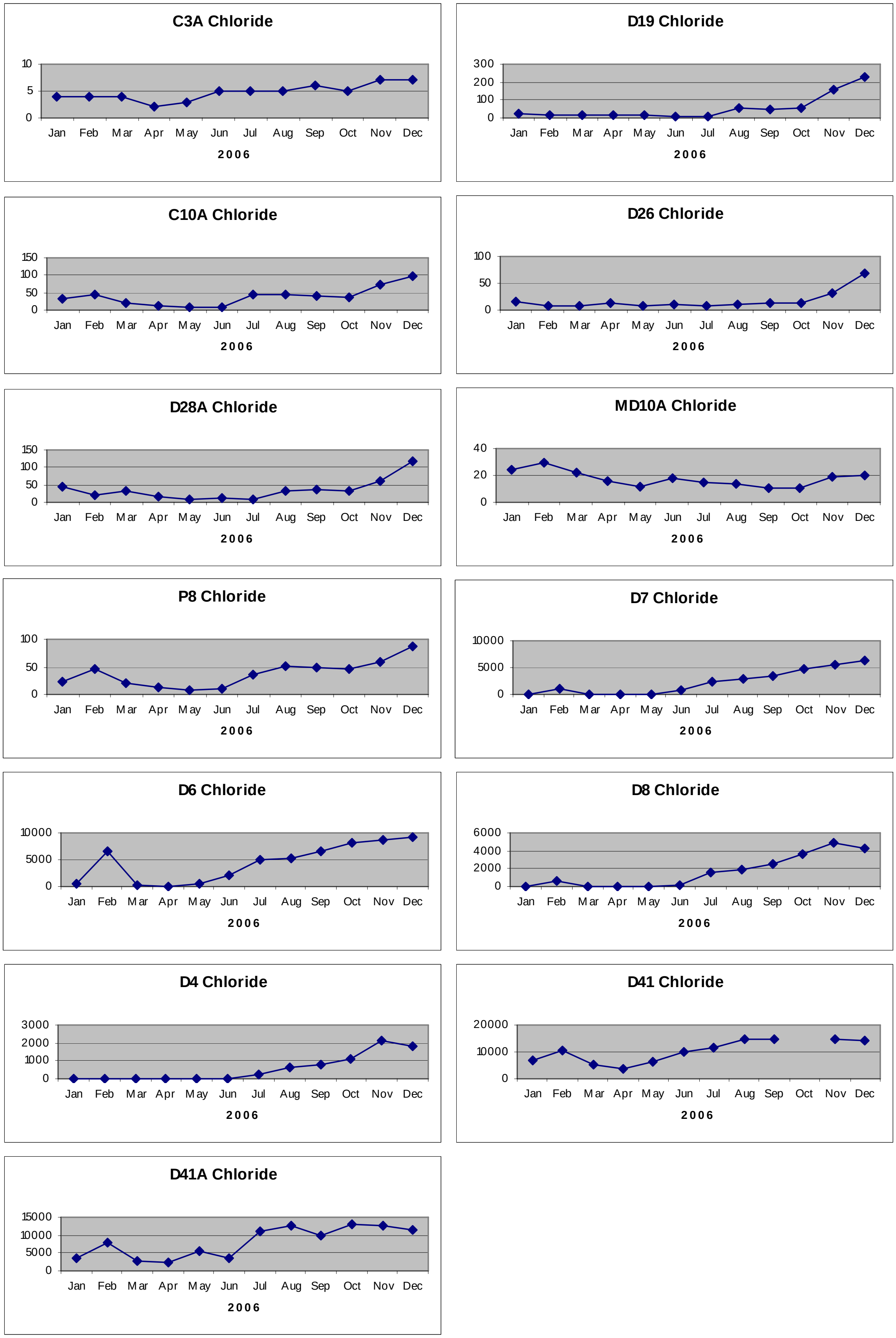

Table 3-1 Water quality parameters measured

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 site
Lower Sacramento River	D4
Lower San Joaquin River	D19 and D26
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

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Chapter 4 Phytoplankton and Chlorophyll

Introduction

DWR and the USBR are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll *a* samples to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (Estuary). The 13 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 2006.

DWR = California Department of Water Resources

USBR = US Bureau of Reclamation

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes that 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 of water. Under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael 1981). In fresh water, the blue-green algae (class Cyanophyceae) are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al. 1995).

Horne, A. and C. Goldman. 1994. *Limnology*. 2nd ed. New York, New York: McGraw-Hill, Inc.

Carmichael, W., ed. 1981. *The Water Environment, Algal Toxins and Health*. New York, NY: Plenum Press.

van den Hoek, C., D.G. Mann, and H.M. Jahns. 1995. *Algae: an introduction to Phycology*. United Kingdom: Cambridge University Press.

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).

Gannon, J. E. and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Trans. Amer. Microsc. 97:16.

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

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 Asian 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).

Alpine, A.E. and J.E. Cloern,. 1992. Trophic interactions and direct physical effects control phytoplankton biomass and production in an estuary. Limnol. Oceanogr. 37: 946-955

Methods

Phytoplankton

New for the 2006 report is an updated phytoplankton classification scheme, which more accurately reflects current phytoplankton taxonomy. However, due to the complexity of algal classification, and the uncertain phylogenetic status of some taxa, discussion of phytoplankton is mainly at the phylum or class levels. The current classification scheme, which has updated taxonomic hierarchies for all species collected by EMP, can be obtained by contacting Tiffany Brown at tbrown@water.ca.gov.

EMP = Environmental Monitoring Program

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 20 randomly chosen fields of a Whipple ocular micrometer grid for each settled aliquot. Sample analysis was conducted at a magnification of 700X using a Wilde M-40 inverted microscope.

Figure 4-1 Chlorophyll and phytoplankton monitoring stations

Utermöhl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton Methodik. Mitt. Int. Verh. Limnol. 9: 38.

mL = milliliter

Organism counts for each sample can be converted to organisms per milliliter using the following formula:

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

where:

Organisms = Number of organisms (#/mL)
C = Count obtained
Ac = Area of cell bottom (mm2)
Af = Area of each grid field (mm2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:

$$\text{Organisms} = C / cV$$

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 8 groups identified, centric diatoms, unidentified flagellates, green algae, and blue-green algae constituted 91.7% of the organisms collected (Figure 4-2).

Figure 4-2 Percent phytoplankton composition by group, 2006

All organisms collected in 2006 fell into these 8 categories:

- Centric diatoms (class Coscinodiscophyceae)
- Unidentified flagellates
- Green algae (classes Chlorophyceae and Zygnematophyceae)
- Blue-green algae (class Cyanophyceae)
- Pennate diatoms (classes Bacillariophyceae and Fragilariophyceae)
- Cryptomonads (class Cryptophyceae)
- Euglenoids (class Euglenophyceae)
- Dinoflagellates (class Dinophyceae)

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

Table 4-1 Phytoplankton genera by group, 2006

The 10 most common genera collected in 2006 were:

- Unidentified flagellates
- *Cyclotella* (centric diatom; class Coscinodiscophyceae)
- *Monoraphidium* (green alga; class Chlorophyceae)
- *Aulacoseira* (centric diatom; class Coscinodiscophyceae)
- Unidentified centric diatoms (class Coscinodiscophyceae)
- *Skeletonema* (centric diatom; class Coscinodiscophyceae)
- *Merismopedia* (blue-green alga; class Cyanophyceae)
- *Planktosphaeria* (green alga; class Chlorophyceae)
- *Cryptomonas* (cryptomonad; class Cryptophyceae)
- Anabaena (blue-green alga; class 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:
www.baydelta.water.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, and 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 1 or 2 high peaks in chlorophyll *a*, which skewed the mean values higher than the median values (Table 4-2 and Figures 4-3a through 4-15b).

Table 4-2 Chlorophyll *a* and pheophytin *a* concentrations, 2006

Monthly chlorophyll *a* concentrations throughout much of the Estuary were low. Of the 156 samples taken in 2006, 93.5% (146 samples) had chlorophyll *a* levels below 10 µg/L. Chlorophyll levels below 10 µg/L are considered limiting for zooplankton growth (Müller-Solger et al. 2002). Those samples with chlorophyll *a* levels above 10 µg/L were all taken from the east Delta, (MD10A), south Delta (P8, C10A), and San Pablo Bay (D41, D41A) in spring and summer.

Müller-Solger, A. B., A. D. Jassby, and D.C. Müller-Navarra. 2002. Nutritional quality of food resources for zooplankton (Daphnia) in a tidal-freshwater system (Sacramento-San Joaquin River Delta). Limnol. Oceanogr.47: 1468-1476.

The mean chlorophyll *a* concentration for all samples in 2006 was 3.58 µg/L, and the median value was 2.06 µg/L. The maximum chlorophyll *a* concentration in 2006 was 32.90 µg/L, recorded in July in the south Delta (C10A). Chlorophyll *a* maxima were recorded in spring and summer for all stations, except D41 (San Pablo Bay) and MD10A (east Delta); these stations both had their chlorophyll *a* maxima in February. The minimum chlorophyll *a* concentration was 0.52 µg/L, recorded in January in the lower San Joaquin River (D26). Chlorophyll *a* minima were recorded in fall and winter at all stations, except C3A, where the minimum was recorded in August.

Pheophytin *a* concentrations varied among stations, with some station recordings remaining relatively constant and others peaking during 1 or more months (Table 4-2 and Figures 4-3a through 4-15b). The mean pheophytin *a* concentration for all samples in 2006 was 1.71 µg/L, and the median value was 1.10 µg/L. The maximum pheophytin *a* concentration was 12.70 µg/L, recorded at C10A (south Delta) in July. Pheophytin *a* maxima were recorded in spring and summer at all stations except D26 (lower San Joaquin River) and D19 (central Delta), where maxima were recorded in the fall. The minimum pheophytin *a* concentration was 0.18 µg/L, recorded at D28A (central Delta) in January. Pheophytin *a* minima were recorded in winter at all stations except C3A (minimum recorded in March) and D41 (minimum recorded in November).

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 4-3a through 4-15b show the results of chlorophyll *a* and pheophytin *a* analysis, and phytoplankton composition at each station. All chlorophyll *a* and pheophytin *a* data can be found at: www.baydelta.water.ca.gov/emp/index.html.

Site C3A: North Delta

Figure 4-3a Pigment concentrations at C3A, 2006

The highest chlorophyll *a* concentration was recorded in April (4.21 µg/L), and the lowest was recorded in August (0.97 µg/L) (Figure 4-3a, Table 4-2). The mean was 2.23 µg/L, and the median was 2.05 µg/L. There was some seasonality, with higher values recorded in spring and summer and lower values recorded in fall and winter.

Pheophytin *a* showed a somewhat seasonal pattern, with higher values occurring in summer, as chlorophyll *a* values dropped (Figure 4-3a). The maximum (3.53 µg/L) was recorded in August, and the minimum (0.43 µg/L) was recorded in March (Table 4-2). The mean was 1.47 µg/L, and the median was 1.24 µg/L.

Phytoplankton density fluctuated slightly for most of the year before experiencing a large peak in blue-green algae in December (Figure 4-3b). No phytoplankton were observed in January and February.

Figure 4-3b Phytoplankton composition at C3A, 2006

Site C10A: South Delta

The maximum chlorophyll *a* concentration was recorded in July (32.90 µg/L), and the minimum was in January (2.33µg/L) (Figure 4-4a, Table 4-2). The large peak in chlorophyll *a* in July skewed the mean (9.41 µg/L) much higher than the median (6.03µg/L). This peak also slightly obscured the seasonal pattern (Figure 4-4a).

Figure 4-4a Pigment concentrations at C10A, 2006

The largest pheophytin *a* value for the year was recorded at this station in July (12.70 µg/L) (Table 4-2). The minimum occurred in January (0.89 µg/L). As with chlorophyll, the large peak in July skewed the mean (4.38 µg/L) higher than the median (3.30 µg/L) (Table 4-2). There was no seasonal pattern; it was slightly higher in summer, and then stable the rest of the year (Figure 4-4a).

There were two large peaks in centric diatoms in summer and fall, and a peak in green algae in December (Figure 4-4b). Otherwise phytoplankton densities were relatively constant all year.

Figure 4-4b Phytoplankton composition at C10A, 2006

Site P8: South Delta

Chlorophyll *a* showed a seasonal pattern, with higher values recorded in spring and summer and lower values in fall and winter (Figure 4-5a). The maximum was recorded in April (10.10 µg/L), and the minimum in November (1.45 µg/L) (Table 4-2). The mean (4.79 µg/L) was slightly higher than the median (4.47 µg/L).

Figure 4-5a Pigment concentrations at P8, 2006

Pheophytin *a* had large peaks in summer and fall, but was relatively stable the rest of the year (Figure 4-5a). As a result, the mean (3.25 µg/L) was skewed much higher than the median (1.67 µg/L) (Table 4-2). The maximum was 8.16 µg/L in August, and the minimum was 0.86 µg/L in January.

Phytoplankton showed a slight seasonal pattern, with higher densities in spring and summer (Figure 4-5b). There was a large peak of centric diatoms in May, and a large peak of unidentified flagellates in October.

Figure 4-5b Phytoplankton composition at P8, 2006

Site MD10A: East Delta

A large spike in chlorophyll *a* in February slightly obscured the seasonal pattern (Figure 4-6a); overall, values were higher in spring and summer. The peak in February was the maximum for the year (29.40 µg/L), and skewed the mean (9.35 µg/L) much higher than the median (6.56 µg/L) (Table 4-2). The minimum was recorded in November (2.20 µg/L).

Figure 4-6a Pigment concentrations at MD10A, 2006

Pheophytin *a* showed no clear pattern, although values in summer were nearly double compared to the rest of the year (Figure 4-6a). This skewed the mean higher than the median (3.20 µg/L and 1.93 µg/L, respectively) (Table 4-2). The maximum was recorded in July (7.32 µg/L), and the minimum in January (0.61 µg/L).

There were large peaks in centric diatoms early in the year (Figure 4-6b); otherwise, phytoplankton densities were fairly stable all year.

Figure 4-6b Phytoplankton composition at MD10A, 2006

Site D26: Lower San Joaquin River

Chlorophyll *a* mostly showed a seasonal pattern, except for a peak in November (Figure 4-7a). The maximum was 3.40 µg/L in April, and the minimum was 0.52 µg/L in January (Table 4-2). The mean was slightly higher than the median (1.55 µg/L and 1.17 µg/L, respectively).

Figure 4-7a Pigment concentrations at D26, 2006

Pheophytin *a* showed no pattern; it was fairly stable all year (Figure 4-7a). The maximum was 1.69 µg/L in November, and the minimum was 0.38 µg/L in January (Table 4-2). The mean and median were nearly the same (0.98 µg/L and 0.97 µg/L, respectively).

There was a large peak of blue-green algae in April, and some smaller peaks of unidentified flagellates in fall and winter (Figure 4-7b). No phytoplankton were observed in June and July.

Figure 4-7b Phytoplankton composition at D26, 2006

Site D19: Central Delta

Chlorophyll *a* concentrations showed a clear seasonal pattern, with the maximum (2.84 µg/L) recorded in August, and the minimum (0.57 µg/L) recorded in January (Figure 4-8a, Table 4-2). The mean and median were very close (1.64 µg/L and 1.60 µg/L, respectively).

Figure 4-8a Pigment concentrations at D19, 2006

Pheophytin *a* showed no clear pattern; it fluctuated throughout the year (Figure 4-8a). The maximum was recorded in September (1.78 µg/L), and the minimum was recorded in January (0.23 µg/L) (Table 4-2). As with chlorophyll a, the mean and median were very close (1.05 µg/L and 1.09 µg/L, respectively).

Phytoplankton densities were low early in the year; no phytoplankton were observed in March (Figure 4-8b). Later in the year there were peaks in blue-green algae, pennate diatoms, and unidentified flagellates.

Figure 4-8b Phytoplankton composition at D19, 2006

Site D28A: Central Delta

Chlorophyll *a* did not show a seasonal pattern; values were stable much of the year except for a peak in April, which was the maximum for the year (7.58 µg/L) (Figure 4-9a, Table 4-2). The minimum of 0.68 µg/L was recorded in January. The large spike in April skewed the mean (1.94 µg/L) higher than the median (1.48 µg/L) (Table 4-2).

Figure 4-9a Pigment concentrations at D28A, 2006

Pheophytin *a* also did not show a seasonal pattern; values were low and stable throughout the year (Figure 4-9a). Consequently, the mean and median were very close (1.06 µg/L and 1.07 µg/L, respectively) (Table 4-2). The maximum of 1.76 µg/L was recorded in April; the minimum of 0.18 µg/L was recorded in January.

Phytoplankton densities were low except for a mix of groups in April, and large peaks in unidentified flagellates from September onward (Figure 4-9b). No phytoplankton were observed in January.

Figure 4-9b Phytoplankton composition at D28A, 2006

Site D4: Lower Sacramento River

Chlorophyll *a* did not show a clear seasonal pattern; after a peak in March, values fluctuated slightly before a small decline in the fall (Figure 4-10a). The maximum was 5.78 µg/L in March; the minimum was 0.81 µg/L in November (Table 4-2). The peak in March skewed the mean (2.39 µg/L) higher than the median (2.19 µg/L).

Figure 4-10a Pigment concentrations at D4, 2006

Pheophytin *a* also did not show a pattern; values were stable with slight increases in summer (Figure 4-10a). The maximum (2.07 µg/L) was recorded in August; the minimum (0.49 µg/L) was recorded in January (Table 4-2). The mean was 1.27 µg/L; the median was 1.19 µg/L.

There was a large peak of centric diatoms in February, followed by a peak in blue-green algae in March (Figure 4-10b). Phytoplankton densities were low the rest of the year, and no phytoplankton were observed in July.

Figure 4-10b Phytoplankton composition at D4, 2006

Site D6: Suisun Bay

Chlorophyll *a* showed a slight seasonal pattern at site D6, peaking in early spring and declining in late fall (Figure 4-11a). The maximum was 3.64 µg/L in March; the minimum was 0.79 µg/L in November (Table 4-2). The mean was 1.97 µg/L, and the median was 1.76 µg/L.

Figure 4-11a Pigment concentrations at D6, 2006

Pheophytin *a* also showed a slight seasonal pattern, increasing in spring and summer, and declining in winter (Figure 4-11a). The maximum was recorded in June (1.61 µg/L), and the minimum was recorded in February (0.35 µg/L) (Table 4-2). The mean and median were nearly identical (0.83 µg/L and 0.82 µg/L, respectively).

Compared to other stations, phytoplankton densities were very low at D6 (Figure 4-11b). There was a small peak of unidentified flagellates in winter, and small peaks of centric diatoms in spring and summer. No phytoplankton were observed October through December.

Figure 4-11b Phytoplankton composition at D6, 2006

Site D7: Suisun Bay

Chlorophyll *a* showed a seasonal pattern with some fluctuation; the maximum was 4.92 µg/L in March, and the minimum was 0.76 µg/L in November (Figure 4-12a, Table 4-2). The mean was 2.20 µg/L, and the median was 1.89 µg/L.

Figure 4-12a Pigment concentrations at D7, 2006

Pheophytin *a* did not show a clear pattern; there were large peaks in summer, but otherwise values were stable (Figure 4-12a). The maximum (6.49 µg/L) was recorded in August; the minimum (0.50 µg/L) was recorded in January (Table 4-2). The mean was 1.68 µg/L; the median was 1.03 µg/L.

There was a large peak of centric diatoms in March, followed by a smaller peak in May (Figure 4-12b). Otherwise, phytoplankton densities for the year were low. No phytoplankton were observed in February, August, or December.

Figure 4-12b Phytoplankton composition at D7, 2006

Site D8: Suisun Bay

Chlorophyll *a* showed a seasonal pattern; the maximum was 3.71 µg/L in March, and the minimum was 0.99 µg/L in September (Figure 4-13a, Table 4-2). Peaks in the spring skewed the mean higher than the median (1.91 µg/L and 1.51 µg/L, respectively).

Figure 4-13a Pigment concentrations at D8, 2006

Pheophytin *a* showed no clear pattern; there was minor fluctuation throughout the year (Figure 4-13a). The maximum (1.61 µg/L) was recorded in August; the minimum (0.41 µg/L) was recorded in February (Table 4-2). The mean and median were nearly the same (0.87 µg/L and 0.85 µg/L, respectively).

Phytoplankton densities were low compared to other stations; there were peaks of centric diatoms in spring, and a peak of unidentified flagellates in late fall (Figure 4-13b). No phytoplankton were observed in December.

Figure 4-13b Phytoplankton composition at D8, 2006

Site D41: San Pablo Bay

Chlorophyll *a* did show a seasonal pattern, although it was slightly obscured due to a large peak in February (Figure 4-14a). This peak was also the maximum for the year (15.80 µg/L) (Table 4-2). The minimum of 0.91 µg/L was recorded in January. The peak in February skewed the mean (4.06 µg/L) much higher than the median (2.29 µg/L) (Table 4-2).

Figure 4-14a Pigment concentrations at D41, 2006

Pheophytin *a* did not show a pattern; values were low and relatively stable all year (Figure 4-14a). The maximum of 2.33 µg/L was recorded in June; the minimum of 0.23 µg/L was recorded in November (Table 4-2). The mean and median were somewhat close (0.87 µg/L and 0.79 µg/L, respectively).

There was a small peak of unidentified flagellates in June, followed by a much larger peak of the same group in July (Figure 4-14b). Otherwise phytoplankton densities remained relatively low. No phytoplankton were observed in December.

Figure 4-14b Phytoplankton composition at D41, 2006

Site D41A: San Pablo Bay

Chlorophyll *a* showed a slight seasonal pattern; there was a large peak in June that was the maximum for the year (10.40 µg/L) (Figure 4-15a, Table 4-2). The minimum of 0.80 µg/L was recorded in January. The peak in June also skewed the mean much higher than the median (3.08 µg/L and 2.75 µg/L, respectively) (Table 4-2).

Figure 4-15a Pigment concentrations at D41A, 2006

Pheophytin *a* did not show a pattern; the maximum of 3.58 µg/L was recorded in April, and the minimum of 0.27 µg/L was recorded in January (Figure 4-15a, Table 4-2). The mean was 1.53 µg/L; the median was 1.40 µg/L.

There was a large peak of blue-green algae in March, followed by a smaller peak of centric diatoms in April (Figure 4-15b). Unidentified flagellates had small peaks in June and October. No phytoplankton were observed in July, September, or November.

Figure 4-15b Phytoplankton composition at D41A, 2006

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2006. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following 8 categories: centric diatoms, unidentified flagellates, green algae, blue-green algae, pennate diatoms, cryptomonads, euglenoids, and dinoflagellates. The 10 most common genera were unidentified flagellates, *Cyclotella*, *Monoraphidium*, *Aulacoseira*, unidentified centric diatoms, *Skeletonema*, *Merismopedia*, *Planktosphaeria*, *Cryptomonas*, and *Anabaena*. Chlorophyll *a* concentrations mostly showed a seasonal pattern; values ranged from 0.52 µg/L to 32.9 µg/L. Pheophytin *a* concentrations mainly did not show a seasonal pattern; values ranged from 0.18 µg/L to 12.70 µg/L. Overall, chlorophyll *a* concentrations were relatively low when compared with the historical data.

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van den Hoek, C., D.G. Mann, and H.M. Jahns. 1995. *Algae: an introduction to Phycology*. United Kingdom: Cambridge University Press.

Figure 4-1 Chlorophyll and phytoplankton monitoring stations

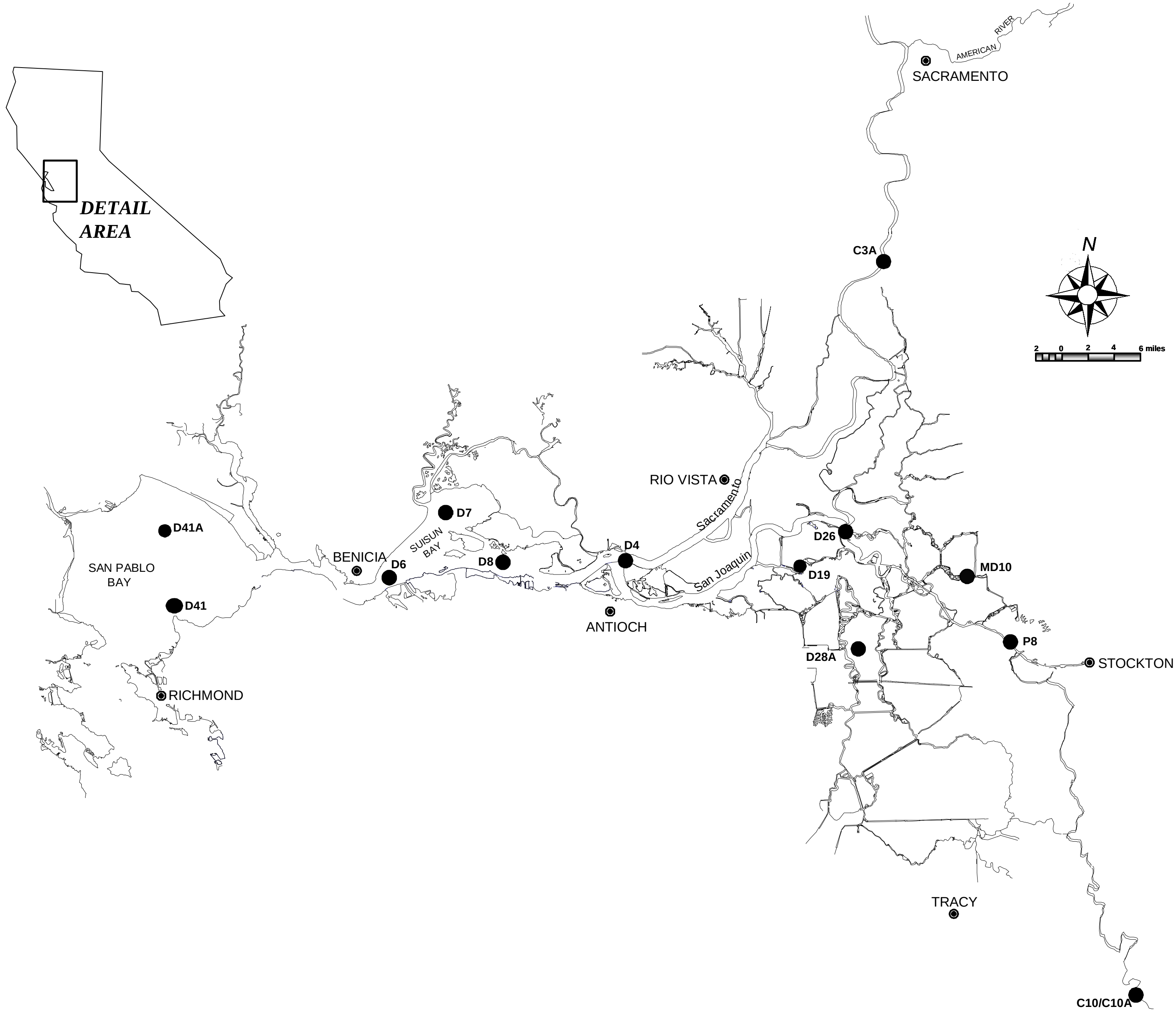

Figure 4-2 Percent phytoplankton composition by group, 2006

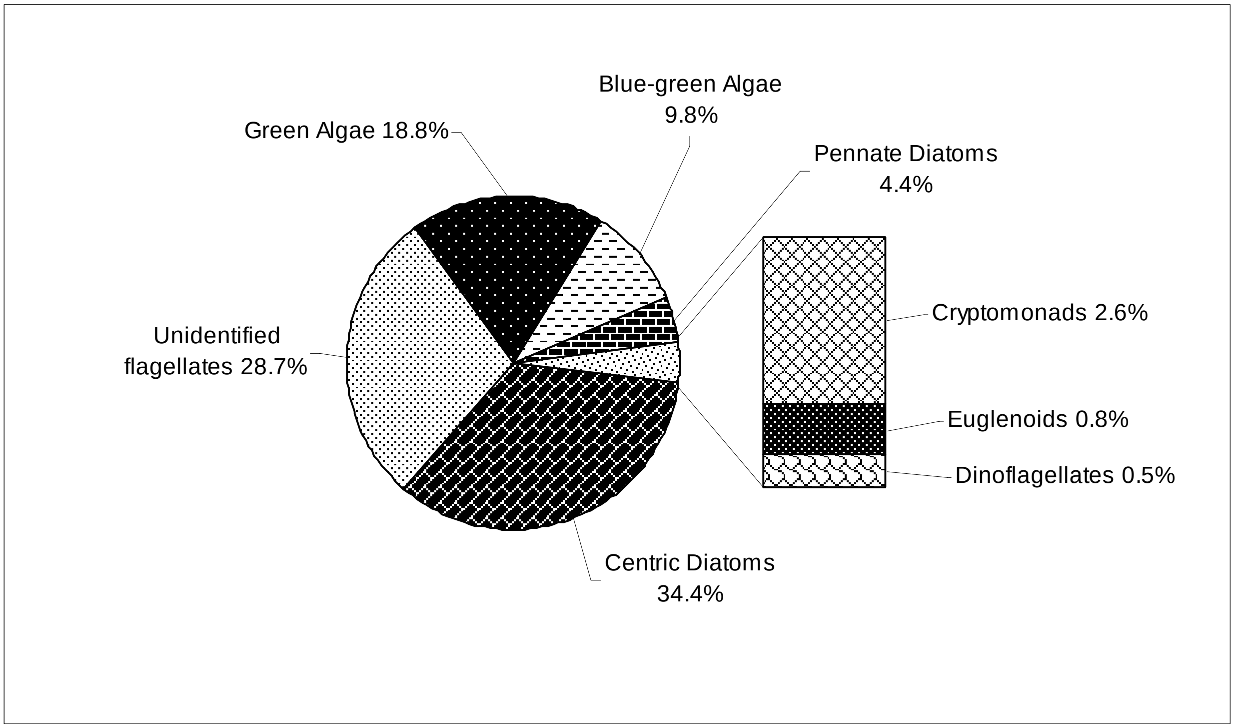

Figure 4-3a Pigment concentrations at C3A, 2006

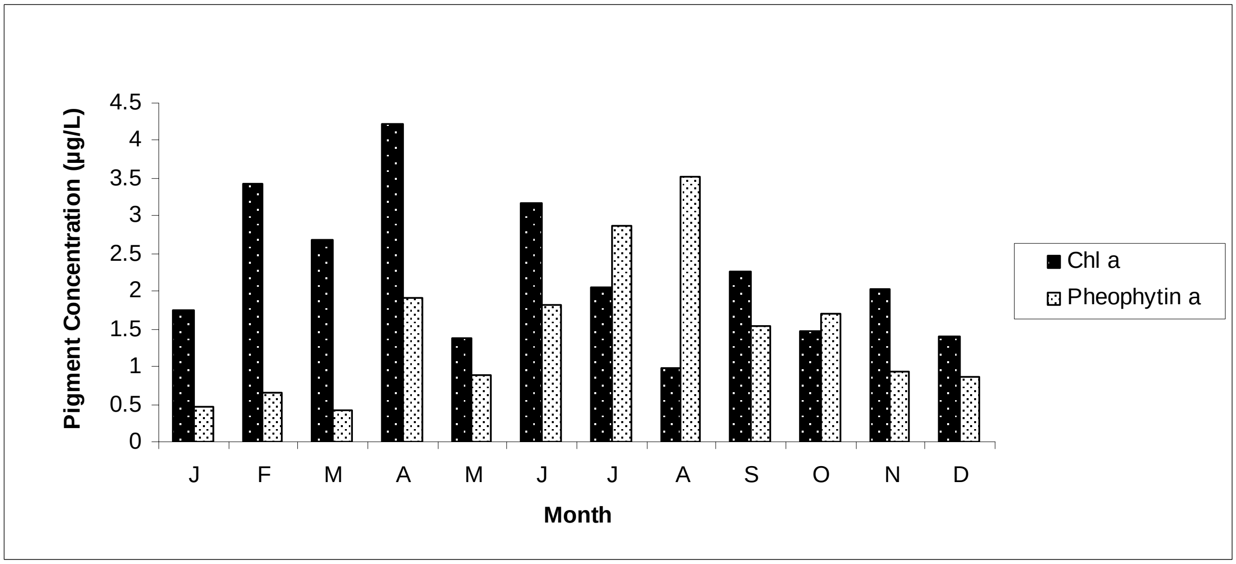

Figure 4-3b Phytoplankton composition at C3A, 2006

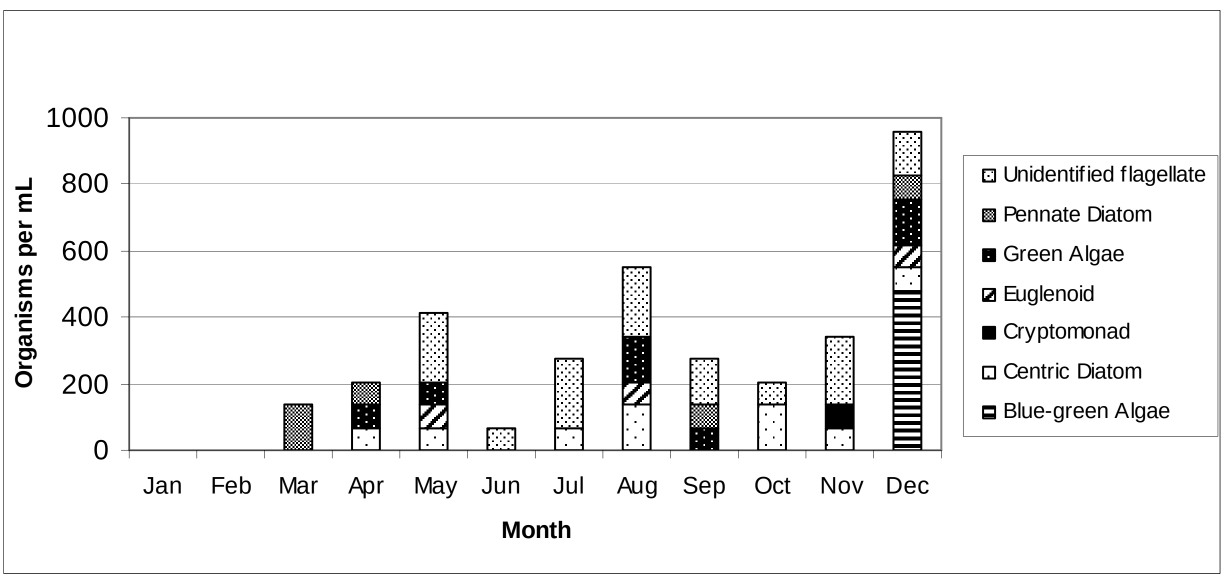

Figure 4-4a Pigment concentrations at C10A, 2006

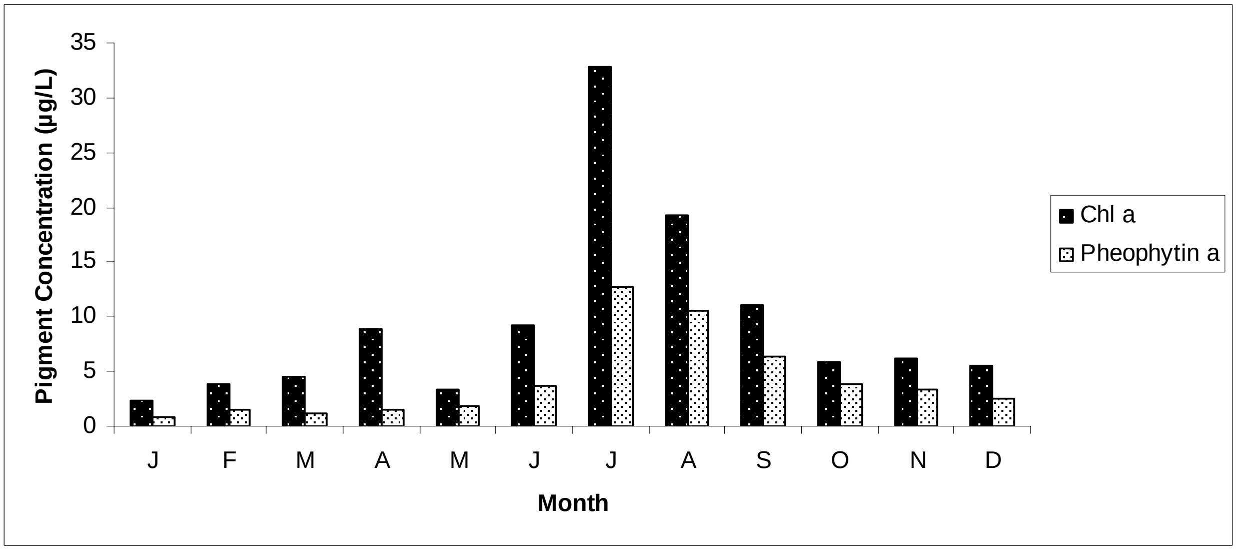

Figure 4-4b Phytoplankton composition at C10A, 2006

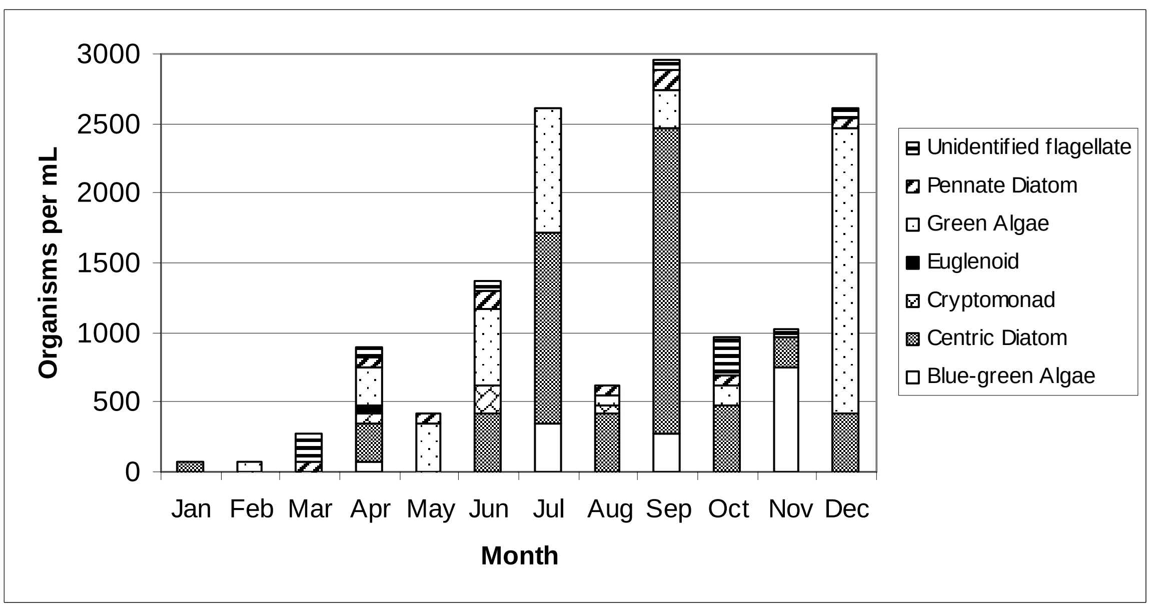

Figure 4-5a Pigment concentrations at P8, 2006

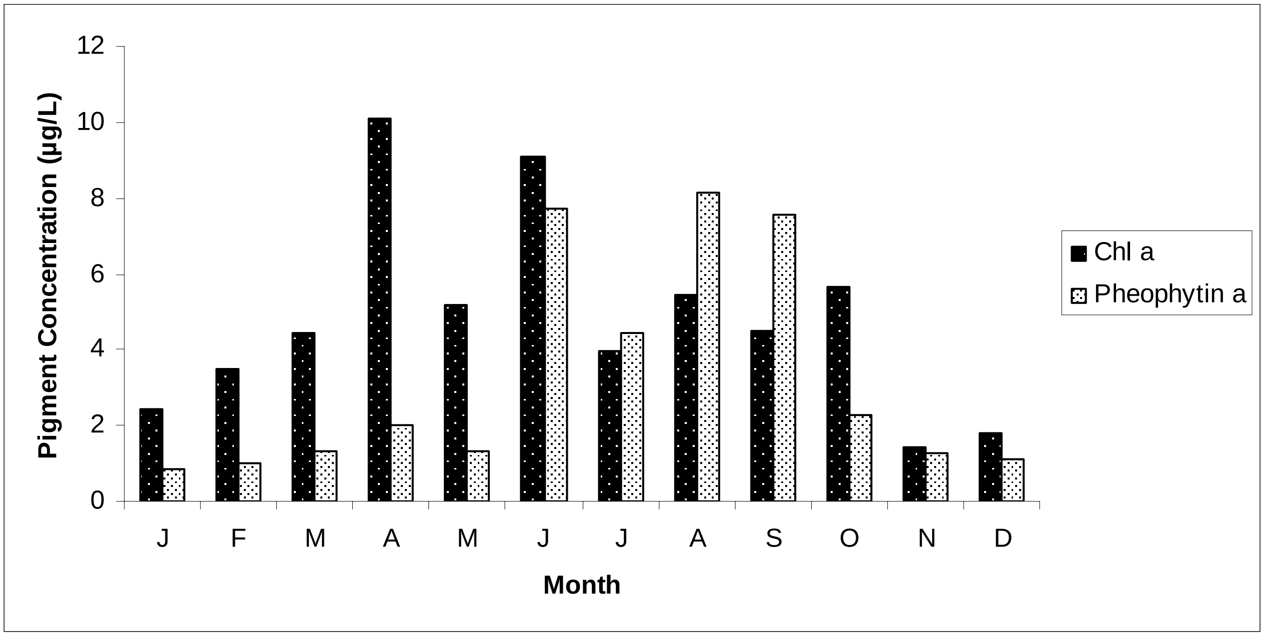

Figure 4-5b Phytoplankton composition at P8, 2006

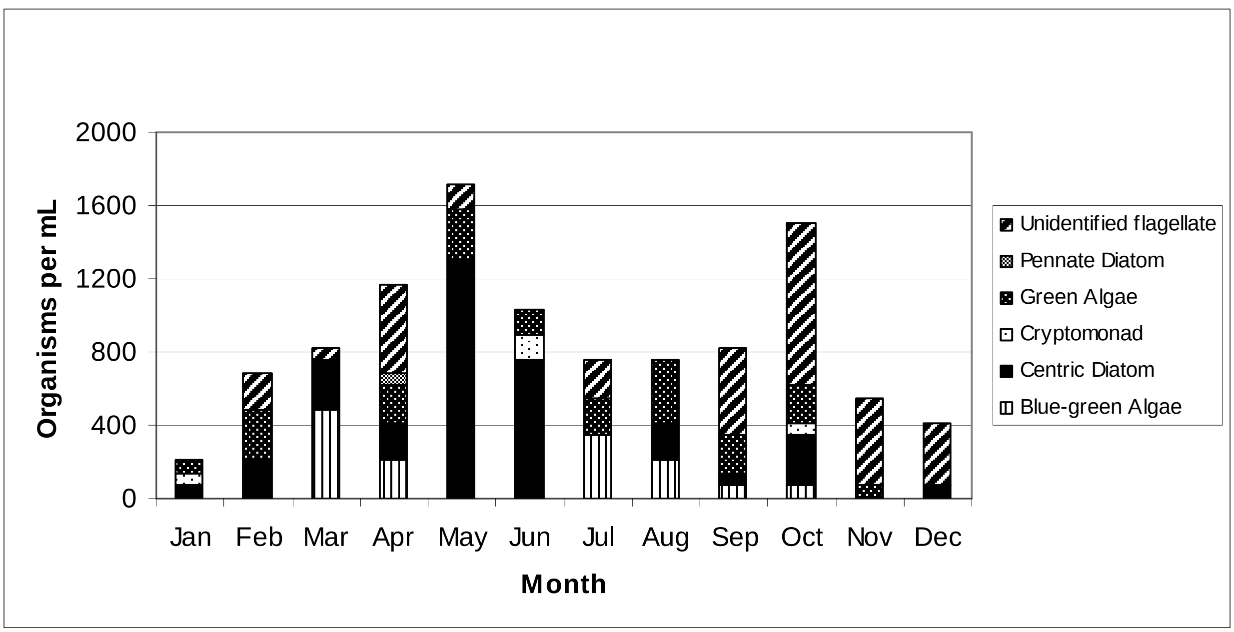

Figure 4-6a Pigment concentrations at MD10A, 2006

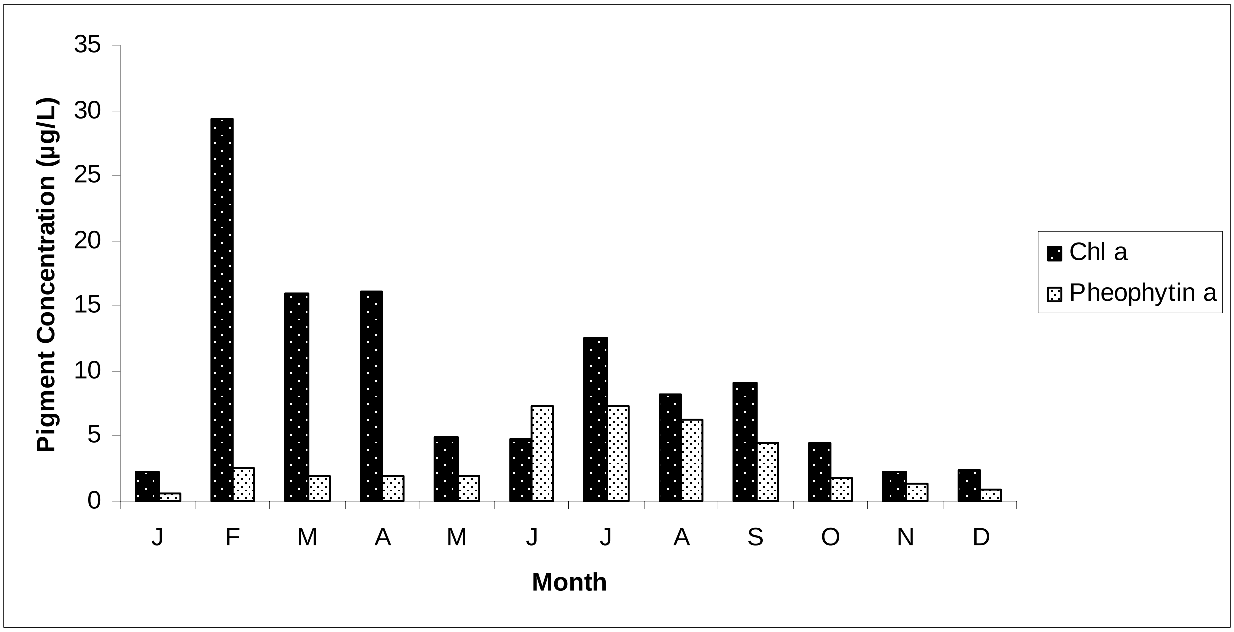

Figure 4-6b Phytoplankton composition at MD10A, 2006

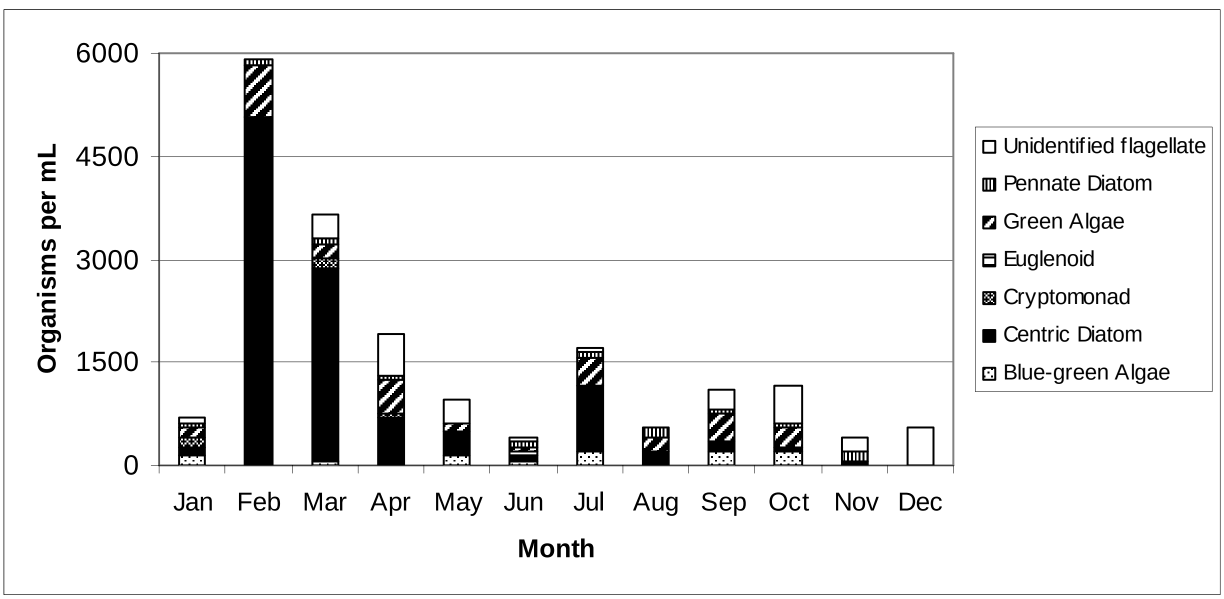

Figure 4-7a Pigment concentrations at D26, 2006

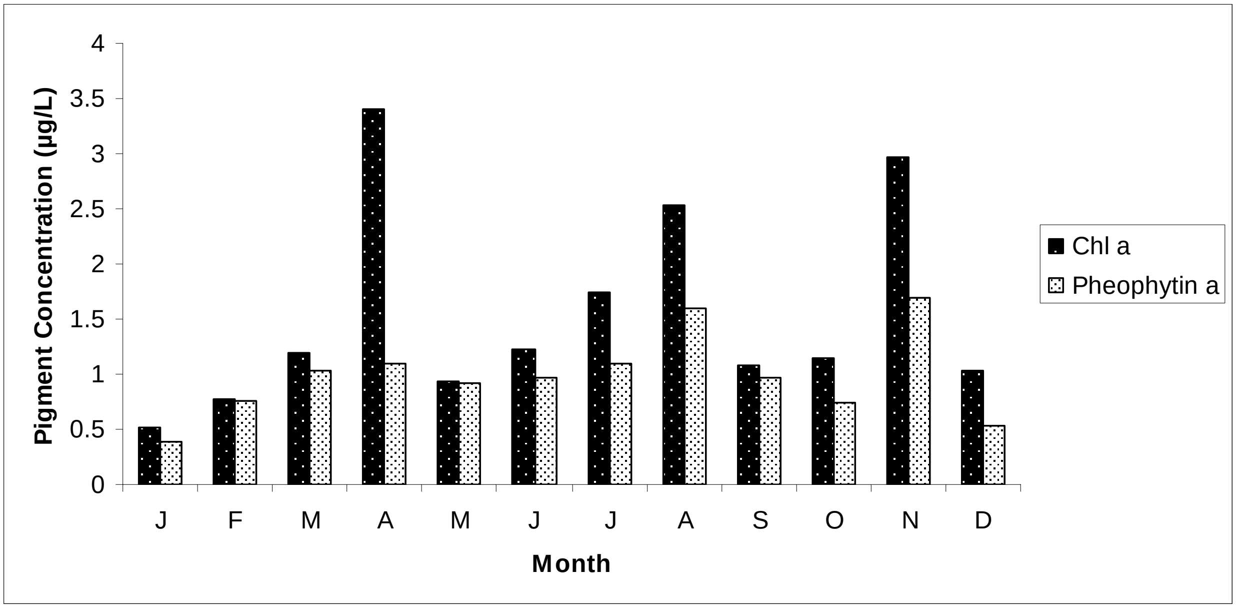

Figure 4-7b Phytoplankton composition at D26, 2006

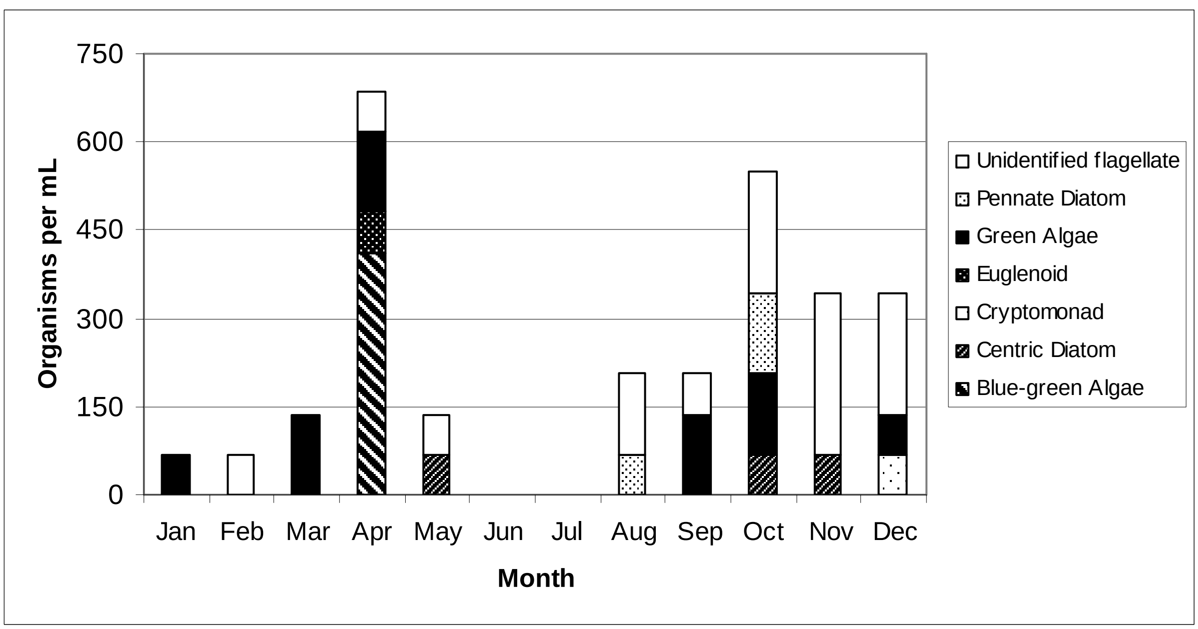

Figure 4-8a Pigment concentrations at D19, 2006

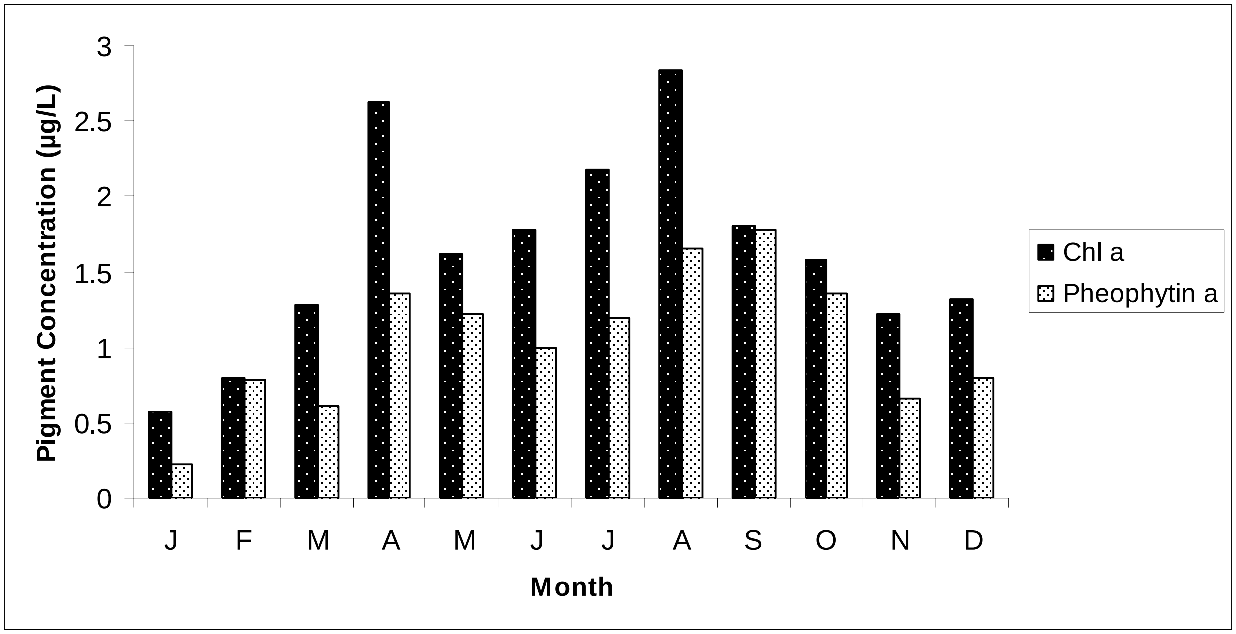

Figure 4-8b Phytoplankton composition at D19, 2006

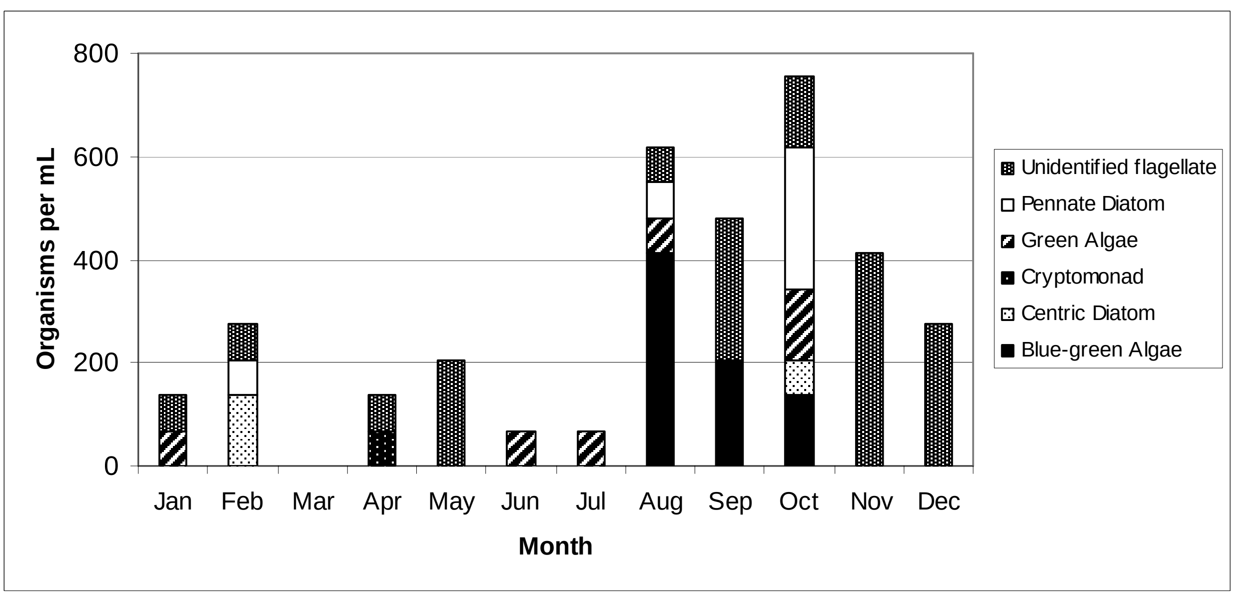

Figure 4-9a Pigment concentrations at D28A, 2006

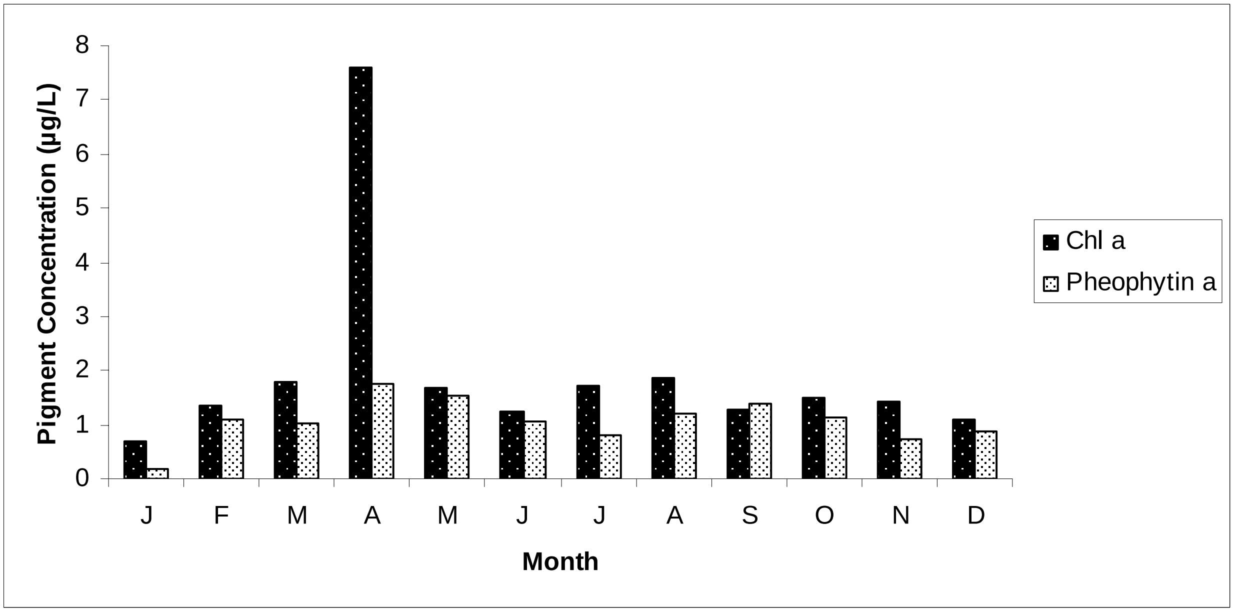

Figure 4-9b Phytoplankton composition at D28A, 2006

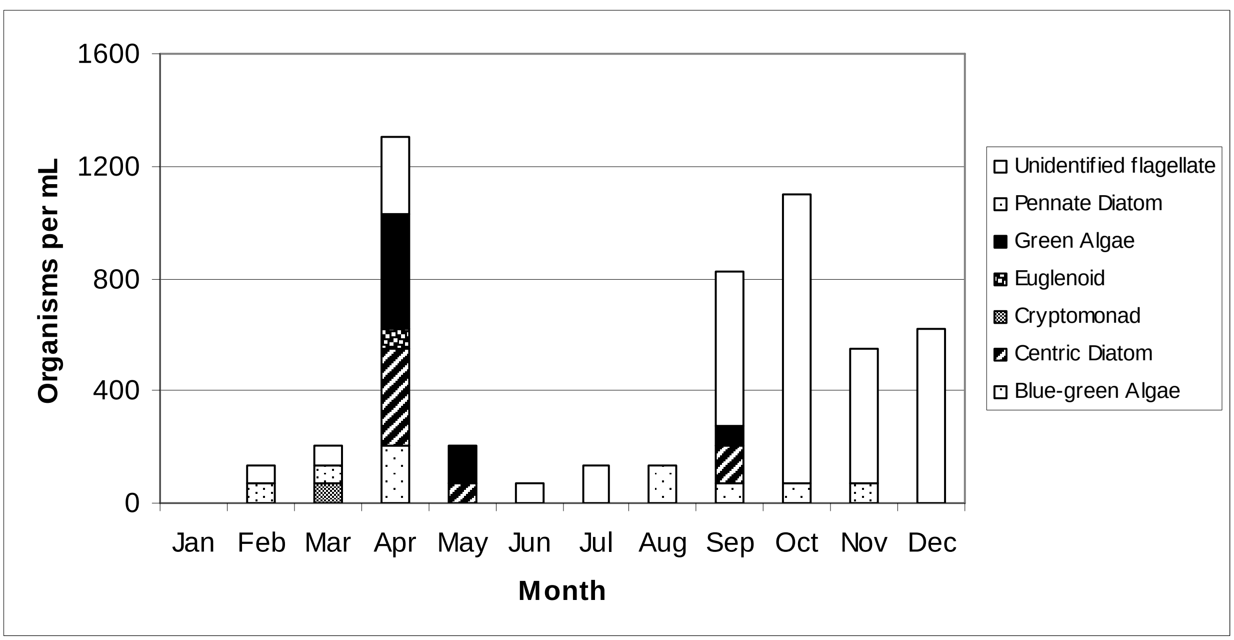

Figure 4-10a Pigment concentrations at D4, 2006

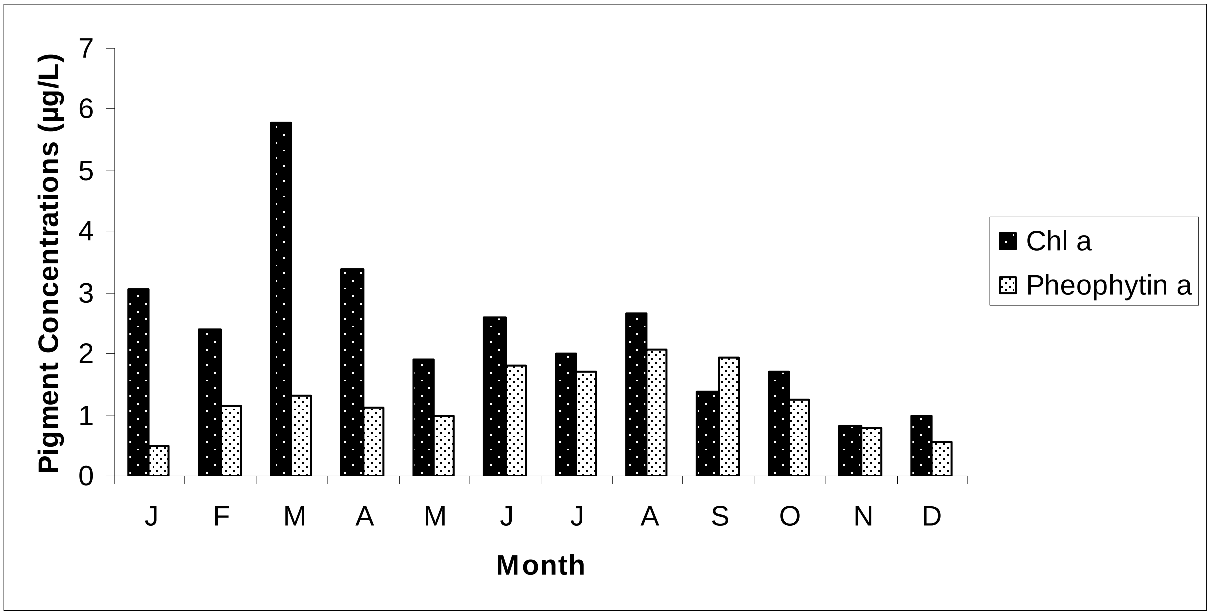

Figure 4-10b Phytoplankton composition at D4, 2006

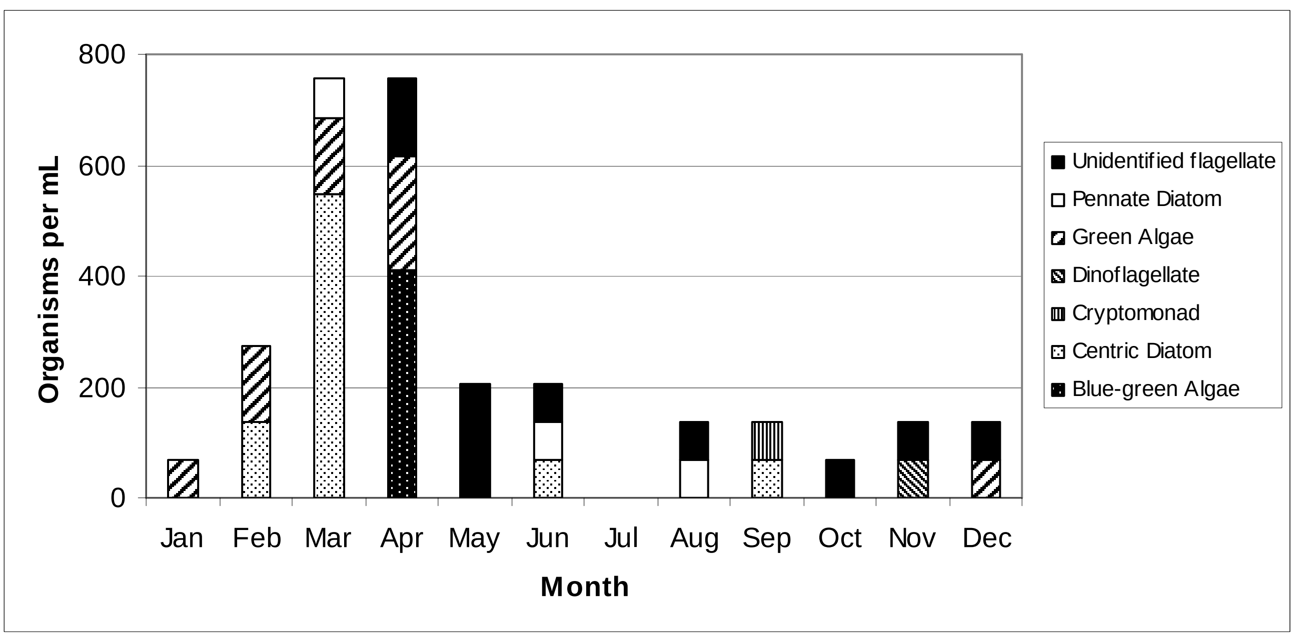

Figure 4-11a Pigment concentrations at D6, 2006

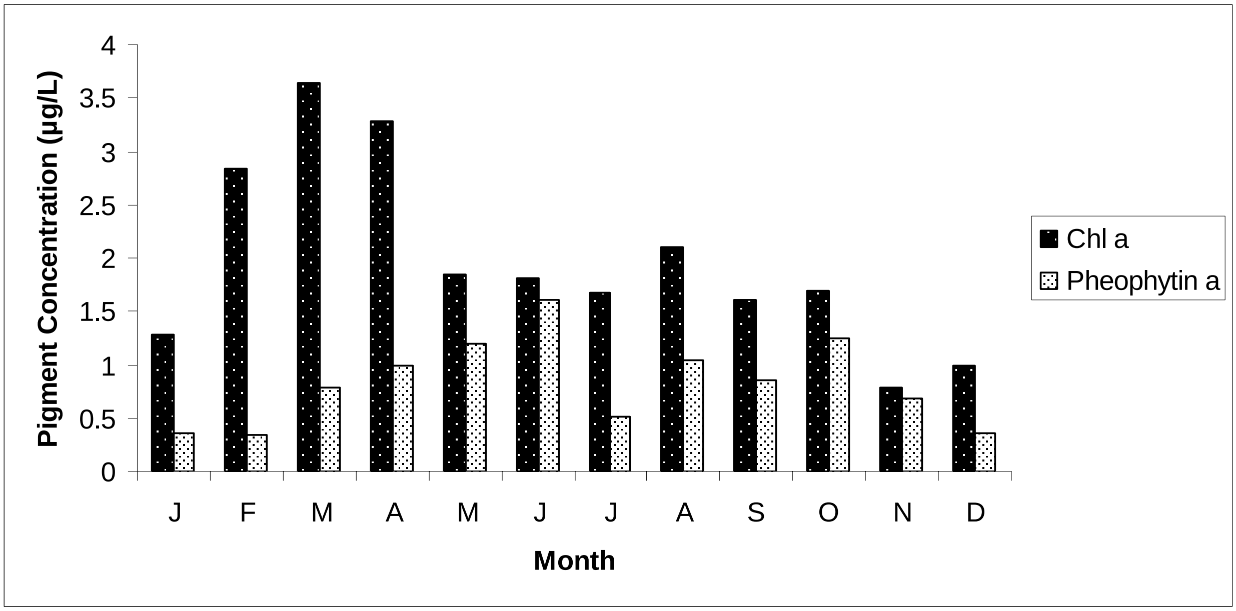

Figure 4-11b Phytoplankton composition at D6, 2006

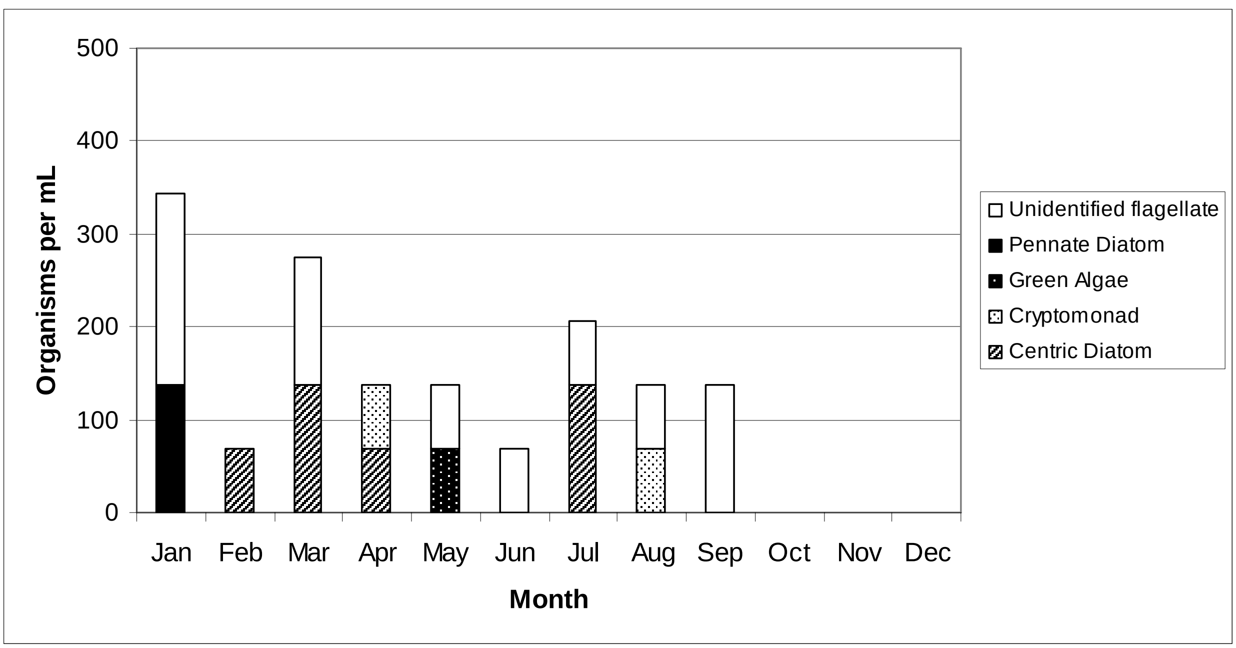

Figure 4-12a Pigment concentrations at D7, 2006

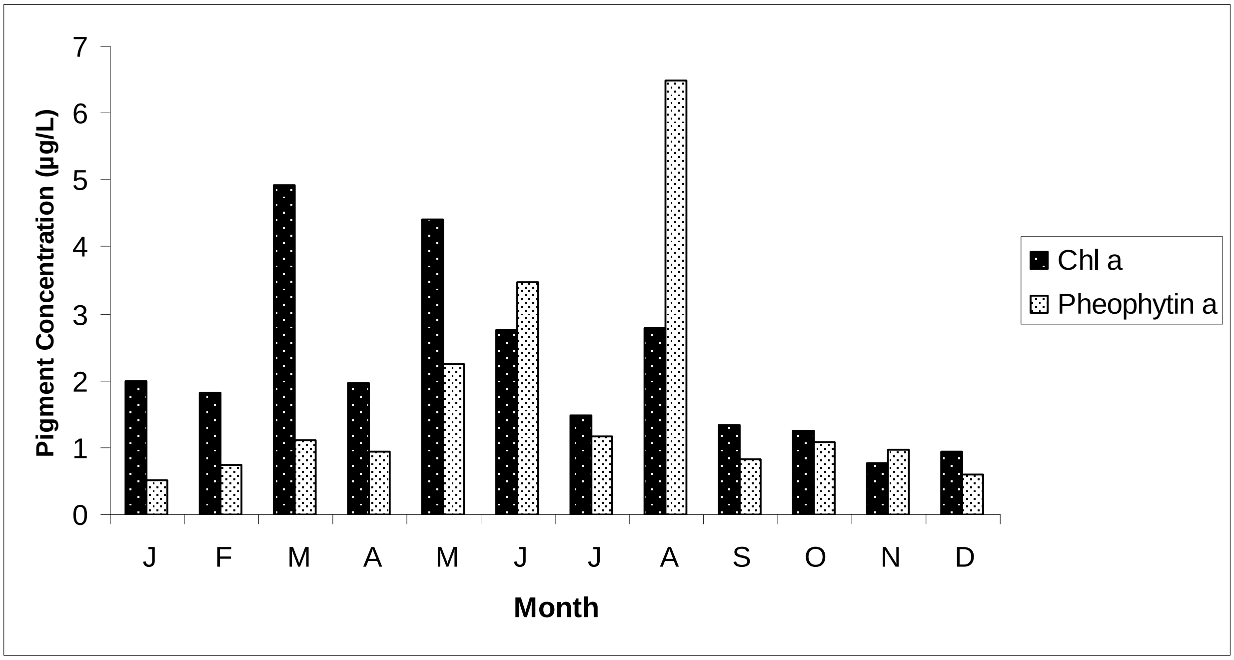

Figure 4-12b Phytoplankton composition at D7, 2006

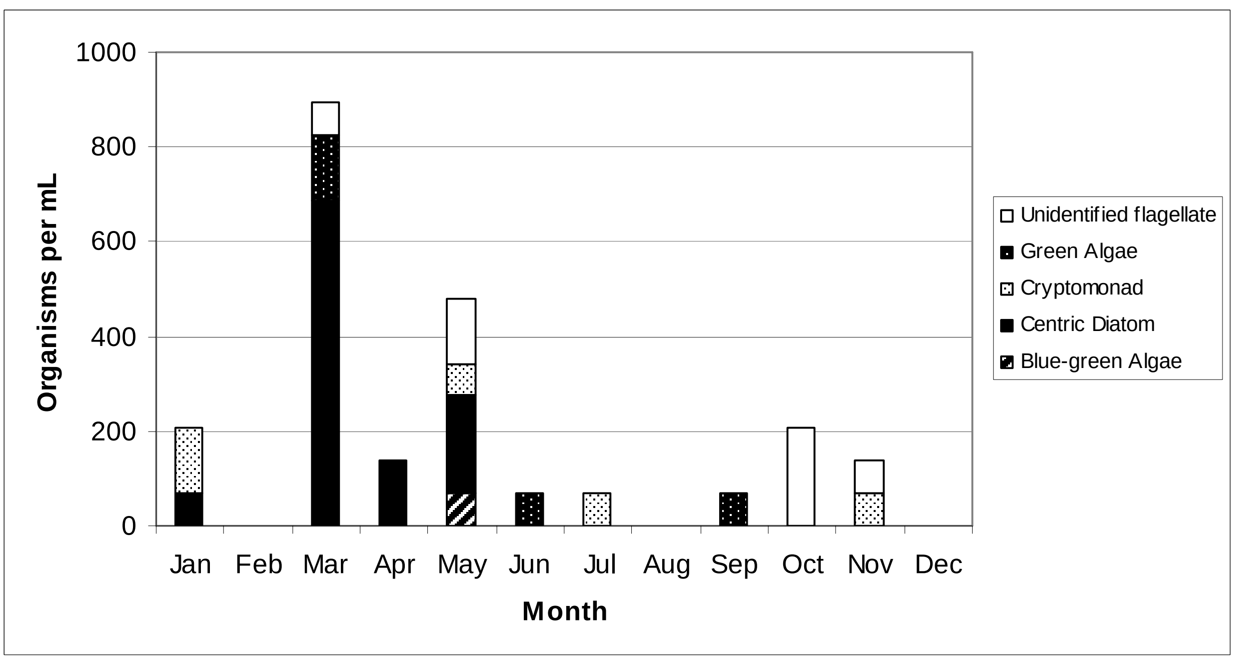

Figure 4-13a Pigment concentrations at D8, 2006

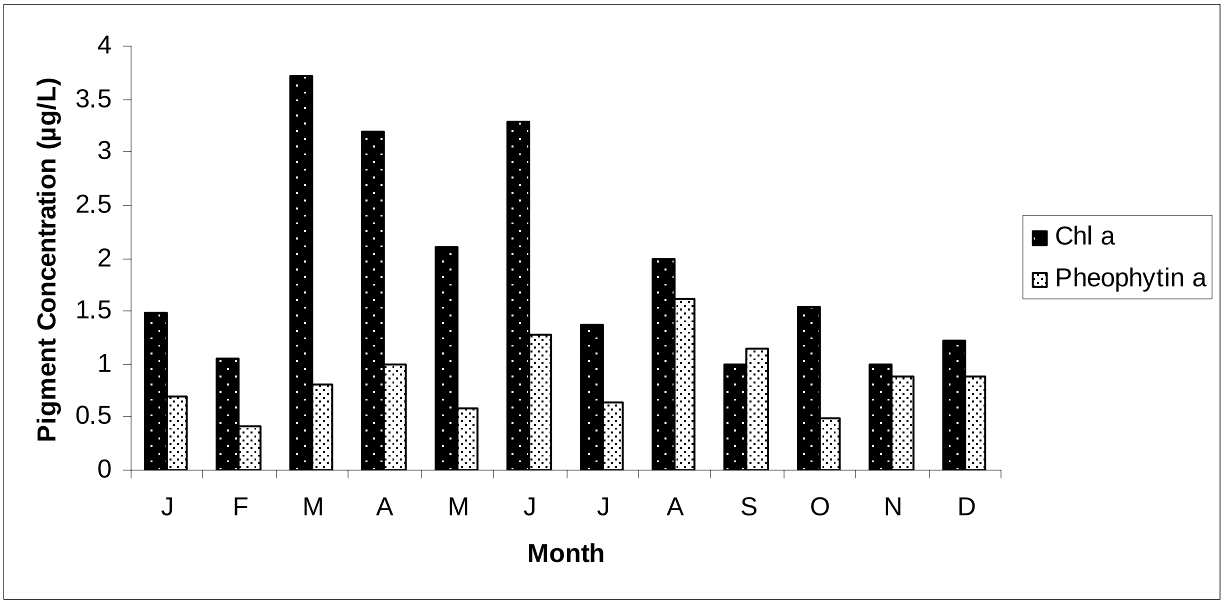

Figure 4-13b Phytoplankton composition at D8, 2006

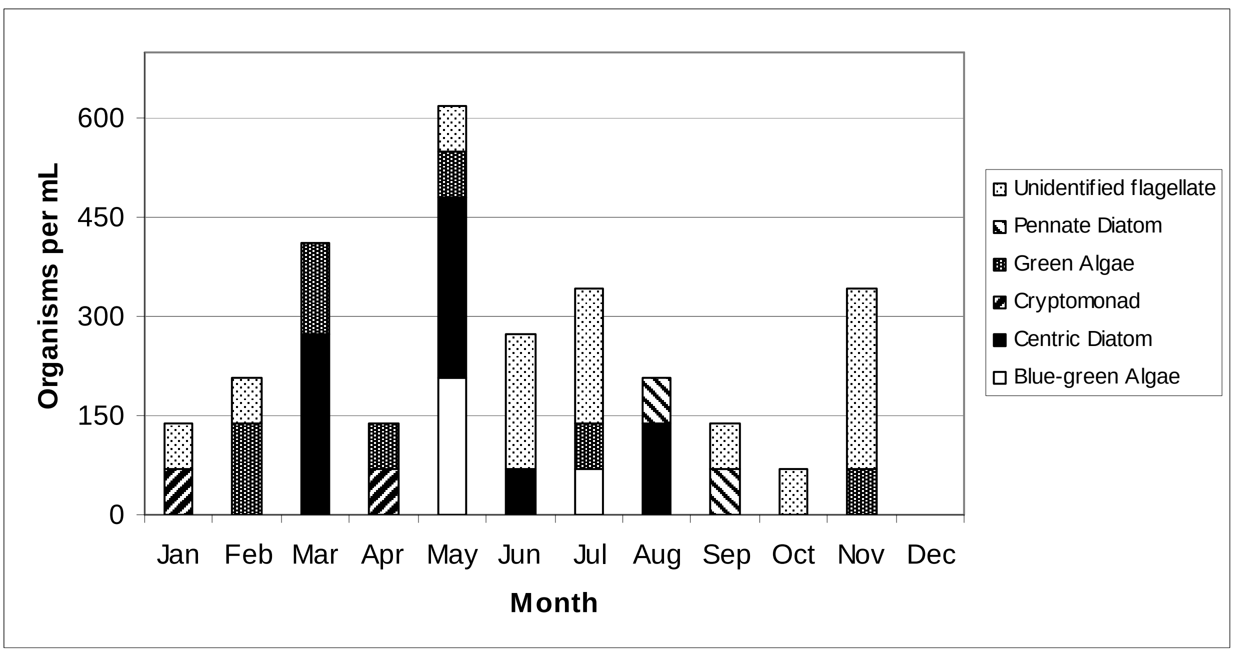

Figure 4-14a Pigment concentrations at D41, 2006

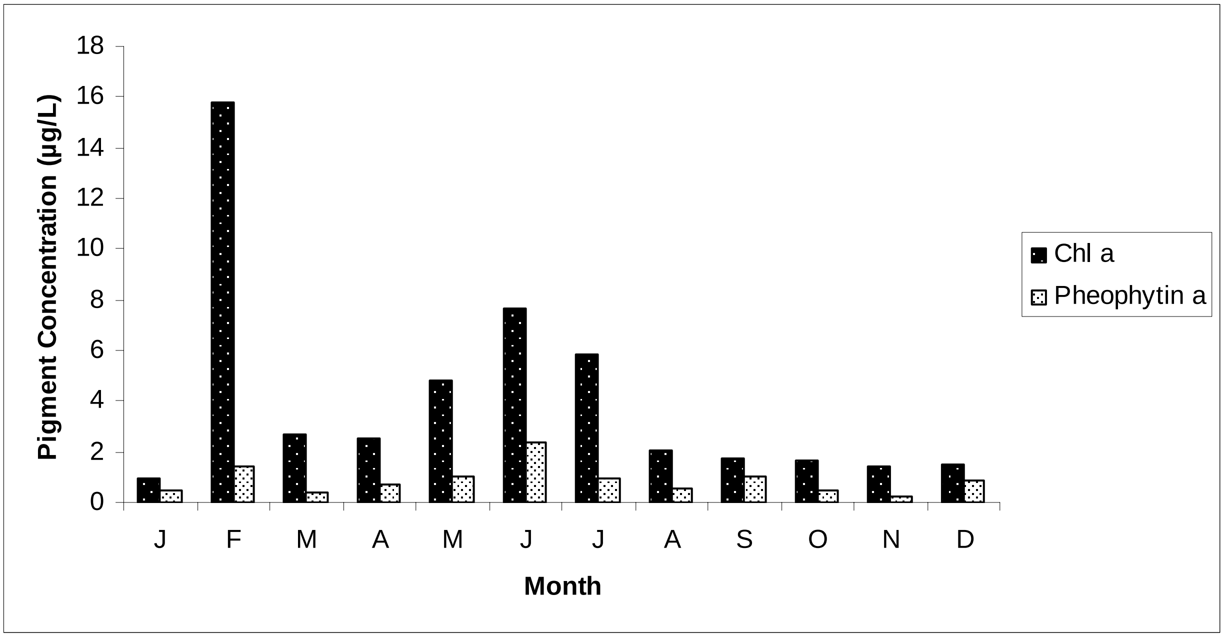

Figure 4-14b Phytoplankton composition at D41, 2006

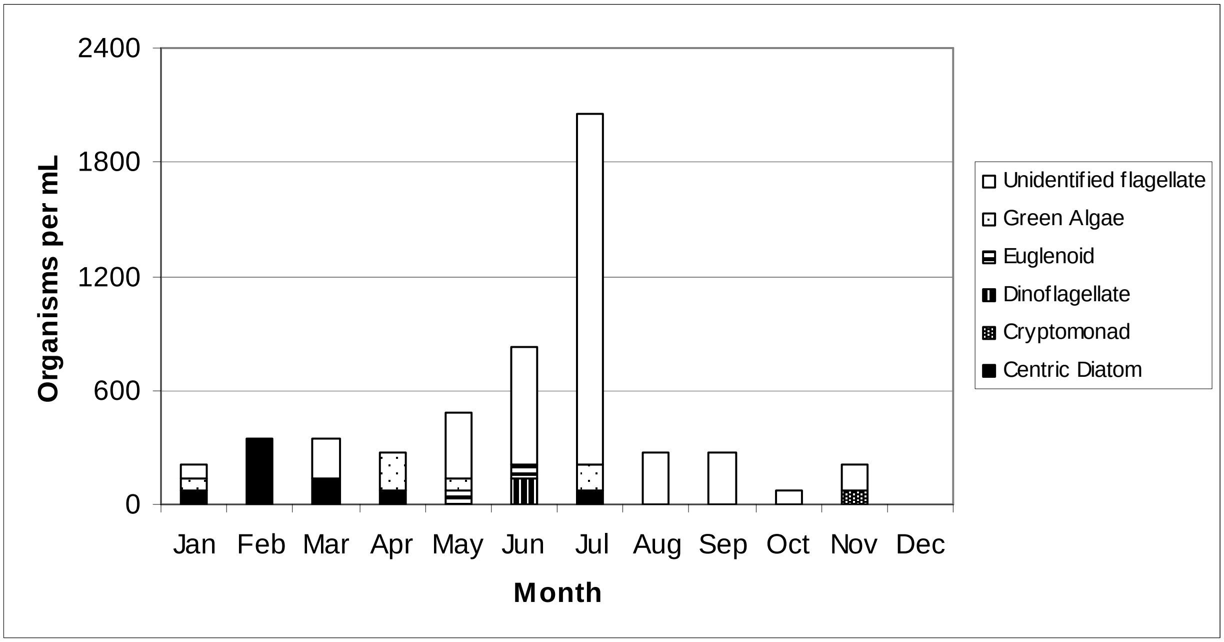

Figure 4-15a Pigment concentrations at D41A, 2006

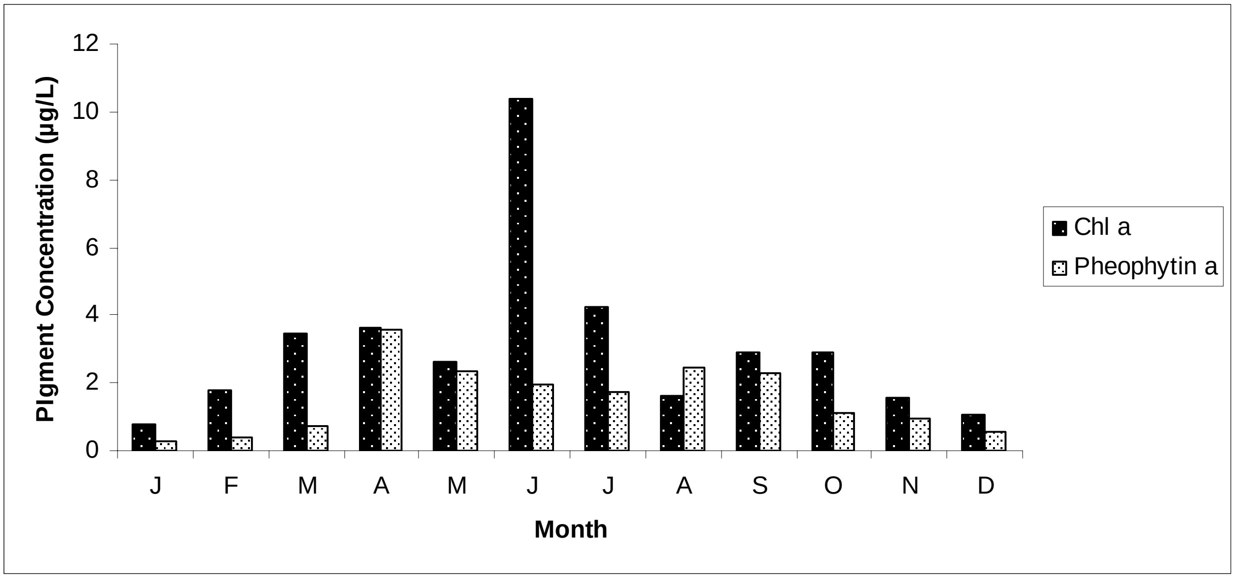

Figure 4-15b Phytoplankton composition at D41A, 2006

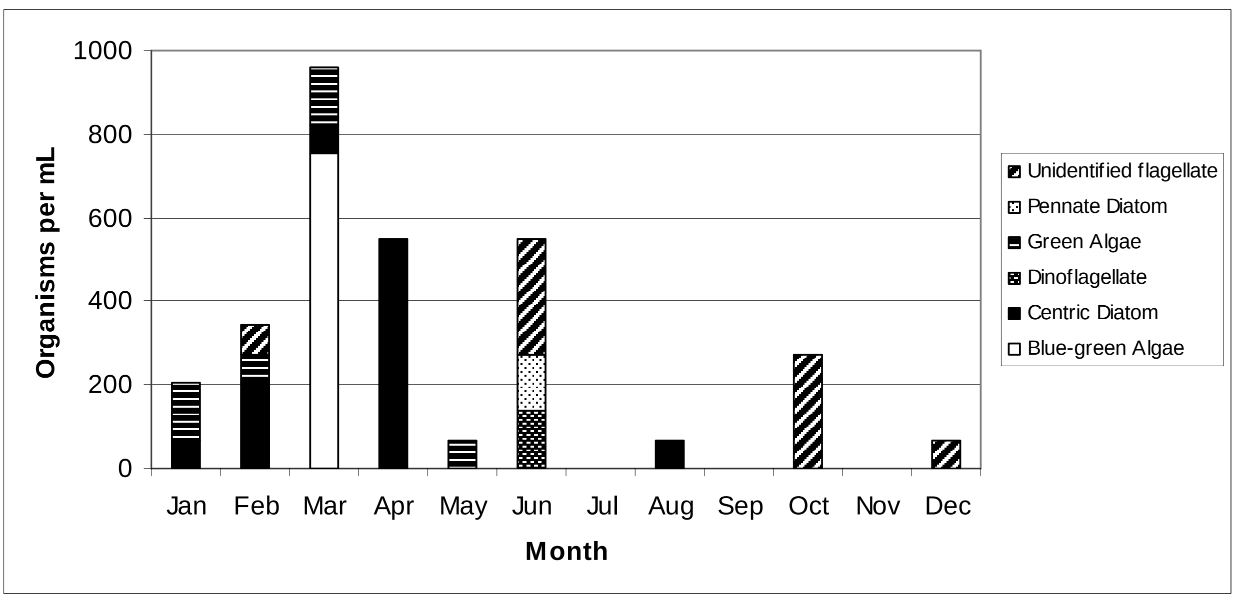

Table 4-1 Phytoplankton genera by group, 2006

Green Algae	**Pennate Diatoms**	**Blue-green Algae**	**Euglenoids**
Actinastrum	*Achnanthes*	*Anabaena*	*Euglena*
Carteria	*Amphiprora*	*Aphanizomenon*	*Phacus*
Chlamydomonas	*Asterionella*	*Chroococcus*	*Trachelomonas*
Chlorella	*Cocconeis*	*Gloeothece*	**Cryptomonads**
Chodatella	*Gomphonema*	*Merismopedia*	*Chroomonas*
Closterium	*Gyrosigma*	*Microcystis*	*Cryptomonas*
Coelastrum	*Navicula*	*Phormidium*	**Dinoflagellates**
Crucigenia	Pennate Diatom	*Planktolyngbya*	*Glenodinium*
Kirchneriella	*Synedra*	*Pseudanabaena*	*Gymnodinium*
Monoraphidium	**Centric Diatoms**	**Unidentified**	
Oocystis	*Aulacoseira*	Unidentified flagellates	
Planktosphaeria	Centric Diatom		
Scenedesmus	*Cyclotella*		
Schroederia	*Melosira*		
Tetraedron	*Skeletonema*		
Tetrastrum	*Stephanodiscus*		

Table 4-2 Chlorophyll *a* and pheophytin *a* concentrations, 2006

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard deviation
C3A	4.21	0.97	2.05	2.23	0.97
C10A	32.90	2.33	6.03	9.41	8.69
P8	10.10	1.45	4.47	4.79	2.64
MD10A	29.40	2.20	6.56	9.35	8.07
D26	3.40	0.52	1.17	1.55	0.92
D19	2.84	0.57	1.60	1.64	0.68
D28A	7.58	0.68	1.48	1.94	1.81
D4	5.78	0.81	2.19	2.39	1.33
D6	3.64	0.79	1.76	1.97	0.88
D7	4.92	0.76	1.89	2.20	1.31
D8	3.71	0.99	1.51	1.91	0.97
D41	15.80	0.91	2.29	4.06	4.24
D41A	10.40	0.80	2.75	3.08	2.54

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard deviation
C3A	3.53	0.43	1.24	1.47	0.97
C10A	12.70	0.89	2.88	4.14	3.85
P8	8.16	0.86	1.67	3.25	2.91
MD10A	7.32	0.61	1.93	3.20	2.48
D26	1.69	0.38	0.97	0.98	0.38
D19	1.78	0.23	1.09	1.05	0.46
D28A	1.76	0.18	1.07	1.06	0.41
D4	2.07	0.49	1.19	1.27	0.52
D6	1.61	0.35	0.82	0.83	0.40
D7	6.49	0.50	1.03	1.68	1.73
D8	1.61	0.41	0.85	0.87	0.35
D41	2.33	0.23	0.79	0.87	0.57
D41A	3.58	0.27	1.40	1.53	1.02

Chapter 5 Zooplankton and Mysid Shrimp

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Chapter 5 Zooplankton and Mysid Shrimp

Introduction

Zooplankton are important food organisms for larval and juvenile salmon, for juvenile striped bass and splittail, and for planktivorous fishes (such as delta smelt) throughout their lives. DFG'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 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. Newly introduced copepods, cladocerans, and rotifers are identified and enumerated as they are detected.

DFG = California Department of Fish and Game

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 locations, and 2 were "floating" stations located where bottom electrical conductance (EC) was 2,000 µS/cm and 6,000 µS/cm, +/-10%. One station in San Pablo Bay and 2 stations in Carquinez Strait were sampled only when their surface EC was less than 20,000 µS/cm. Monthly sampling was scheduled so that each station was sampled at high slack tide.

Figure 5-1 Zooplankton sampling stations in Delta and Suisun Bay

EC = electrical conductance

CB = Clarke-Bumpus

µm = micrometer

At each station, 3 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 were 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 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.

EC = electrical conductance

In past reports, the abundance of copepods, rotifers, and cladocerans was the sum of a taxon's CB and pump sample abundance (number per cubic meter). 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*. Abundance for both gears for these latter 2 species are reported here 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 3 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). Monthly and annual abundance for each taxon was calculated as the mean number per cubic meter 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 (log10 (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 3, 4, or 5 top-ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Abundance rankings were determined using catch per unit effort (CPUE)

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 ranging from 12% to 51% of the entrapment zone abundance (Figure 5-2). Seasonality was similar among zones, with peaks in spring and summer through early fall.

Table 5-1 Mysids (CPUE), 2006

Figure 5-2 Monthly *Acanthomysis bowmani* upstream, in, and downstream of the entrapment zone (CPUE), 2006

Neomysis japonica may be present in the Estuary; it is very similar to the native *Neomysis kadiakensis*. Until the 2 species are differentiated, they will be grouped together as *Neomysis 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 6 months and in very low numbers (Figure 5-3). Abundance peaked in early spring and summer within and downstream of the entrapment zone.

Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Neomysis mercedis was the third most abundant mysid, collected mainly within and upstream of the entrapment zone (Table 5-1, Figure 5-4). Numbers downstream were extremely low. Until the mid-1990s, this native species was the most common mysid in the Estuary. In 2006, abundance peaked in early spring and summer, and then declined the rest of the year.

Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

The native *Alienacanthomysis macropsis* prefers higher salinities and was collected mainly downstream of the entrapment zone (Figure 5-5). One collection occurred in the entrapment zone in 2006, with no upstream collections. *A. macropsis* was collected in most months of the year for 2006, but in very low numbers.

Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in 2006 (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.

Table 5-2 Calanoid Copepods (CPUE), 2006

Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

The genus *Acartia* consists of 3 native brackish water species, and it was the second most common calanoid copepod overall (Table 5-2). It was by far the most common taxon collected downstream. Within and upstream of the entrapment zone, it appeared in only 6 months between the 2 zones (Figure 5-7). Downstream, abundance was highest in late winter and early spring, and then declined sharply in the summer.

Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Eurytemora spp. was the third most common calanoid copepod in 2006 (Table 5-2), switching ranks with *Acartiella sinensis*, which was third in 2005. *Eurytemora* spp. was most common in the entrapment zone. Upstream and downstream showed similar seasonal trends, with peaks in late winter and early spring (Figure 5-8). In the entrapment zone, abundance peaked in spring and then declined sharply in the summer.

Figure 5-8 Monthly *Eurytemora* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

The introduced *Acartiella sinensis* was the fourth most abundant calanoid copepod, with highest abundance within the entrapment zone (Table 5-2). Abundance upstream peaked in the fall, but abundance downstream and in the entrapment zone peaked in late summer (Figure 5-9).

Figure 5-9 Monthly *Acartiella* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Sinocalanus doerrii was the fifth most common calanoid copepod in 2006 (Table 5-2), as it had been in 2005. It was most common in the entrapment zone, where abundance peaked in spring (Figure 5-10). A similar trend was seen downstream of the entrapment zone, but upstream abundance peaked in summer.

Figure 5-10 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

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 3 zones, with the majority occurring in and downstream of the entrapment zone (Table 5-3). Upstream of the entrapment zone, abundance in both the CB and pump samples peaked in summer and fall (Figure 5-11). Within the entrapment zone, numbers were stable all year for both gears, with no sharp increases or decreases. Downstream samples showed a similar pattern, except for a peak in the CB samples in November.

Table 5-3 Cyclopoid Copepods (CPUE), 2006

Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Another introduced species, *Oithona davisae*, was the second most abundant cyclopoid copepod in 2006 (Table 5-3). It was most common downstream of the entrapment zone (both CB and pump samples) (Figure 5-12). Numbers were fairly low upstream of the entrapment zone for both gears, except for 2 sharp peaks in summer and fall in the pump samples. The entrapment zone showed a similar pattern, with a sharp peak in the fall in the pump samples. Downstream of the entrapment zone, the 2 gears diverged early in the year, with the CB samples having higher numbers than the pump samples. But starting in August, both gears showed nearly identical increases before declining in the fall.

Figure 5-12 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod in 2006, and was most abundant in and upstream of the entrapment zone (Table 5-3). Patterns of abundance for all zones were similar, with declines in winter followed by large peaks in spring, and then a second decline in summer and fall (Figure 5-13).

Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Cladocerans

The most common cladocerans collected by this study are mainly freshwater; the majority of them are found upstream of the entrapment zone. *Bosmina* spp. was the most abundant cladoceran overall (Table 5-4) and was most common upstream. Upstream numbers were relatively high all year. In and downstream of the entrapment zone, abundance peaked in early spring and declined in summer (Figure 5-14). Both zones saw increases in fall, but the increase in the entrapment zone was much higher.

Table 5-4 Cladocerans (CPUE), 2006

Figure 5-14 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

The second most abundant cladoceran in 2006 was *Daphnia* spp. (Table 5-4), switching ranks with *Diaphanosoma* spp., which was second most abundant in 2005. It was most common upstream, where abundance peaked in spring and summer (Figure 5-15). In the entrapment zone, abundance peaked in late winter and early spring; after a second peak in June, abundance declined in the fall. Downstream, there was a small peak in abundance in spring followed by declining numbers the rest of the year.

Figure 5-15 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Diaphanosoma spp. was the third most abundant cladoceran in 2006 (Table 5-4). As with *Bosmina* and *Daphnia*, it was most common upstream where abundance peaked in summer and fall (Figure 5-16). Both in and downstream of the entrapment zone, there were small peaks in summer and fall, with low numbers the rest of the year.

Figure 5-16 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Rotifers

In 2006, the common rotifer taxa kept the same ranks as in 2005. Like cladocerans, rotifers are primarily freshwater organisms. The most common rotifer in 2006 was *Synchaeta* spp. (Table 5-5). It was most common upstream of the entrapment zone, but its numbers were relatively high in the other zones as well (Figure 5-17). Abundance in all zones remained fairly stable throughout the year, with the exception of a sharp decline in June in the entrapment zone.

Table 5-5 Rotifers (CPUE), 2006

Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Keratella spp. was the second most abundant rotifer in 2006 (Table 5-5). Abundance trends varied among zones. It was relatively stable upstream, declining in December, but there were several sharp peaks and declines in the entrapment zone (Figure 5-18). Downstream abundance fluctuated mildly throughout the year.

Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Polyarthra spp. was the third most common rotifer in 2006 (Table 5-5). Like the other 2 species, abundance was stable upstream of the entrapment zone (Figure 5-19). Within the entrapment zone, abundance was high early in the year, but declined sharply in summer and fall. Downstream of the entrapment zone, abundance was also high early in the year, and saw a sharp decline in summer before increasing again in the fall.

Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

Summary

In 2006, the annual rankings of the most common zooplankton were the same as in 2005, with a few exceptions. Monthly abundance patterns between 2005 and 2006 were also similar. The introduced *Acanthomysis bowmani* and the *Neomysis kadiakensis/japonica* complex remained the 2 most abundant mysids, followed by the native *Neomysis mercedis* and *Alienacanthomysis macropsis*. *Pseudodiaptomus forbesi*, ranked first in 2005, was again the most common calanoid copepod. The native *Acartia* spp. was second, followed by *Eurytemora* spp., *Acartiella sinensis,* and *Sinocalanus doerrii*. In 2005, *Acartiella sinensis* was third, and *Eurytemora* spp. fourth. The 3 most common cyclopoid copepods remained the introduced *Limnoithona tetraspina* and *Oithona davisae*, followed by the native *Acanthocyclops vernalis*. The top 3 cladocerans changed in 2006. *Bosmina* spp. was again most common, but *Daphnia* spp. was second, and *Diaphanosoma* spp. third. In 2005, *Diaphanosoma* spp. was second most common, and *Daphnia* spp. third. The rotifers maintained their ranks in 2006, with *Synchaeta* spp. most common, followed by *Keratella* spp. and *Polyarthra* spp.

Figure 5-1 Zooplankton sampling stations in Delta and Suisun Bay

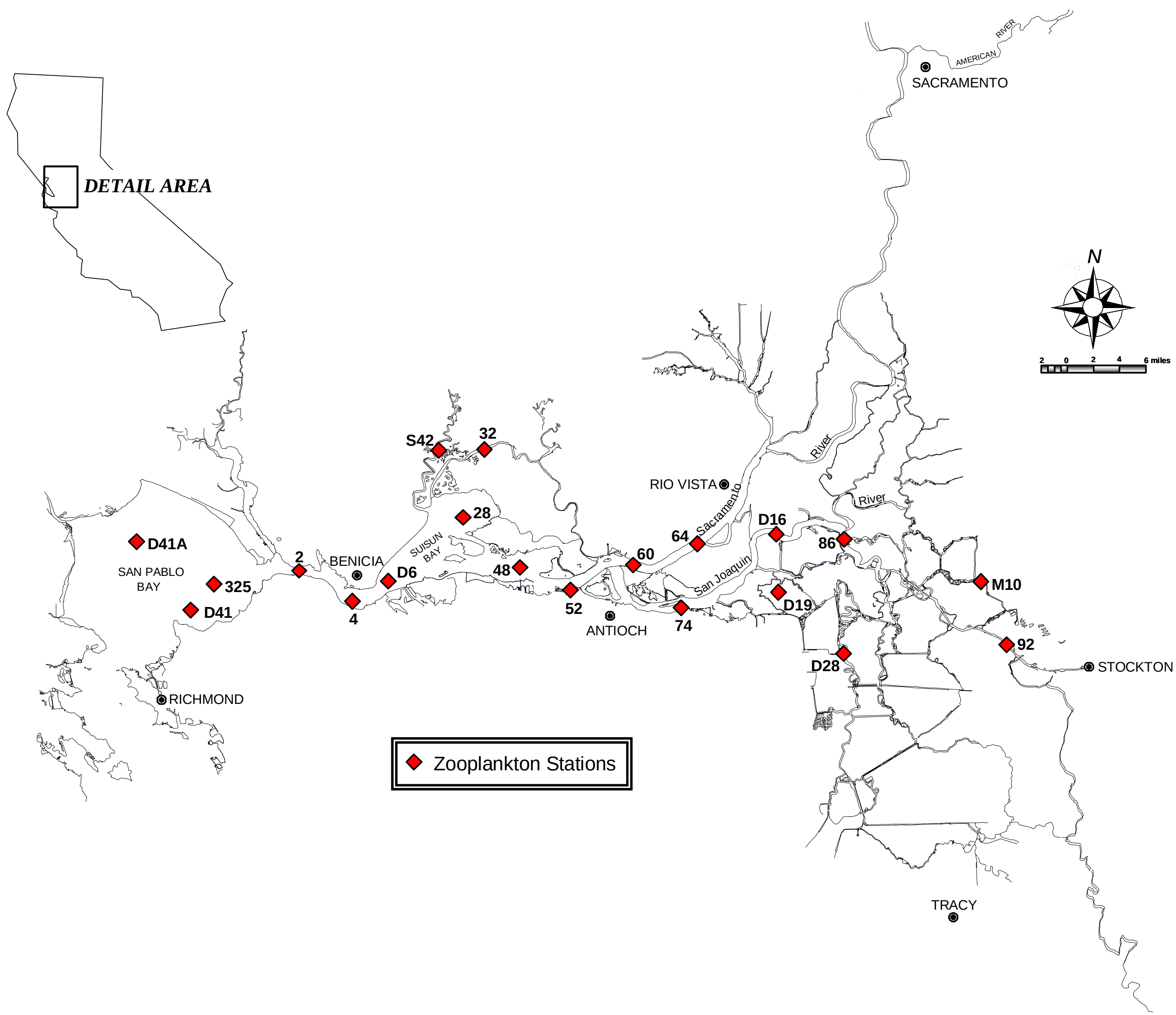
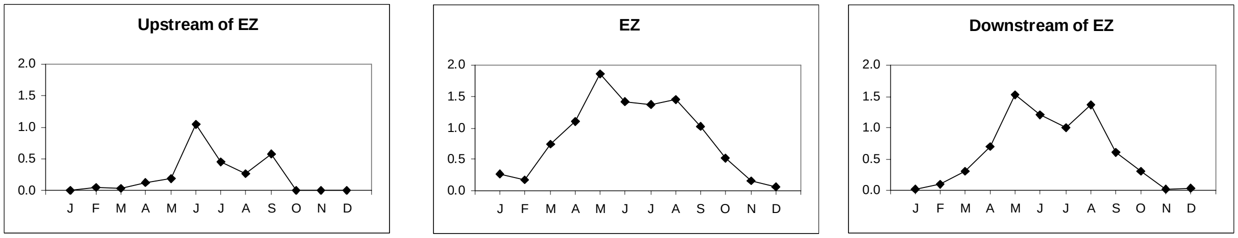


Figure 5-2 Monthly *Acanthomysis bowmani* upstream, in, and downstream of the entrapment zone (CPUE), 2006



CPUE = catch per unit effort

Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

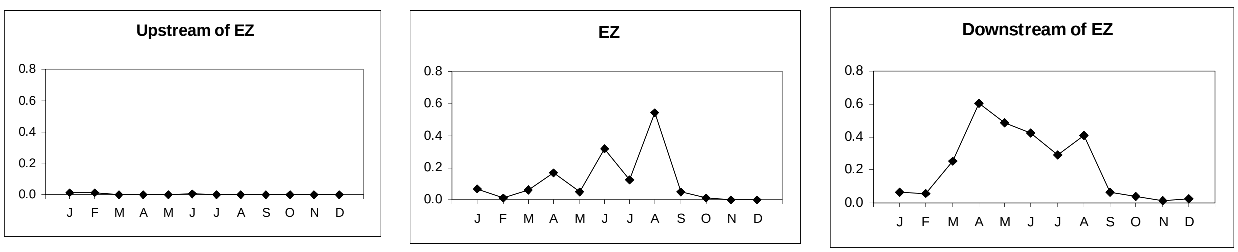


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

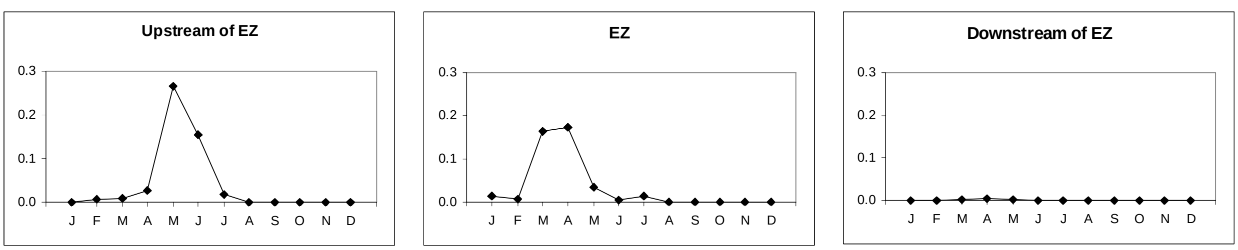


Figure 5-5 Monthly *Alienacanthomysis macropsis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

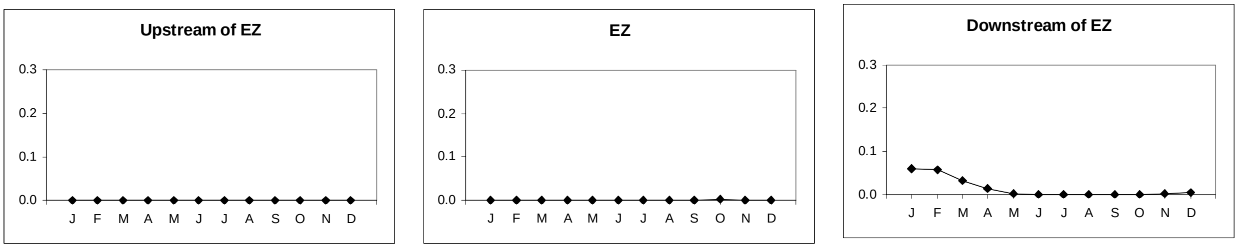


Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

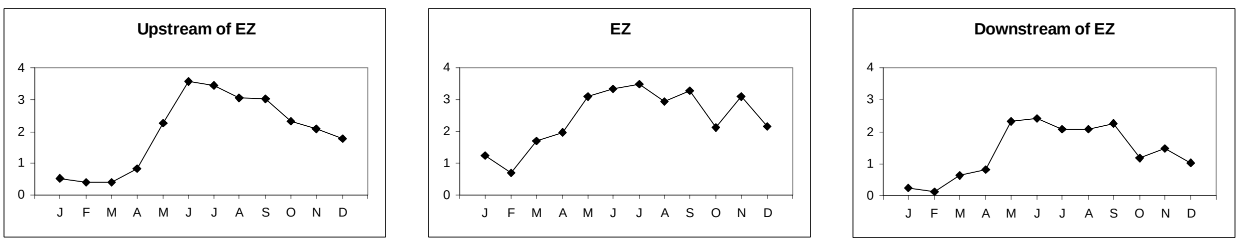


Figure 5-7 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

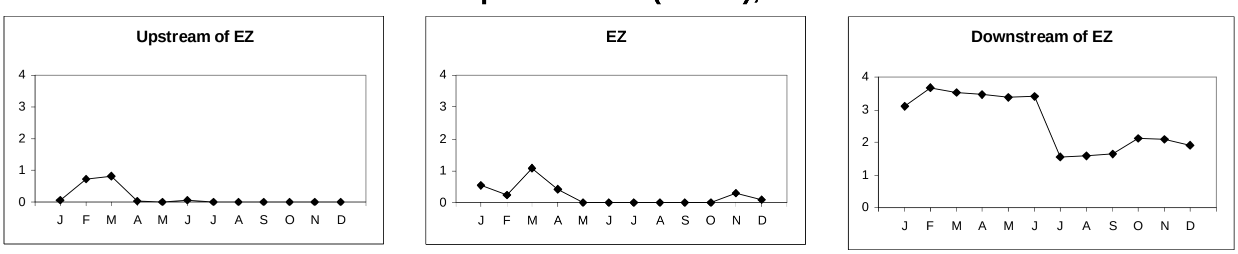


Figure 5-8 Monthly *Eurytemora* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

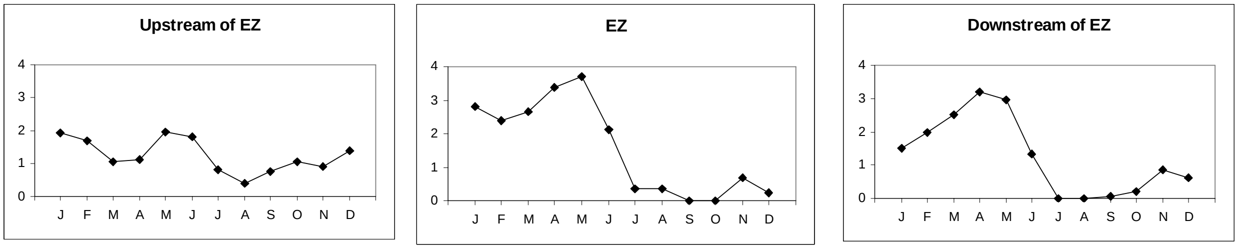


Figure 5-9 Monthly *Acartiella* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

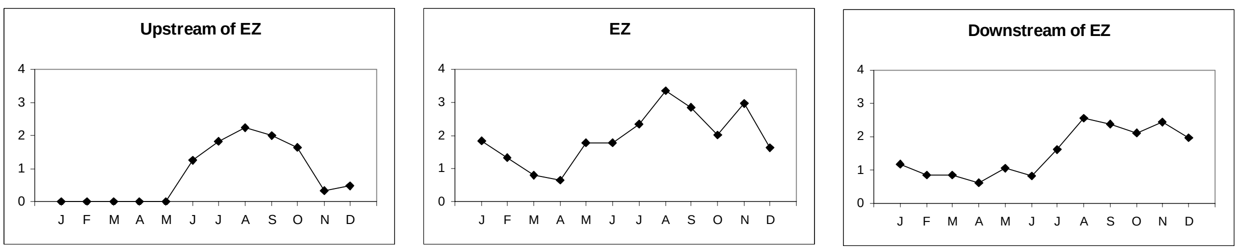


Figure 5-10 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

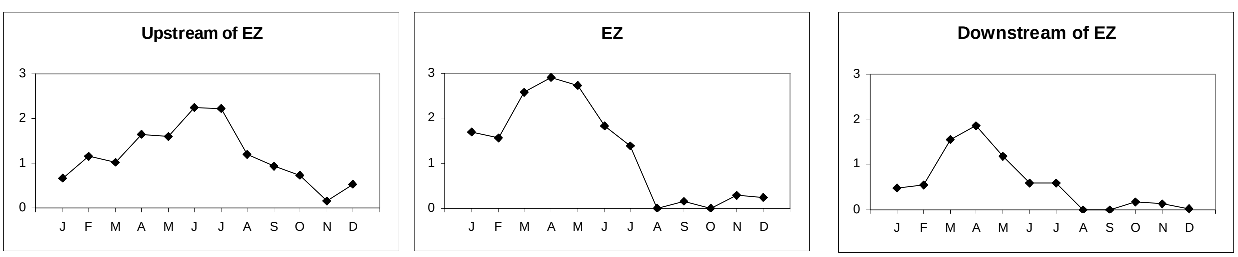


Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

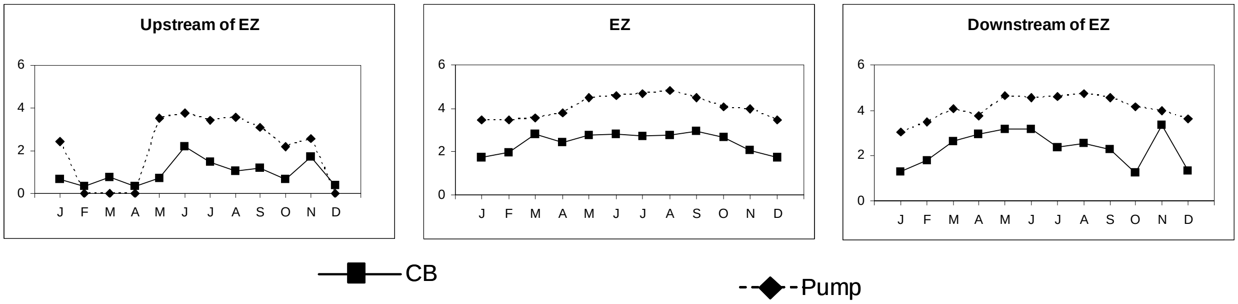


Figure 5-12 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

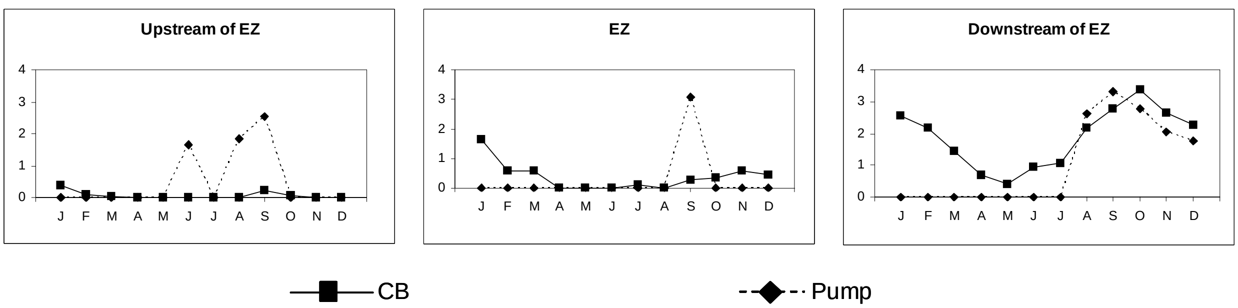


Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

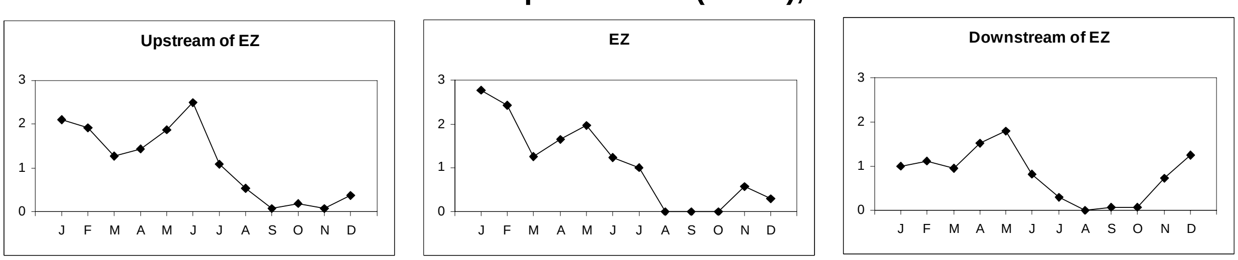


Figure 5-14 Monthly *Bosmina* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

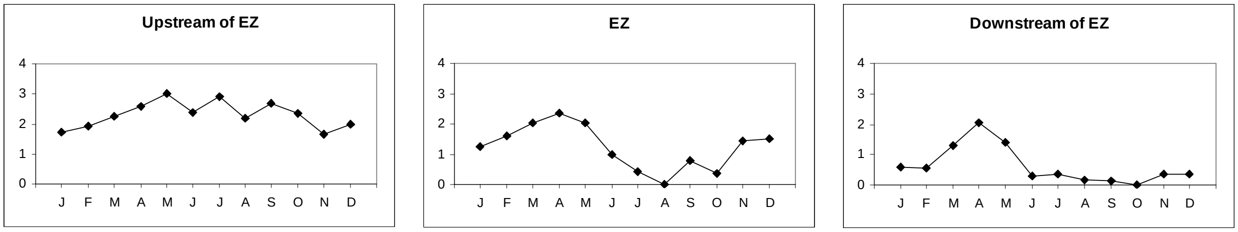


Figure 5-15 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

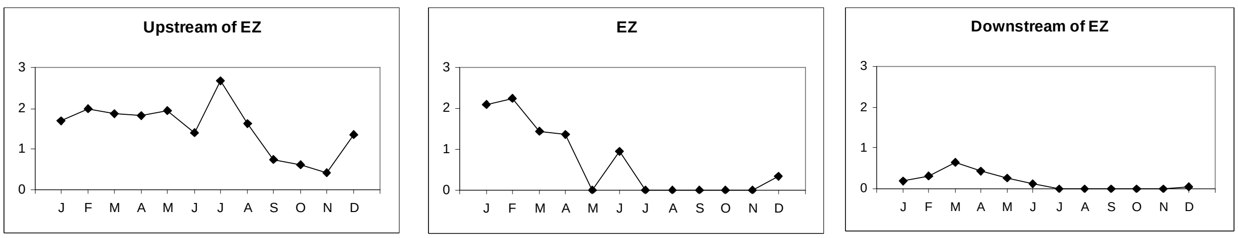


Figure 5-16 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

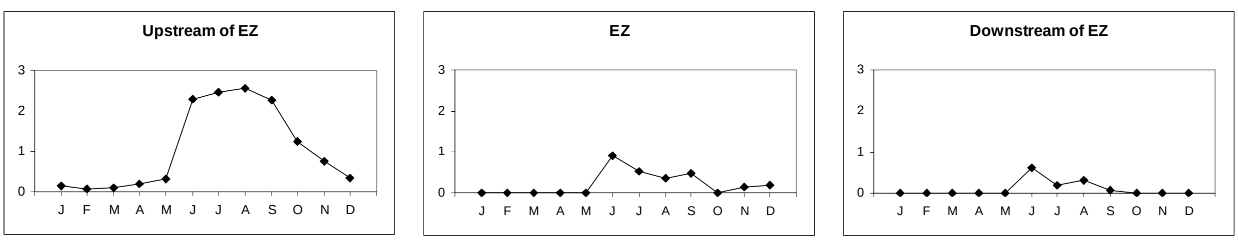


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

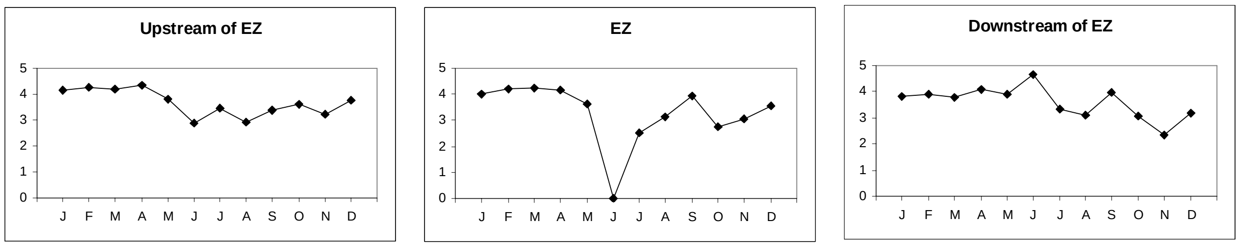


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

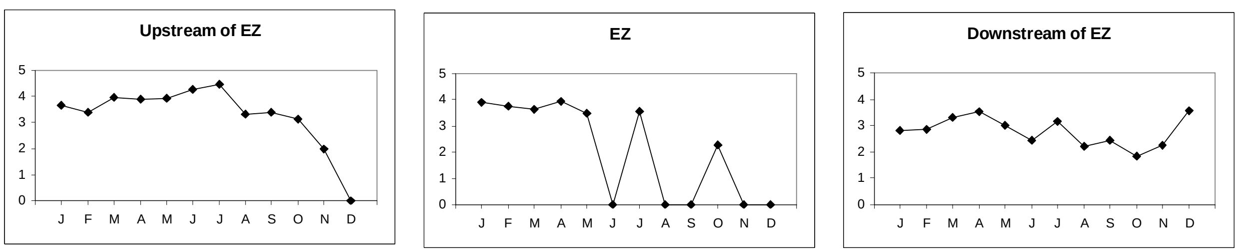


Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone (CPUE), 2006

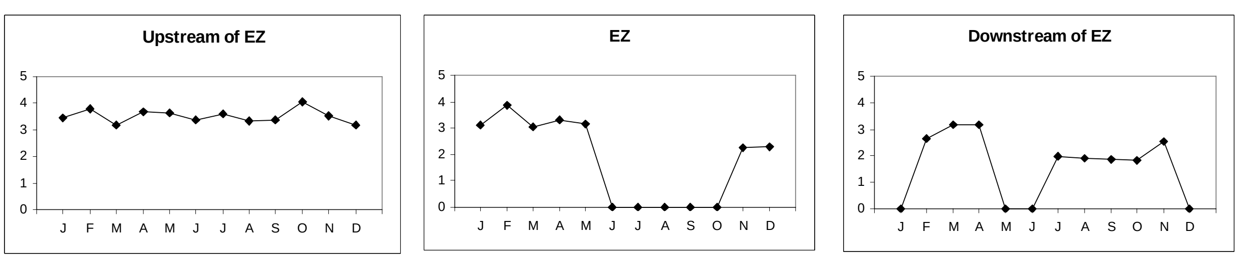


Table 5-1 Mysids: Catch per unit effort (CPUE), 2006

Species	Upstream	EZ	Downstream	Grand total
Acanthomysis bowmani	1.65	13.23	6.75	5.08
Neomysis kadiakensis/japonica	0.01	0.40	0.74	0.31
Neomysis mercedis	0.16	0.07	0.00	0.09
Alienacanthomysis macropsis	0.00	0.00	0.03	0.01

Table 5-2 Calanoid Copepods (CPUE), 2006

Species	Upstream	EZ	Downstream	Grand total
Pseudodiaptomus forbesi	789.1	993.9	77.4	578
Acartia spp.	1.0	1.1	1176.5	399
Eurytemora spp.	35.6	548.7	183.6	161
Acartiella sinensis	26.5	384.7	119.0	110
Sinocalanus doerrii	44.8	114.5	8.0	43

Table 5-3 Cyclopoid Copepods (CPUE), 2006

Clarke-Bumpus Net

Species	Upstream	EZ	Downstream	Grand total
Limnoithona tetraspina	25.6	394.7	673.1	299
Oithona davisae	0.2	4.8	393.9	134
Acanthocyclops vernalis	69.1	93.1	11.1	53

Pump

Species	Upstream	EZ	Downstream	Grand total
Limnoithona tetraspina	1544	22640	22118	11608
Oithona davisae	32	102	304	135

Table 5-4 Cladocerans (CPUE), 2006

Species	Upstream	EZ	Downstream	Grand total
Bosmina spp.	331.9	37.5	9.7	180
Daphnia spp.	77.7	33.4	0.6	45
Diaphanosoma spp.	78.7	1.1	0.4	41

Table 5-5 Rotifers (CPUE), 2006

Species	Upstream	EZ	Downstream	Grand total
Synchaeta spp.	9467	5924	7573	8308
Keratella spp.	8177	2842	1145	5009
Polyarthra spp.	3752	1236	273	2203

Chapter 6 Benthic Monitoring

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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 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.

[DWR] California 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).

The benthic monitoring program began in 1975. From 1975 through 1979, the program collected samples biannually from 11 to 16 sites. In 1980, DWR revised the benthic monitoring program and began monthly sampling at 5 sites. In 1995, major programmatic revisions were implemented to form the current program. Since 1996, monitoring has usually been conducted at 10 sites that are sampled monthly. Between October 2003 and September 2004, quarterly sampling was conducted to allow special studies to be carried out to assess potential changes to the program.

Table 6-1 Macrobenthic monitoring station characteristics, 2006

IEP = Interagency Ecological Program

EMP = Environmental Monitoring Program

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).

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

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. DWR

Methods

Benthic Organisms

In 2006, field sampling was conducted monthly at 10 sites throughout the estuary. Figure 6-1 shows the location of each site, and Table 6-1 summarizes latitude, longitude, salinity range, and substrate composition for each site. The research vessels *Endeavor* and *San Carlos*, both equipped with a hydraulic winch and a Ponar dredge, were used to conduct this sampling. The Ponar dredge samples a bottom area of 0.053 square meters. 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).

Figure 6-1 Location of macrobenthic monitoring stations

mm = millimeter

[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.

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 on a slide and examined under a compound microscope. If more than 3 hours of picking 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 picked, and the results were multiplied by 4 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.

[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.

[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 159 species collected, 10 represented 84.4% of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods

Americorophium stimpsoni

Americorophium spinicorne

Corophium alienense

Gammarus daiberi

Sabellidae Polychaete

Laonome sp. *A*

Tubificidae Worms

Varichaetadrilus angustipenis

Limnodrilus hoffmeisteri

Ilyodrilus frantzi

Asian Clams

Corbula amurensis

Corbicula fluminea

Of the 10 dominant species, *Corbula amurensis* represents macrofauna that inhabit a typically higher saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *Corophium alienense, Americorophium stimpsoni, Americorophium spinicorne, Limnodrilus hoffmeisteri, Ilyodrilus frantzi*, 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 3 species—*Gammarus daiberi*, *Varichaetadrilus angustipenis*, and *Corbicula fluminea*—are predominantly freshwater species and were collected at sites east of Suisun Bay.

Data Management and Summarization

The EMP maintains a database containing all information on benthic organisms identified within the upper Estuary. This database continuously undergoes peer review and updating. When a new organism is found at any of the sampling sites, the organism is identified to the lowest possible taxonomic level and added to the database. All data are available at http://www.baydelta.ca.gov.

All organisms collected during 2005 fell into 9 phyla:

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

Of the 9 phyla identified, Annelida, Arthropoda, and Mollusca constituted 99.3% 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 2006

Organism abundance (organism per square meter 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) are 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).

org/m^2 = organisms per square meter

Benthic Abundance

Maximum abundances in 2006 ranged from 33,064 organisms per square meter in December at Station D6 to 480 organisms per square meter in August at Station D16. Minimum abundances ranged from 3,073 organisms per square meter in October at Station D4 to 38 organisms per square meter in December at Station D16.

Site C9: South Delta

Maximum abundance in 2006 occurred in May with a total of 18,544 organisms per square meter (Figure 6-3). *Limnoldrilus hoffmeisteri* (5,382 org/m^2) and *Varichaetiadrilus angustipenis* (5,026 org/m^2) were the dominant species. The minimum abundance in 2006 occurred in November with a total of 347 organisms per square meter. *Limnodrilus hoffmeisteri* (114 org/m^2) and *Varichaetadrilus angustipenis* (128 org/m^2) were the dominant species.

Figure 6-3 Total abundance at Station C9, 2006

Site P8: South Delta

The maximum abundance in 2006 was in August with a total of 5,980 organisms per square meter (Figure 6-4). *Limnodrilus hoffmeisteri* (1,938 org/m^2) was the dominant species. The minimum abundance in 2006 was in November with a total of 1,287 organisms per square meter. *Varichaetadrilus angustipenis* (394 org/m^2) and *Corbicula fluminea* (385 org/m^2) were the dominant species.

Figure 6-4 Total abundance at Station P8, 2006

Site D28A: Central Delta

Maximum abundance in 2006 occurred in June with a total of 18,967 organisms per square meter (Figure 6-5). *Gammarus diaberi* (6,099 org/m^2), and *Corbicula fluminea* (4,386 org/m^2) were the dominant species. The minimum abundance in 2006 occurred in August with a total of 2,626 organism per square meter. *Corbicula fluminea* (1,230 org/m^2) was the dominant species.

Figure 6-5 Total abundance at Station D28A, 2006

Site D16: Lower San Joaquin River

Maximum abundance in 2006 occurred in August with a total of 480 organisms per square meter (Figure 6-6). *Corbicula fluminea* (161 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in December with a total of 38 organisms per square meter. *Corbicula fluminea* (38 org/m^2) was the dominant species.

Figure 6-6 Total abundance at Station D16, 2006

Site D24: Lower Sacramento River

Maximum abundance in 2006 occurred in September with a total of 14,112 organisms per square meter (Figure 6-7). *Americorophium stimpsoni* (9,771 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in April with a total of 608 organisms per square meter. *Corbicula fluminea* (328 org/m^2) was the dominant species.

Figure 6-7 Total abundance at Station D24, 2006

Site D4: Lower Sacramento River

Maximum abundance in 2006 occurred in May with a total of 27,583 organisms per square meter (Figure 6-8). *Americorophium spinicorne* (8,650 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in October with a total of 3,073 organisms per square meter. *Corbicula fluminea* (1,268 org/m^2) was the dominant species.

Figure 6-8 Total abundance at Station D4, 2006

Site D6: Suisun Bay

Maximum abundance in 2006 occurred in December with a total of 33,064 organisms per square meter (Figure 6-9). *Corbula amurensis* (32,747 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in July with a total of 451 organisms per square meter. *Corbula amurensis* (342 org/m^2) was the dominant species.

Figure 6-9 Total abundance at Station D6, 2006

Site D7: Suisun Bay

Maximum abundance in 2006 occurred in August with a total of 18,748 organisms per square meter (Figure 6-10). *Corbula amurensis* (13,984 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in May with a total of 2,342 organisms per square meter. *Corophium alienense* (1,149 org/m^2) was the dominant species.

Figure 6-10 Total abundance at Station D7, 2006

Site D41: San Pablo Bay

Maximum abundance in 2006 occurred in August with a total of 7,462 organisms per square meter (Figure 6-11). *Corbula amurensis* (6,826 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in January with a total of 831 organisms per square meter. *Phoronopsis virdis* (546 org/m^2) was the dominant species.

Figure 6-11 Total abundance at Station D41, 2006

Site D41A: San Pablo Bay

Maximum abundance in 2006 occurred in November with a total of 8,840 organisms per square meter (Figure 6-12). *Ampelisca abdita* (3,852 org/m^2) was the dominant species. The minimum abundance in 2006 occurred in June with a total of 594 organisms per square meter. *Corbula amurensis* (423 org/m^2) was the dominant species.

Figure 6-12 Total abundance Station D41A, 2006

Sediment Analysis

Sediment organic content was determined using the ash-free dry weight and is given as a percent of the total sample mass. In 2006, organic content ranged from 0% at Station D16 to 33.0% at Station D4.

Site C9: South Delta

Fine sediment dominated the winter months while sand and a mixture of silty sand dominated the sediment at site C9 for 2006 (Figure 6-13). The percentage of organic content ranged from 0.3% to 3.3%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

Figure 6-13 Sediment grain size and organic content at Station C9 during 2006

Site P8: South Delta

Sand dominated the sediment at site P8 for most of 2006 with the exception of August and September when fine sediment dominated (Figure 6-14). The organic matter ranged from 1.7% to 4.4%, with the higher values typically coinciding with an influx of finer sediments.

Figure 6-14 Sediment grain size and organic content at Station P8 during 2006

Site D28A: Central Delta

Sandy sediment dominated the sediment at site D28A for 2006 (Figure 6-15). The organic matter ranged from 2.2% to 13.0%. Higher percentages of organic matter occurred during the months with the highest percentages of fine sediment.

Figure 6-15 Sediment grain size and organic content at Station D28A during 2006

Site D16: Lower San Joaquin River

Sand dominated the sediment type at site D16 for 2006 (Figure 6-16). With the exception of August when the percent of organic matter was 1.1%, the amount of organic matter at this site ranged from 0% to 0.6%.

Figure 6-16 Sediment grain size and organic content at Station D16 during 2006

Site D24: Lower Sacramento River

Sand dominated the sediment at site D24 during 2006 (Figure 6-17). The amount of organic matter ranged from 0.4% to 2.3% with higher values coinciding with higher percentages of fine sediment.

Figure 6-17 Sediment grain size and organic content at Station D24 during 2006

Site D4: Lower Sacramento River

For part of 2006, a homogenous mix of sand and fine sediment dominated site D4. The exceptions to this were May, July, and August when sand dominated and September and October when fine sediment dominated (Figure 6-18). The percent of organic matter (3.7% to 33.0%) at this site was high for most of the year, except in cases where the percent of fines increased.

Figure 6-18 Sediment grain size and organic content at Station D4 during 2006

Site D6: Suisun Bay

Fine sediments dominated site D6 for all of 2006 (Figure 6-19). Organic matter at this site was relatively stable for most of the year, ranging from 2.1% to 5.6%. The only exception to this was June when the percent of organic matter was 8.6%.

Figure 6-19 Sediment grain size and organic content at Station D6 during 2006

Site D7: Suisun Bay

Fine sediments dominated site D7 for all of 2006 (Figure 6-20). The organic matter at this site was stable throughout the year ranging from 2.2% to 4.7%.

Figure 6-20 Sediment grain size and organic content at Station D7 during 2006

Site D41: San Pablo Bay

Fine sediments dominated site D41 for every month in 2006 except for January and June when there was a homogenous mix of sand and fine sediment (Figure 6-21). The organic matter at this site ranged from 1.5% to 5.1%.

Figure 6-21 Sediment grain size and organic content at Station D41 during 2006

Site D41A: San Pablo Bay

Fine sediments dominated site D41A for all of 2006 (Figure 6-22). The percent organic matter at this site ranged from 1.9% to 5.1%.

Figure 6-22 Sediment grain size and organic content at Station D41A during 2006

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 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda and Mollusca constituted 99.3% of the organisms collected during the study period. Ten species represent 84.4% of all organisms collected during this period. These species are: (1) the amphipods—*Americorophium stimpsoni, Americorophium spinicorne, Corophium alienense*, and *Gammarus daiberi*; (2) the Sabellidae polychaete—*Laonome* sp. *A*; (3) the Tubificidae worms,*Varichaetadrilus angustipenis, Limnodrilus hoffmeisteri*, and *Ilyodrilus frantzi*; and (4) 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.

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Figure 6-1 Location of macrobenthic monitoring stations

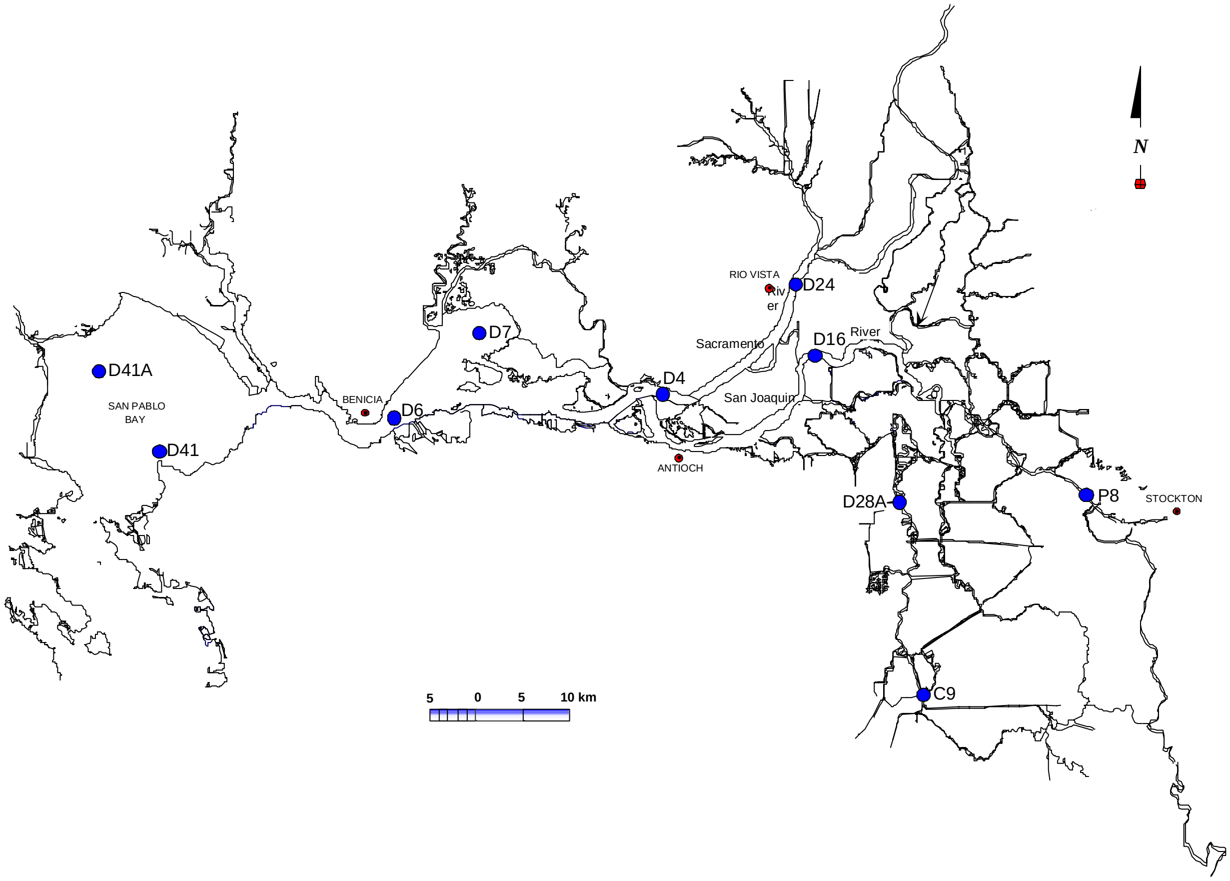


Figure 6-2 Total contribution by phyla for all stations during 2006

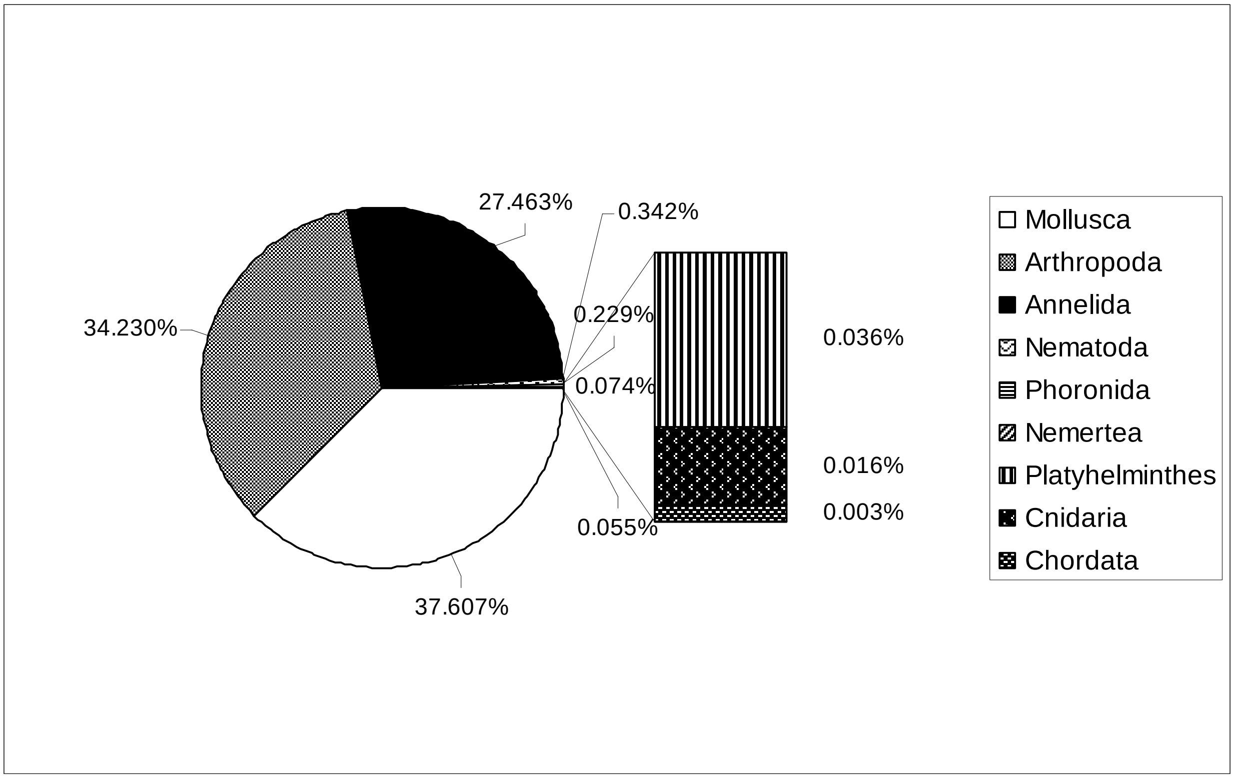


Figure 6-3 Total abundance at Station C9, 2006

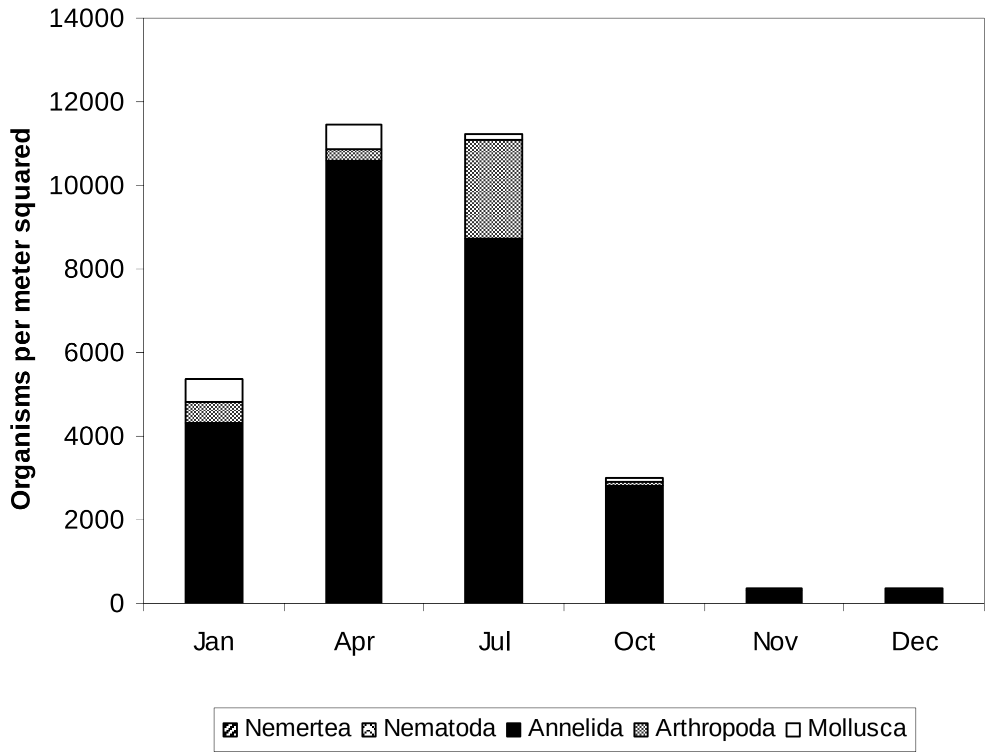


Figure 6-4 Total abundance at Station P8, 2006

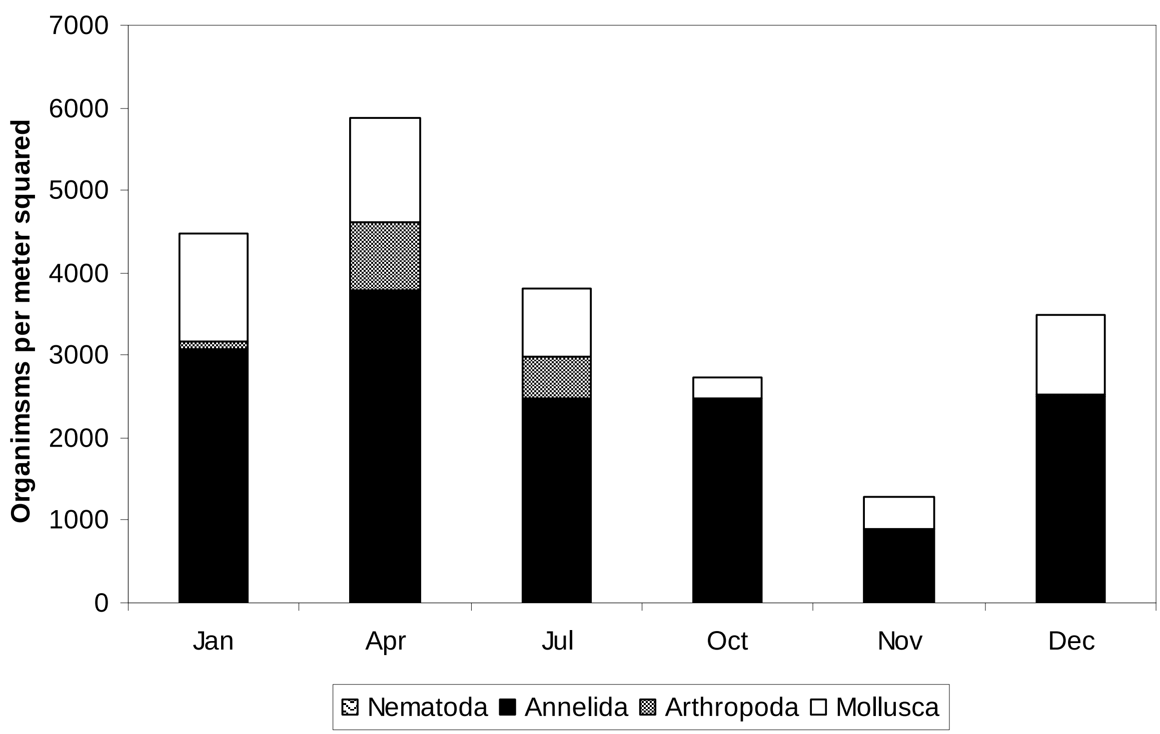


Figure 6-5 Total abundance at Station D28A, 2006

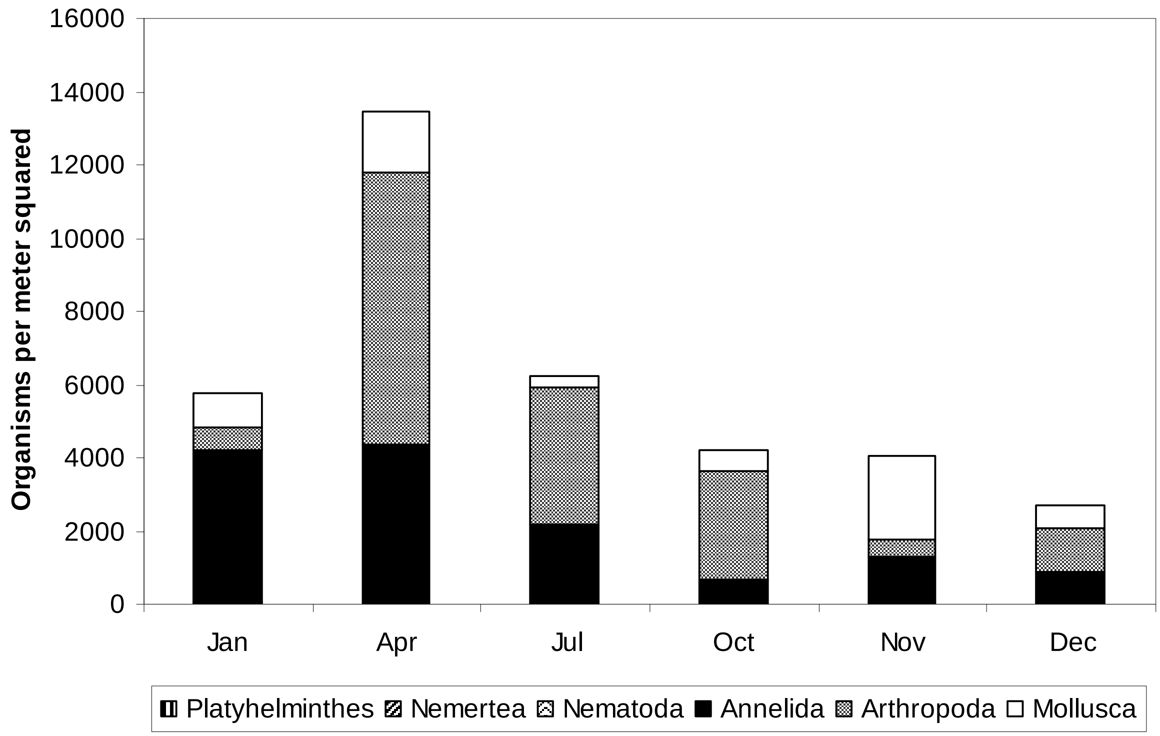


Figure 6-6 Total abundance at Station D16, 2006

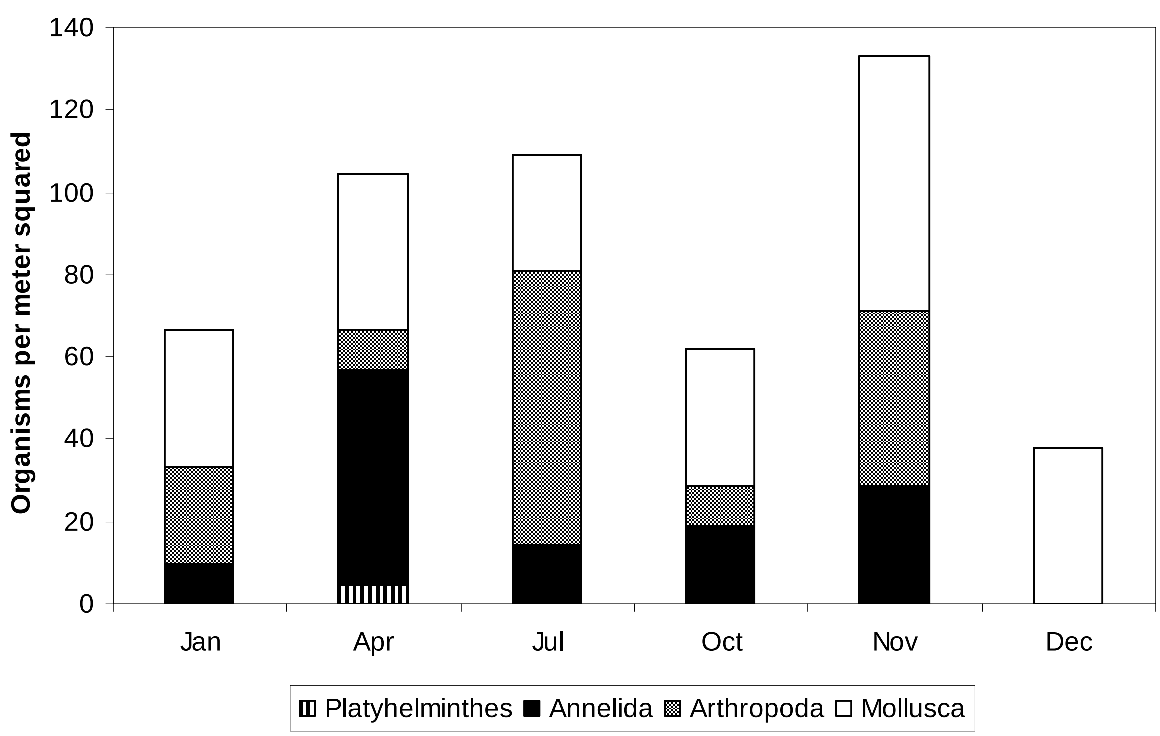


Figure 6-7 Total abundance at Station D24, 2006

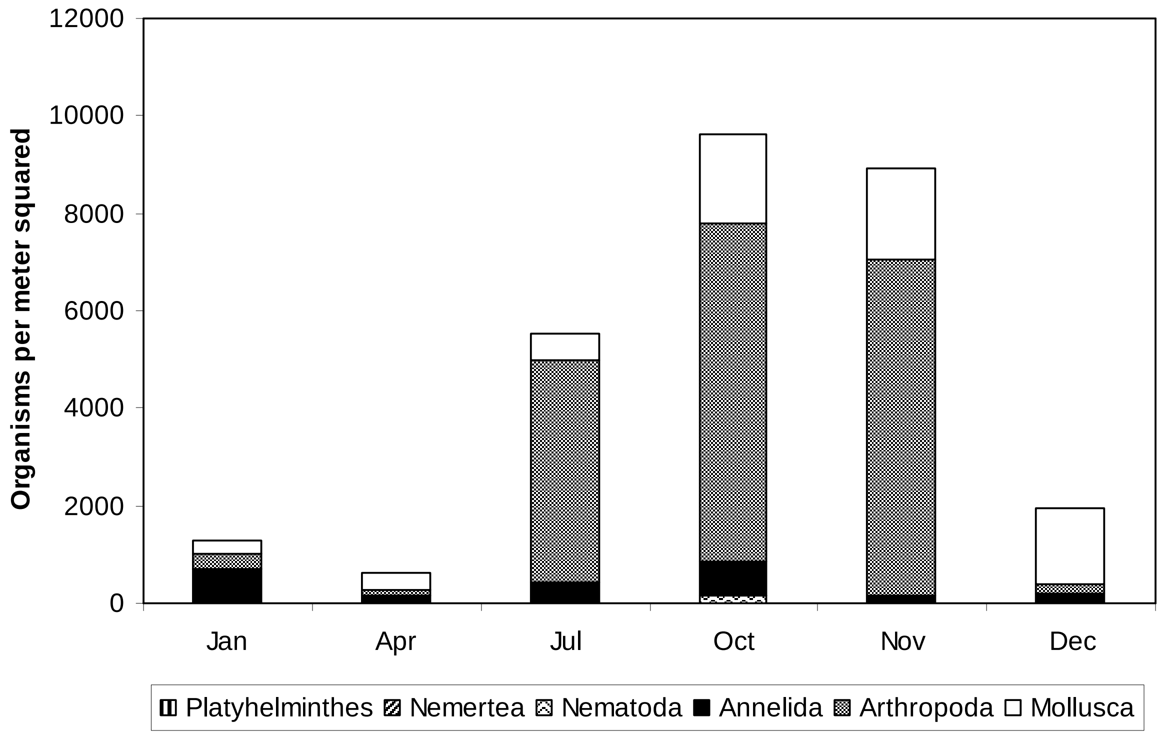


Figure 6-8 Total abundance at Station D4, 2006

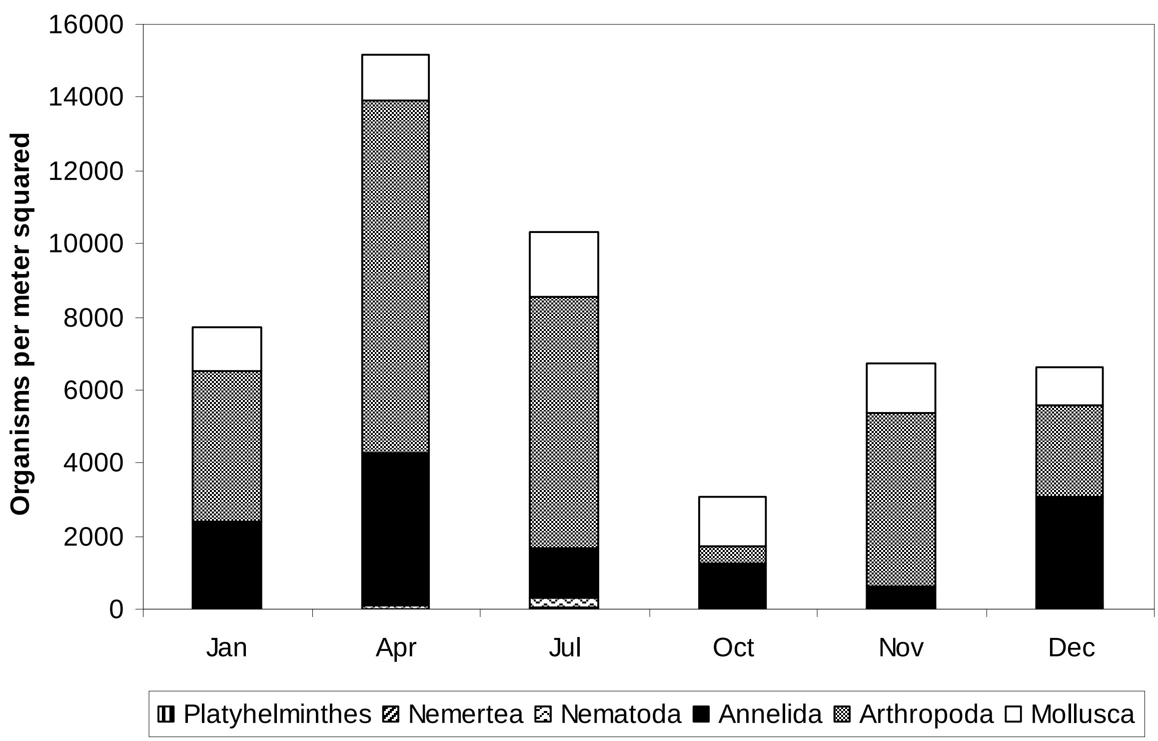


Figure 6-9 Total abundance at Station D6, 2006

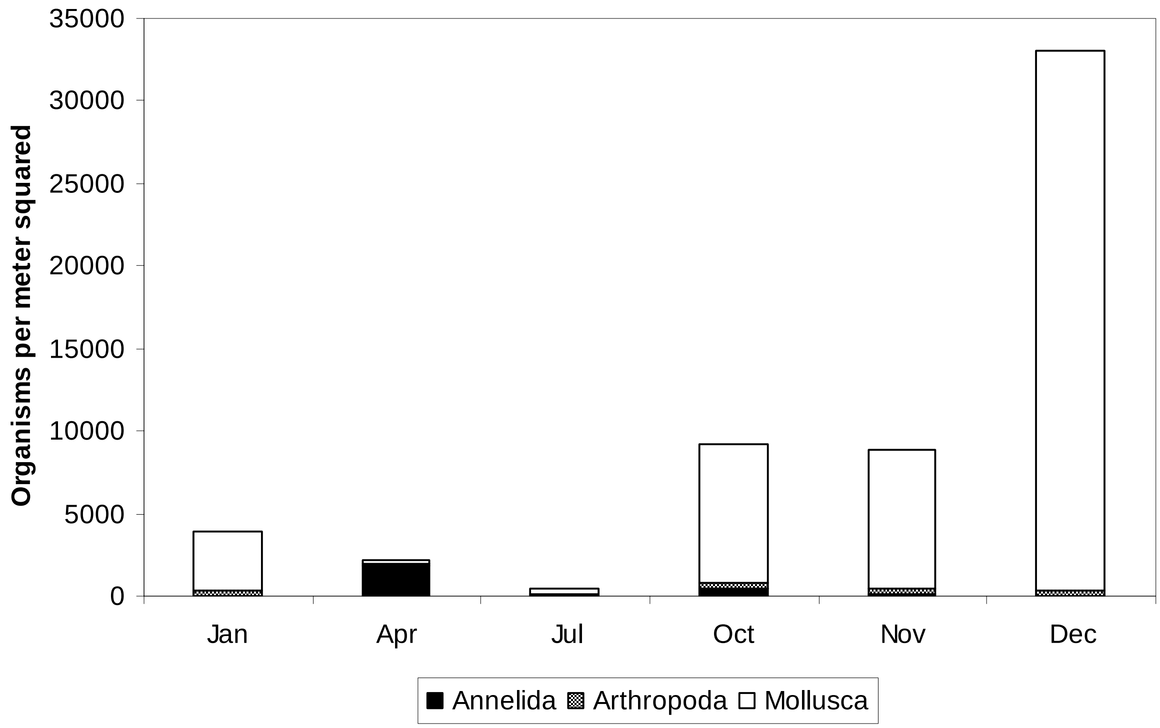


Figure 6-10 Total abundance at Station D7, 2006

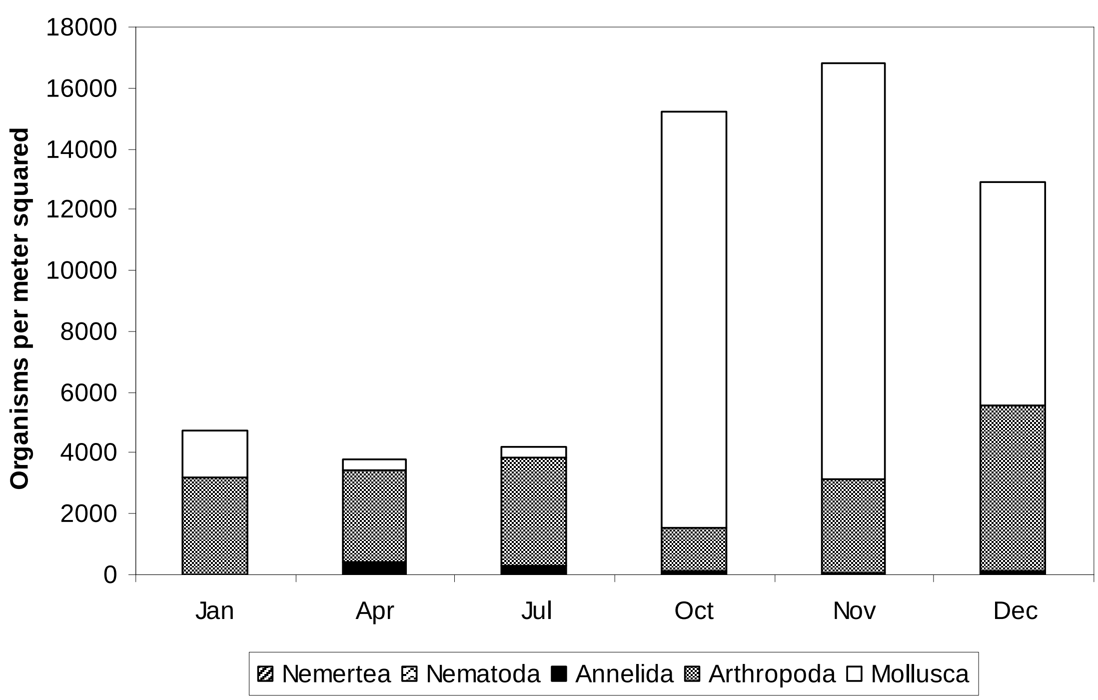


Figure 6-11 Total abundance at Station D41, 2006

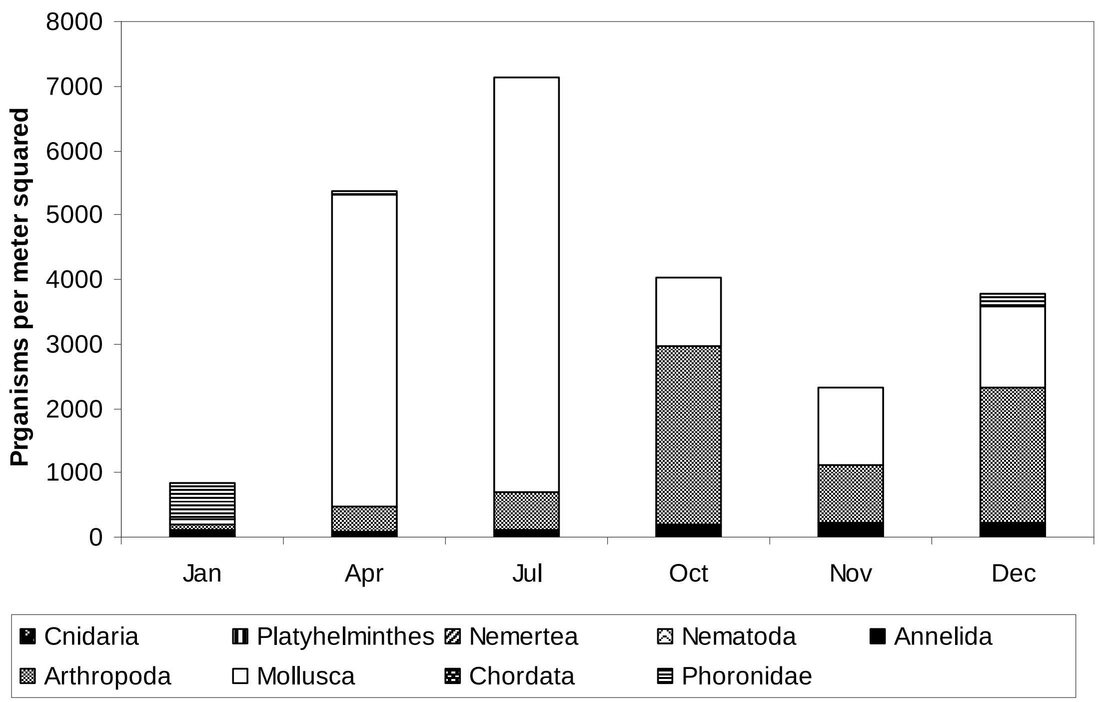


Figure 6-12 Total abundance at Station D41A, 2006

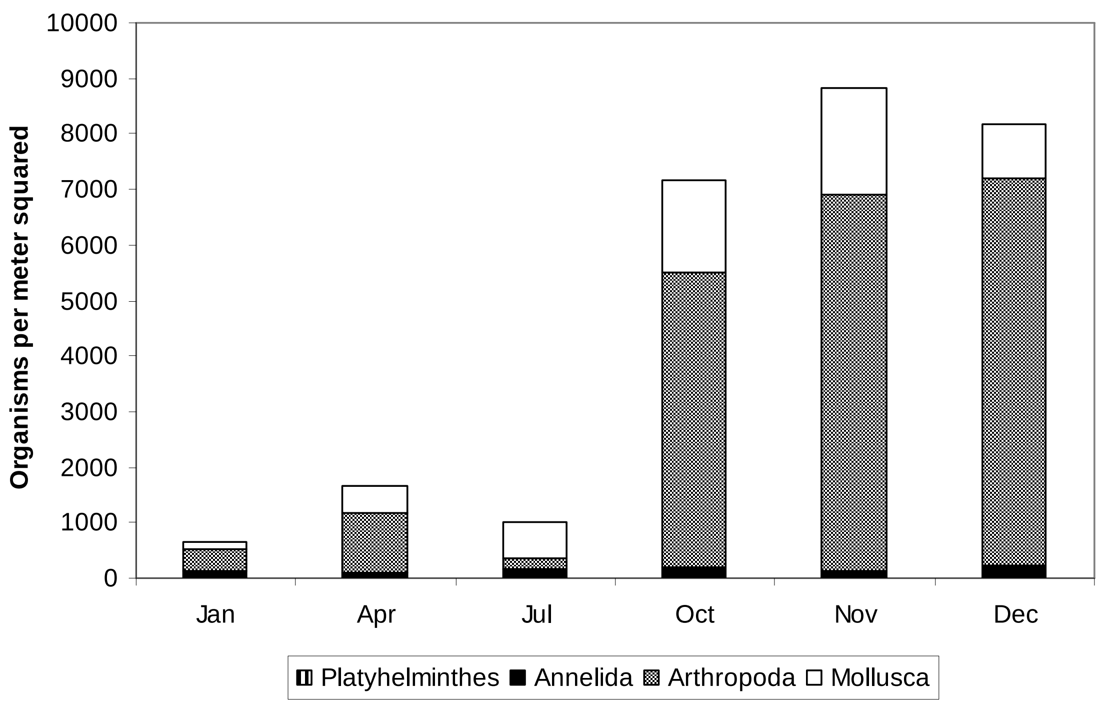
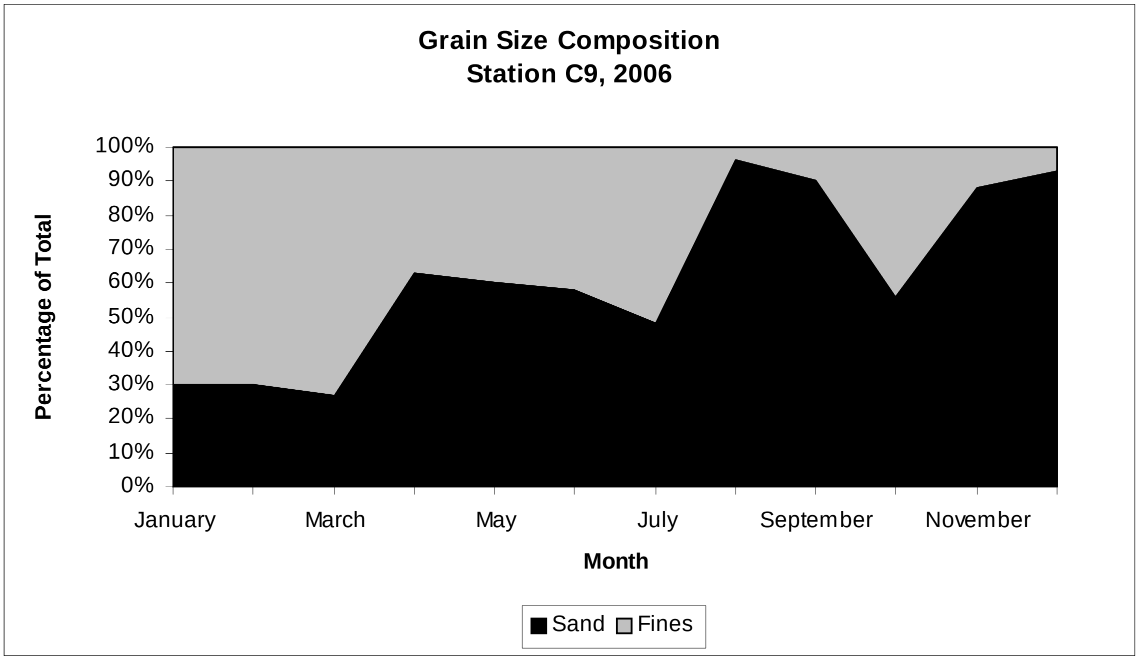


Figure 6-13 Sediment grain size and organic content at Station C9 during 2006



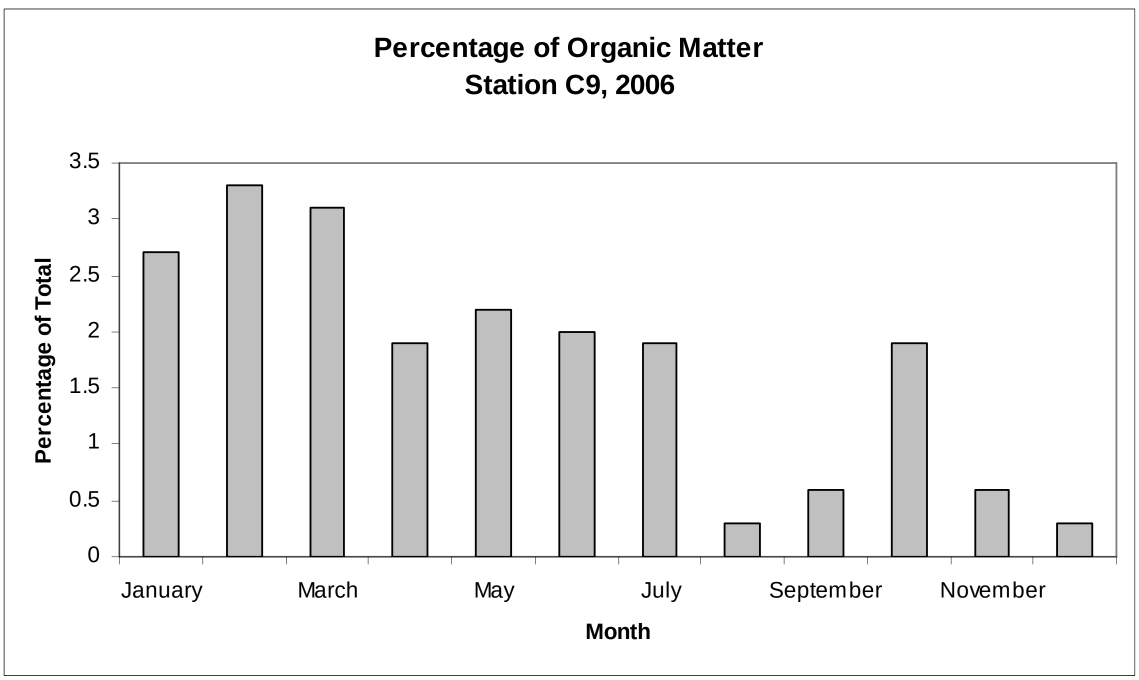
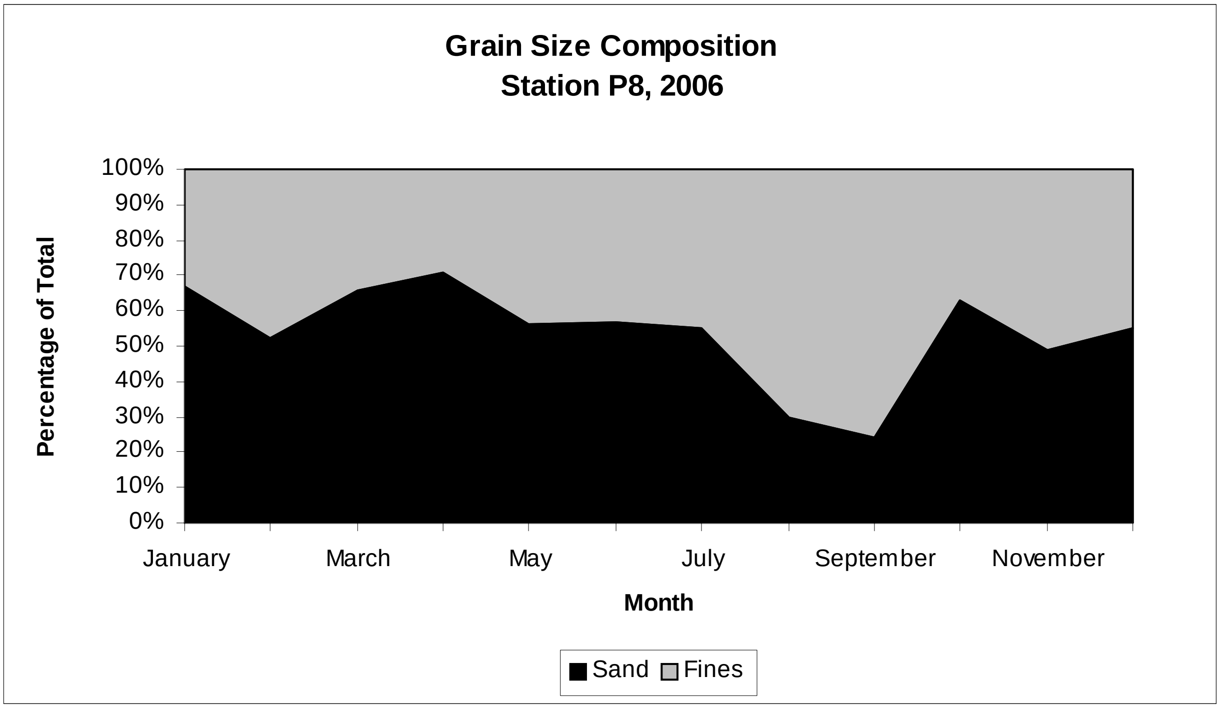


Figure 6-14 Sediment grain size and organic content at Station P8 during 2006



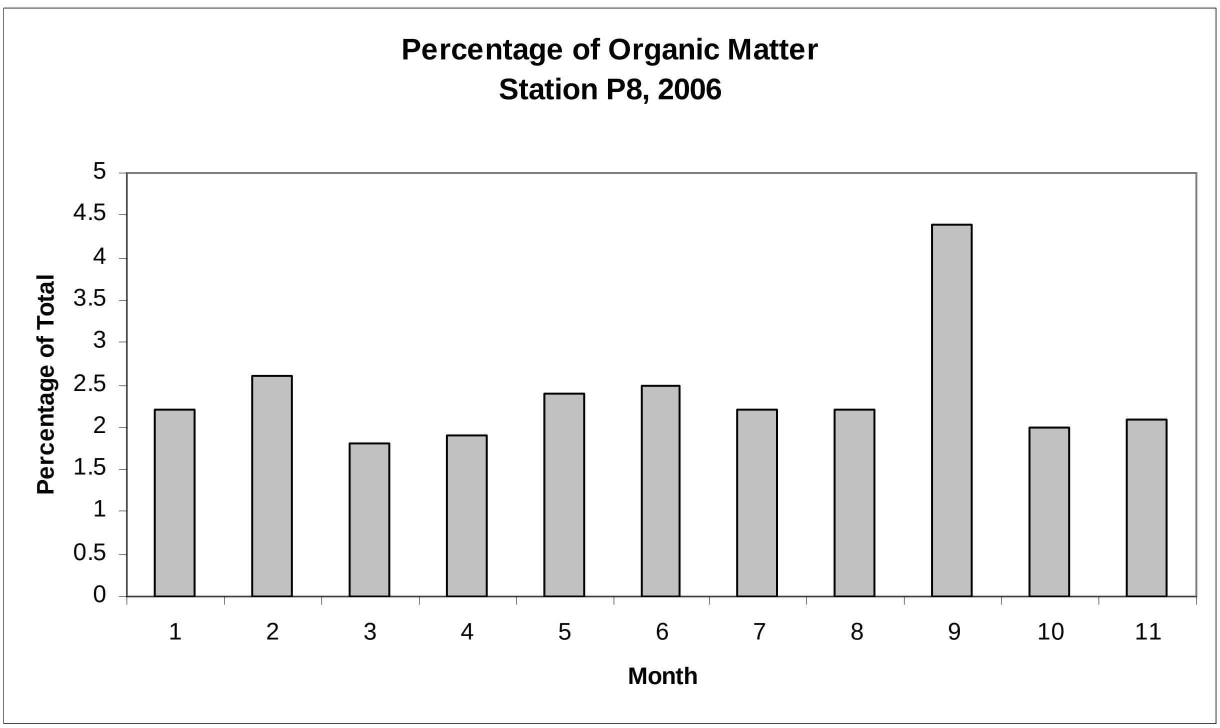
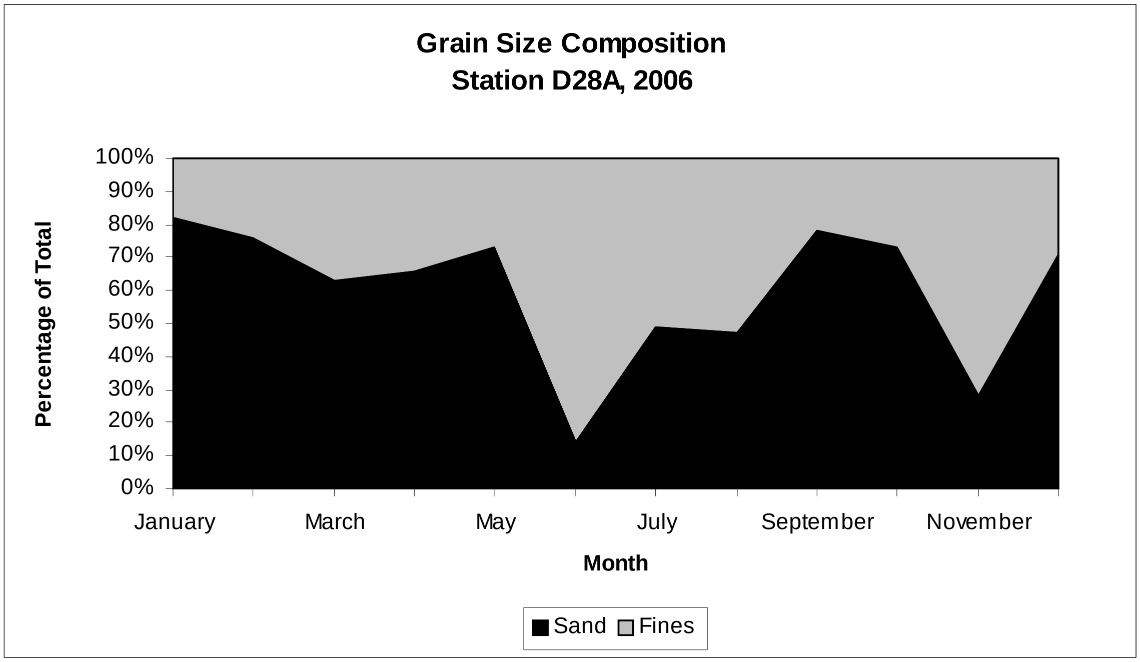


Figure 6-15 Sediment grain size and organic content at Station D28A during 2006



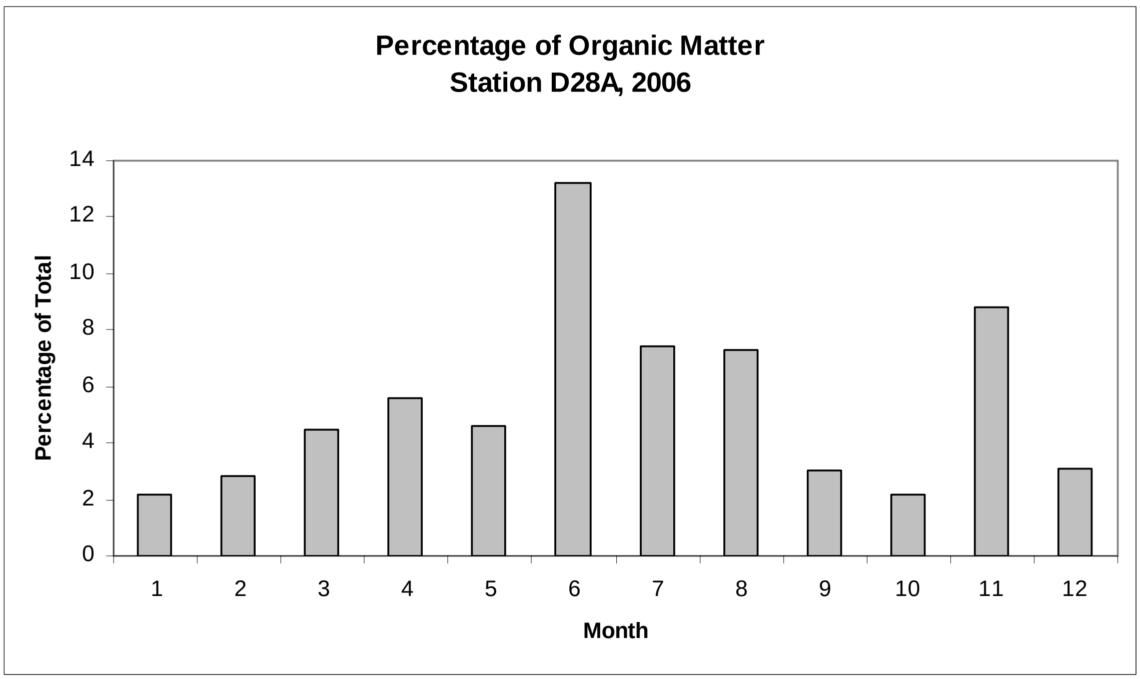
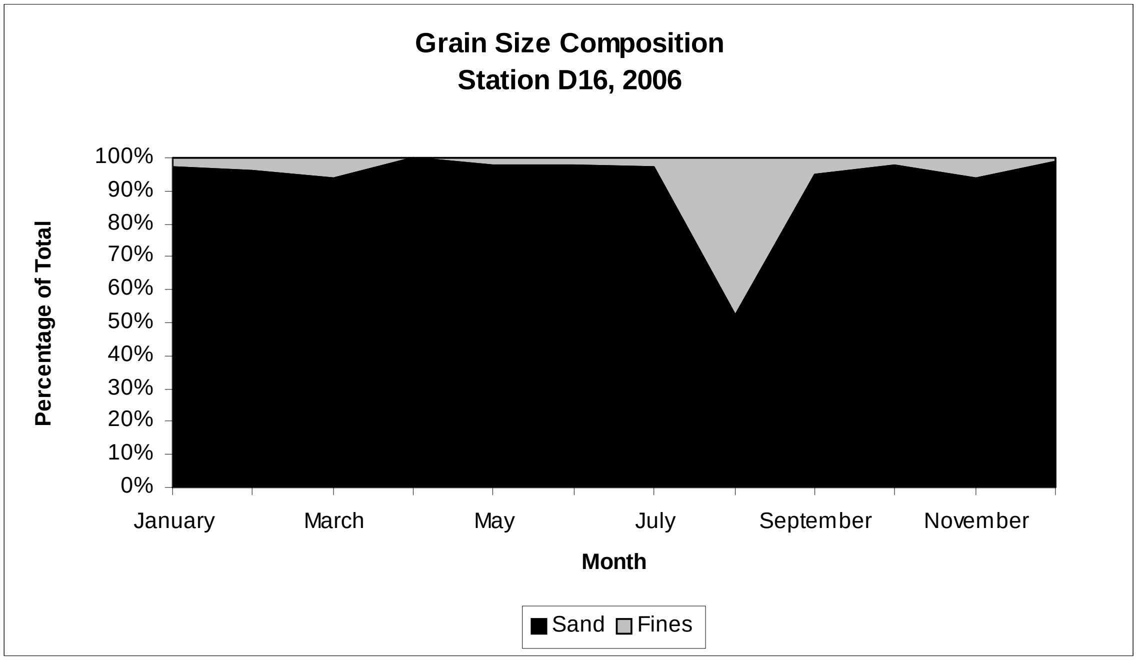


Figure 6-16 Sediment grain size and organic content at Station D16 during 2006



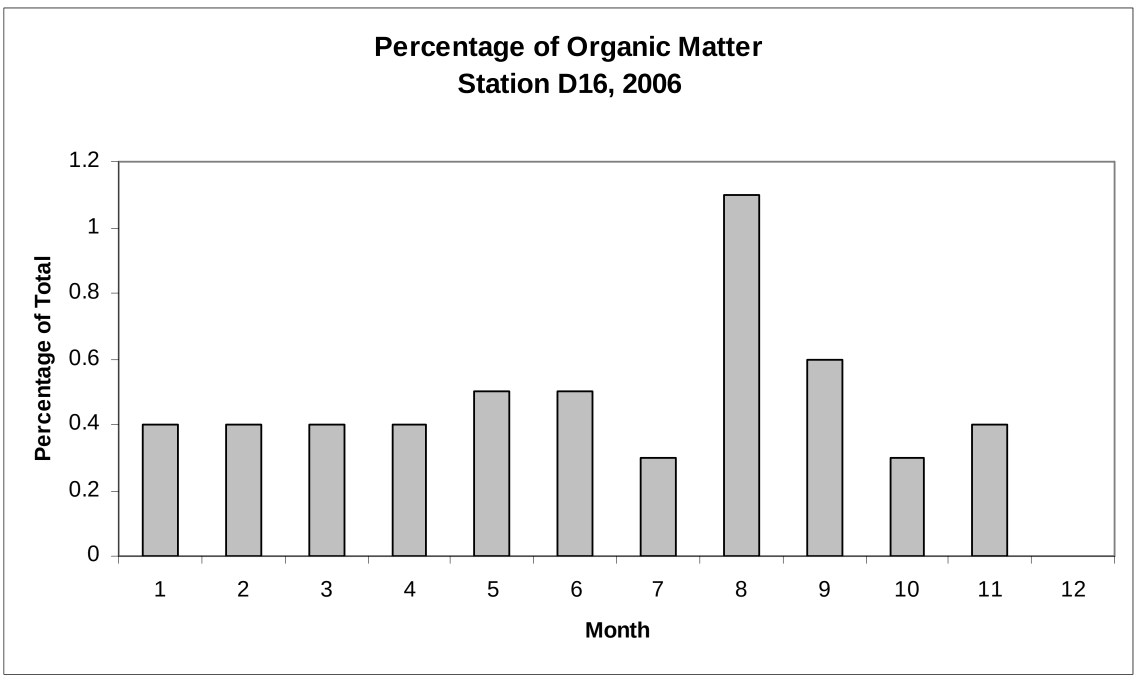
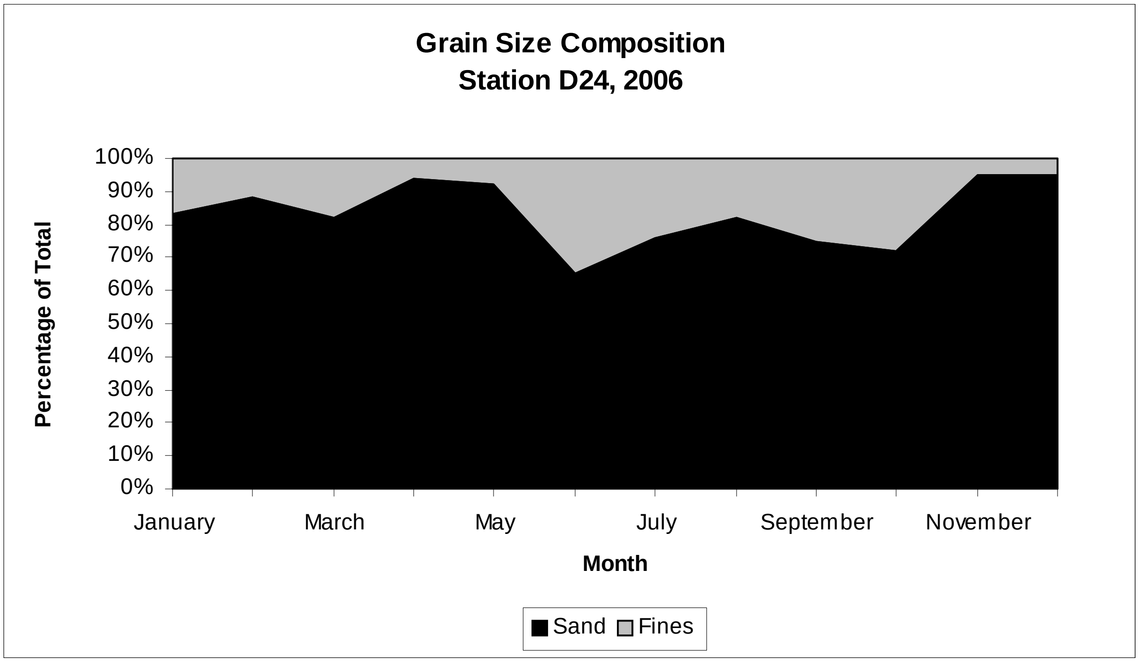


Figure 6-17 Sediment grain size and organic content at Station D24 during 2006



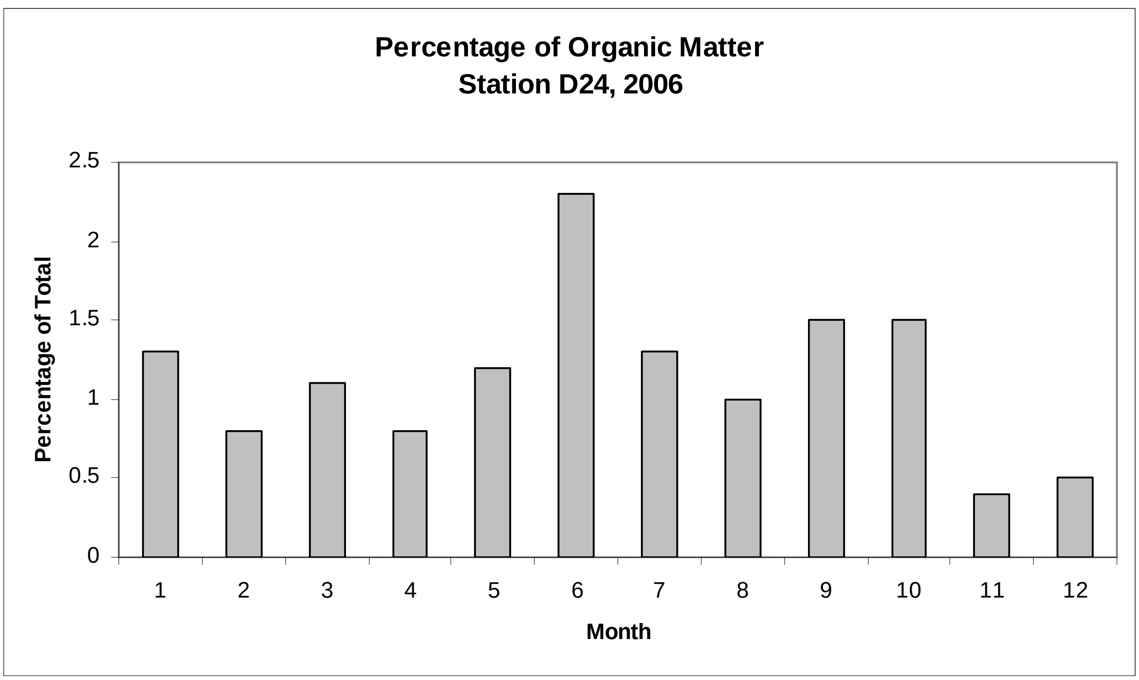
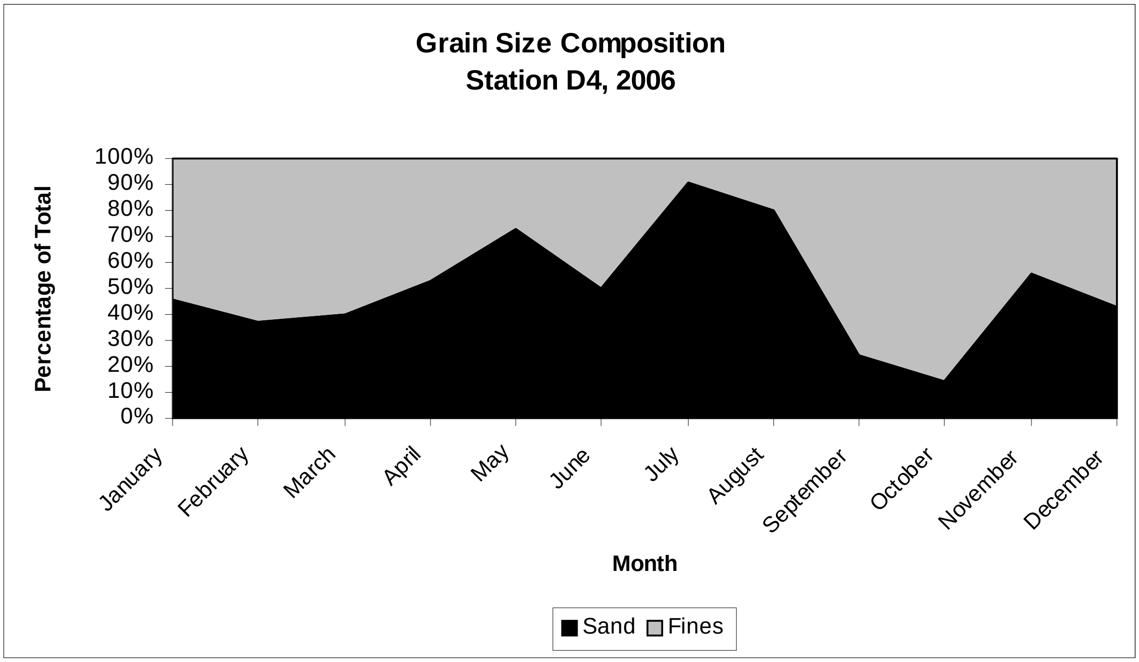


Figure 6-18 Sediment grain size and organic content at Station D4 during 2006



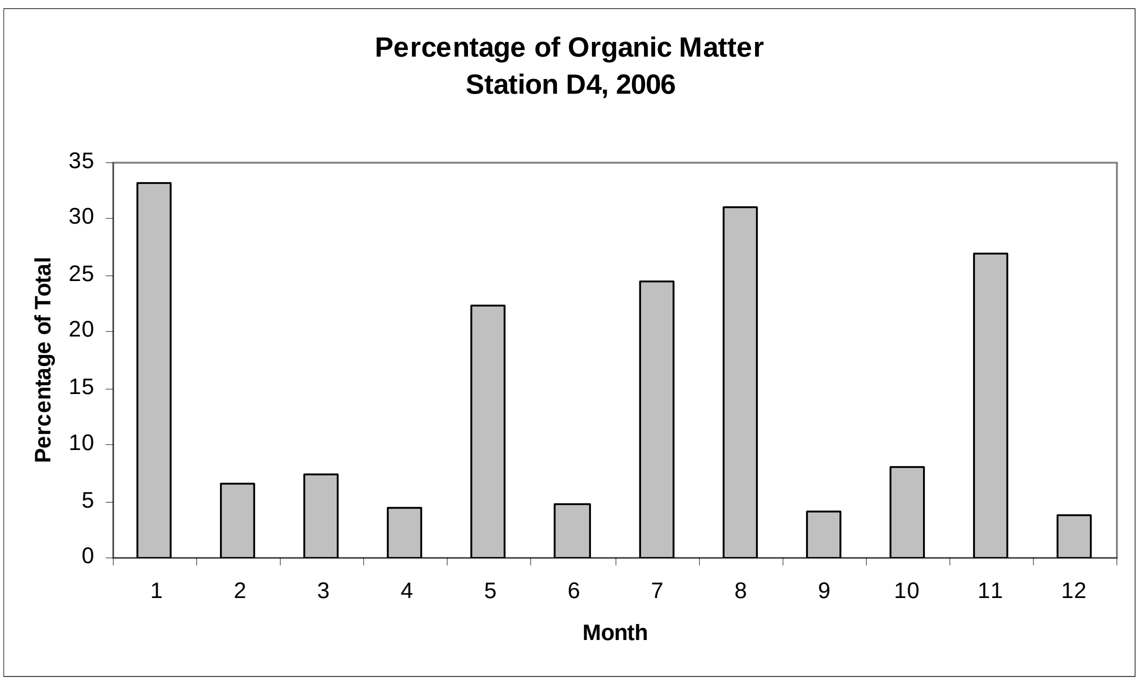
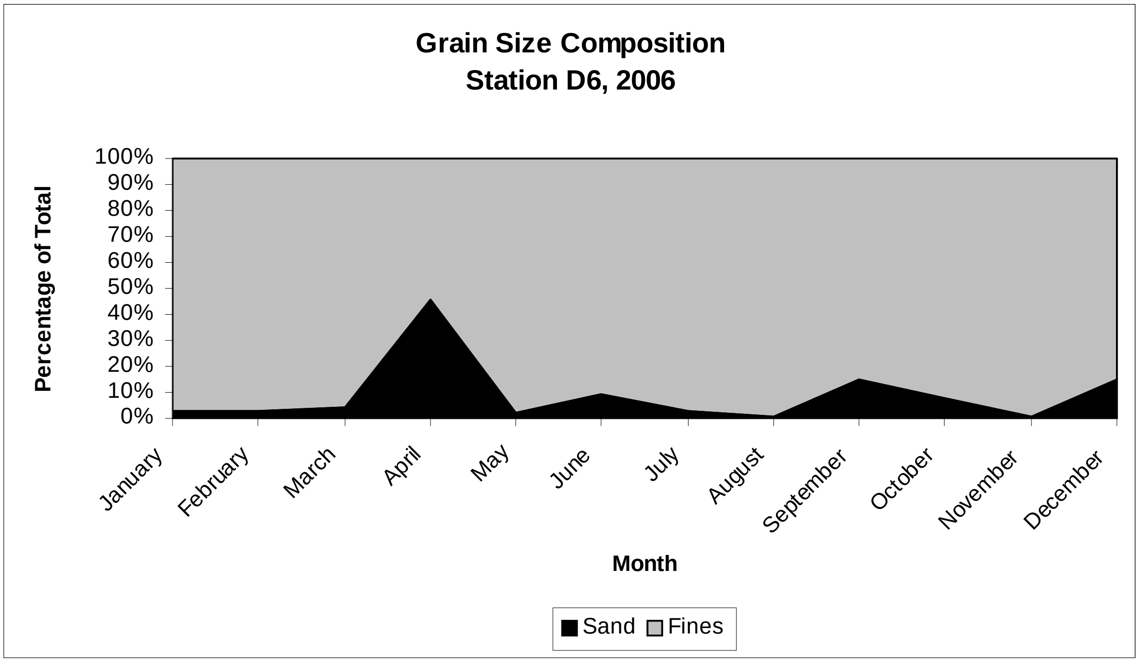


Figure 6-19 Sediment grain size and organic content at Station D6 during 2006



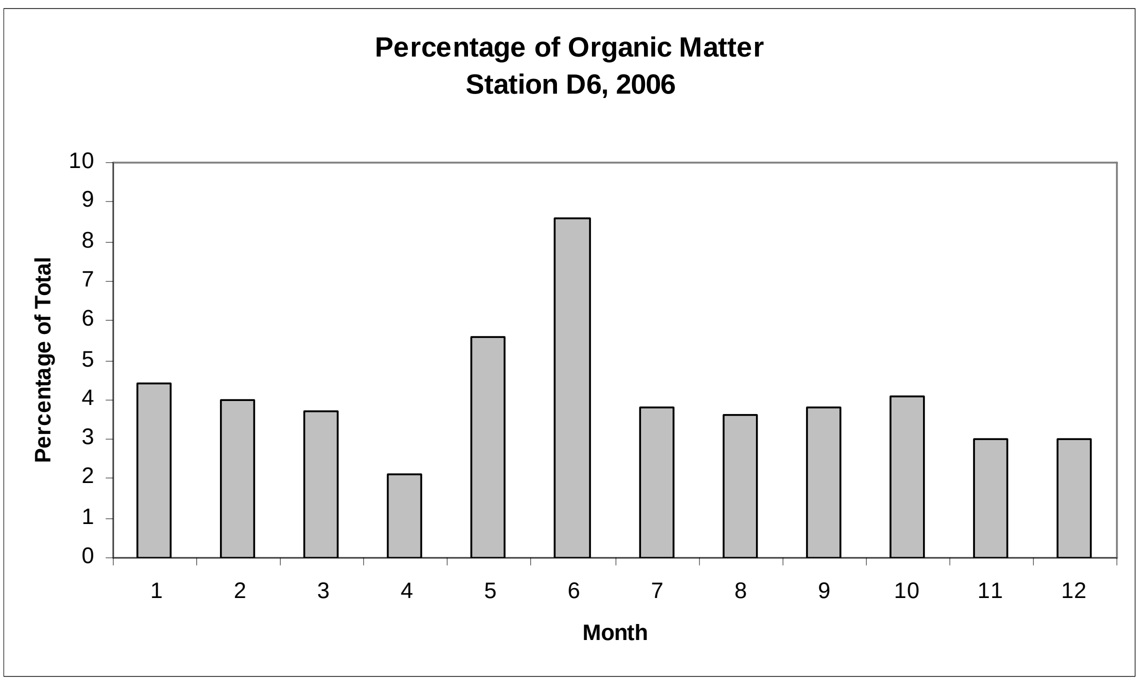
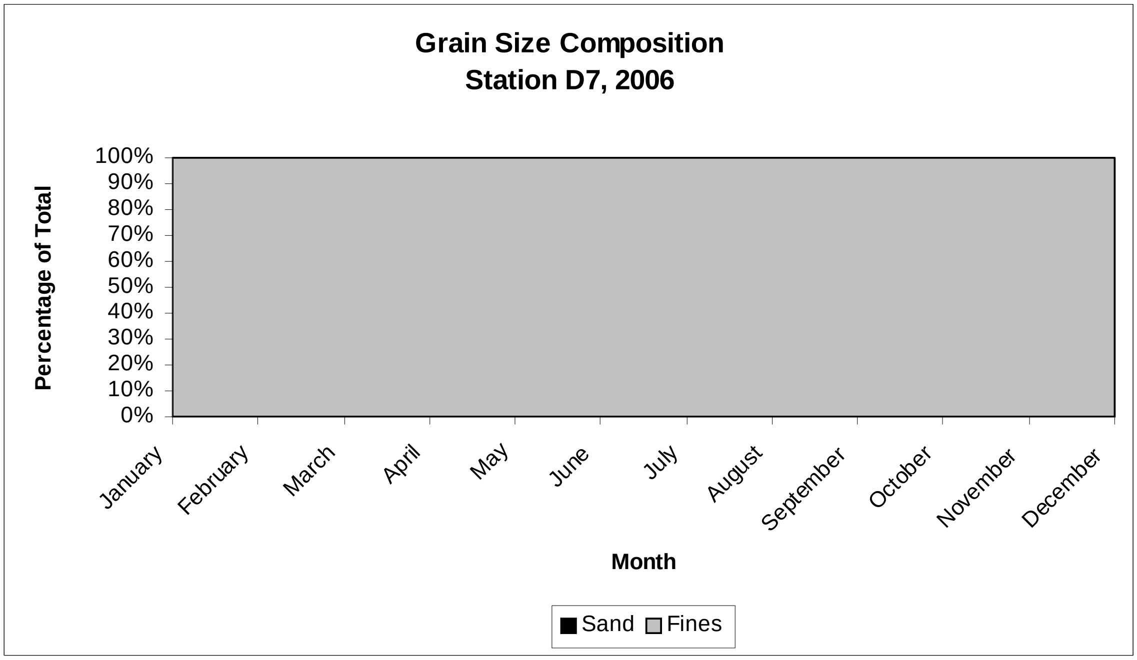


Figure 6-20 Sediment grain size and organic content at Station D7 during 2006



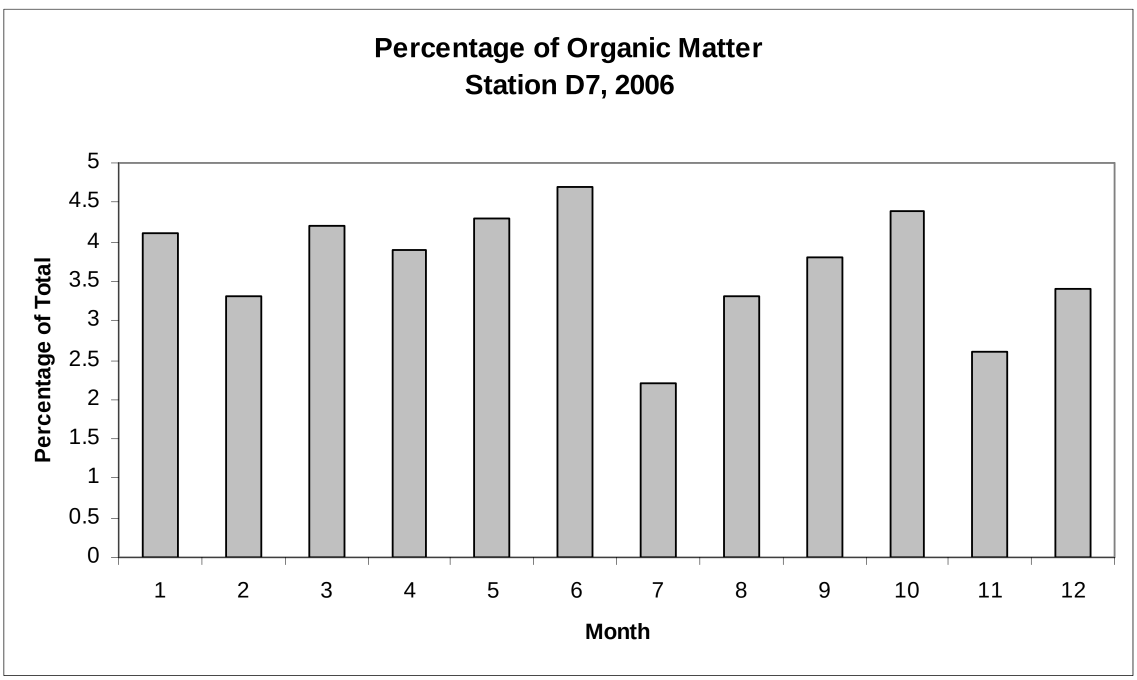
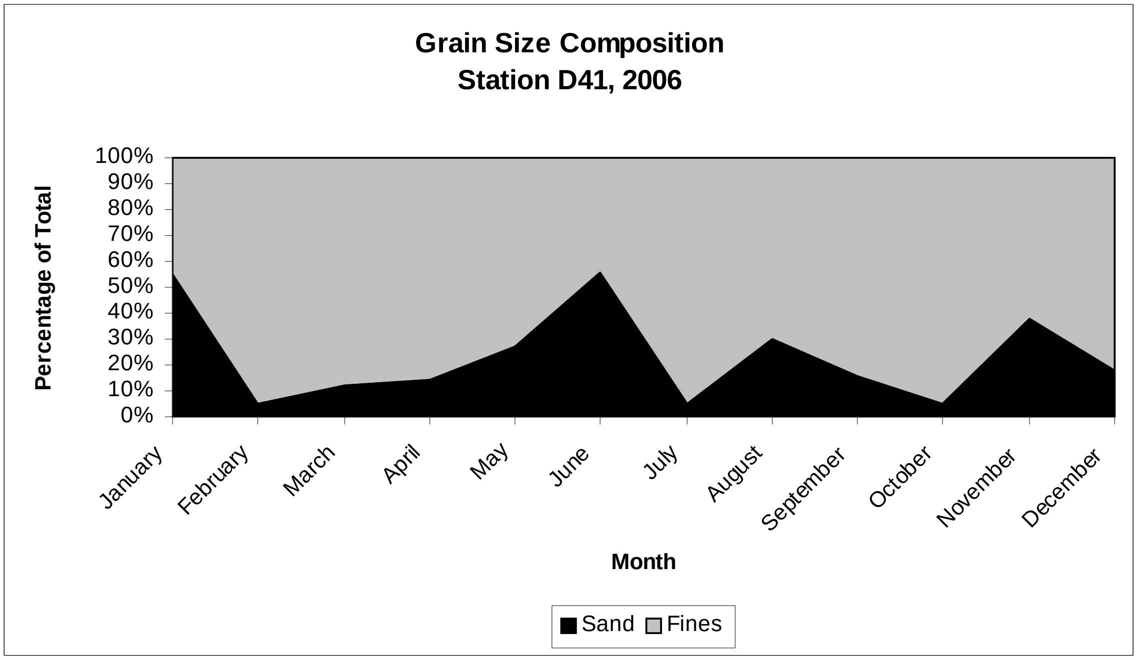


Figure 6-21 Sediment grain size and organic content at Station D41 during 2006



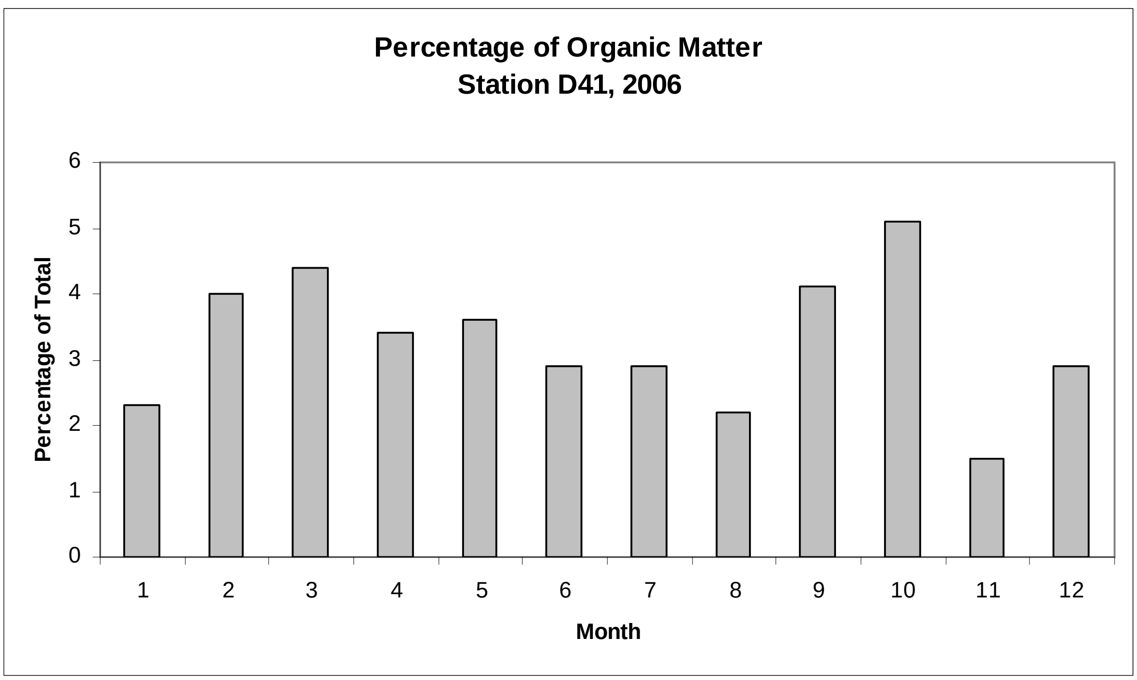
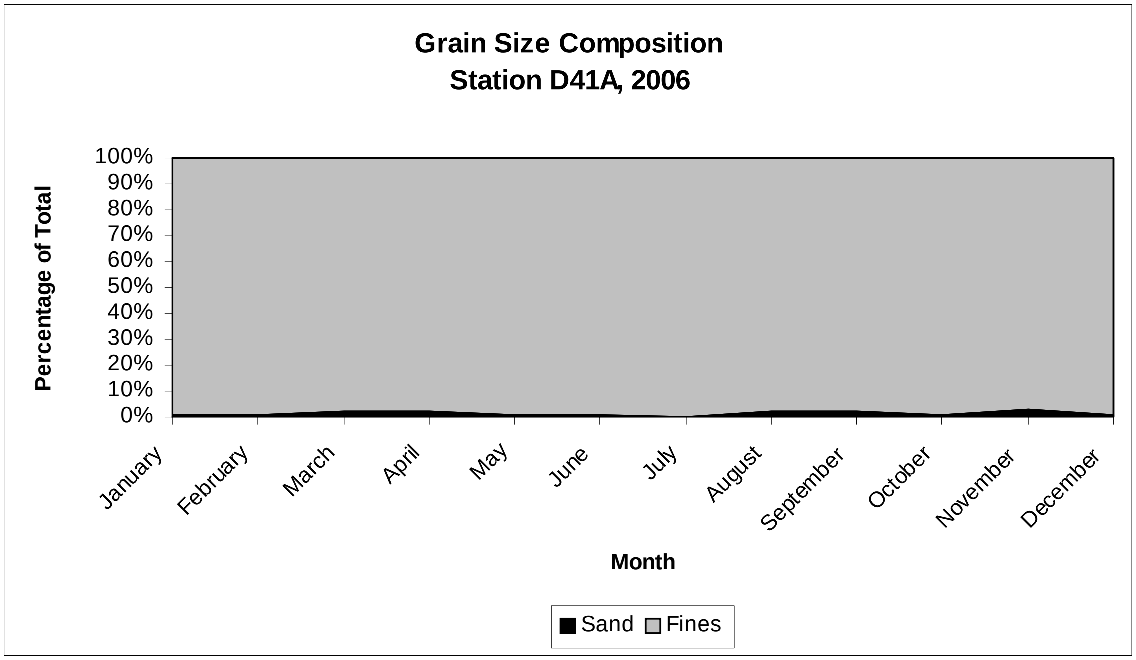


Figure 6-22 Sediment grain size and organic content at Station D41A during 2006



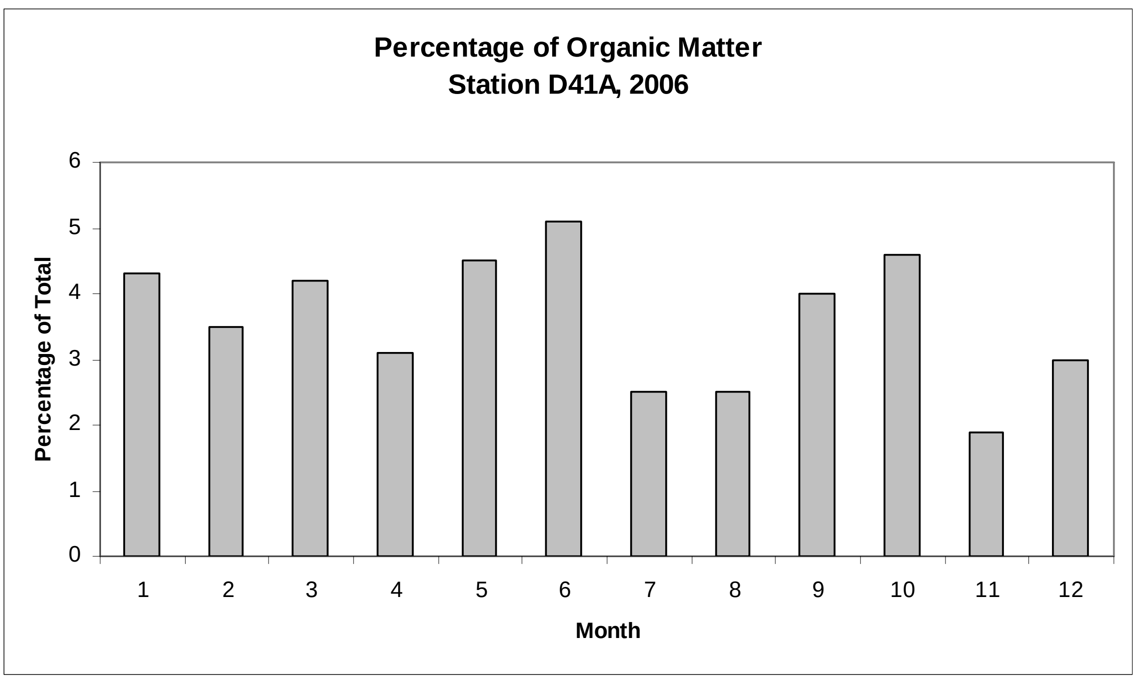


Table 6-1 Macrobenthic monitoring station characteristics, 2006

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

Chapter 7 Dissolved Oxygen Monitoring in the Stockton Ship Channel

Content

Figures

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.

DO = Dissolved oxygen

BOD = biochemical oxygen demand

mg/L = milligrams per liter

Because low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the SWRCB has established specific water quality objectives to protect these uses. Within the channel, 2 separate DO objectives have been established. The most recent Basin Plan (1998) of the CVRWQCB establishes a baseline objective of 5.0 milligrams per liter for the entire Delta region (including the Stockton Ship Channel) throughout the year. However, an objective of 6.0 mg/L was adopted for the period from September through November by the SWRCB in its latest Bay-Delta Plan (1995). This objective is established to protect fall-run Chinook salmon and applies to the lower San Joaquin River between Stockton and Turner Cut, which includes the eastern channel.

[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*. 4th ed.

[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. 44pp.

As part of a 1969 Memorandum of Understanding between DWR, the U.S. Fish and Wildlife Service, USBR, and DFG, DWR has installed a rock barrier across the mouth of Old River during periods of projected low San Joaquin River outflow. The head of Old River barrier (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 cubic feet per second (cfs) or less.

DWR = California Department of Water Resources

DFG = California Department of Fish and Game

USBR = U.S. Bureau of Reclamation

cfs = cubic feet per second

Due to high San Joaquin River flows and favorable DO levels, the barrier was not installed in fall 2006.

Methods

Monitoring of DO concentrations in the Stockton Ship Channel was conducted by vessel on 9 monitoring runs from July 24 to November 20, 2006[1]. During each of the monitoring runs, 14 sites were sampled at low water slack, beginning at Prisoners Point (station 1) in the central Delta and ending at the Stockton turning basin at the terminus of the Stockton Ship Channel (station 14). For geographic reference and simplicity of reporting, 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

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

[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.

Because monitoring results differ along the channel[3], sampling stations are grouped into western, central, and eastern regions. These regions are highlighted in Figure 7-1. The western channel begins at Prisoners Point (station 1) and ends at light 14 (station 5). The central channel begins at light 18 (station 6) and ends at light 34 (station 9). Finally, the eastern channel begins at light 40 (station 10) and ends at light 48 (station 13). The Stockton 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 hydro-morphology of station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from the surface) and bottom (1 meter from the bottom) of the water column at each station at low water slack, and 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 Seabird SBE3 temperature probe or a YSI 6600 sonde equipped with a model no. 6560 thermistor temperature probe.

[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

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

USGS = U.S. Geological Survey

Flows of the San Joaquin River past Stockton used in this report were obtained from data 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]. Due to low inflows, upstream agricultural diversions, and export pumping, net daily flows at Stockton can frequently approach zero and can sometimes reverse direction. During the period from August through November 2006, net flow at Stockton reached a minimum of 340 cfs. No net reverse flows were recorded during this period.

[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.

Results

During the period of this study (July 24 to November 20, 2006), DO levels varied significantly throughout the season but only slightly between regions within the channel (excluding the turning basin). Overall seasonal range was 4.7 to 9.5 mg/L at the surface and 4.9 to 9.7 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 5.3 to 9.4 mg/L at the surface and 6.4 to 9.3 mg/L at the bottom. In the central portion of the channel, DO concentrations were relatively high and showed a steady increase as the season progressed, ranging from 4.7 to 8.4 mg/L at the surface and 4.9 to 8.6 mg/L at the bottom. In the eastern channel, the DO levels were also high and stable, ranging from 5.3 to 9.5 mg/L at the surface and 6.5 to 9.7 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 6,690 cfs in August to a low of 2,242 cfs in November. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 2,310 cfs in October to a low of 340 cfs in November.

The findings for the summer and fall of 2006 are briefly summarized by month as follows.

July

Monitoring during a sampling run on July 24 showed surface DO levels ranging from 4.7 mg/L (station 7) to 9.5 mg/L (station 12). Bottom DO levels were not measured during this run due to a malfunction of the DO probe on the YSI 6600 sonde. A DO sag[7] (below 5 mg/L) was observed at the surface at stations 6 and 7.

Water temperatures during the July sampling run ranged from 26.2 °C (station 1) to 29.7 °C (station 11) at the surface and 25.9 °C (station 1) to 27.7 ˚C (station 13) at the bottom. This temperature range is an increase over the temperatures recorded during the 2005 sampling season, where the maximum water temperature was 27.3 °C.

Flows on the San Joaquin River near Vernalis ranged from 3,866 to 4,170 cfs during the end of July.

August

Monitoring during 2 cruises, August 9 and 24, showed surface DO levels ranging from 4.9 mg/L at station 7 to 9.5 mg/L at station 13 (Figure 7-2). Bottom DO levels ranged from 4.9 mg/L at station 8 to 9.7 mg/L at station 13.

Figure 7-2 DO concentrations at 14 stations in the Stockton Ship Channel, summer/fall 2006

A DO sag (<5.0 mg/L) was observed at the surface (station 7) and bottom (station 8) on August 9. On August 24, no DO sag was present.

August water temperature values ranged from 22.0 ^{o}C (station 1) to 24.8 ^{o}C (station 10) at the surface, and from 21.8 °C (station 1) to 24.0 °C (stations 6 and 7) at the bottom (Figure 7-3).

Figure 7-3 Water temperatures (˚C) at 14 stations in the Stockton Ship Channel, summer/fall 2006

[7] In this report, we define a DO "sag" as a region within the channel where DO levels do not meet the SWRCB objective.

Average daily flows on the San Joaquin River past Vernalis in August ranged from 3,232 to 6,690 cfs. Net flow in the San Joaquin River past Stockton ranged from 1,220 to 1,550 cfs (Figure 7-4).

Figure 7-4 San Joaquin River mean daily flow, summer/fall 2006

September

Monitoring during 2 cruises, September 7 and 19, showed surface DO levels ranging from 5.7 mg/L at station 7 to 8.3 mg/L at station 12 (Figure 7-2). Bottom DO levels ranged from 6.0 mg/L at station 6 to 8.0 mg/L at station 13 on September 7. Bottom DO levels were not measured during the September 19 monitoring cruise due to a malfunction of the DO probe on the YSI 6600.

During the September 7 cruise, a DO sag (<6 mg/L) was observed at station 7 (surface DO). By September 19, all stations had DO levels at or above the SWRCB objective.

September surface water temperatures ranged from 19.7 °C at station 13 to 23.2 °C at stations 7, 8, and 9. Bottom temperatures ranged from 19.7 °C at stations 12 and 13 to 23.0 °C at stations 6 and 7 (Figure 7-3).

Flow rates past Vernalis during September ranged from 2,670 to 3,456 cfs. Flows at Stockton during September ranged from a low of 1,200 cfs to a high of 1,960 cfs (Figure 7-4).

October

Monitoring cruises were conducted on October 5 and 18. Surface DO levels ranged from 7.2 mg/L at station 6 to 9.4 mg/L at station l. Bottom DO levels ranged from 7.0 mg/L at station 6 to 9.3 mg/L at station 1 (Figure 7-2). All DO levels measured during the month were well above the SWRCB objective.

Surface water temperatures in October ranged from 15.7 °C at station 13 to 18.5 ^{o}C at station 5 (Figure 7-3). Bottom water temperatures were similar, ranging from 15.6 ^{o}C at station 13 to 18.4 °C at stations 5 and 6.

Average daily flows of the San Joaquin River at Vernalis ranged from 3,111 to 4,569 cfs during the month of October (Figure 7-4). Net daily flows at Stockton ranged from 1,940 to 2,310 cfs.

November

DWR conducted 2 monitoring cruises in November, 6 and 20. Surface DO levels ranged from 7.9 mg/L at station 12 to 8.7 mg/L at station 1. Bottom DO levels ranged from 7.6 mg/L at station 12 to 9.0 mg/L at station 1. All DO levels measured during the month were well above the SWRCB objective.

Surface water temperatures ranged from 13.8 °C at stations 8 and 9 to 15.5 °C at stations 1 through 5 and station 13. Bottom water temperatures ranged from 13.7 ^{o}C at station 8 to 15.5 °C at stations 1 through 4 (Figure 7-3).

San Joaquin River flows at Vernalis ranged from 2,242 to 3,450 cfs. Net daily flows past Stockton ranged from 340 cfs to 2,090 cfs (Figure 7-4).

Stockton Turning Basin

DO levels in the Stockton turning basin were well above SWRCB objectives at the surface during the entire study period, and bottom DO levels dropped below the SWRCB standard on only 1 occasion (September 7). DO levels in August ranged from 9.6 mg/L at the surface to 5.6 mg/L at the bottom (Figure 7-2). September DO levels at the surface and bottom ranged from 7.4 to 7.5 mg/L, respectively. DO levels in October ranged from 8.1 mg/L at the surface to 6.9 mg/L at the bottom. November DO readings were well above SWRCB objectives, ranging from 9.4 mg/L at the surface to 7.2 mg/L at the bottom.

Summary

DO concentrations in the Stockton Ship Channel fell below the SWRCB's 5.0 mg/L and 6.0 mg/L objectives on 3 occasions this season: on July 24 at stations 6 and 7 in the central channel, on August 9 at stations 7 and 8 (central channel), and on September 7 at station 7. All sites were above the SWRCB DO objective on subsequent sampling runs.

Flows on the San Joaquin River near Vernalis ranged from a high of 6,690 cfs in August to a low of 2,242 cfs in November. Net daily flow on the San Joaquin River past Stockton ranged from a high of 2,310 cfs in October to a low of 340 cfs in November. The head of Old River barrier was not installed in fall 2006 due to favorable flow and DO conditions.

Further monitoring operations for the fall 2006 special study were suspended after November 20, 2006.

References

[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.

[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.* 4th ed.

[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. 44pp.

Figure 7-1 Monitoring sites in the Stockton Ship Channel

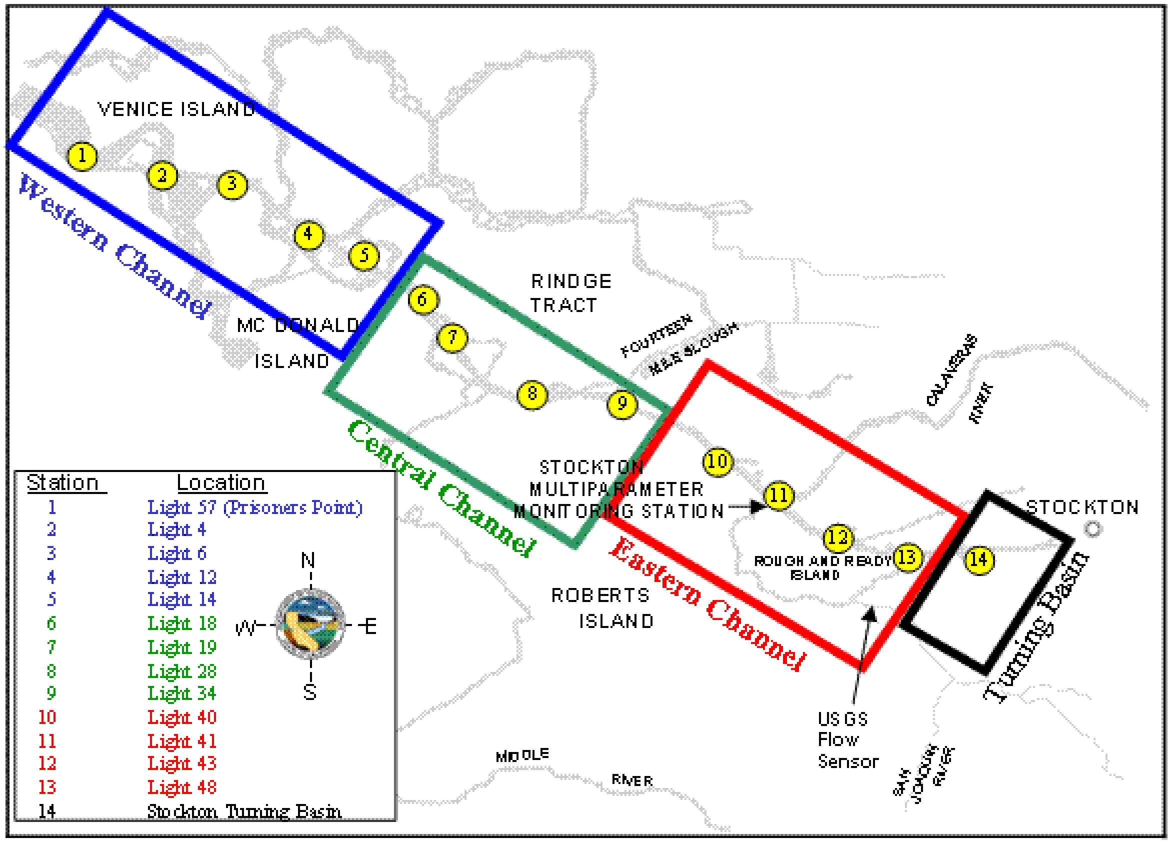


Figure 7-2 Dissolved oxygen concentrations at 14 stations in the Stockton Ship Channel, summer/fall 2006

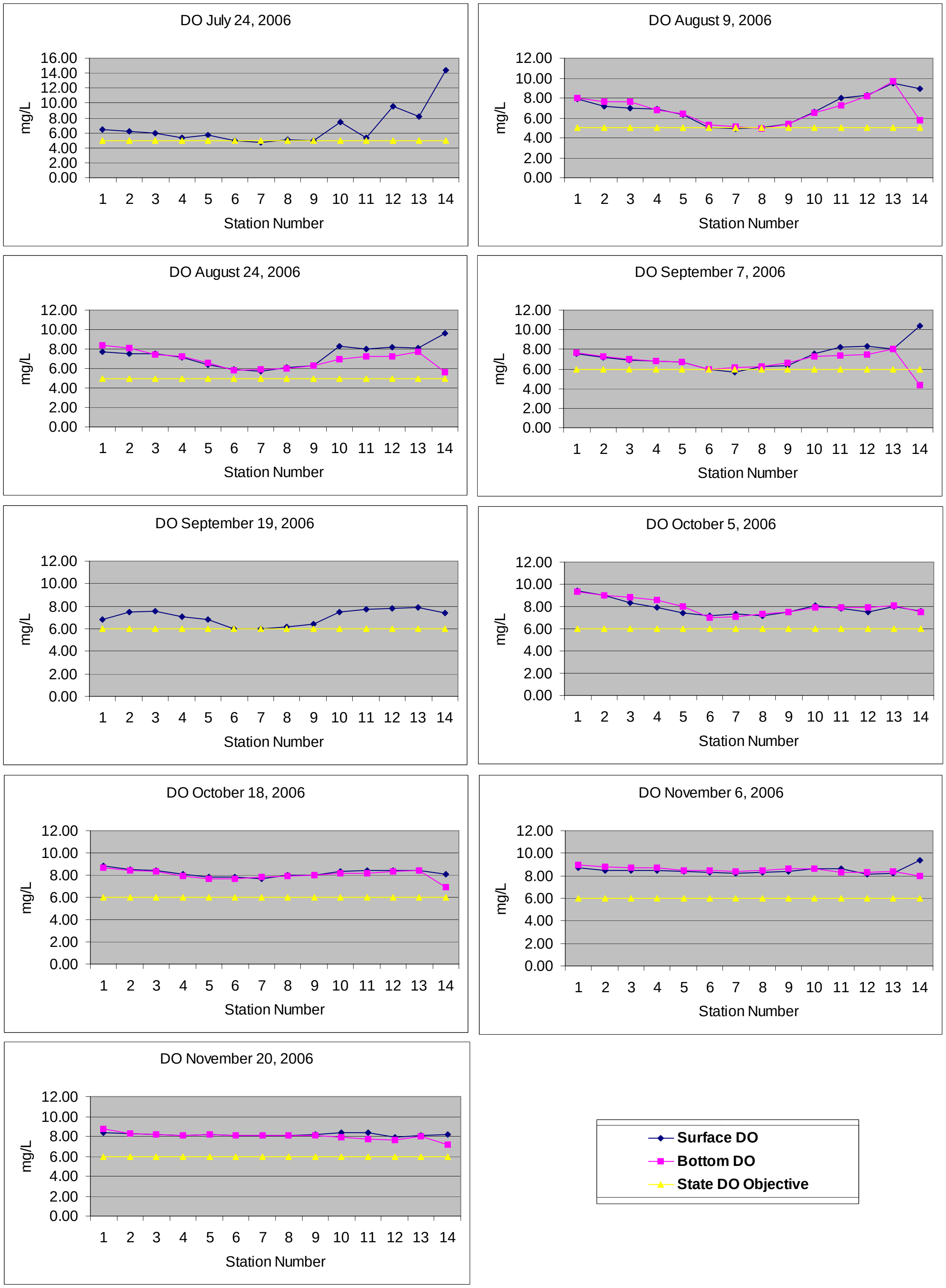


Figure 7-3 Water temperatures (°C) at 14 stations in the Stockton Ship Channel, summer/fall 2006

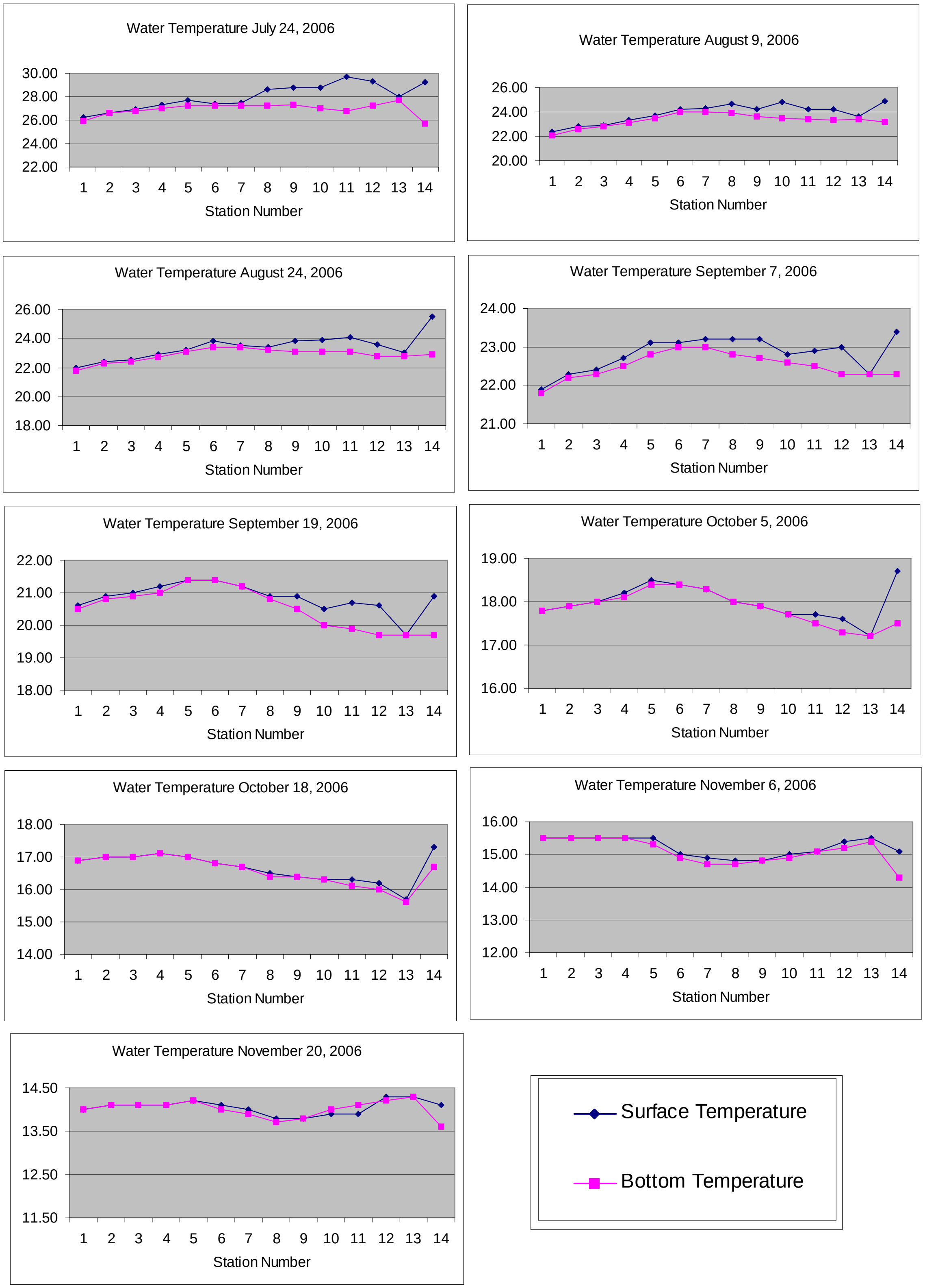
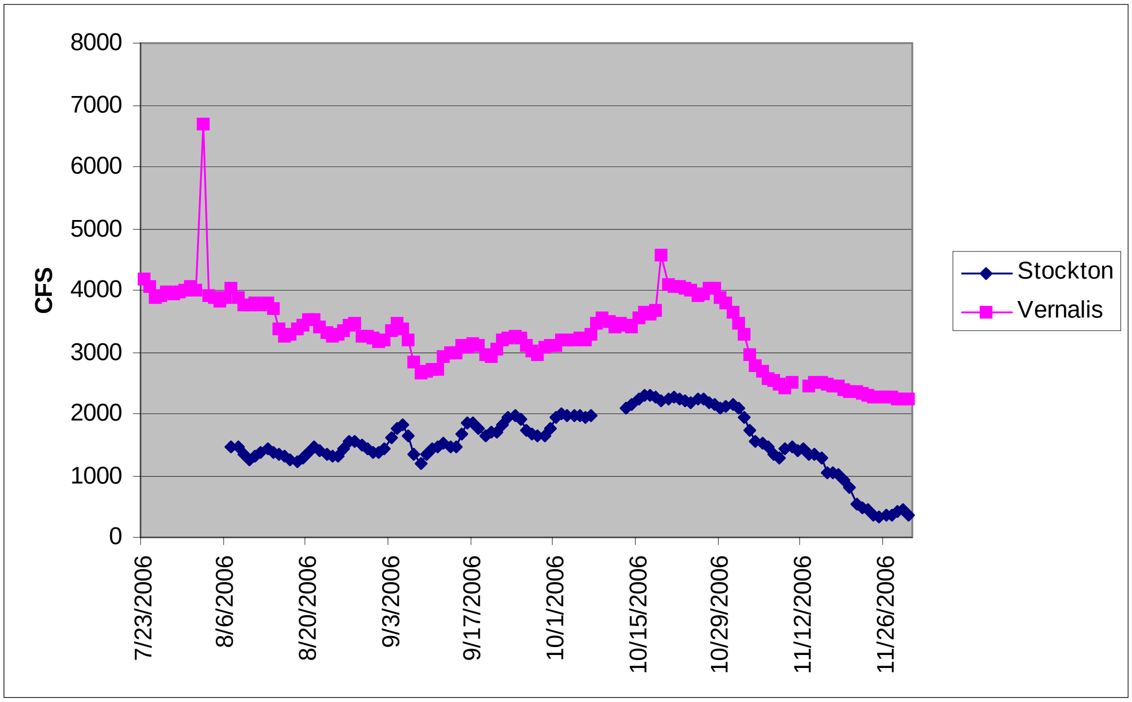


Figure 7-4 San Joaquin River mean daily flow, summer/fall 2006



Chapter 8 Data Management

Content

Chapter 8 Data Management

Introduction

All data collected by the 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 BDAT. At present, the EMP continuous water quality data are available on BDAT under the category <BDAT Links> and then <Time Series>.

EMP = Environmental Monitoring Program

BDAT = Bay Delta and Tributaries database

IEP = Interagency Ecological Program

BDAT consolidates and provides public access to environmental data contributed by more than 50 organizations. The database includes water quality, biological, and meteorological data from throughout the Estuary. The EMP water quality, benthic and phytoplankton data stored in this database are available at baydelta.water.ca.gov.

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

Metadata information describes sampling site locations, sampling methodology, and field and laboratory processing for all the data variables and is available on the IEP website at 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 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 data are stored, how 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

DWR = California Department of Water Resources

FLIMS = Field and Laboratory Information Management System

During monthly sampling runs, field measurements are recorded on datasheets and entered into the field module of the DWR Field and Laboratory Information Management System (FLIMS). 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 review the data against 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 baydelta.water.ca.gov/index.html.

For more information regarding management and access to discrete water quality data, contact Brianne Noble at bnoble@water.ca.gov.

Continuous Water Quality Data

Data from automated continuous water quality monitoring stations are retrieved by downloading each station's data recorders onto a handheld "pocket PC." Data are then 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 review these data for accuracy, completeness, and consistency using probe verification and calibration records. Data that are the result of a measuring instrument that was operating out of proper calibration are "flagged" and are retained in the database. The "flagged" 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 baydelta.water.ca.gov/index.html.

A subset of the data from automated continuous water quality monitoring stations is sent 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 cdec.water.ca.gov/

CDEC = California Data Exchange Center

For more information regarding management and access to continuous water quality data, contact Darrell Kaff at dkaff@water.ca.gov.

Benthic Data

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 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 review 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 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 review 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 baydelta.water.ca.gov/index.html.

For more information regarding phytoplankton data, contact Tiffany Brown at tbrown@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 DFG's Bay-Delta Branch Laboratory. Data are entered directly into a computer during processing and stored electronically in a Microsoft Access database. Data are periodically reviewed for accuracy and completeness by DFG staff. Currently zooplankton data are only available through DFG; however, construction is under way of a zooplankton database able to export data to BDAT.

DFG = CaliforniaDepartment of Fish and Game

Data are available upon request from April Hennessy at ahennessy@dfg.ca.gov.

Chapter 9 Continuous Monitoring

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Chapter 9 Continuous Monitoring

Introduction

DWR's Continuous Monitoring Program supplements the EMP's monthly discrete Compliance Monitoring Program by providing real-time hourly and 15-minute water quality and environmental data from 9 shore-based automated sampling stations in the upper San Francisco Estuary (Figure 9-1). These stations provide continuous measurements of 7 water quality parameters and 4 environmental parameters. Operators of the SWP and the CVP use these measurements to assess the impacts of and adjust project operations in order 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 9 sites for calendar year 2006. The stations are divided into 3 regions to allow for detail in the plots:

Figure 9-1 Location of 9 shore-based automated sampling stations in the upper San Francisco Estuary

SWP = State Water Project
CVP = Central Valley Project

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

Methods

Continuous data are collected for the water quality and weather parameters shown in Table 9-1. Each of the 9 monitoring stations collects continuous data for water temperature, pH, DO, 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 the Bay-Delta Plan (SWRCB 1995). Weather data—such as air temperature, solar radiation, wind speed, and direction—are measured at all stations except Mossdale (only air temperature) and Prisoners Point, Vernalis, and Hood stations (none) as part of Water Right Decision 1641's Table 3 objectives (SWRCB 1999).

Table 9-1 Parameters

DO = dissolved oxygen

[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. 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. 211pp.

Except for bottom specific conductance and data collected at Prisoners 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, Prisoners Point and Vernalis data, and weather data—such as solar radiation, wind speed, and wind direction data—are recorded at 15-minute intervals.

Complete hourly or 15-minue data for air and water temperature, pH, DO, surface and bottom specific conductance, chlorophyll florescence, turbidity, wind velocity, wind direction, solar radiation intensity, and river stage are available on the 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, DO, surface and bottom specific conductance, chlorophyll fluorescence, and turbidity for calendar year 2006 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. The Prisoners Point and Vernalis stations use a YSI6600 sonde.

Estuary = San Francisco Estuary

Average monthly water temperatures in the San Francisco Estuary (Estuary) ranged from 9.3 °C in December 2006 at the Hood station on the Sacramento River to 25.7 °C in July 2006 at the Stockton station on the San Joaquin River (Figure 9-2). These values are similar to the same time period in 2005.

Figure 9-2 Average monthly water temperature at 9 stations, 2006

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

DO was measured using a Schneider Instruments RM25C-033 measuring circuit with a Clark-polarographic probe. The Prisoners Point and Vernalis stations use a YSI6600 sonde. From August 22, 2006, the Vernalis station used the new technology optical DO sensor.

Average monthly DO values for the 9 monitoring stations ranged from 6.0 mg/L to 10.9 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 6.0 mg/L was calculated for the Stockton station in August 2006, and a value of 10.9 mg/L was calculated for the Hood station for March 2006. All other stations showed monthly averages between 6.9 mg/L and 10.9 mg/L with the Stockton station recording lower values starting in July 2006. All compliance-monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the CVRWQCB in the Basin Plan (1998). Monthly average DO values at the Stockton station were highly variable and ranged from 6.0 mg/L to 10.0 mg/L. The Stockton station, located in the Stockton Deep Water Ship Channel, showed a small DO sag of 7.3 mg/L in April 2006. The San Joaquin River stations at Prisoners Point, Mossdale, and Vernalis showed a similar drop in DO. The pattern of winter sag, first identified in 2000, was not evident in 2006. The 2006 sag occurred in April.

Figure 9-3 Average monthly DO at 9 stations, 2006

[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.* 4th ed.

During summer and fall 2006, monthly average DO values at the Mossdale and Vernalis stations showed a familiar pattern of increase for July and August. Monthly average DO values in previous years showed a similar

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

pattern from June to September. The July increase to 9.0 mg/L at the Mossdale station in 2006 showed a continued decrease in summer DO levels from a high of 12.1 mg/L in 2004. The high average summer DO levels seen at the Mossdale station coincided with high chlorophyll fluorescence during the same period (Figure 9-8a).

Figure 9-8a Average monthly chlorophyll at 9 stations, 2006

Specific Conductance

Specific conductance was measured using a Schneider Instruments RM25C-032 system. The Prisoners Point and Vernalis stations use a YSI6600 sonde.

Monthly average surface specific conductance for the Estuary ranged from 94 µS/cm to 24,954 µS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 9-4a). The 2006 data is very similar to the 2005 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 9-4b).

Figure 9-4a Average monthly specific conductance at 9 stations, 2006

Figure 9-4b Average monthly specific conductance at 6 river stations

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

Figure 9-5 Average monthly surface and bottom specific conductance at 3 tidally influenced stations, 2006

pH

The pH was measured using a Schneider Instruments RM25C-035 system. The Prisoners Point and Vernalis stations use a YSI6600 sonde.

Figure 9-6 Average monthly pH at 9 stations, 2006

Monthly average pH levels for the Estuary for all stations ranged from 6.8 to 8.0 pH units (Figure 9-6). Unlike 2005—when the stations on the San Joaquin River showed a fairly constant level of pH values in April, May, and June—there was a decrease in pH at all San Joaquin River stations during the same time period in 2006.

Air Temperature

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

Monthly average air temperatures in the Estuary ranged from 7.6 °C in December 2006 at the Stockton station on the San Joaquin River to 25.1 °C July 2006 at the Rio Vista station on the Sacramento River (Figure 9-7).

Figure 9-7 Monthly average air temperature at 6 stations, 2006

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured using a Turner Designs SCUFA® Fluorometer set-up with a continuous flow system using chlorophyll *a* filters. The Prisoners Point and Vernalis stations use a YSI6600 sonde.

FU = fluorescence units

Monthly average chlorophyll fluorescence recorded at the stations in the Estuary ranged from minima of 0.9 fluorescence units (FU) in October 2006 at the Mallard station on the Sacramento River to maxima of 12.5 FU in July 2006 at the Vernalis station on the San Joaquin River (Figure 9-8a-c).

Figure 9-8a Average monthly chlorophyll at 9 stations, 2006

Figure 9-8b Average monthly chlorophyll at 2 Sacramento River stations,

Figure 9-8c Average monthly chlorophyll at 4 San Joaquin River stations, 2006

Figure 9-8d Average monthly chlorophyll at 3 tidally influenced stations, 2006

Turbidity

Turbidity was measured using a Turner Designs SCUFA® Fluorometer. The Prisoners Point and Vernalis stations use a YSI6600 sonde.

Monthly average turbidity was recorded at the stations in the Estuary ranged from minima of 3 NTU at the Mossdale station on the San Joaquin River in October 2006 to maxima of 48 NTU at the Martinez station in the Carquinez Strait in January 2006 (Figure 9-9a-d).

Figure 9-9a Average monthly turbidity at 9 stations, 2006

Figure 9-9b Average monthly turbidity at 2 Sacramento River stations, 2006

Figure 9-9c Average monthly turbidity at 4 San Joaquin River stations, 2006

Figure 9-9d Average monthly turbidity at 3 tidally influenced stations, 2006

Stockton Ship Channel Dissolved Oxygen

As part of DWR's mandate to monitor water quality in the Delta, a special monitoring study focuses on DO conditions in the Stockton Ship Channel from Prisoners Point to the Stockton Turning Basin (see Chapter 7). Continuous data from a monitoring station in the ship channel (Stockton Station P8a) supplement monthly discrete sampling and alert DWR personnel when DO levels become critical.

CVRWQCB has established a baseline objective of 5.0 mg/L for the entire Delta (CVRWQCB 1998); however, due to the special concerns in the Stockton Ship Channel to protect fall-run Chinook salmon, a DO objective of 6.0 mg/L has been established for September through November by SWRCB (1995).

For 2006, average monthly DO values at the Stockton station remained above the 6.0 mg/L standard during the mandated months of September through November (Figure 9-10).

Monthly average DO values in 2006 ranged from 6.0 to 10.9 mg/L. The lowest DO value occurred in August 2006 at the Stockton station on the San Joaquin River, and the highest value of 10.9 mg/L occurred in March 2006 at the Hood station on the Sacramento River. Monthly average DO values did not drop below the state-mandated standards. In 2006, hourly values ranged from 3.8 to 10.8 mg/L. The minimum value of 4.1 mg/L was recorded in July 2006. As seen in previous years, the DO levels drop during the summer months of July, August, and September. The pattern of falling DO levels in the winter, first observed in 2000, was not observed in 2006: DO levels remained above the 5.0 mg/L standard.

Figure 9-10 Range of monthly DO values, San Joaquin at Rough and Ready Island 2006

The box plots (Figure 9-10) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal "whiskers" indicate the range of hourly DO values for each month. Boxes represent monthly medians and 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 2006 were usually in the expected range of values for water temperature, DO, 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 chlorophyll *a* fluorescence values in July than any other station in the Estuary. The San Joaquin station at Mossdale showed higher DO values in July and August than any other station in the Estuary, and the Stockton station showed the lowest values for DO in July and August. Unlike 2005, the pH values at all stations on the San Joaquin River dropped during the months of April, May, and June and remained near or lower than pH values measured at the other Estuary stations during the rest of the year.

The San Joaquin River station at Stockton remained above the 5.0 mg/L standard, as set by CVRWQCB (1998), for the entire period. The DO levels did not drop below the 6.0 mg/L standard (SWRCB 1995) for the passage of fall-run Chinook salmon through the Stockton Deep Water Ship Channel for the 2006 control period.

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*. 4th ed.

[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. 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. 211pp.

Figure 9-1 Location of 9 shore-based automated sampling stations in the upper San Francisco Estuary

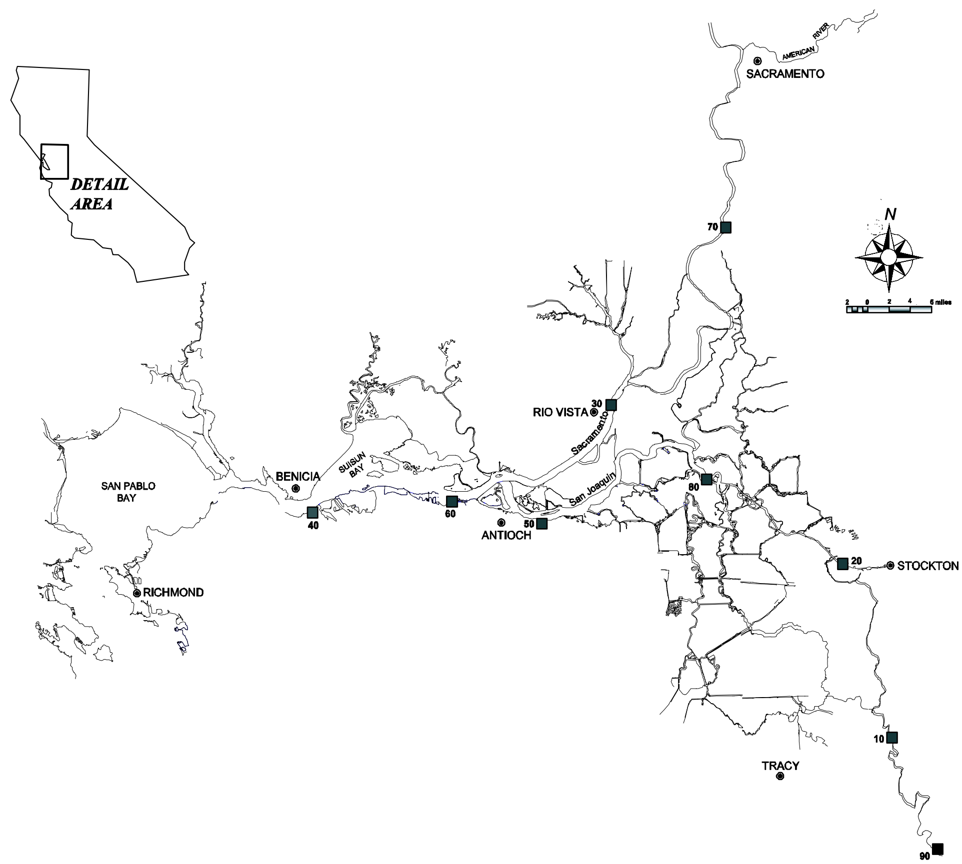


Figure 9-2 Average monthly water temperature at 9 stations, 2006

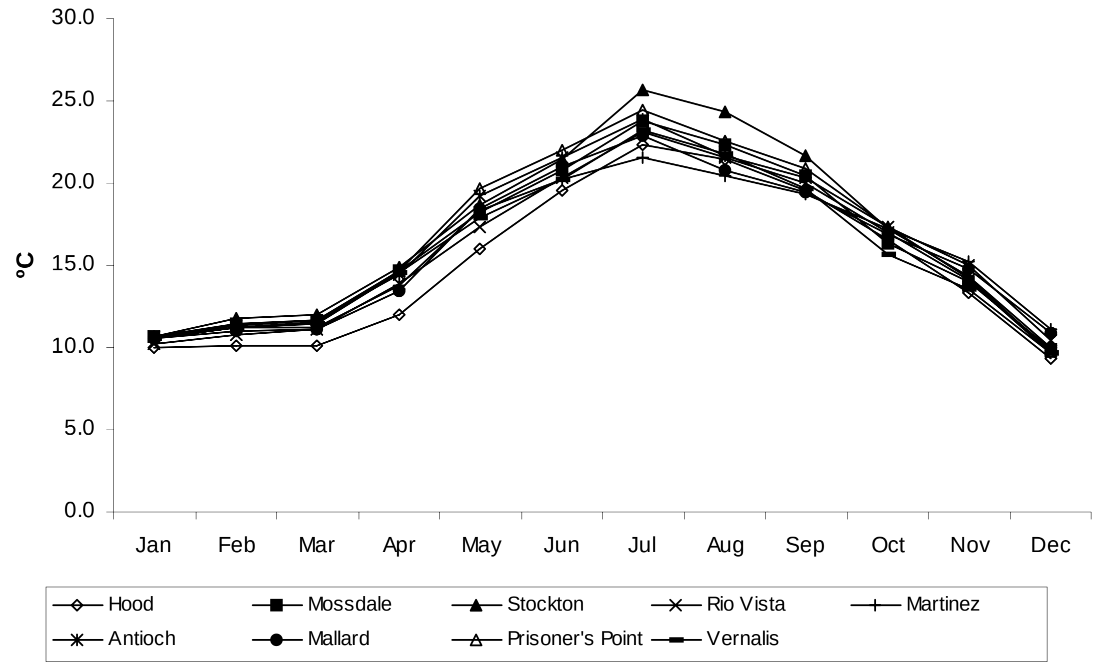


Figure 9-3 Average monthly dissolved oxygen at 9 stations, 2006

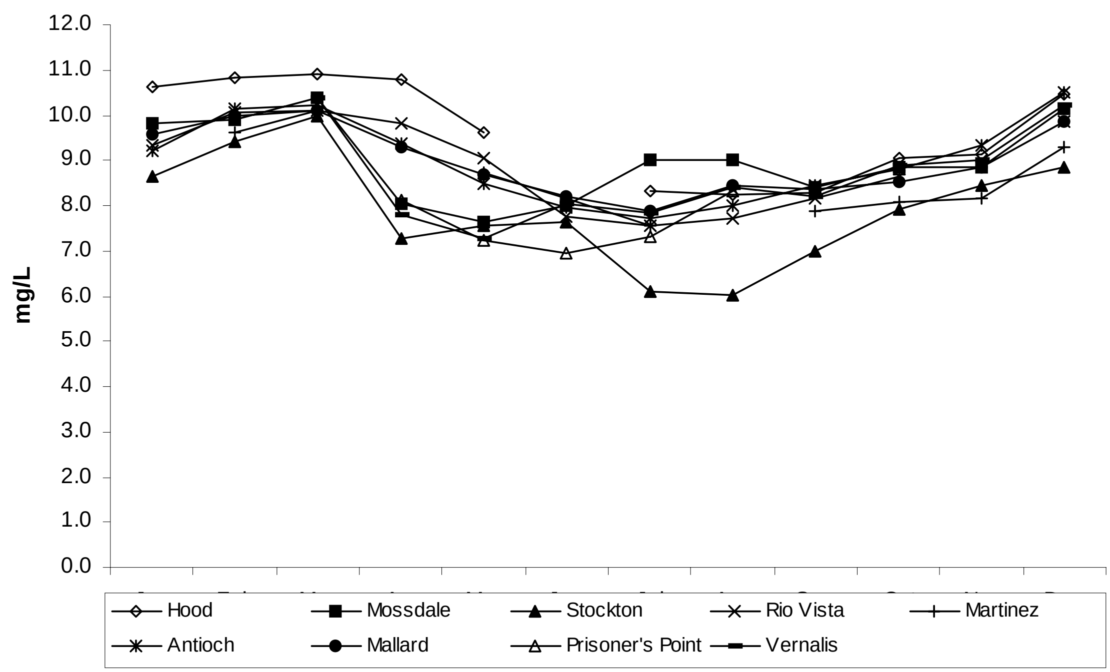


Figure 9-4a Average monthly specific conductance at 9 stations, 2006

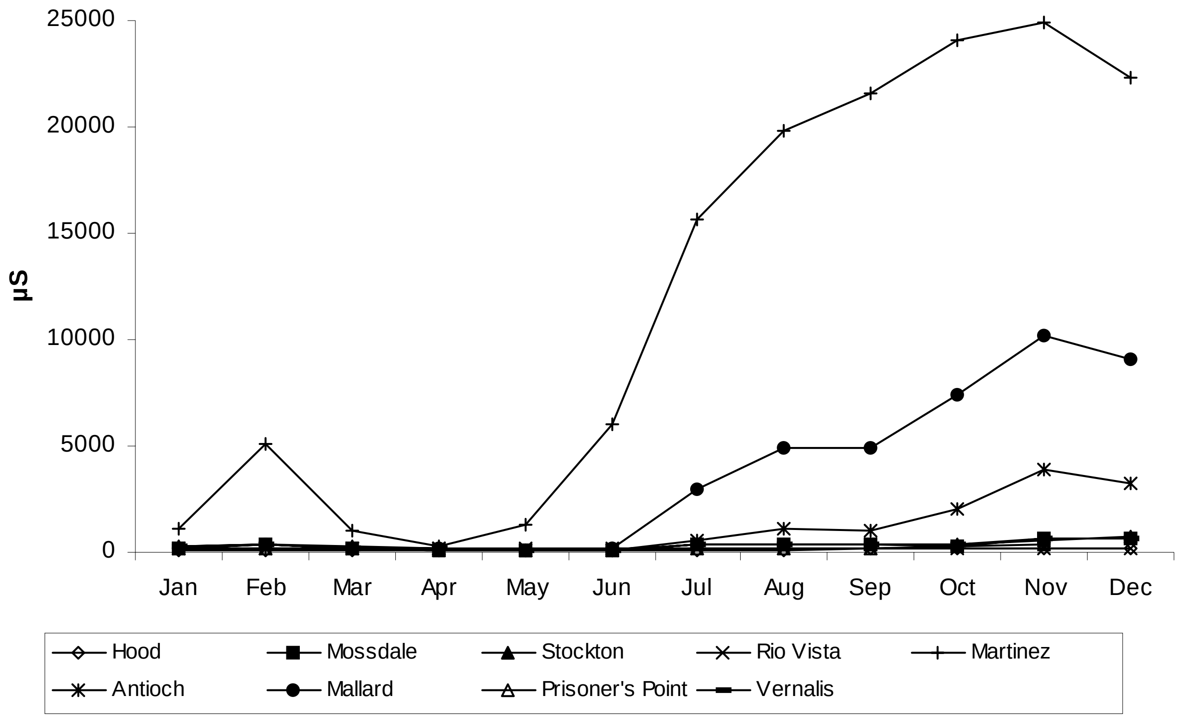


Figure 9-4b Average monthly specific conductance at 6 river stations

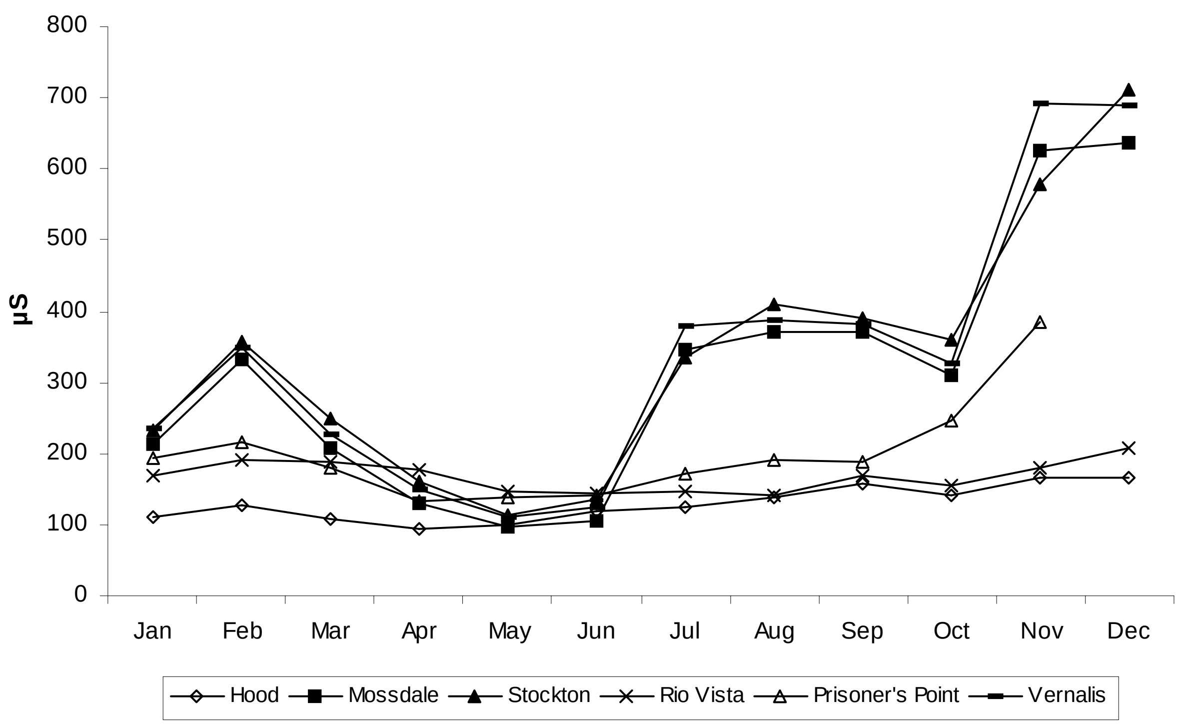


Figure 9-5 Average monthly surface and bottom specific conductance at 3 tidally influenced stations, 2006

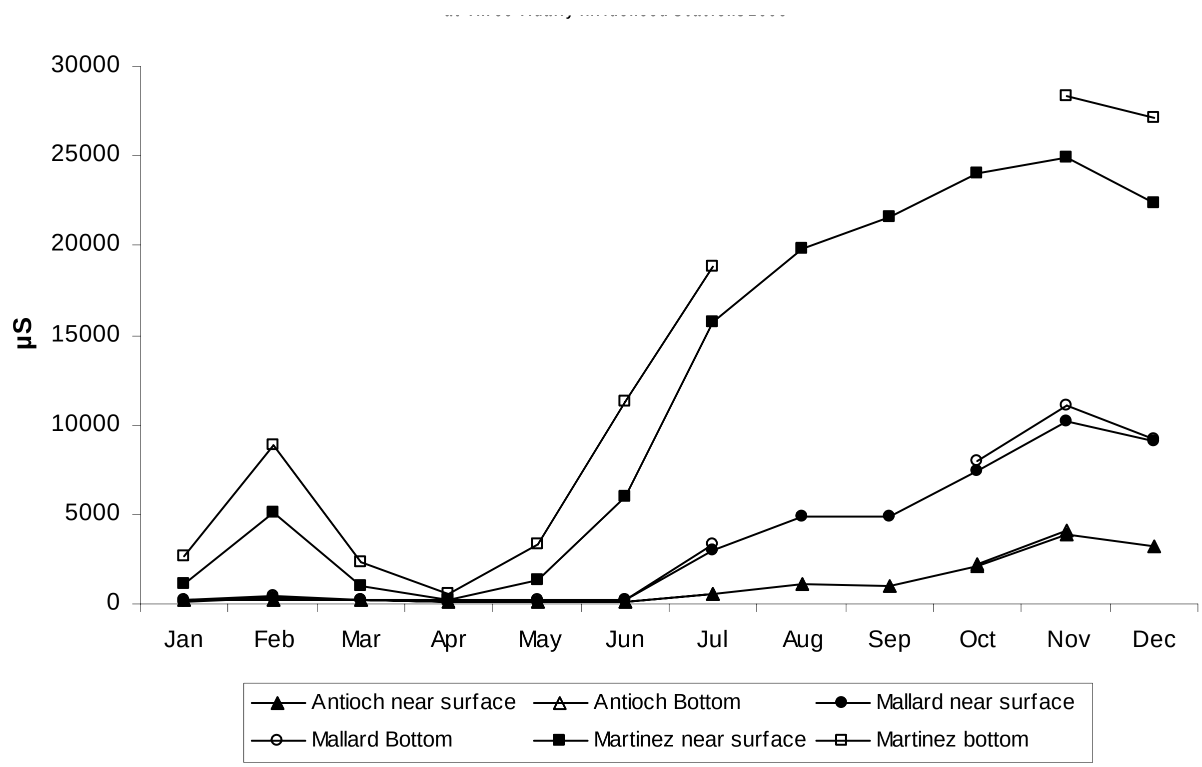


Figure 9-6 Average monthly pH at 9 stations, 2006

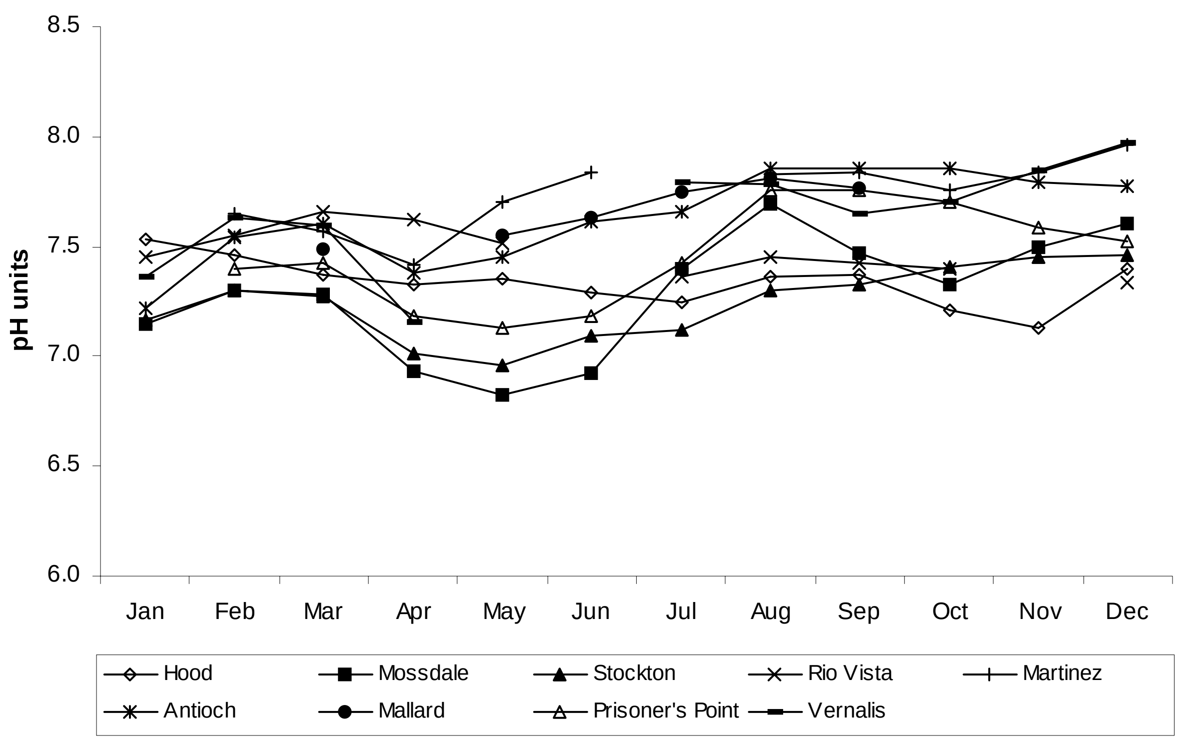


Figure 9-7 Monthly average air temperature at 6 stations, 2006

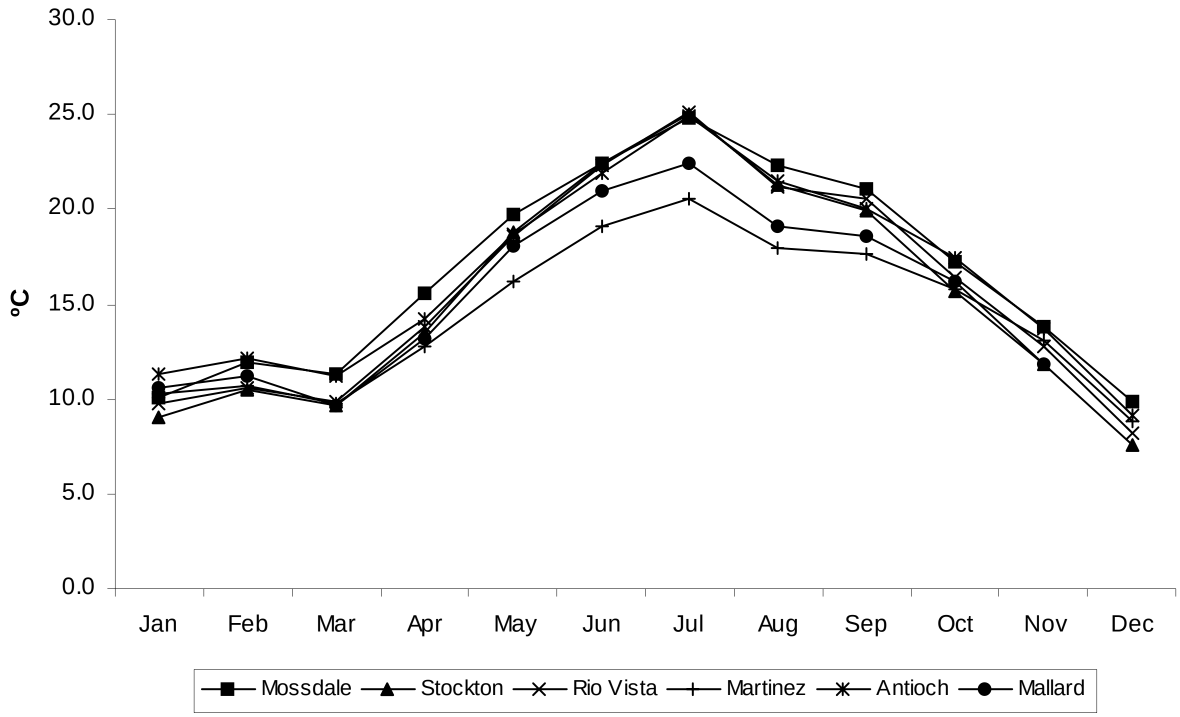


Figure 9-8a Average monthly chlorophyll at 9 stations, 2006

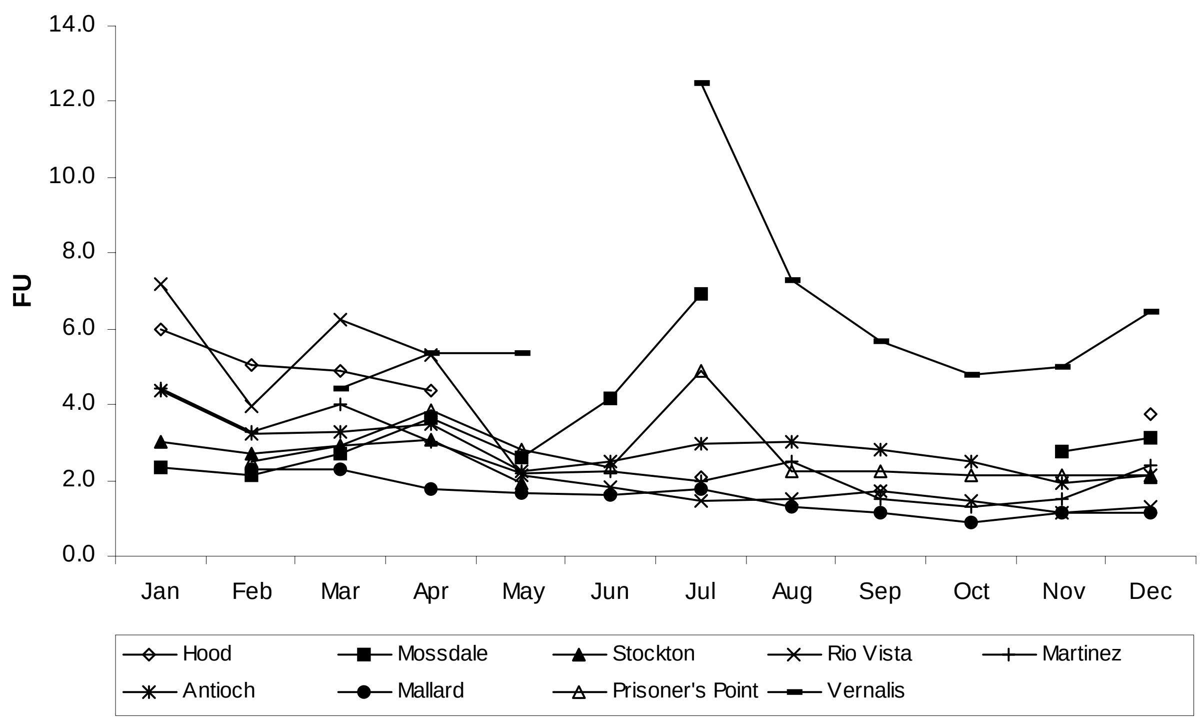


Figure 9-8b Average monthly chlorophyll at 2 Sacramento River stations, 2006

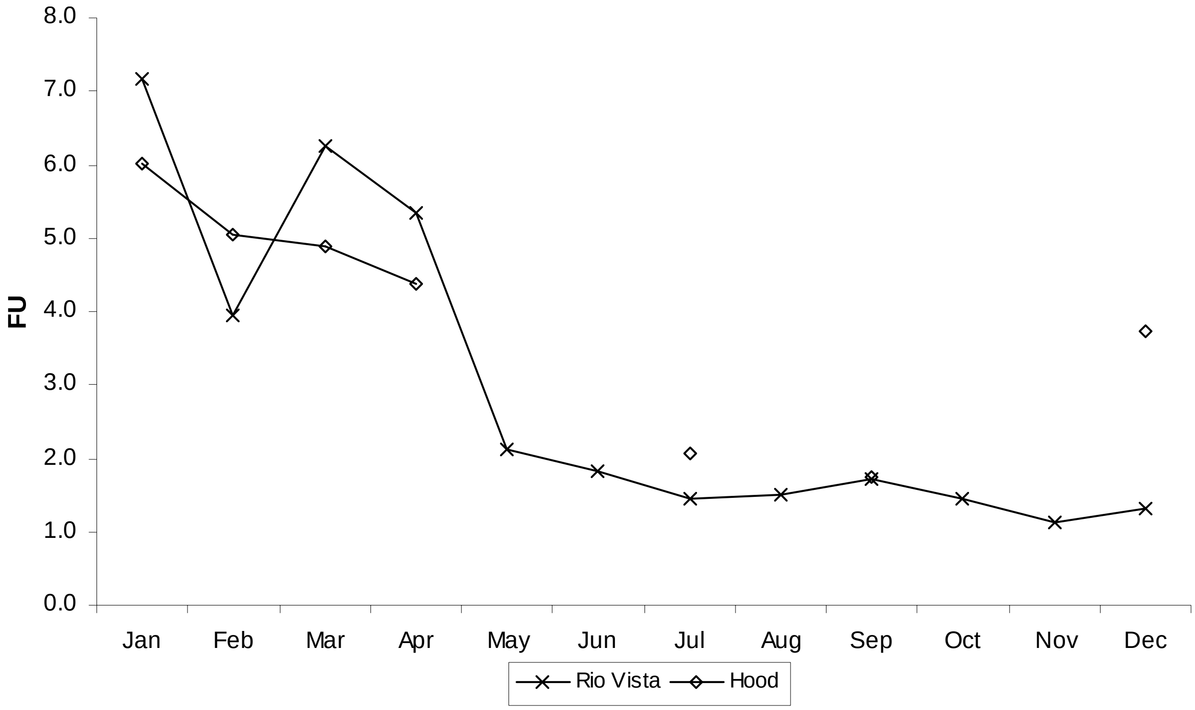


Figure 9-8c Average monthly chlorophyll at 4 San Joaquin River stations, 2006

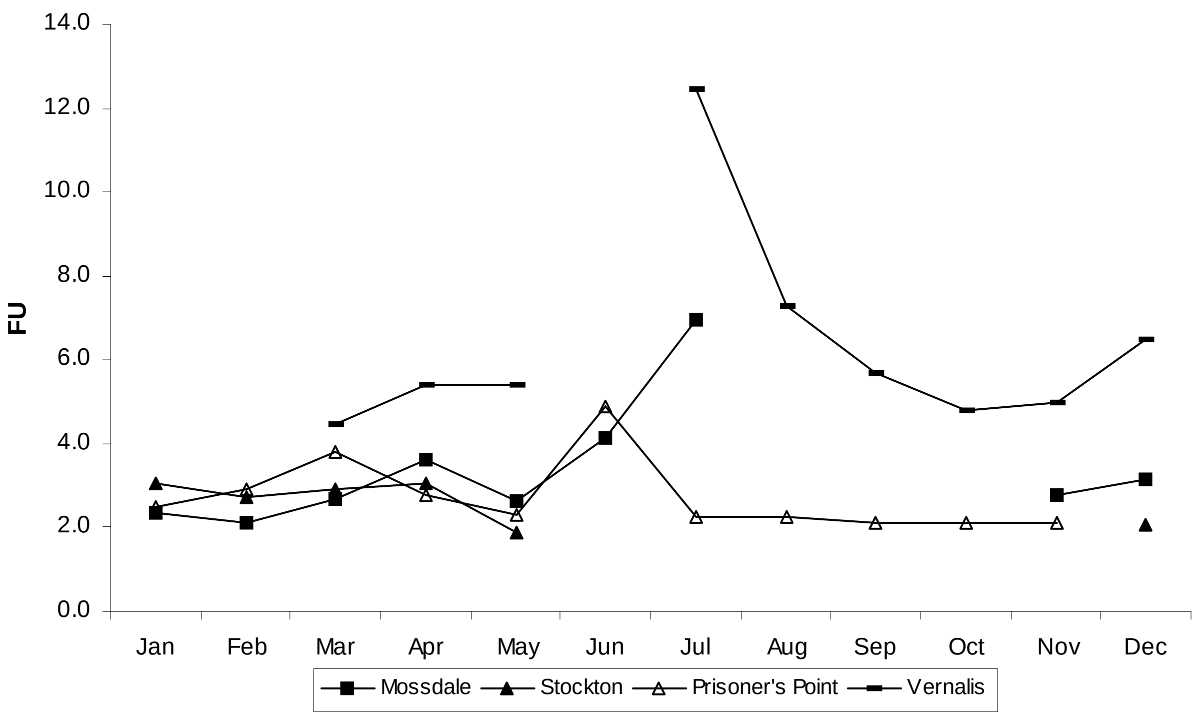


Figure 9-8d Average monthly chlorophyll at 3 tidally influenced stations, 2006

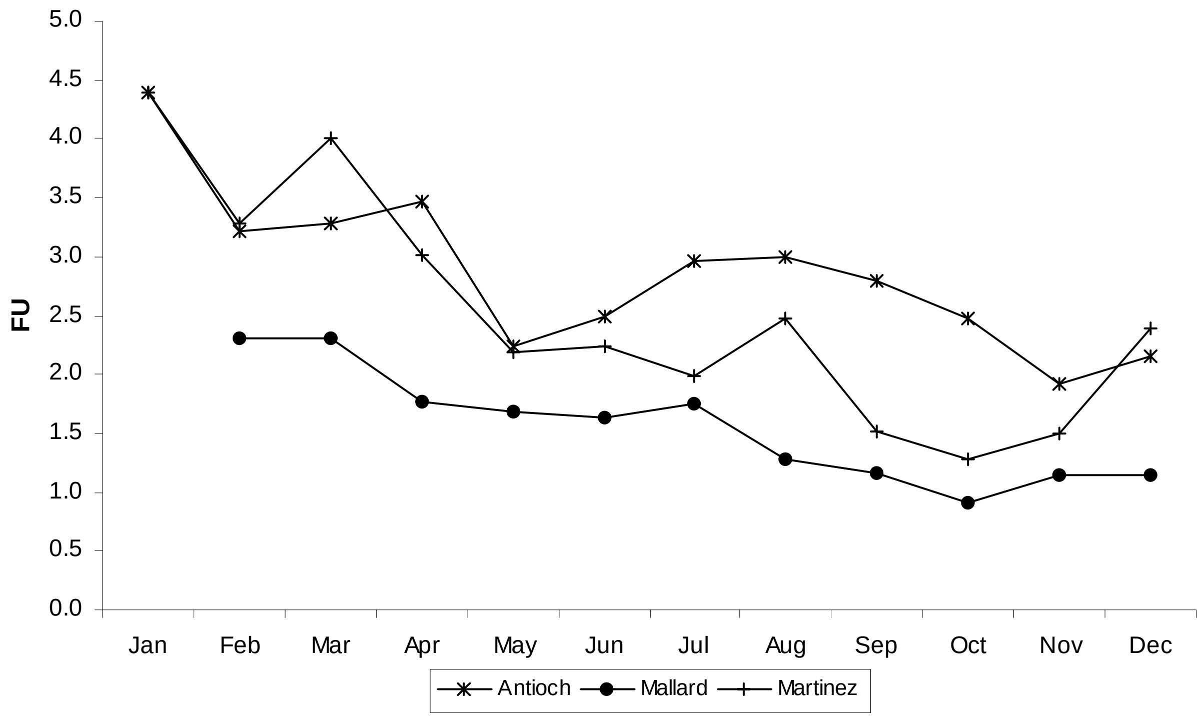


Figure 9-9a Average monthly turbidity at 9 stations, 2006

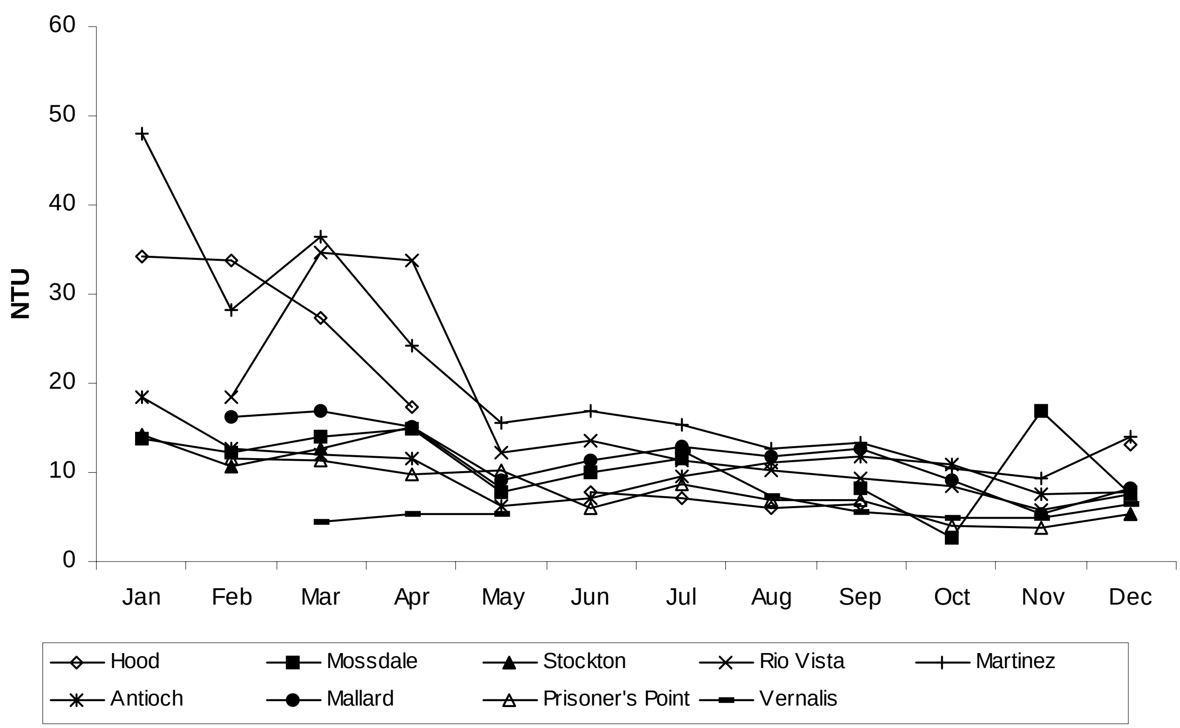


Figure 9-9b Average monthly turbidity at 2 Sacramento River stations, 2006

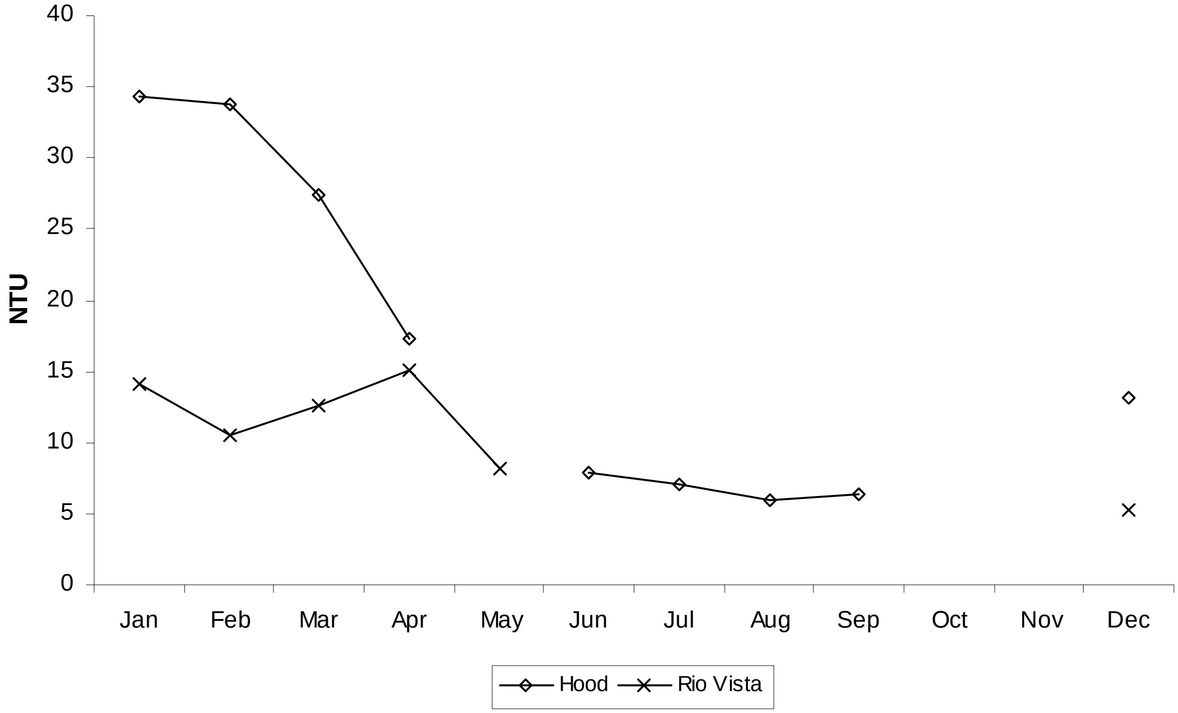


Figure 9-9c Average monthly turbidity at 4 San Joaquin River stations, 2006

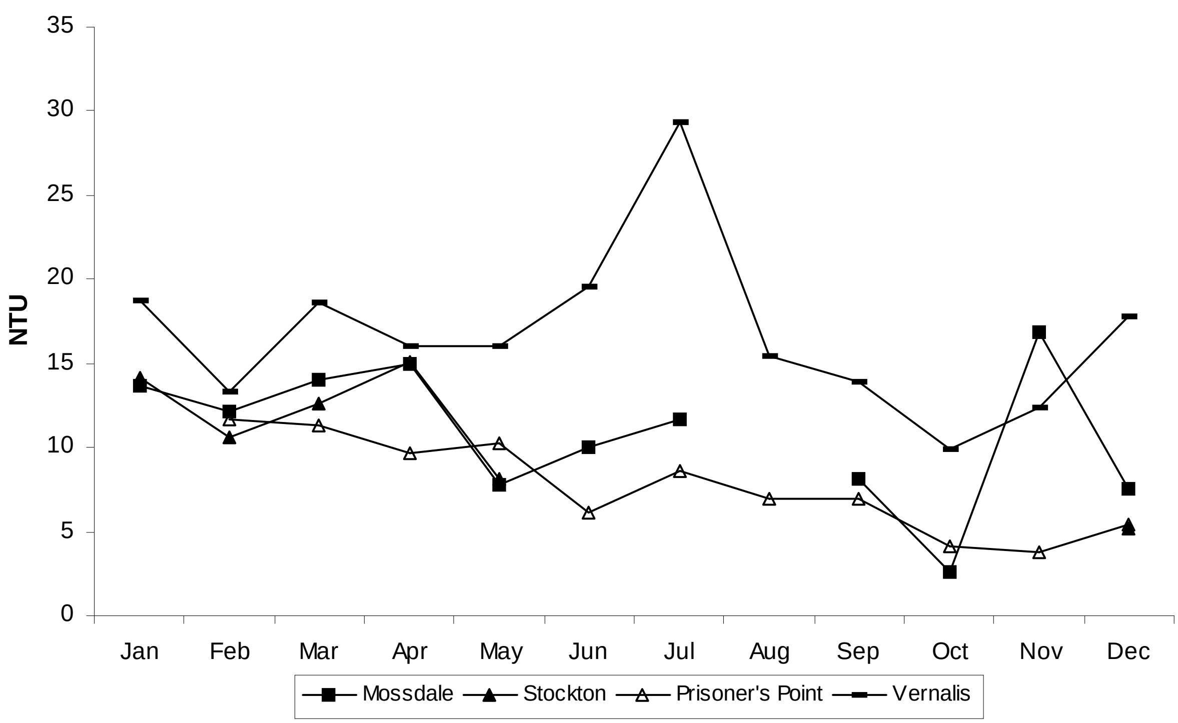


Figure 9-9d Average monthly turbidity at 3 tidally influenced stations, 2006

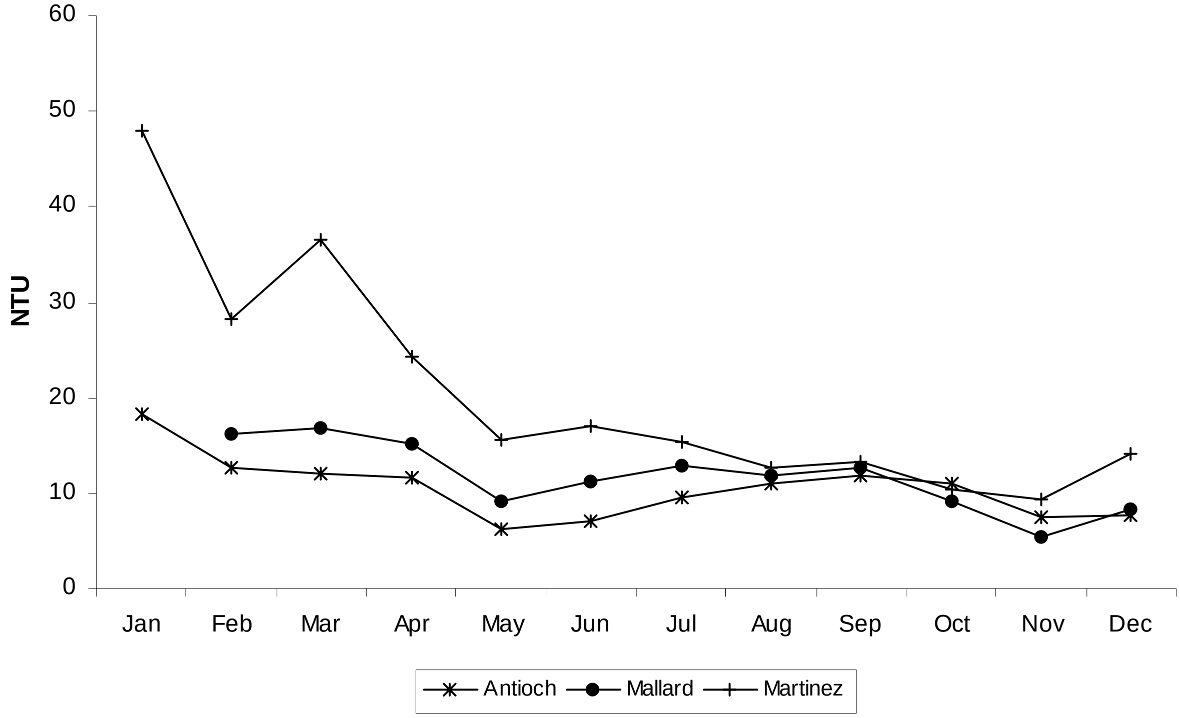
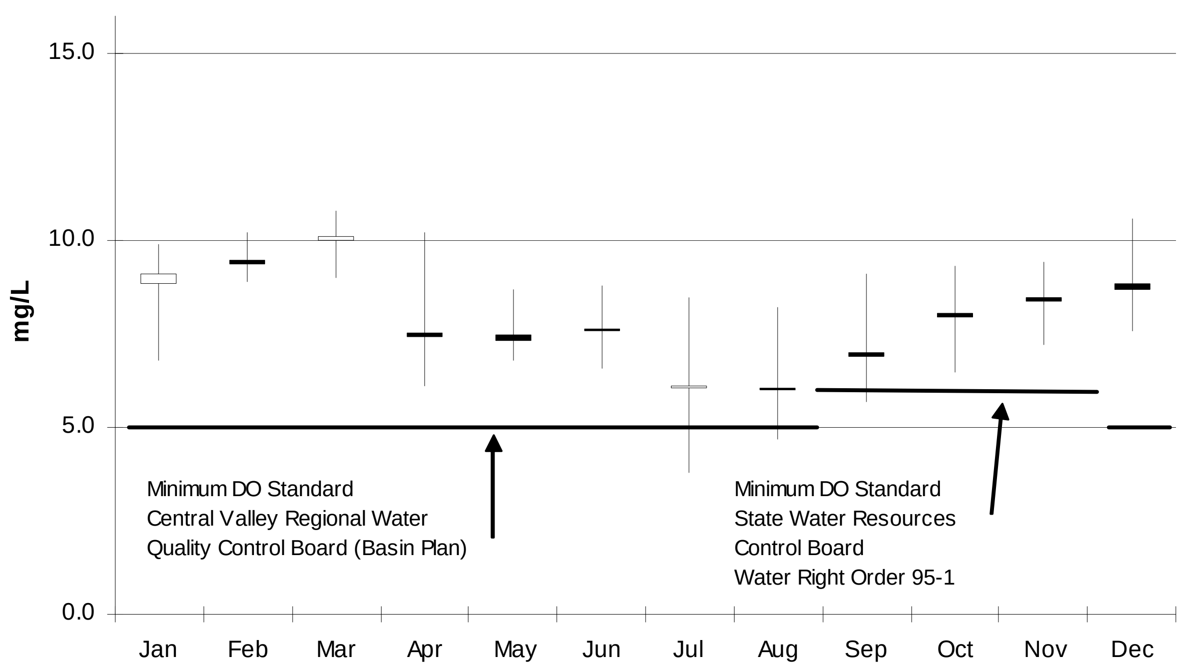


Figure 9-10 Range of monthly DO values at San Joaquin at Rough and Ready Island, 2006



*Solid boxes when monthly average higher than monthly median

Table 9-1 Parameters

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