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 2008

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

April 2010

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Governor	Secretary for Resources	Director
State of California	Natural Resources Agency	Department of Water Resources

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Executive Summary 2008

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 2008. This monitoring is mandated by Water Right Decision 1641 (D-1641) and this report is being submitted to fulfill the reporting requirements of this decision.

The 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 2008 showed seasonal patterns and were generally below 10 µg/L for most regions and concentrations ranged between 0.76 µg/L and 226.42 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 2008 fell into twelve categories: centric diatoms, cyanobacteria, unidentified flagellates, green algae, pennate diatoms, cryptomonads, euglenoids, haptophytes, chrysophytes, unknown genus, dinoflagellates and synurophytes. Of the twelve groups identified, centric diatoms, cyanobacteria, unidentified flagellates, chrysophyte flagellates, cryptophyte flagellates, green algae and pennate diatoms constituted 96.88% of the organisms collected.

Zooplankton were collected at 22 sampling sites in the estuary. The introduced *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) and the *Neomysis kadiakensis/japonica* complex remained the two most abundant mysids, followed by the native *Alienacanthomysis macropsis* and *Neomysis mercedis*. *Pseudodiaptomus forbesi* was the most common calanoid copepod followed by the native *Acartia* spp. The introduced *Acartiella sinensis* was third most abundant. 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 *Polyarthra* spp. and *Keratella* spp. *Limnoithona tetraspina* continued to be the most abundant zooplankton in the estuary.

Benthic monitoring was conducted at 10 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 2008 fell into nine phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida and Platyhelminthes. Of these nine phyla, Annelida, Arthropoda and Mollusca constituted 99.1% of the organisms collected during the study period. Ten species in these phyla represent 82.8% of all organisms collected during this period.

The 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 2008. 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 June 16 to November 25 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 varied little between regions within the channel (not including the turning basin), with an overall range of 4.5 to 10.3 mg/L at the surface and 4.3 to 9.8 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	micro Siemens
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 rights 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 diversion 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 1999/2000), and revised by order WR 2000-02 in March 2000.

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. 1999/2000. 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.

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 2008*, summarizes the findings of the EMP for calendar year 2008. 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. 1999/2000. Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh. Sacramento.

Chapter 2 Hydrologic Conditions

List of Figures and Tables

Figure 2-1 Net Delta Outflow Indices for water year 2008

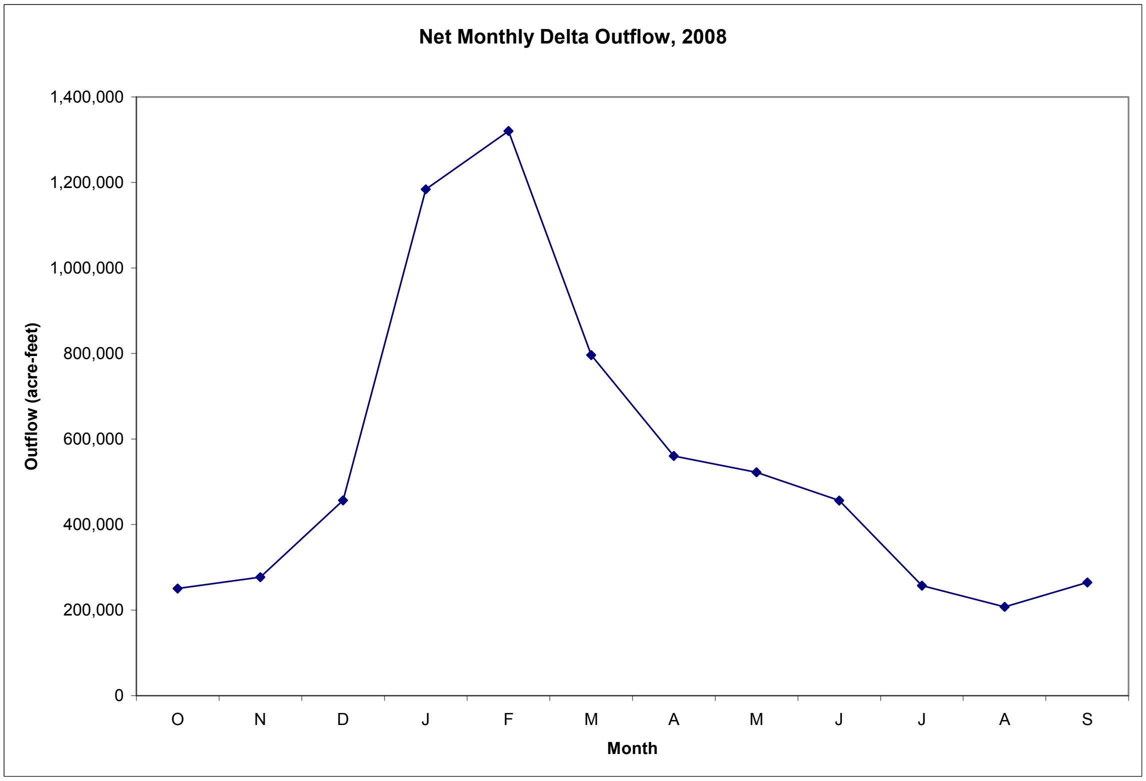

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, water years 1998–2008

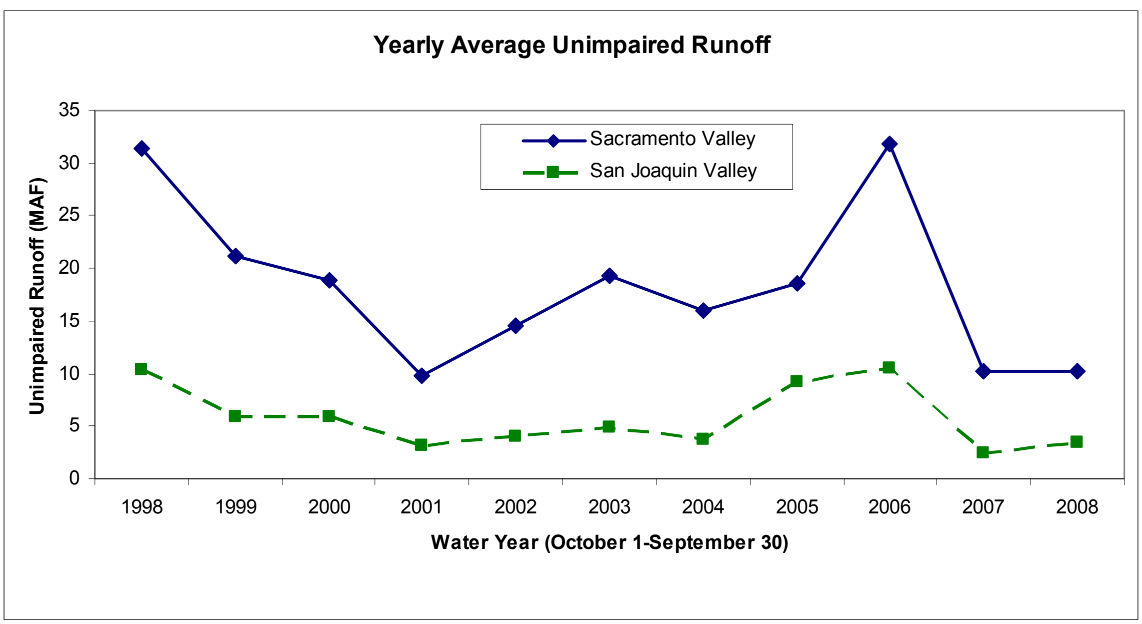

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, water years 1998–2008

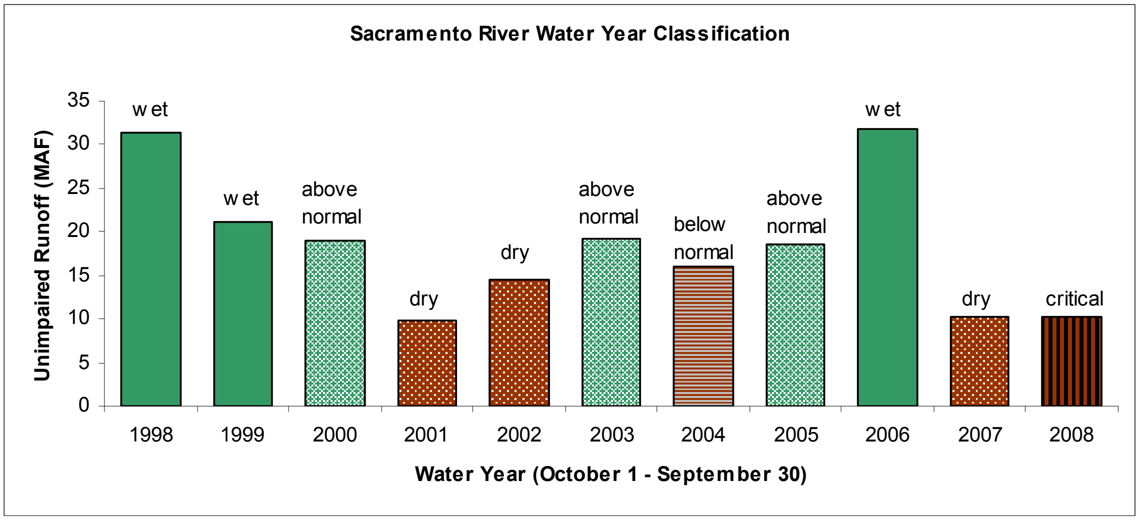

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, water years 1998–2008

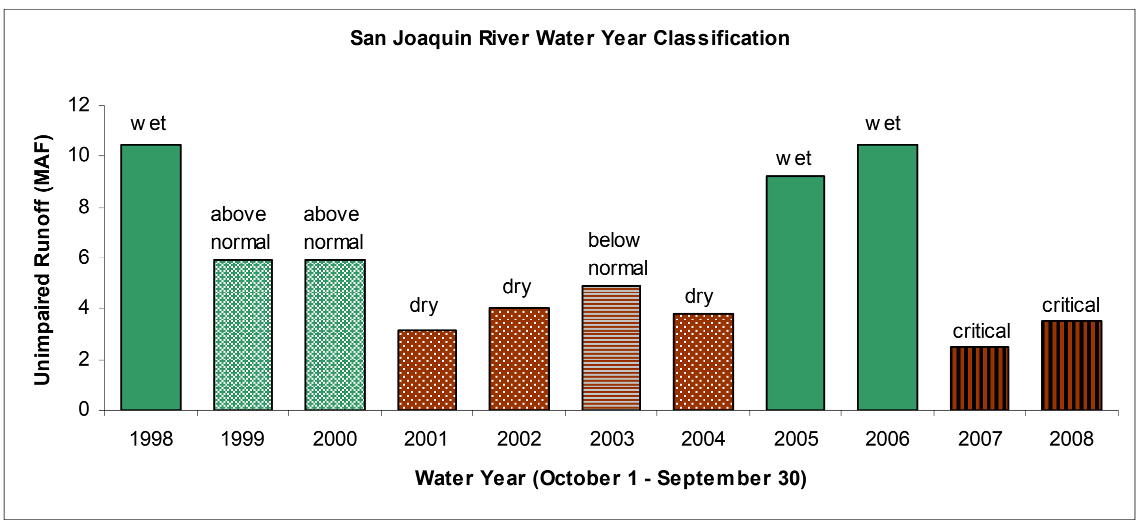

Table 2-1 Summary of statewide major hydrologic characteristics on May 1 in water years 2002–2008

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	108*	105	150
2006	140	170	115	125*
2007	65	55	85*	39*
2008	78	60	72	102

Note: Measurements made May 1 denote conditions Oct 1 through April 30 of respective water year.
*Numbers different from those reported in 2007.

Table 2-2 Unimpaired runoff for Sacramento and San Joaquin rivers, water years 2002–2008

Sacramento River				San Joaquin River			
Year	Oct 1- Mar 30 (MAF)	Apr1- Jul 30 (MAF)	Whole year (MAF)	Year	Oct 1- Mar 30 (MAF)	Apr1- Jul 30 (MAF)	Whole year (MAF)
2002	9.32	4.57	14.6	2002	1.27	2.75	4.06
2003	10.71	7.74	19.31	2003	1.25	3.49	4.87
2004	10.95	4.4	16.04	2004	1.51	2.25	3.81
2005	8.4	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
2007	6.56	3.02	10.25	2007	0.98	1.44	2.46
2008	5.89	3.78	10.21	2008	0.98	2.46	3.5

Chapter 3 Water Quality Monitoring

Introduction

Water quality monitoring in 2008 continued according to the amended protocol implemented by DWR in 1996, with the incorporation of several changes recommended by the 2001-2002 EMP review (http://www.baydelta.water.ca.gov/emp/EMP_Review_Final.html). Discrete water quality sampling sites included the 11 representative sites as described in the 1996 Water Quality Report (Lehman et al 2001), with the addition of two more sampling sites in May 2004, a move from station C3 to C3A in November 2004, and a move from station C10 to C10A in 2005.

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

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

Table 3-1 Water Quality Parameters Measured

As shown in Table 3-2, thirteen sampling sites were used in this study to represent eight 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 restrictions of the sample site, which requires sampling equipment to be deployed from 50 feet above the water's surface.

Water Temperature

Water temperature was measured in degrees Celsius (°C) with a YSI thermistor. For all sites except for C3A and C10A, temperatures were measured from water collected from a through-hull pump at a depth of one 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 one meter in depth.

Figure 3-2 Water Temperature Comparisons, 2008

A water temperature minimum of 8.4°C was recorded in January 2007 at station C3A in the north Delta (Figures 3-2 and 3-3). This minimum temperature represents an increase of 1.3 °C from the previously recorded minimum in 2007 (Riordan et al. 2008).

Figure 3-3 Water Temperature (°C) by Station, 2008

Temperature minima at all sites during 2008 occurred during the month of January. The timing of these temperature minima is the same as the 2007 study period, where all temperature minima occurred during January. (Riordan et al. 2008).

A water temperature maximum of 26.3 °C was recorded in July at station C10A, in the south Delta. This maximum is a 1.0 °C decrease over the temperature maximum reported for 2007 (Riordan et al. 2008). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

Dissolved Oxygen

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

Figure 3-4 Dissolved Oxygen Comparisons, 2008

During 2007, dissolved oxygen concentrations ranged from 5.6 mg/L at site MD10A in July, to 11.2 mg/L at site C10A in June (Figures 3-4 and 3-5). Seasonal trends were evident in most regions, with dissolved oxygen concentrations decreasing during the summer and rising in the winter. Reduced summer DO levels coincided with warmer water temperatures. 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 3-5 Dissolved Oxygen (mg/L) by Station, 2008

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 a continuous monitoring station (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.

Figure 3-6 Specific Conductance Comparisons, 2008

Specific conductance varied greatly between sites monitored, ranging from 77.4 µS/cm at site C3A in November to 45,179 µS/cm at site D41 in December (Figures 3-6 and 3-7). This range of specific conductance was broader than the range of 136 - 44,357 µS/cm reported for 2007 (Riordan et al 2008).

Figure 3-7 Specific Conductance(µS/cm) by Station, 2008

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

Sites with high average specific conductivity such as D4, D6, D7, D8, D41 and D41A tended to show stronger seasonal variations, with specific conductance varying from lows in February and March, to highs in 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 cm. Secchi disk transparency was recorded as the average depth in which visual determination of the disk was lost as it was lowered into the water column, and the depth of its visual perception as it was raised. All measurements were made from the shaded side of the vessel.

Figure 3-8 Secchi Disk Depth Comparisons, 2008

A Secchi depth minimum of 16 cm was recorded at site D8 in Suisun Bay in February. (Figures 3-8 and 3-9). A Secchi depth maximum of 215 cm was recorded at sampling site MD10A (east Delta) in February. Secchi values during 2007 were similar, ranging from 22 to 220 cm (Riordan et al 2008).

Figure 3-9 Secchi Disk Depth (cm) by Station, 2008

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 MD10A.

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 Hach 2100P Turbidimeter, due to their inaccessibility by vessel.

Figure 3-10 Turbidity Comparisons, 2008

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 1.5 NTU at site MD10A (east Delta) in November, to 60.5 NTU at site C3A (north Delta) in January. This range of turbidity was greater than the 1.2 to 42.8 NTU range reported for 2007 (Riordan et al 2008). In August, data for six interior Delta sites is missing due to an equipment failure.

Figure 3-11 Turbidity (NTU) by Station, 2008

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 USEPA (1983) colorimetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate is 0.01 mg/L.

Figure 3-12 Orthophosphate Comparisons, 2008

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest orthophosphate value was 0.02 mg/L at station C10A in June. The 2007 study period showed the lowest value (below reporting limit) of orthophosphate occurring at site MD10A in February (Riordan et al 2008).

Figure 3-13 Orthophosphate (mg/L) by Station, 2008

The highest value of orthophosphate, 0.25 mg/L, was recorded at site P8 in January. During 2007, site P8 also had the highest orthophosphate concentration (0.25 mg/L) in April (Riordan et al 2008).

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.

Figure 3-14 Total Phosphorus Comparisons, 2008

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 USEPA (1983) colorimetric semi-automated method 365.4. The minimum reporting limit for total phosphorus is 0.01 mg/L.

Figure 3-15 Total Phosphorus (mg/L) by Station, 2008

Values for total phosphorus varied considerably between sites and across seasons (Figures 3-14 and 3-15) and showed distributions similar to those reported for orthophosphate. The lowest value of 0.04 mg/L was recorded at site MD10A during November. This value is slightly higher than the minimum value of 0.03 mg/L recorded during 2007 at site MD10A in

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

October (Riordan et al 2008). A maximum value of 0.5 mg/L was recorded at site MD10A in January. This value is higher than the maximum value of 0.31 mg/L recorded during 2007 at site P8 in April (Riordan et al 2008).

Sites P8 and C10A had the highest average total phosphorus concentrations during 2008. Sites D28A, D19 and D41 had the lowest average total phosphorus concentrations.

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 USEPA (1983) colorimetric semi-automated method 352.1. The minimum reporting limit for Kjeldahl nitrogen is 0.01 mg/L.

Figure 3-16 Kjeldahl Nitrogen Comparisons, 2008

Kjeldahl nitrogen concentrations ranged from a low of 0.1 mg/L at site D26 in April to 1.5 mg/L at sites C10A in June and P8 in January (Figures 3-16 and 3-17). During 2007, kjeldahl nitrogen levels peaked at sites D19 and P8 in December with a high of 1.4 mg/L (Riordan et al 2008).

Figure 3-17 Kjeldahl Nitrogen (mg/L) by Station, 2008

Kjeldahl nitrogen concentrations were generally highest at sites C3A, C10A and P8. No strong seasonal or intra-annual trends were apparent among all the sites.

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is a measure of total ammonium (NH_4^+), 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 USEPA (1983) colorimetric, automated, phenate method 350.1; and for nitrate and nitrite according to the colorimetric automated cadmium reduction method 353.2 (USEPA 1983). DIN was calculated as the sum of total ammonia plus nitrate and nitrite. The minimum reporting limit for inorganic nitrogen is 0.01 mg/L.

Figure 3-18 Dissolved Inorganic Nitrogen Comparisons, 2008

DIN concentrations ranged from a minimum of 0.09 mg/L at site MD10A in September to a maximum of 3.74 mg/L at site P8 in December. (Figures 3-18 and 3-9). This range is higher than the values observed during 2007, which

Figure 3-19 Dissolved Inorganic Nitrogen (mg/L)

recorded a minimum value of 0.11 mg/L at sites D28A and MD10A in September and a maximum of 2.94 mg/L at station P8 in December (Riordan et al 2008). Unlike the other delta stations, the majority of the DIN concentrations in the Sacramento River below Freeport (C3A) were in the form of NH_4^+ rather than NO_3 and NO_2 (see Figure 3-19).

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

Figure 3-20 Dissolved Organic Nitrogen Comparisons, 2008

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 USEPA (1983) colorimetric, semi-automated method 351.2. The minimum reporting limit for DON is 0.1 mg/L.

Figure 3-21 Dissolved Organic Nitrogen (mg/L) by Station, 2008

DON concentrations were below the minimum reporting limit at station C3A in March, April, May, July, October and December, stations D26 and D28A in April, and station D7 in March. A maximum concentration of 1.2 mg/L was recorded at station MD10A in January. (Figures 3-20 and 3-21). Peak DON during 2007 was lower, reaching 0.7 mg/L at station P8 in February. (Riordan et al 2008).

Most sites showed peak DON concentrations during January.

Total Dissolved Solids

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

Figure 3-22 Total Dissolved Solids Comparisons, 2008

Total dissolved solids were measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size.

Figure 3-23 Total Dissolved Solids (mg/L) by Station, 2008

The filtrate was immediately refrigerated at 4 °C and later transported to Bryte Laboratory for analysis, using USEPA (1983) method 160.1.

TDS in the estuary varied over a wide range, from 63 mg/L at site C3A in April to 29,260 mg/L at site D41 in August (Figures 3-22 and 3-23). The values were similar during 2007, which had a range of 76 mg/L to 27,900 mg/L (Riordan et al 2008). 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 freshwater 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.

Total Suspended Solids

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

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

Figure 3-24 Total Suspended Solids Comparisons, 2008

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

Figure 3-25 Total Suspended Solids (mg/L) by Station, 2008

TSS in the Delta varied over a wide range, from below the minimum reporting limit (<1.0 mg/L) at site D19 in September and at MD10A in November to 124 mg/L at site D41A in July (Figures 3-24 and 3-25). These results are different from the 2007 study period, where the highest TSS value was recorded at site D7 (114 mg/L) in March and the lowest TSS value was below the minimum reporting limit at site MD10A in November (Riordan et al 2008).

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

Figure 3-26 Volatile Suspended Solids Comparisons, 2008

Volatile Suspended Solids

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

Figure 3-27 Volatile Suspended Solids (mg/L) by Station, 2008

VSS levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions, and reached a high of 31.0 mg/L at site D41A in July (Figures 3-26 and 3-27). These results were different than those observed in 2007, which had a maximum value of 35.0 mg/L at site C10A in July (Riordan et al 2008). Most sites showed a high degree of variability, with no apparent seasonal trends.

Silica

Water samples for silica analysis were taken from aliquots collected from a depth of 1 meter 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.

Figure 3-28 Silica Comparisons, 2008

Figure 3-29 Silica (mg/L) by Station, 2008

Silica concentrations ranged from a low of 3.1 mg/L at site D7 in July to a high of 22.9 mg/L at site C3A in January (Figures 3-28 and 3-29). By comparison, values during 2007 ranged from below the minimum reporting limit at site D41 in August to 22.7 mg/L at site C3A in December (Riordan et al 2008). A slight seasonal trend of declining silica levels in spring months followed by increased silica concentrations in late summer and fall was observed at the majority of sites.

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, 2008

Chloride concentrations in the estuary varied over a wide range from 6 mg/L at site C3A in June and July to 16,500 mg/L at site D41 in December (Figures 3-30 and 3-31). These results are very similar to those observed during 2007, which recorded a low of 5 mg/L at site C3A in April and July and a high of 15,600 mg/L at site D41 in December (Riordan et al 2008). The high values seen in San Pablo Bay are likely due to tidal influences of seawater entering the Delta, while the low values seen at site C3A are likely due to spring flows of fresh water down the Sacramento River. Values of

Figure 3-31 Chloride (mg/L) by Station, 2008

chloride concentrations are closely correlated to values reported for specific conductance and total dissolved solids (TDS) reported earlier in this chapter.

Summary

The Department's monitoring and reporting of water quality data shown here is mandated in order to ensure compliance with water quality objectives; identify meaningful changes potentially related to the operation of the State Water Project and the Central Valley Project; and to reveal trends in ecological changes potentially related to project operations. Flow rates, influenced by 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 historic comparison of a wide range of water quality parameters and show an overall consistency with recent years.

References

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

Riordan, D., T. Brown, M. Dempsey, J. Evans, A. Hennessy, L. Jones, B. Noble and M. Vayssieres. 2008. Water Quality Conditions in the Sacramento-San Joaquin Delta during 2007. California Department of Water Resources, Sacramento, California.

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. California Department of Water Resources, Sacramento, California.

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

Chapter 3 Water Quality Monitoring

Figure 3-1 Discrete Water Quality Sampling Stations

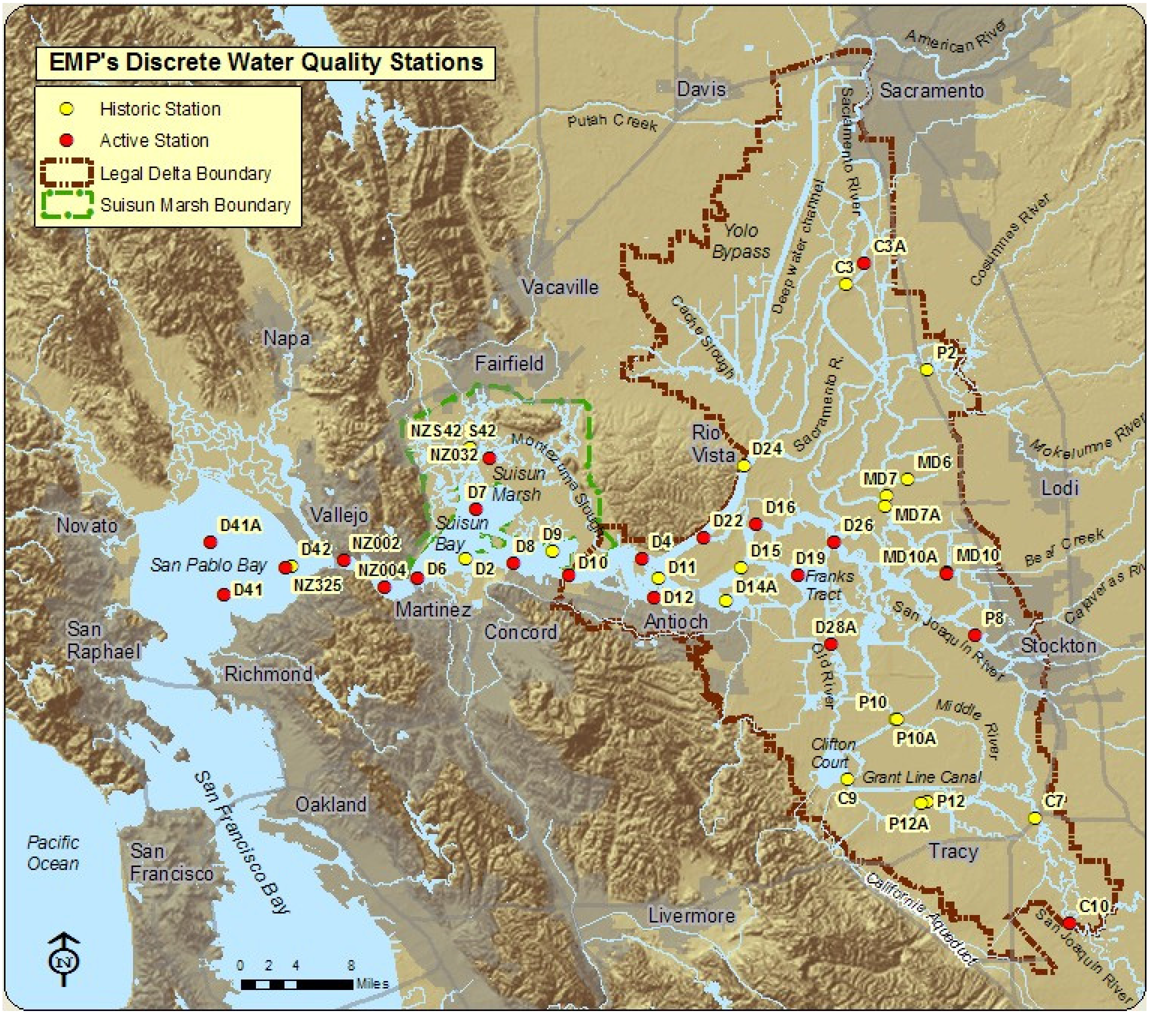

Figure 3-2 Water Temperature Comparisons, 2008

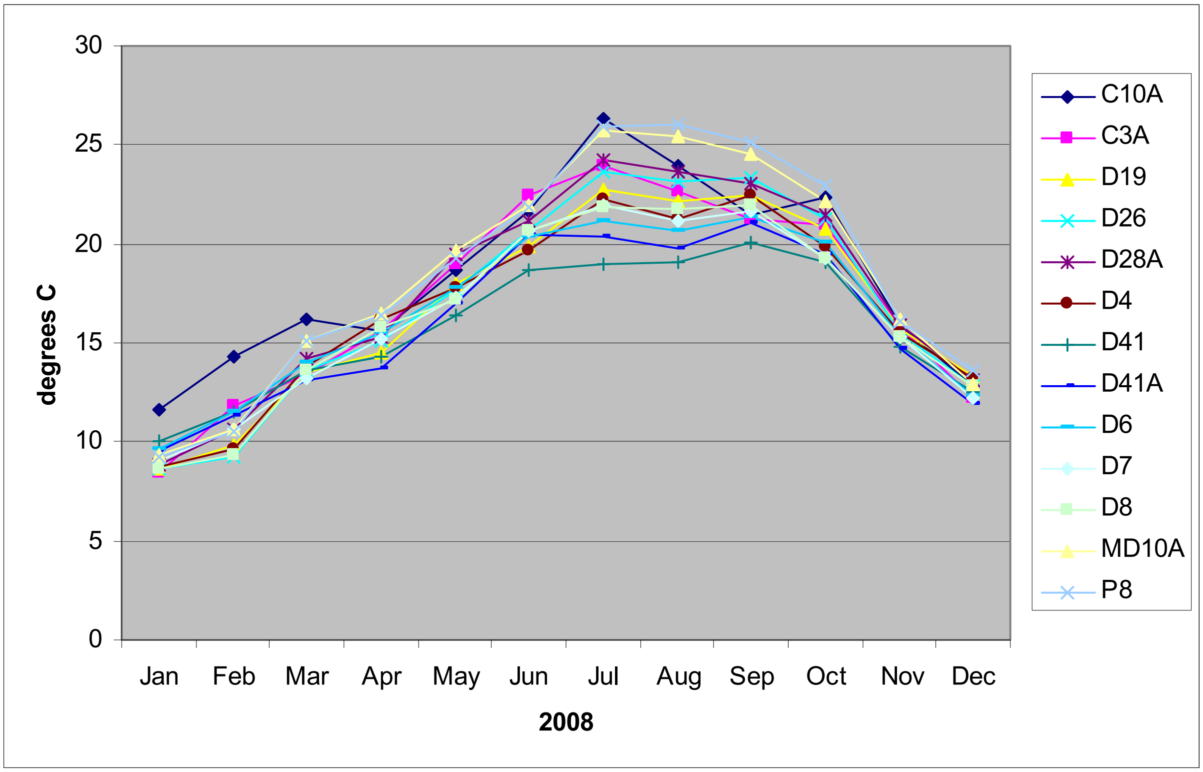

Figure 3-3 Water Temperature (°C) by Station, 2008

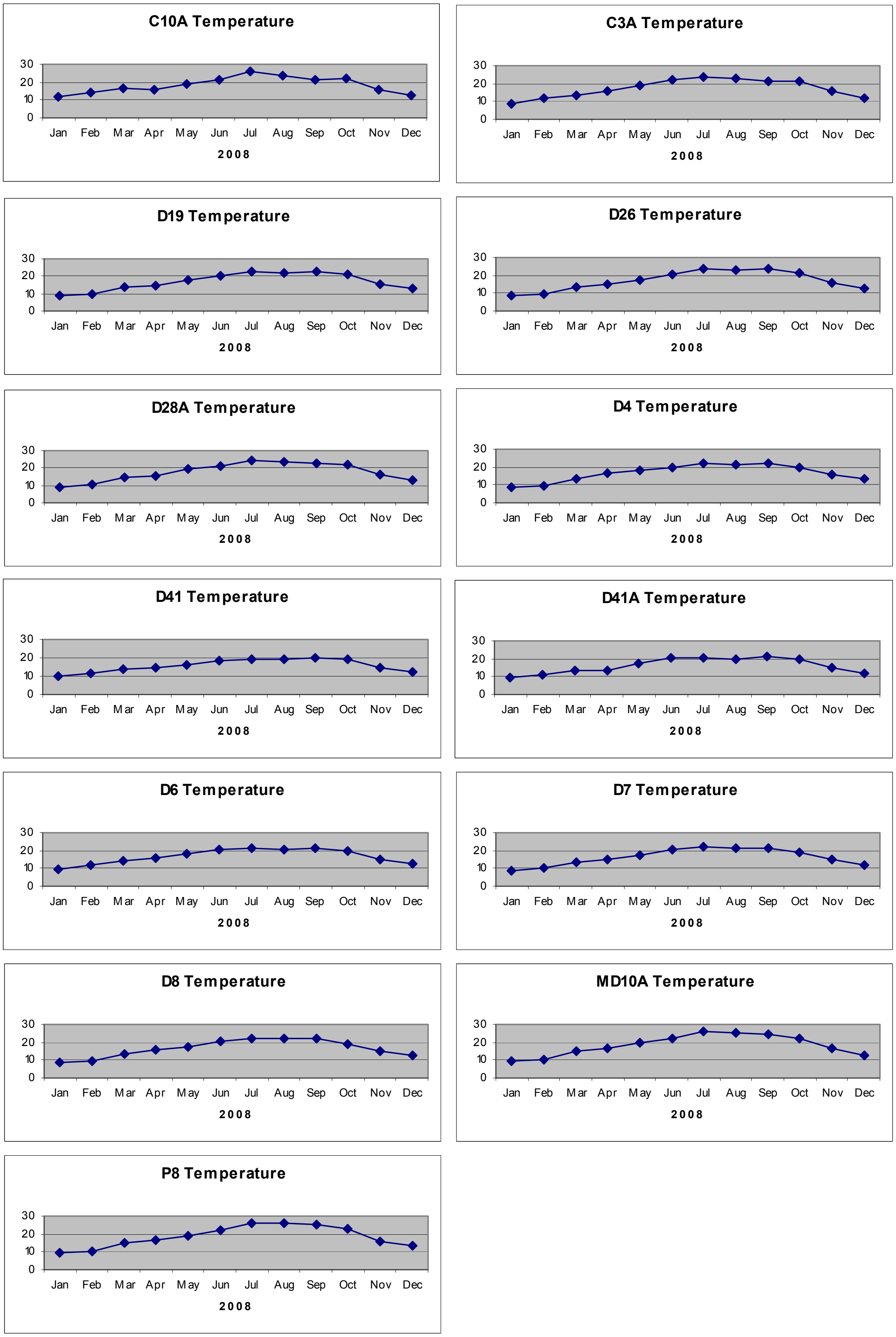

Figure 3-4 Dissolved Oxygen Comparisons, 2008

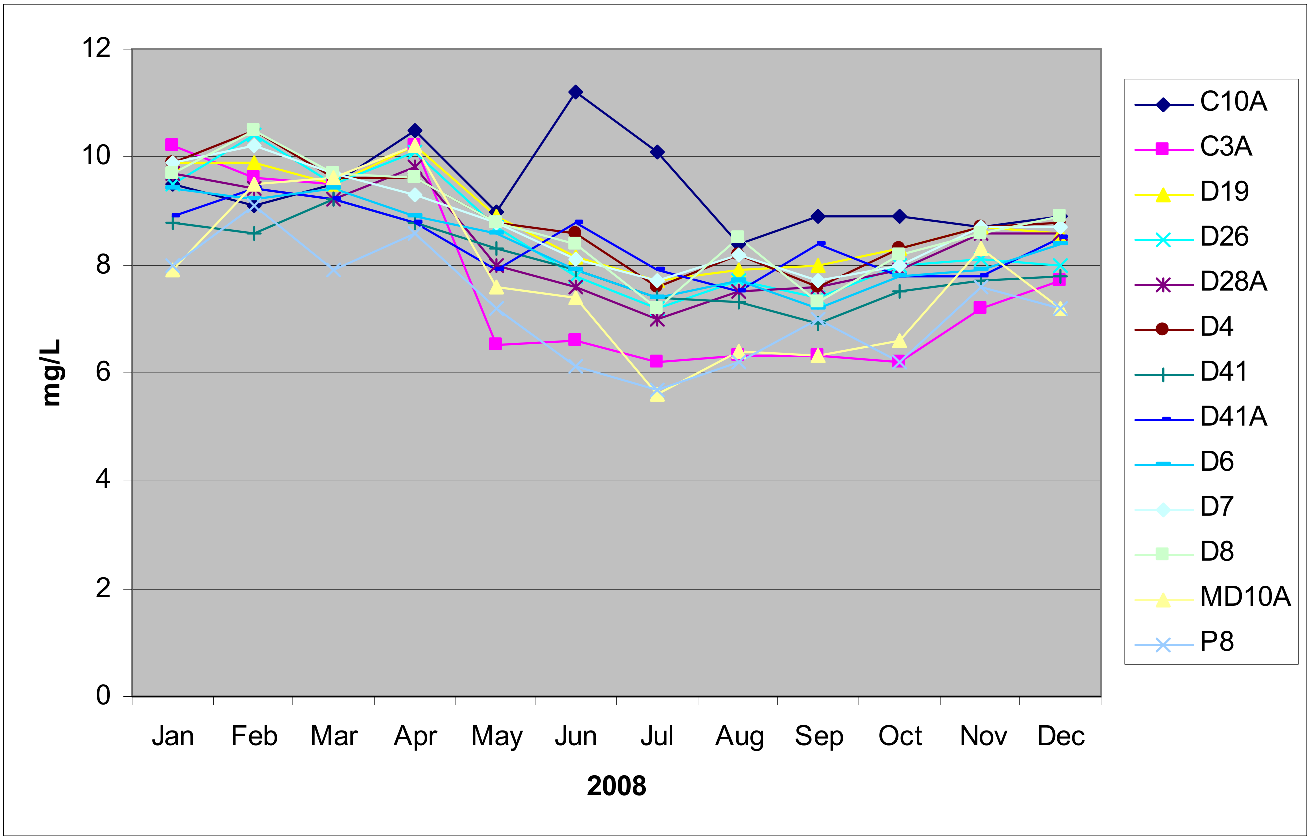

Figure 3-5 Dissolved Oxygen (mg/L) by Station, 2008

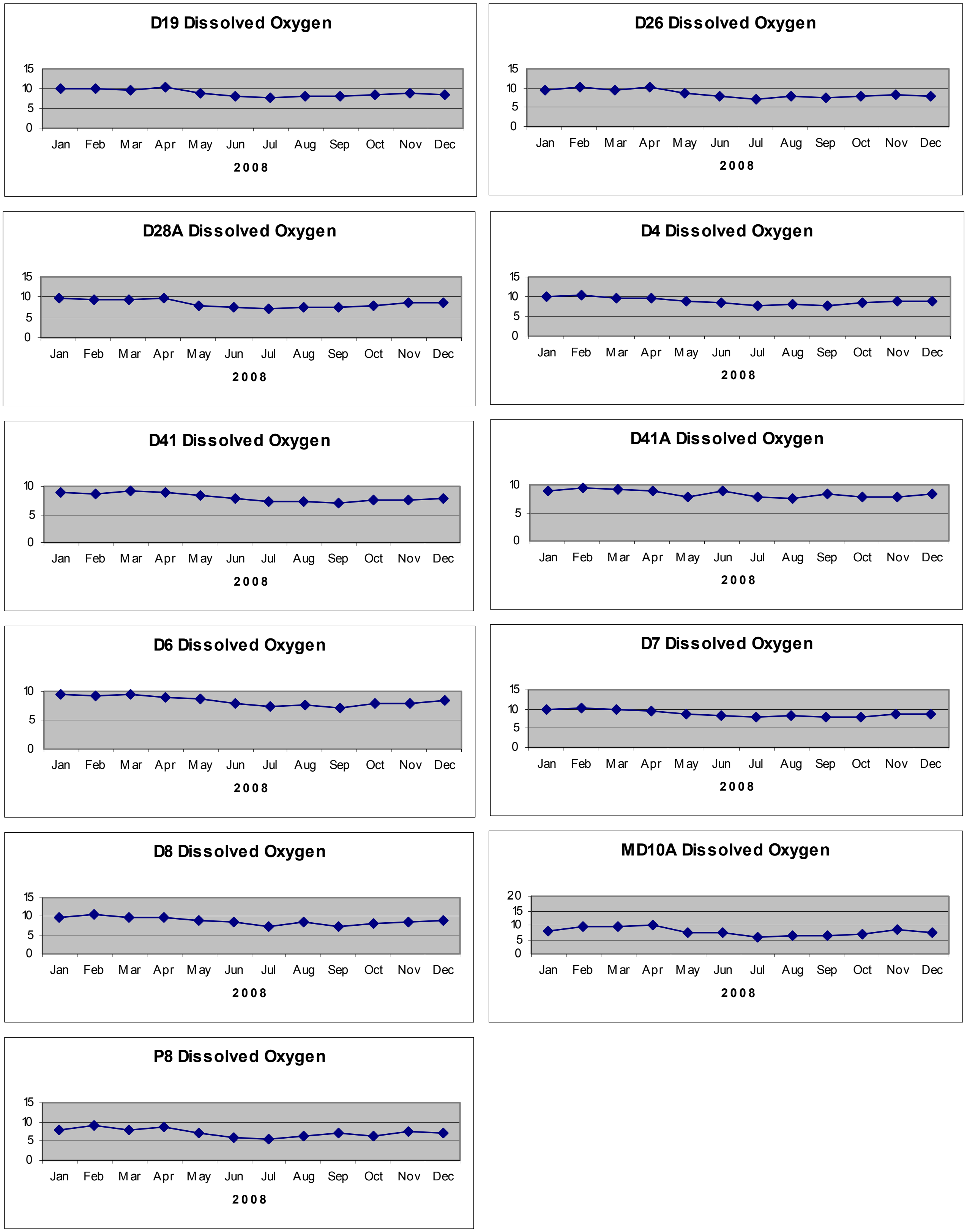

Figure 3-6 Specific Conductance Comparisons, 2008

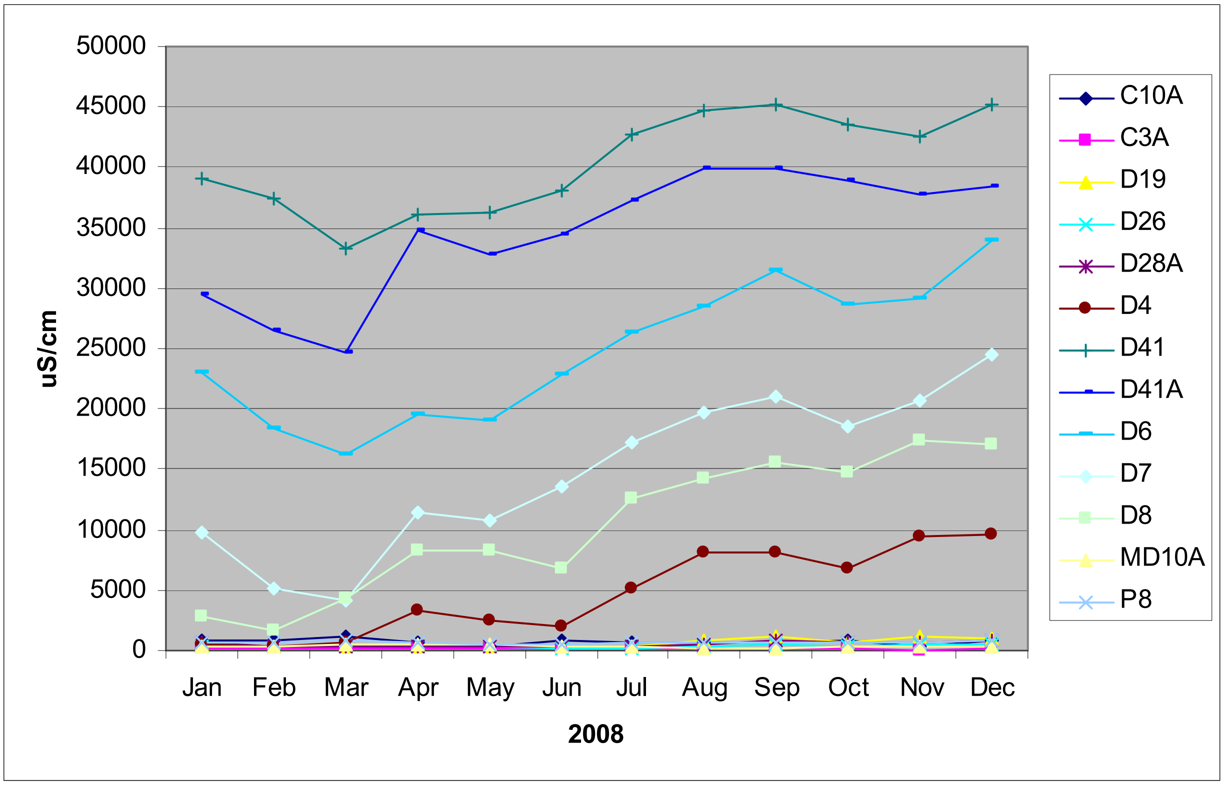

Figure 3-7 Specific Conductance (µS/cm) by Station, 2008

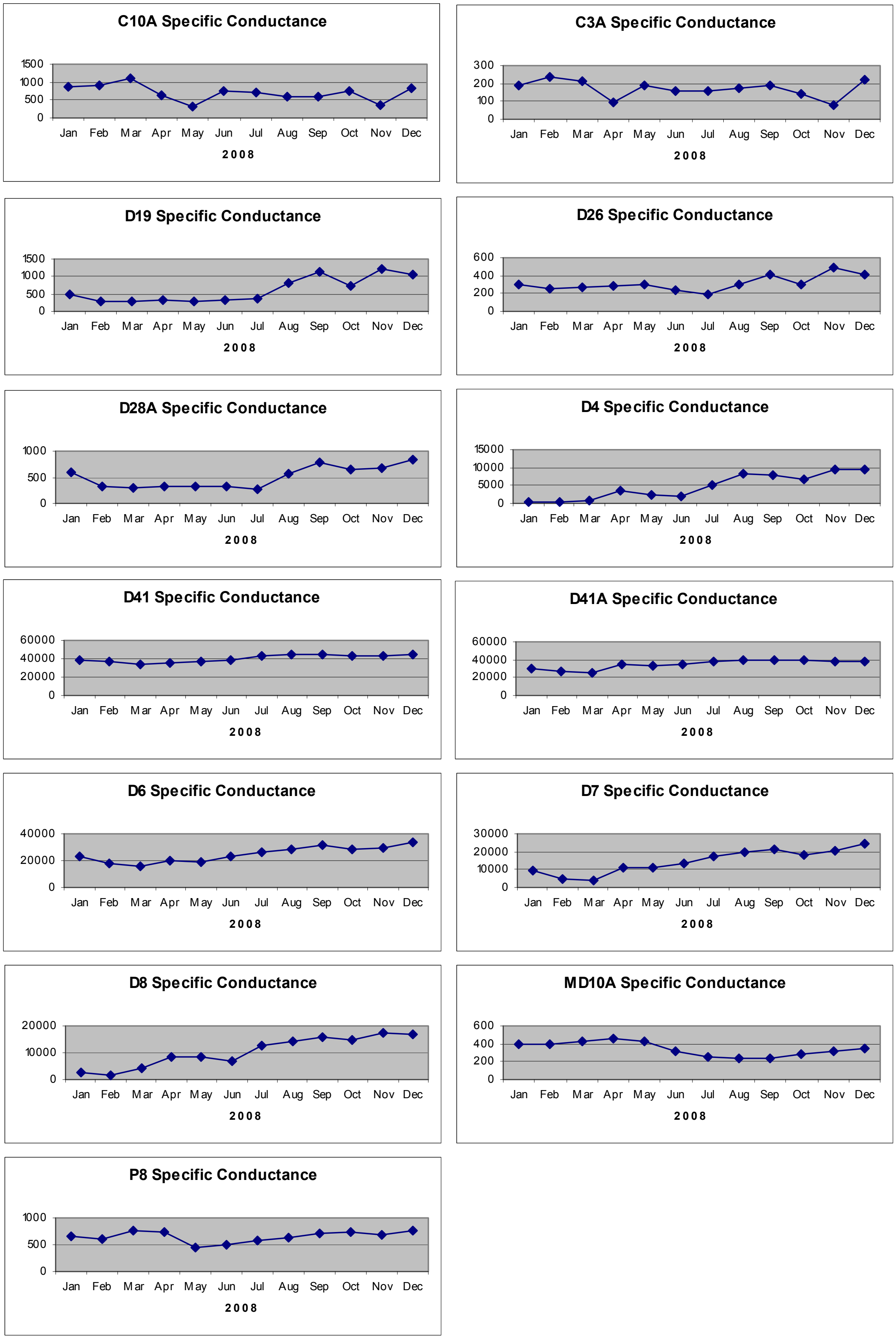

Figure 3-8 Secchi Disk Depth Comparisons, 2008

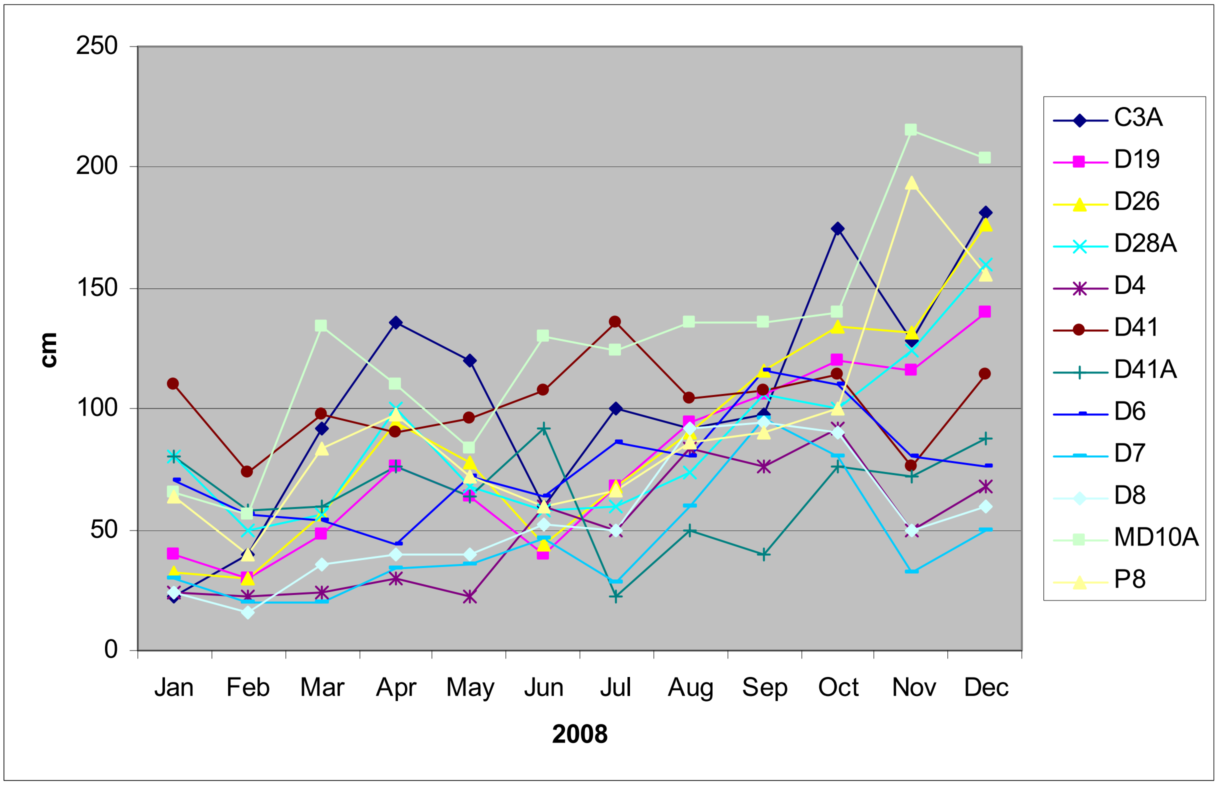

Figure 3-9 Secchi Disk Depth (cm) by Station, 2008

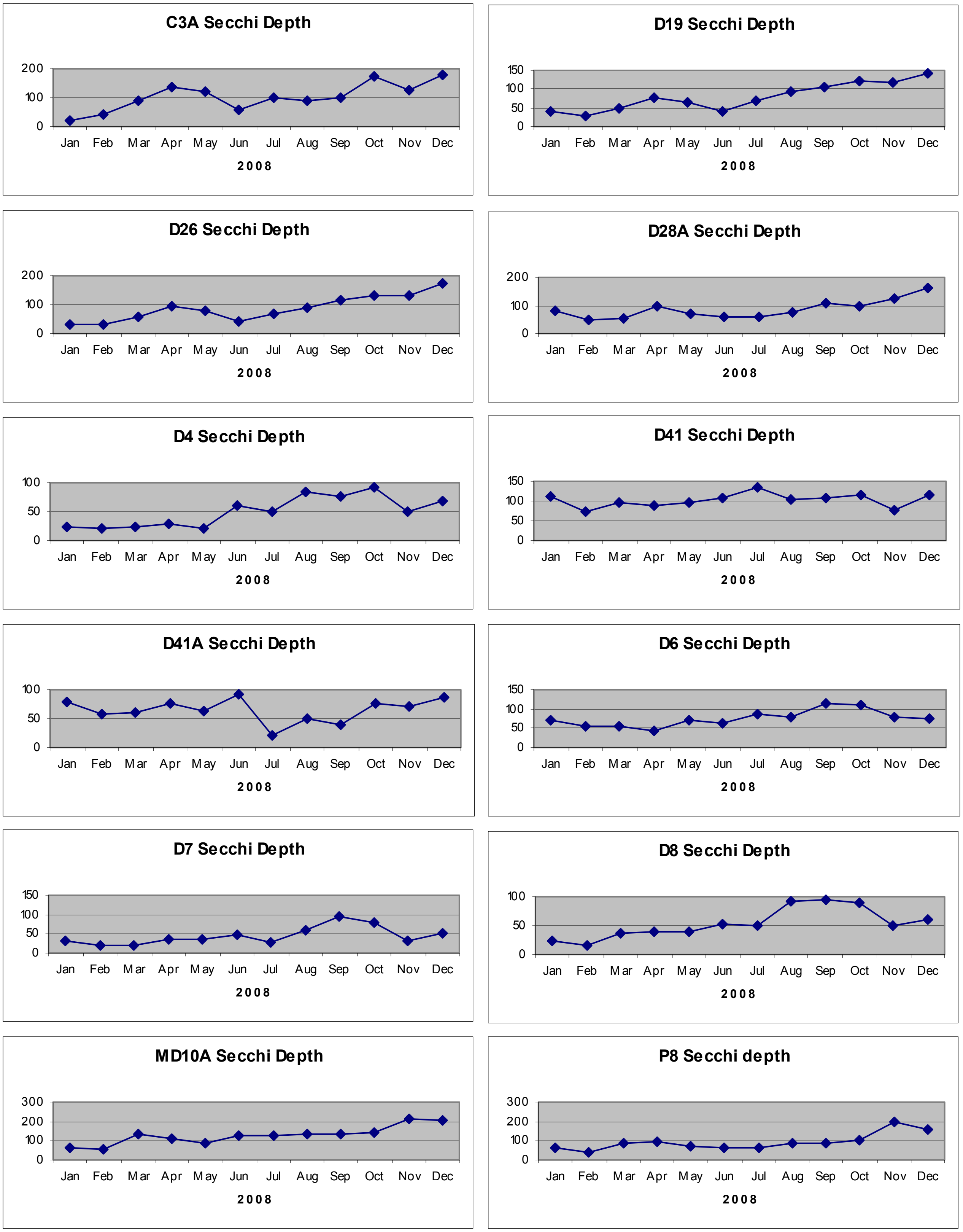

Figure 3-10 Turbidity Comparisons, 2008

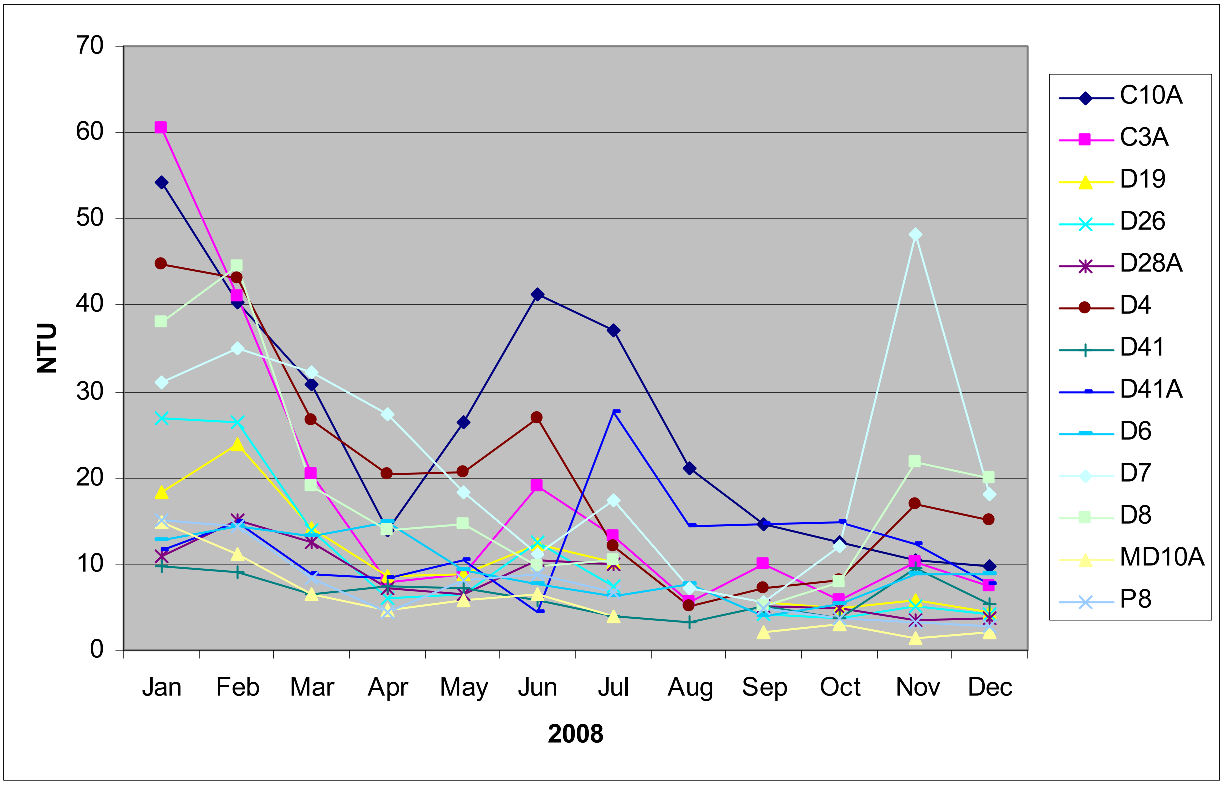

Figure 3-11 Turbidity (NTU) by Station, 2008

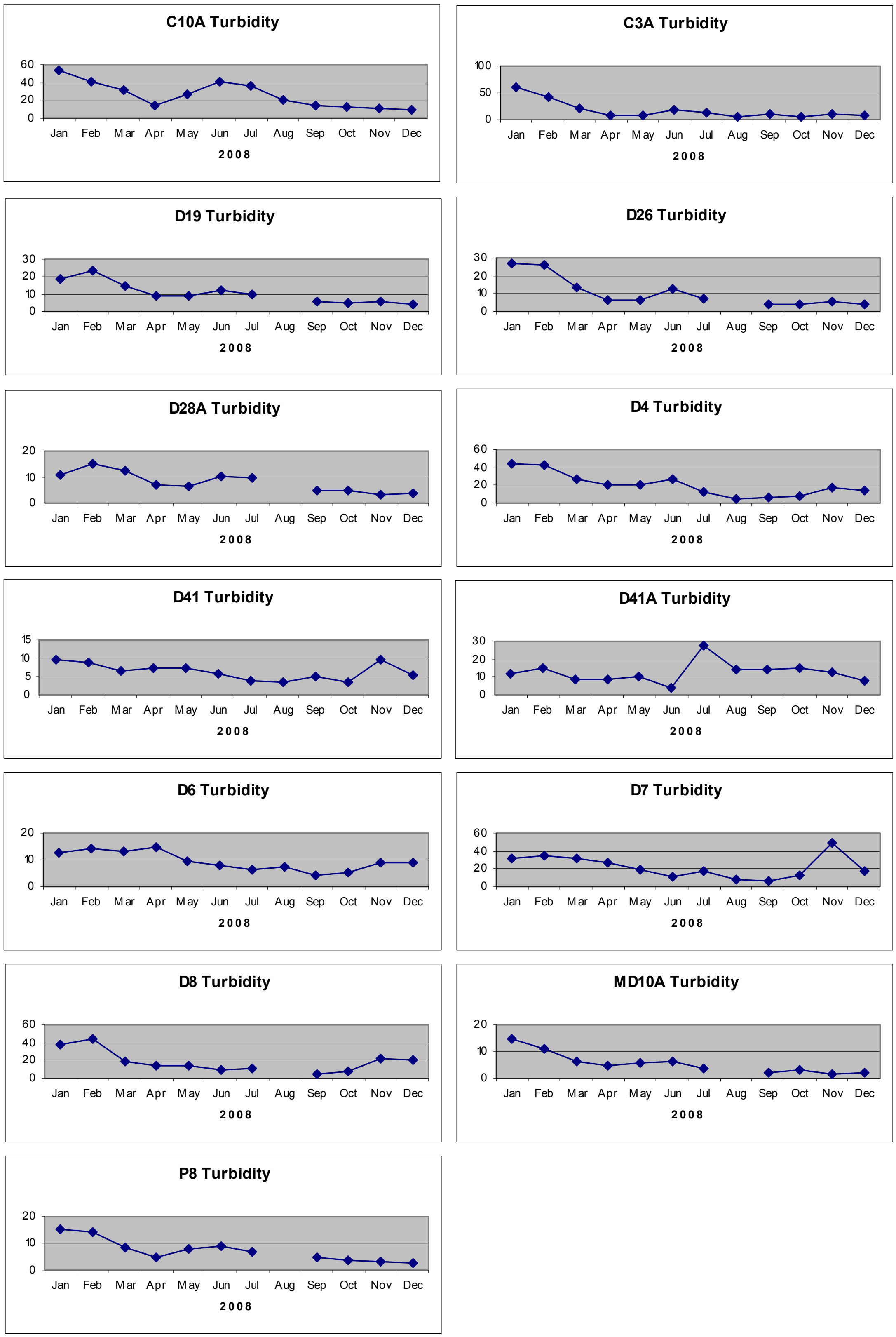

Figure 3-12 Orthophosphate Comparisons, 2008

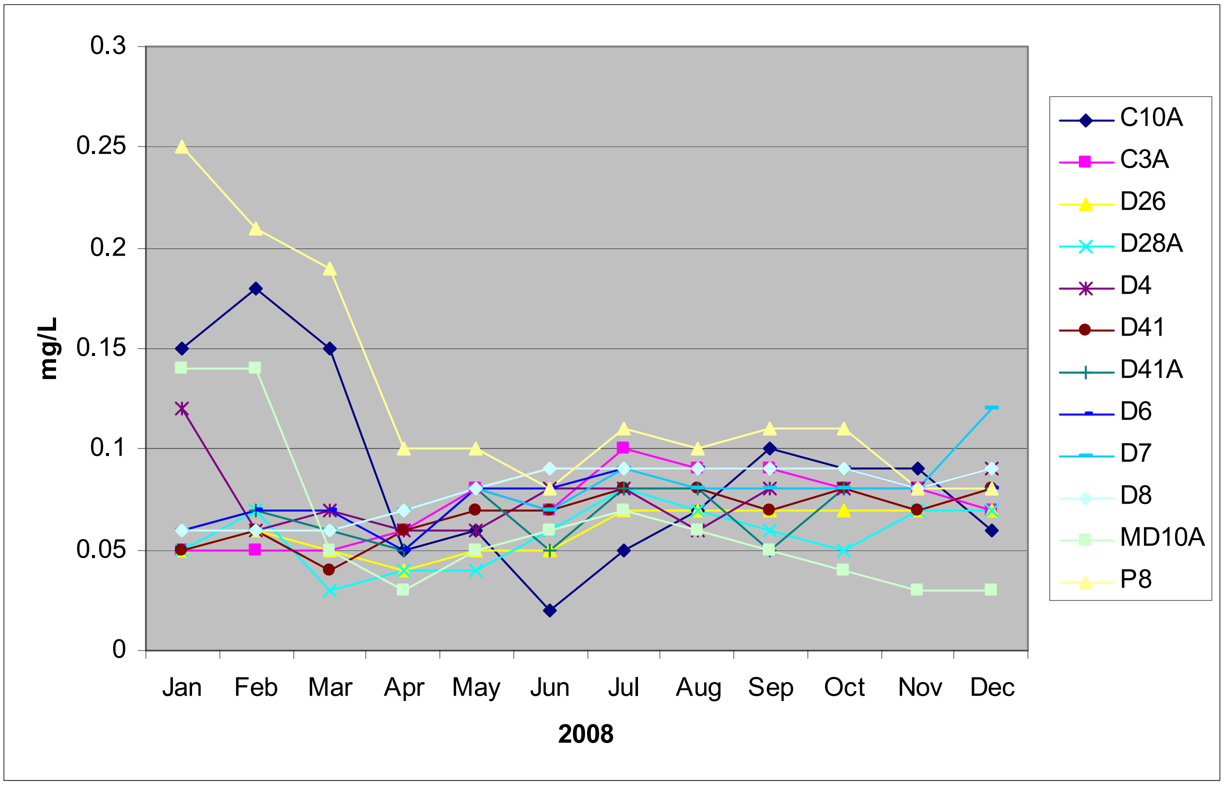

Figure 3-13 Orthophosphate (mg/L) by Station, 2008

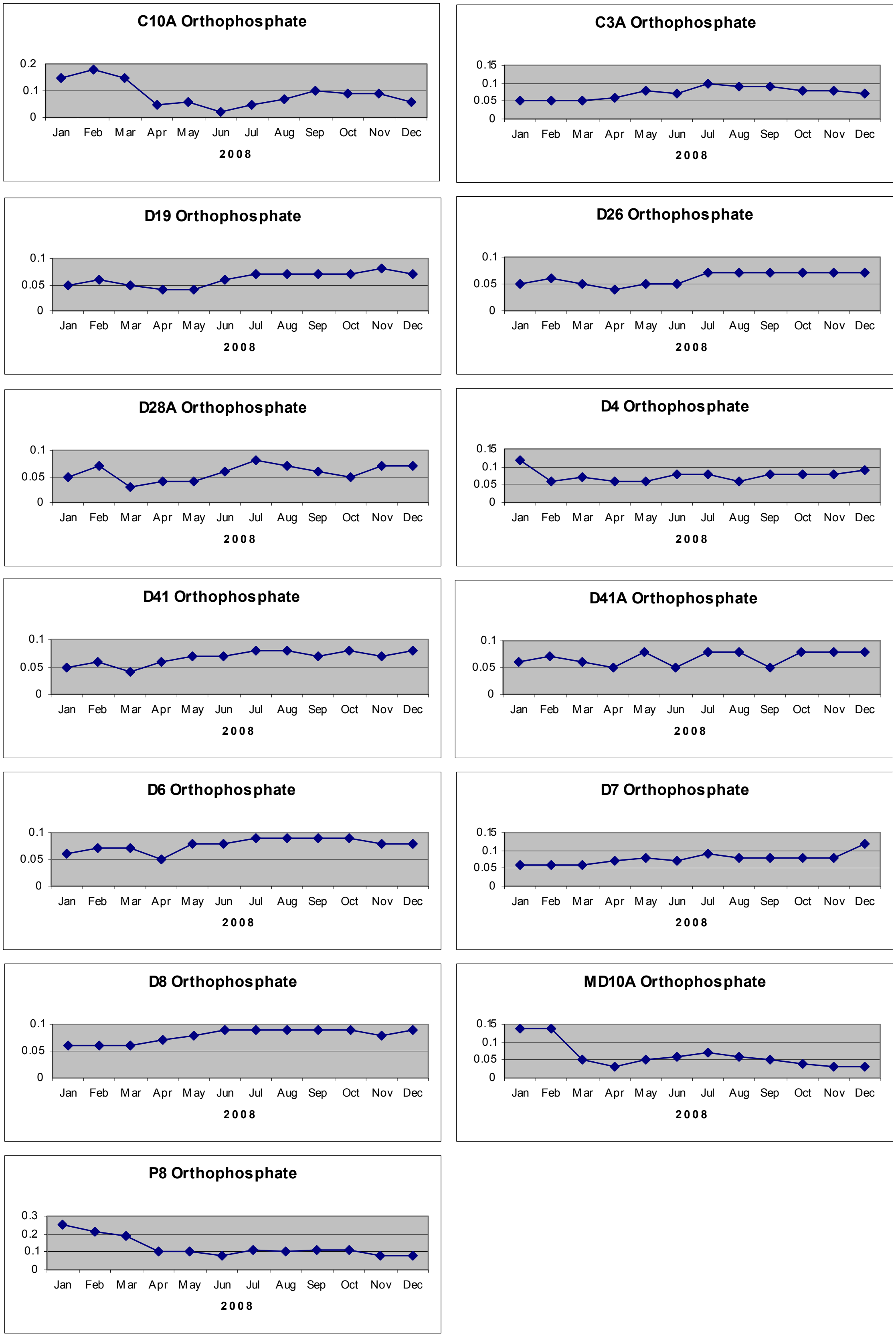

Figure 3-14 Total Phosphorus Comparisons, 2008

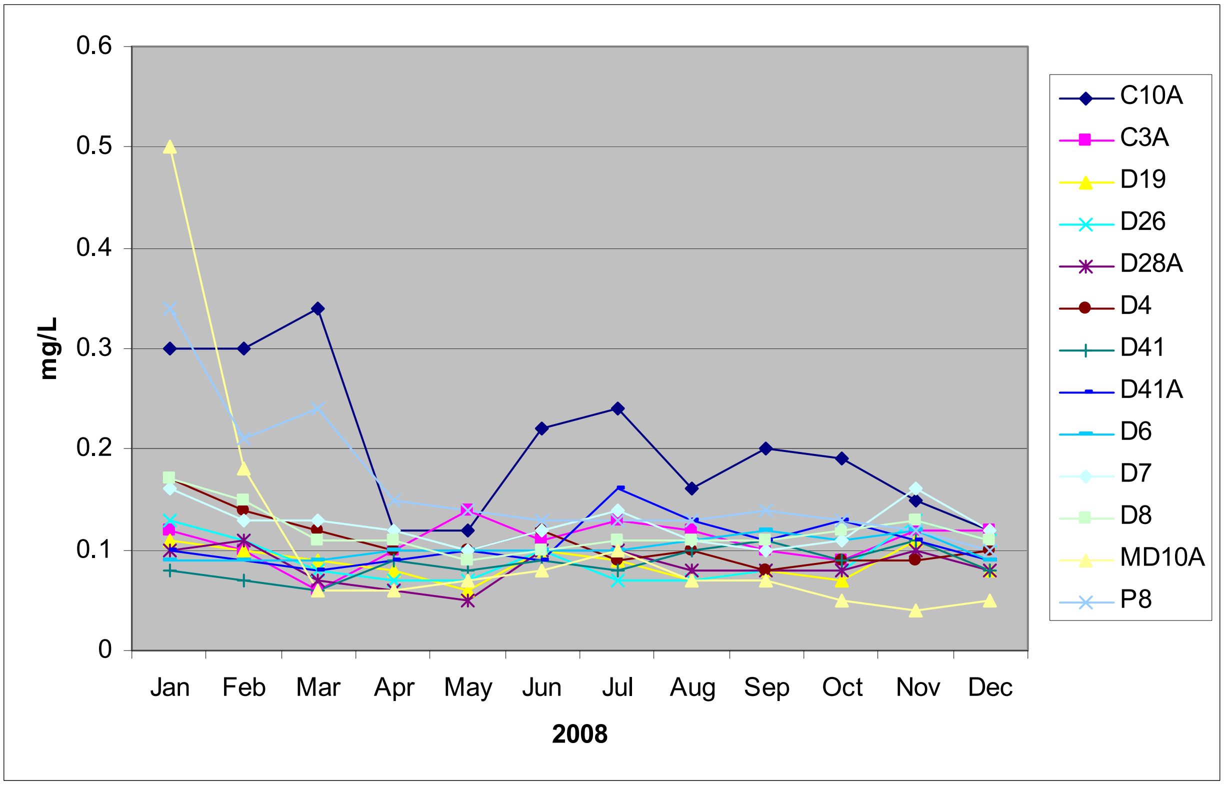

Figure 3-15 Total Phosphorus (mg/L) by Station, 2008

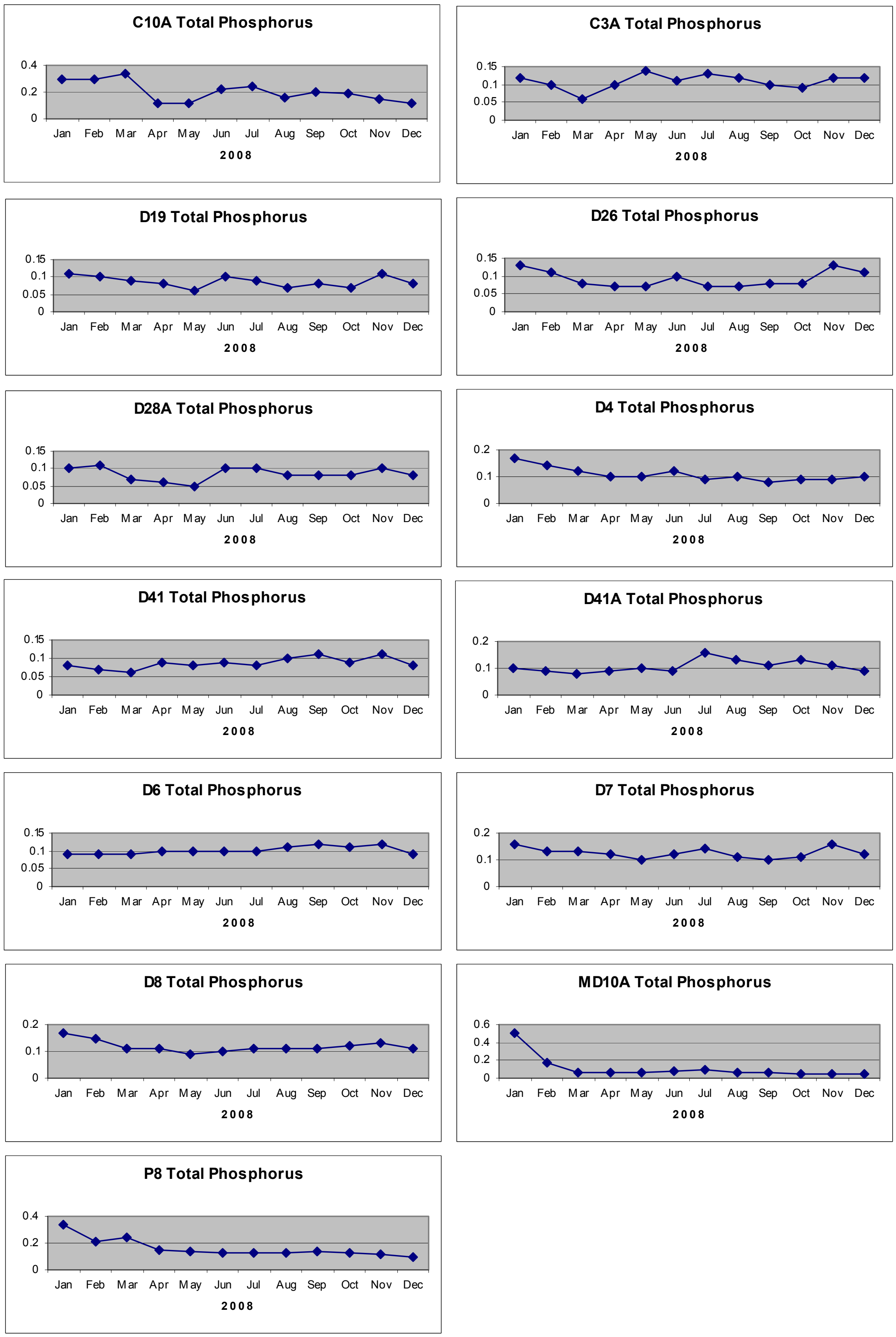

Figure 3-16 Kjeldahl Nitrogen Comparisons, 2008

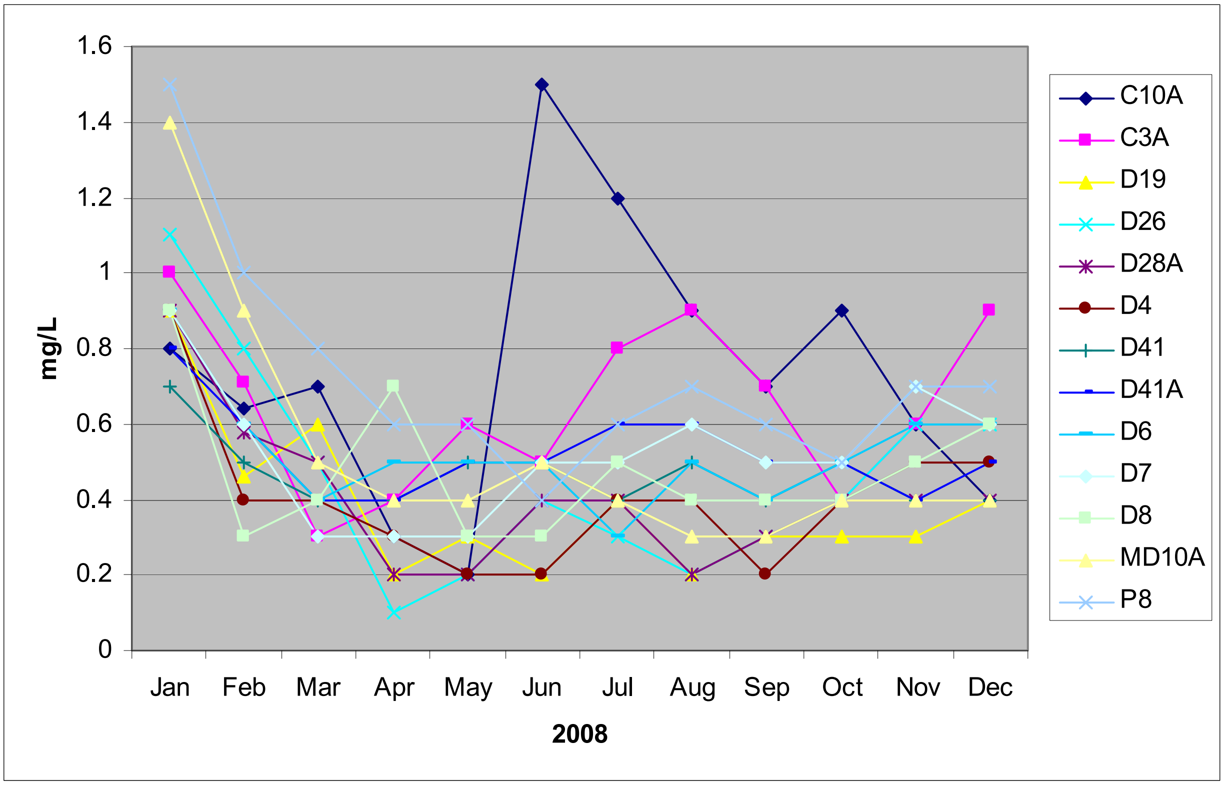

Figure 3-17 Kjeldahl Nitrogen (mg/L) by Station, 2008

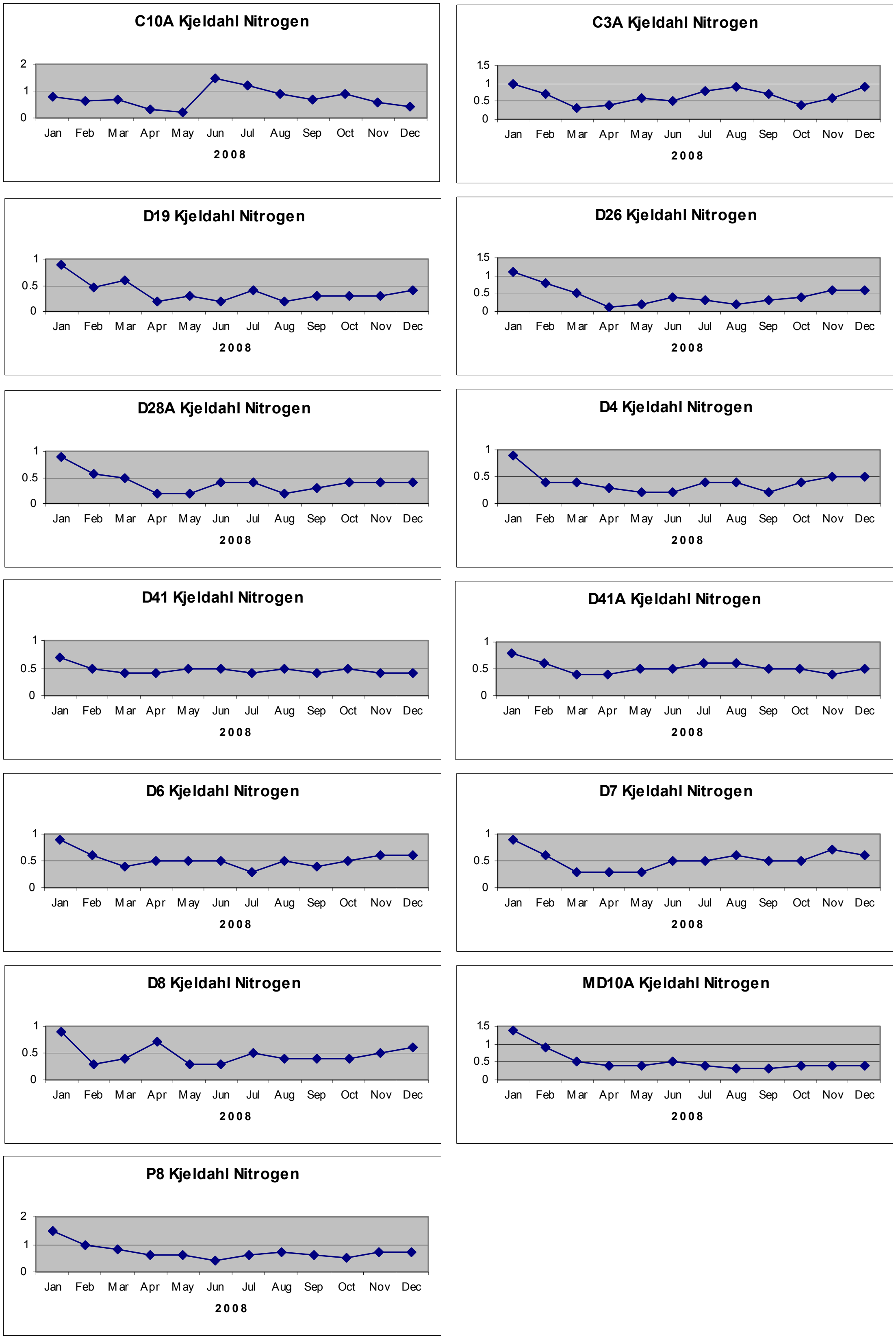

Figure 3-18 Dissolved Inorganic Nitrogen Comparisons, 2008

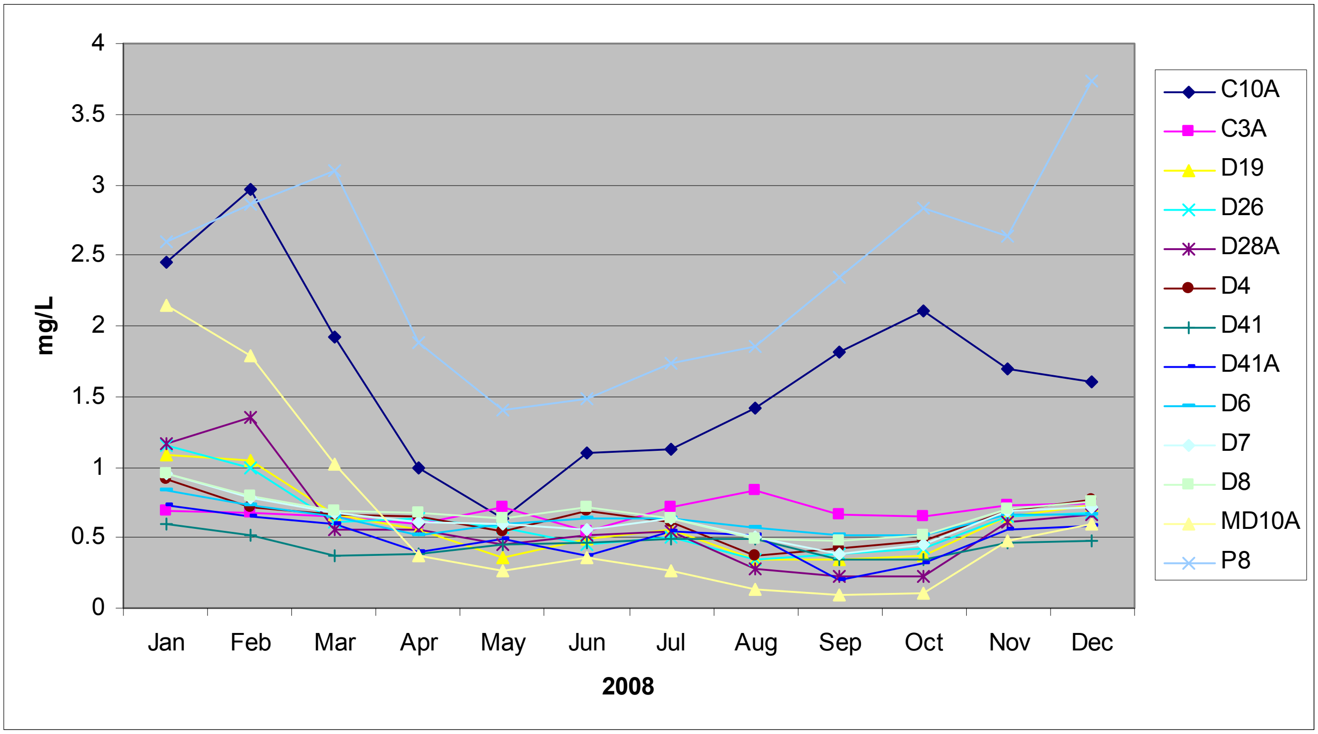

Figure 3-19 Dissolved Inorganic Nitrogen (mg/L), 2008

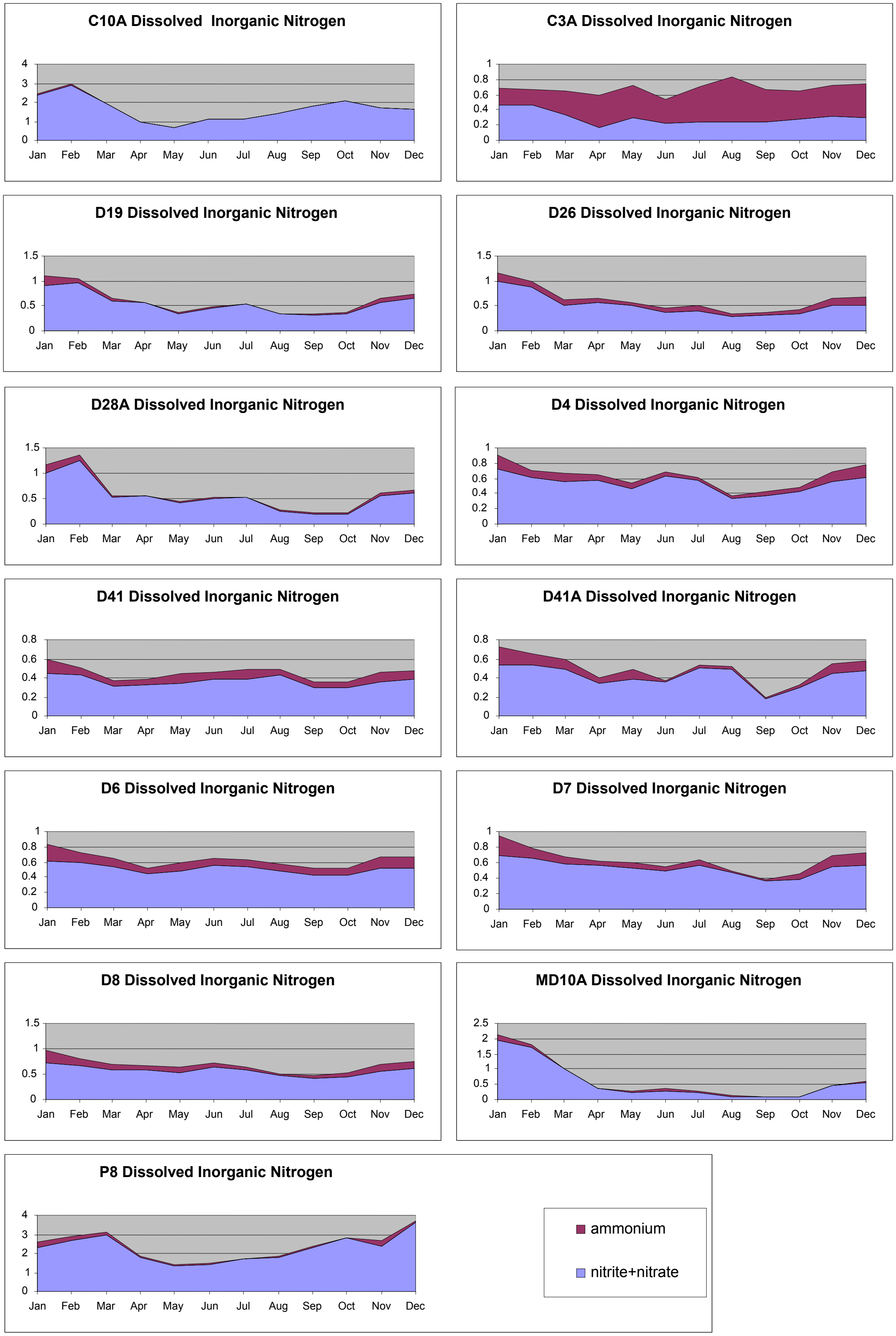

Figure 3-20 Dissolved Organic Nitrogen Comparisons, 2008

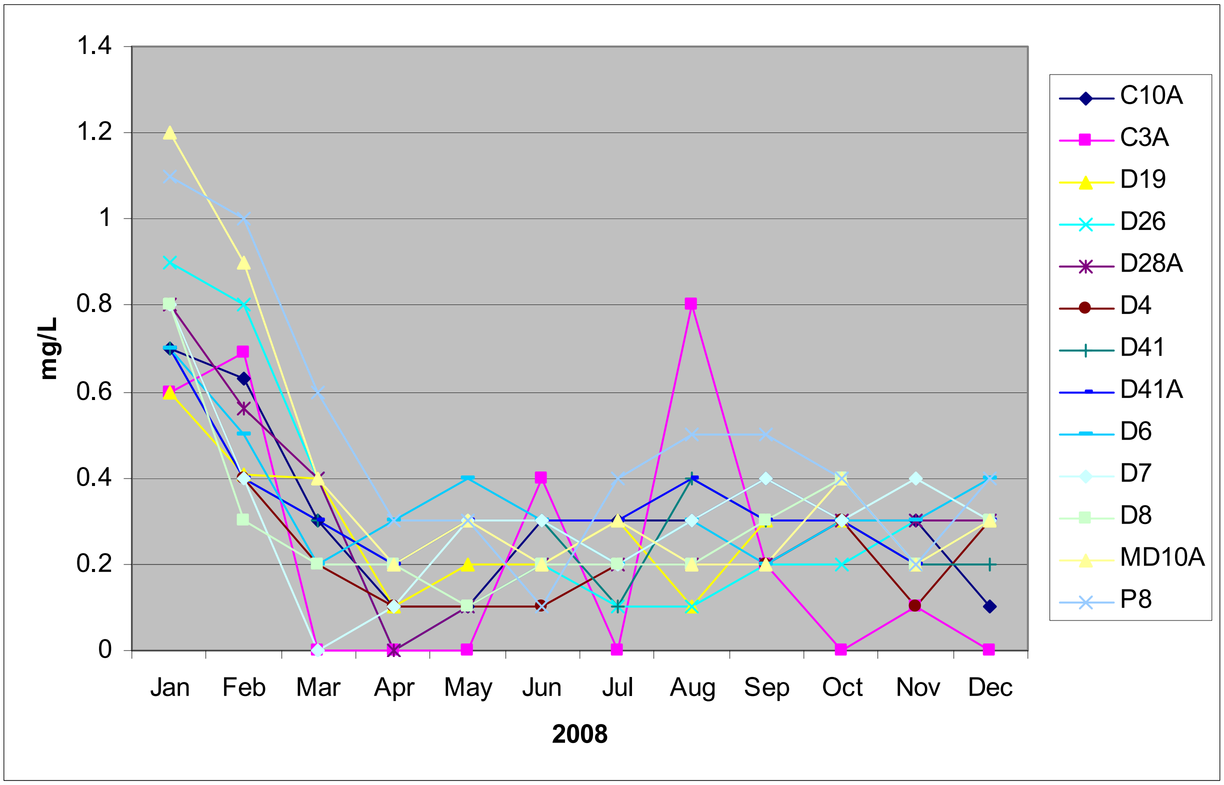

Figure 3-21 Dissolved Organic Nitrogen (mg/L) by Station, 2008

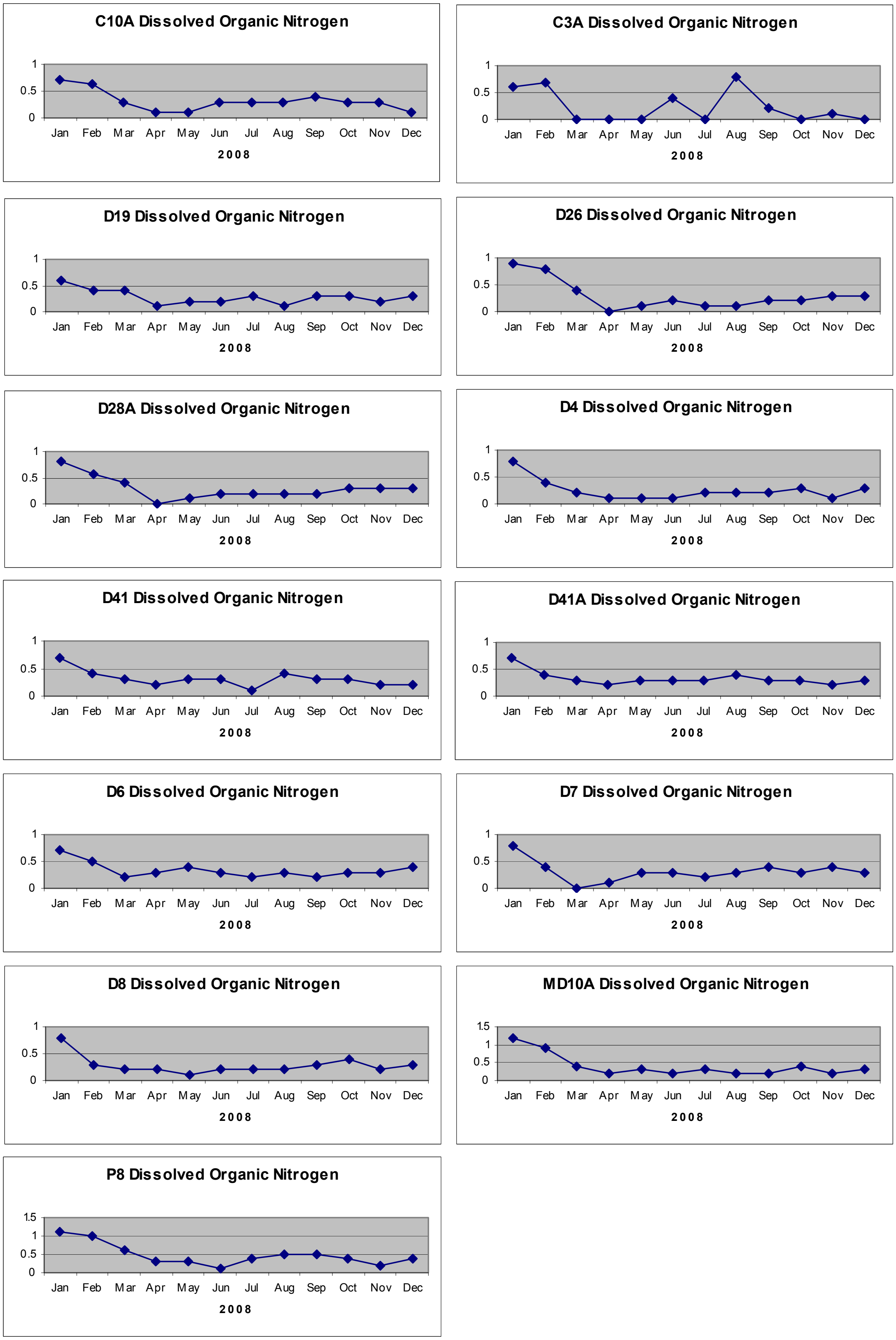

Figure 3-22 Total Dissolved Solids Comparisons, 2008

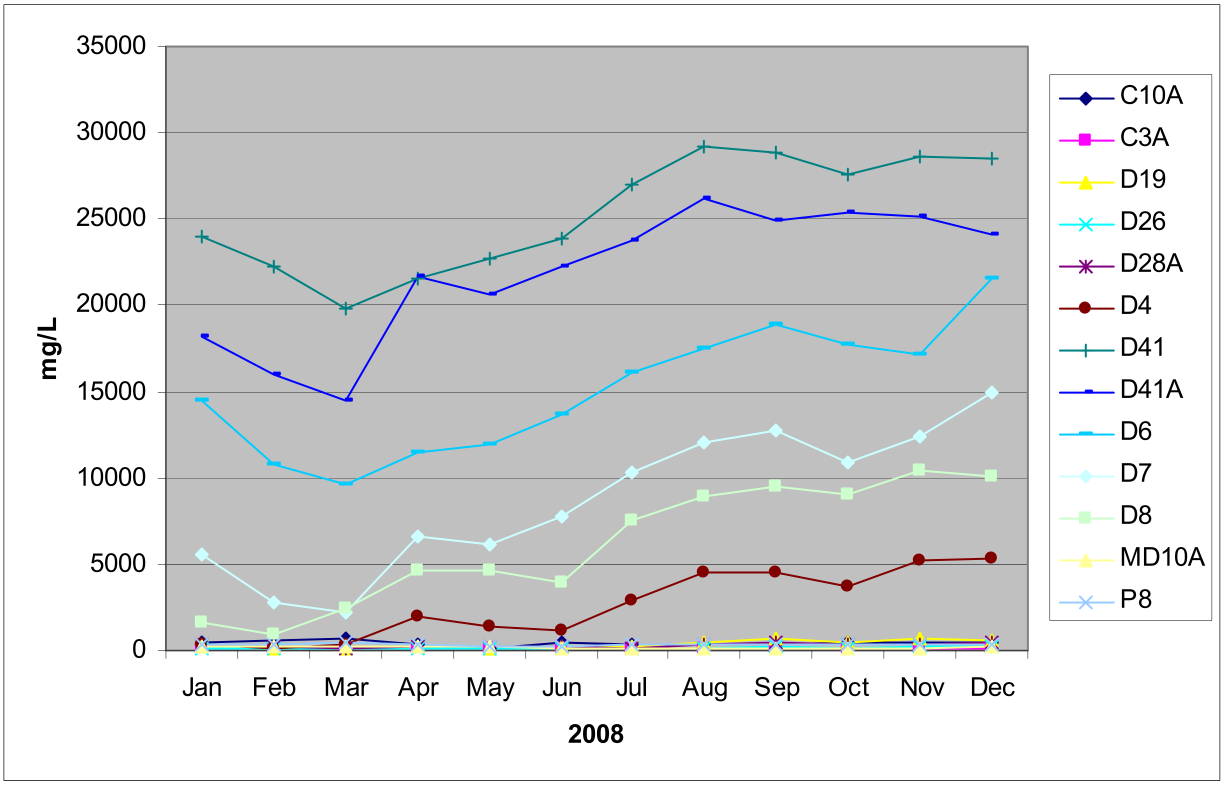

Figure 3-23 Total Dissolved Solids (mg/L) by Station, 2008

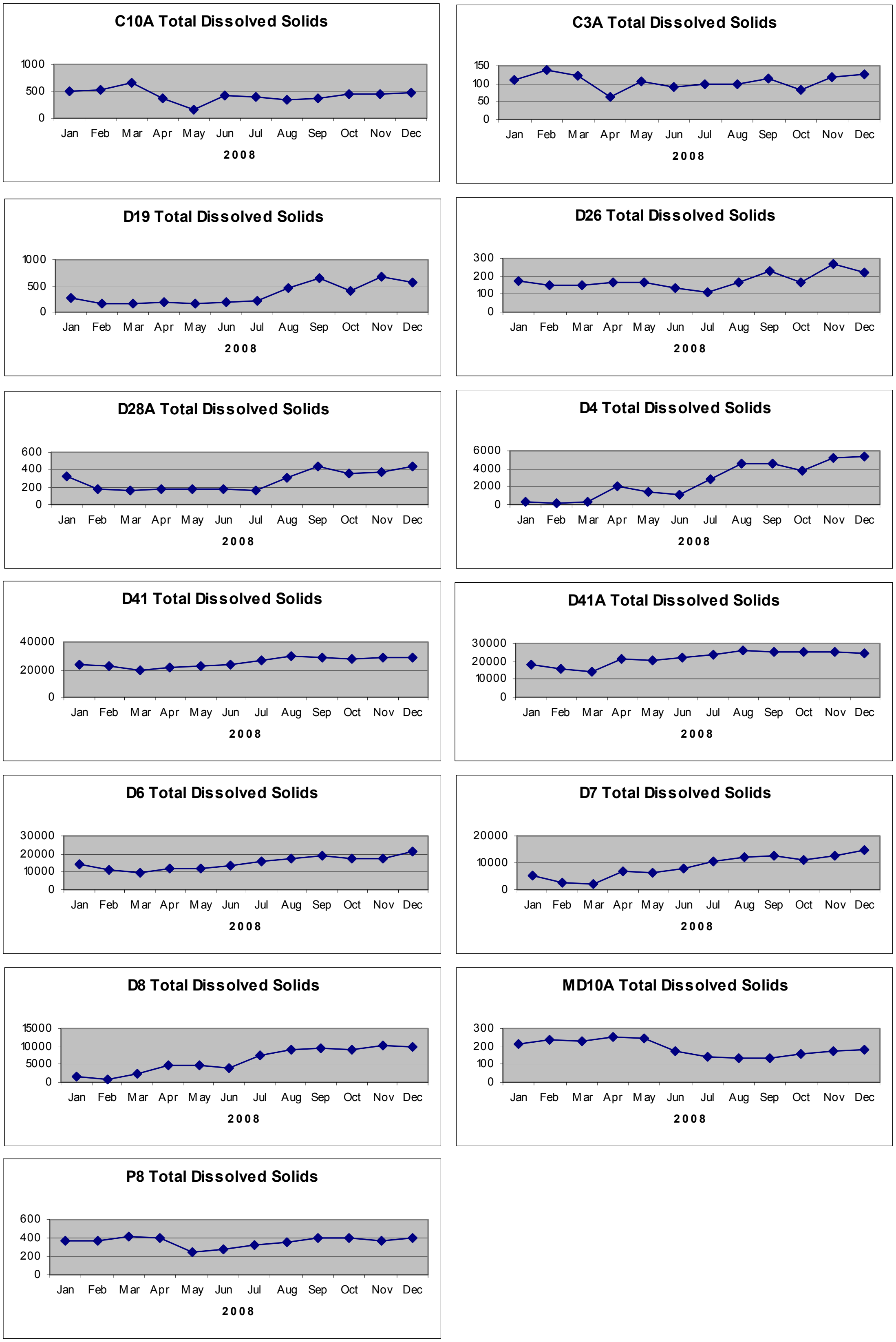

Figure 3-24 Total Suspended Solids Comparisons, 2008

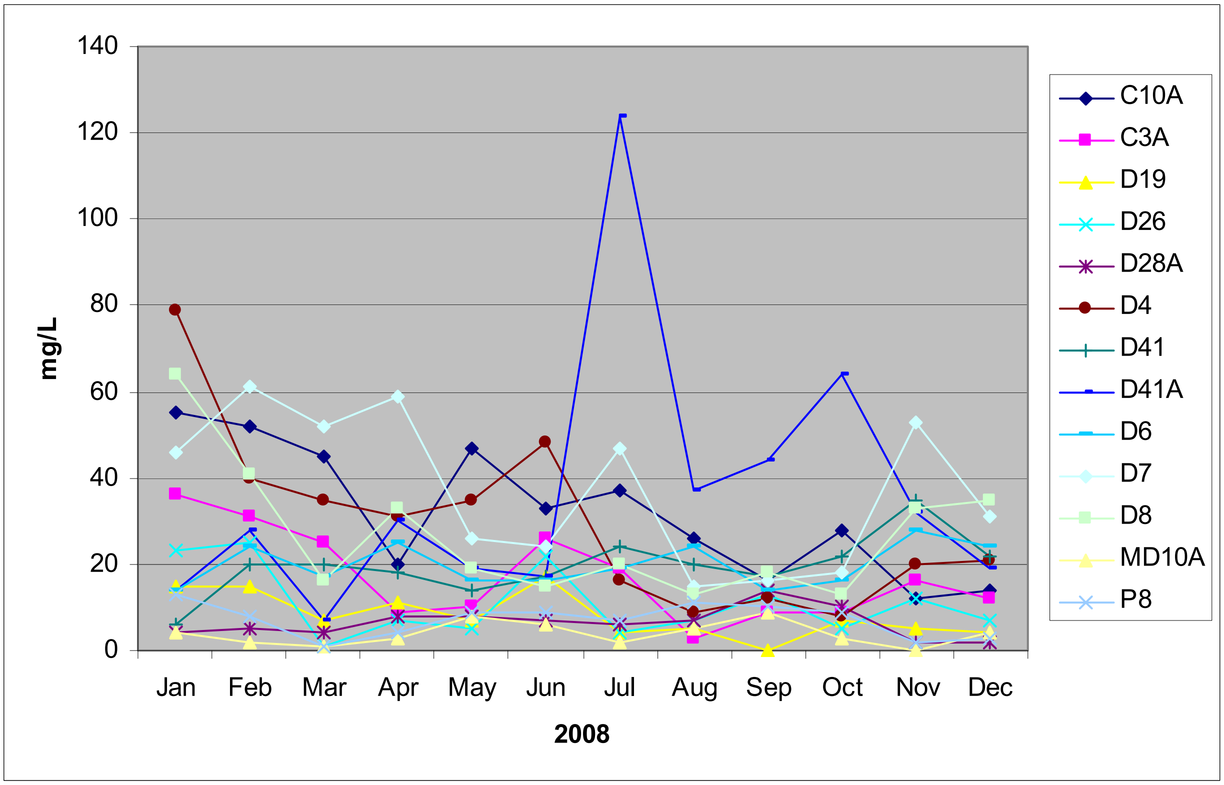

Figure 3-25 Total Suspended Solids (mg/L) by Station, 2008

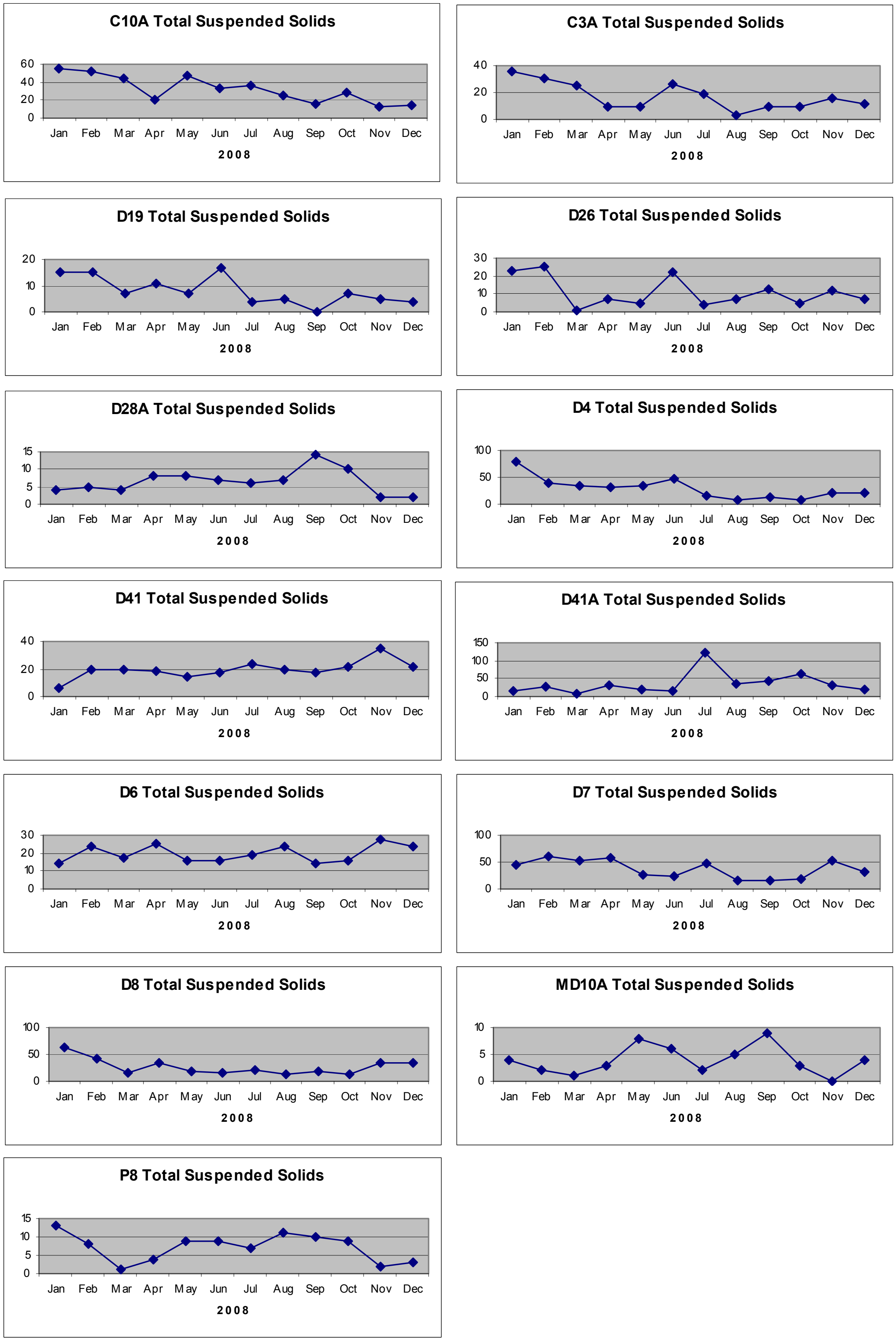

Figure 3-26 Volatile Suspended Solids Comparisons, 2008

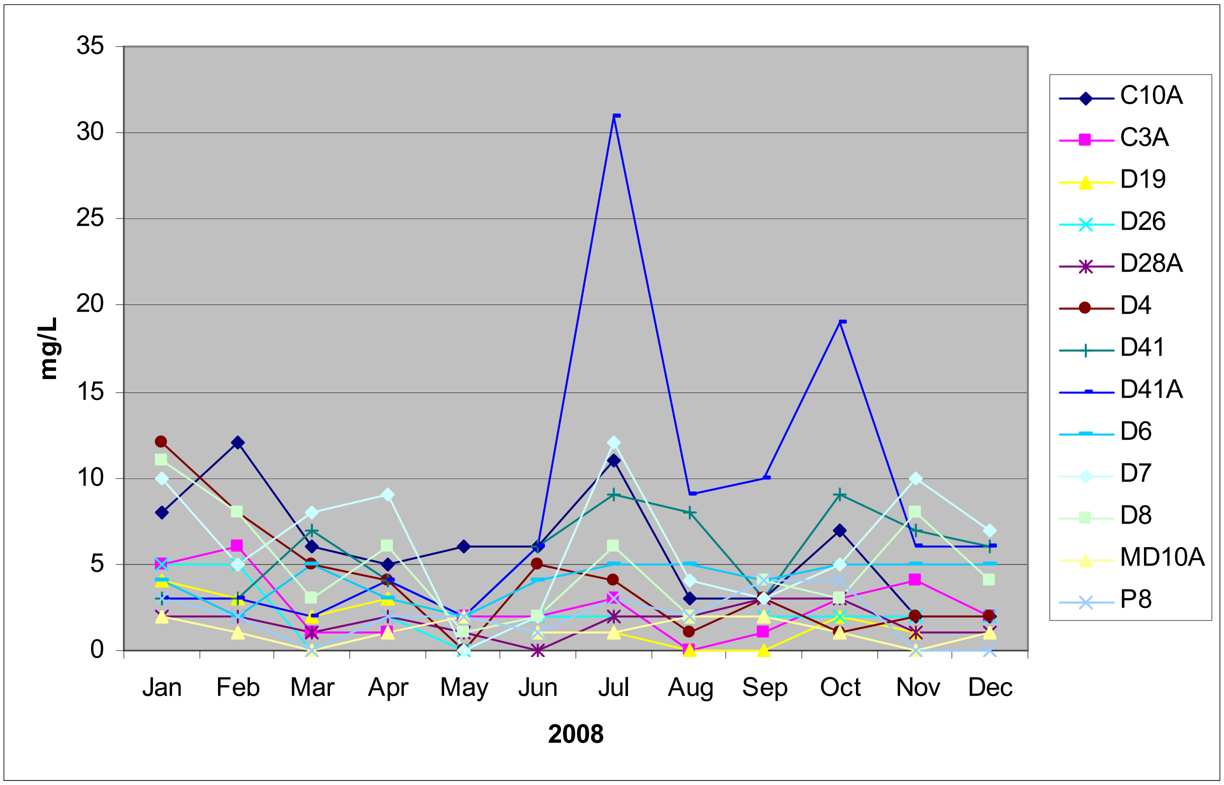

Figure 3-27 Volatile Suspended Solids (mg/L) by Station, 2008

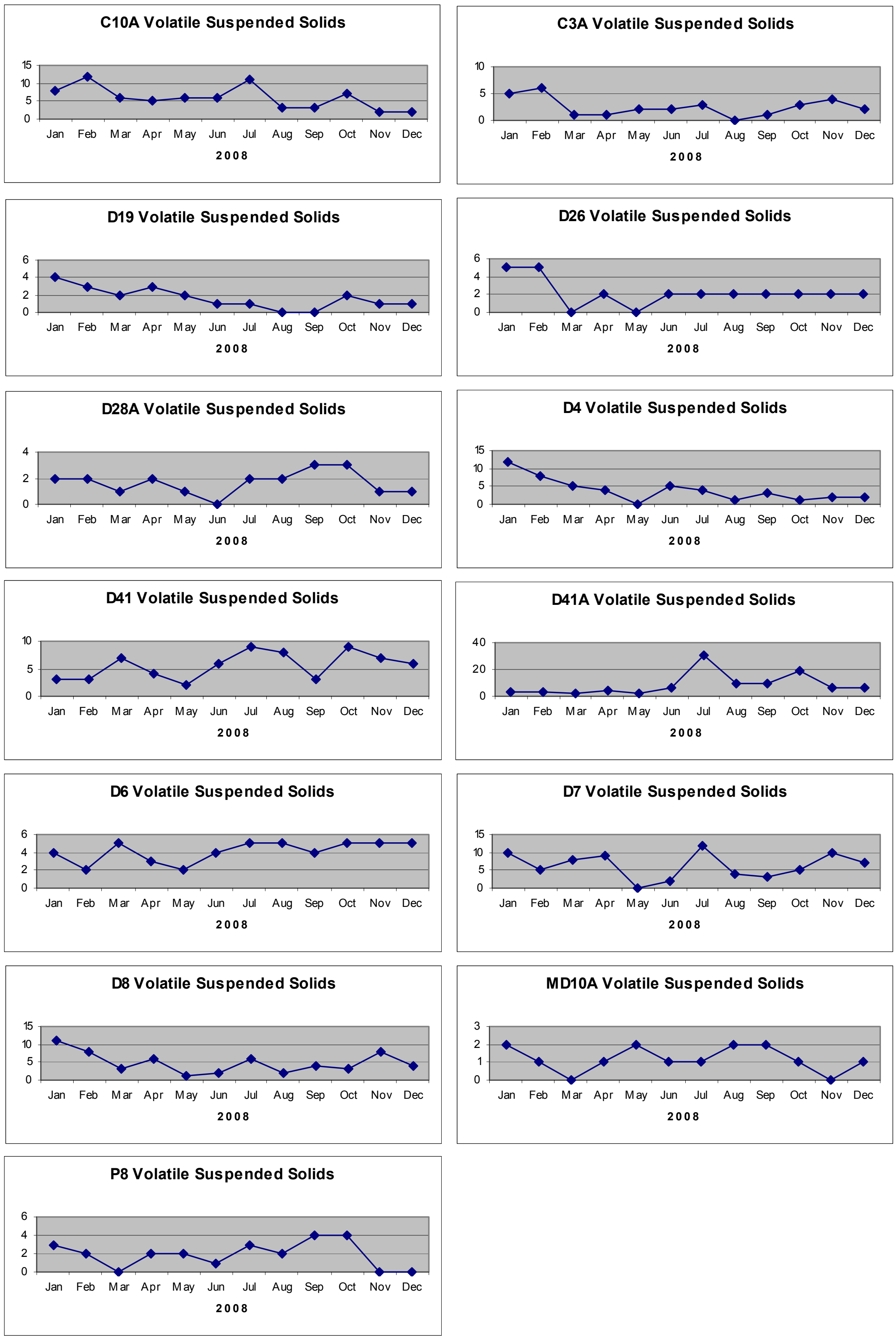

Figure 3-28 Silica Comparisons, 2008

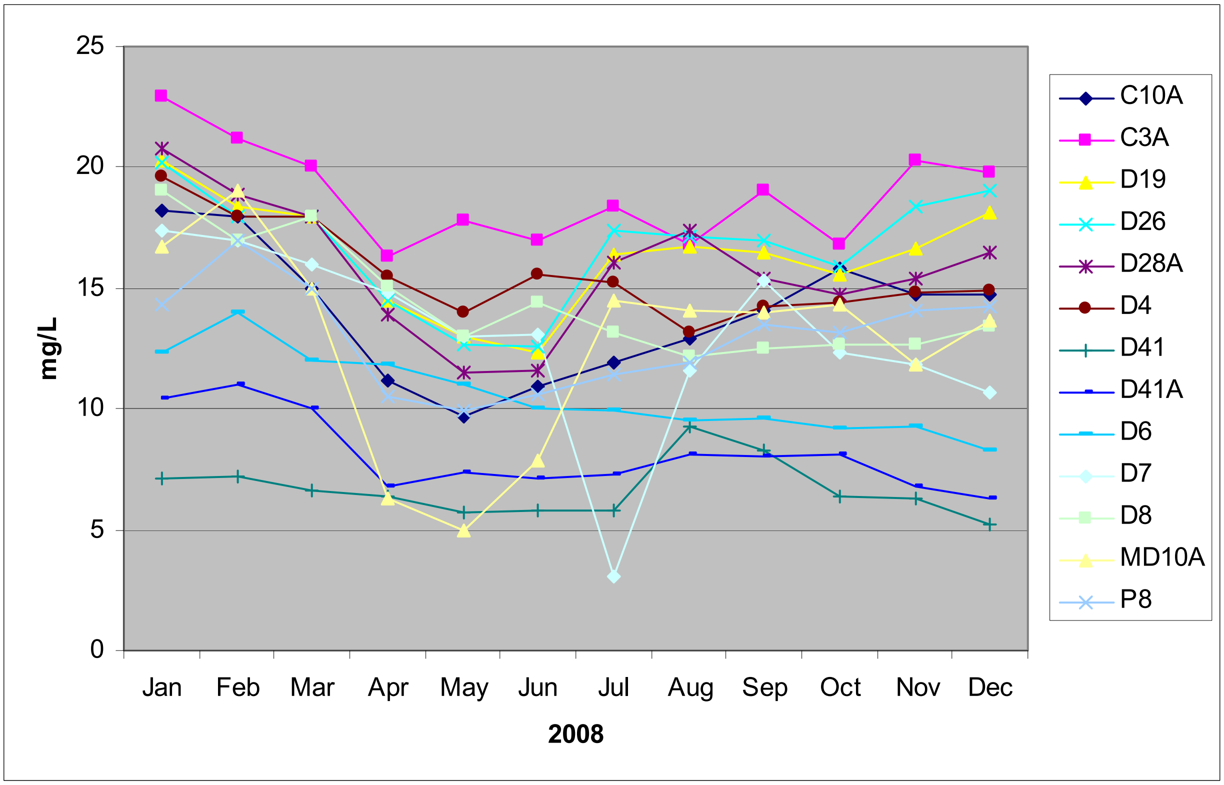

Figure 3-29 Silica (mg/L) by Station, 2008

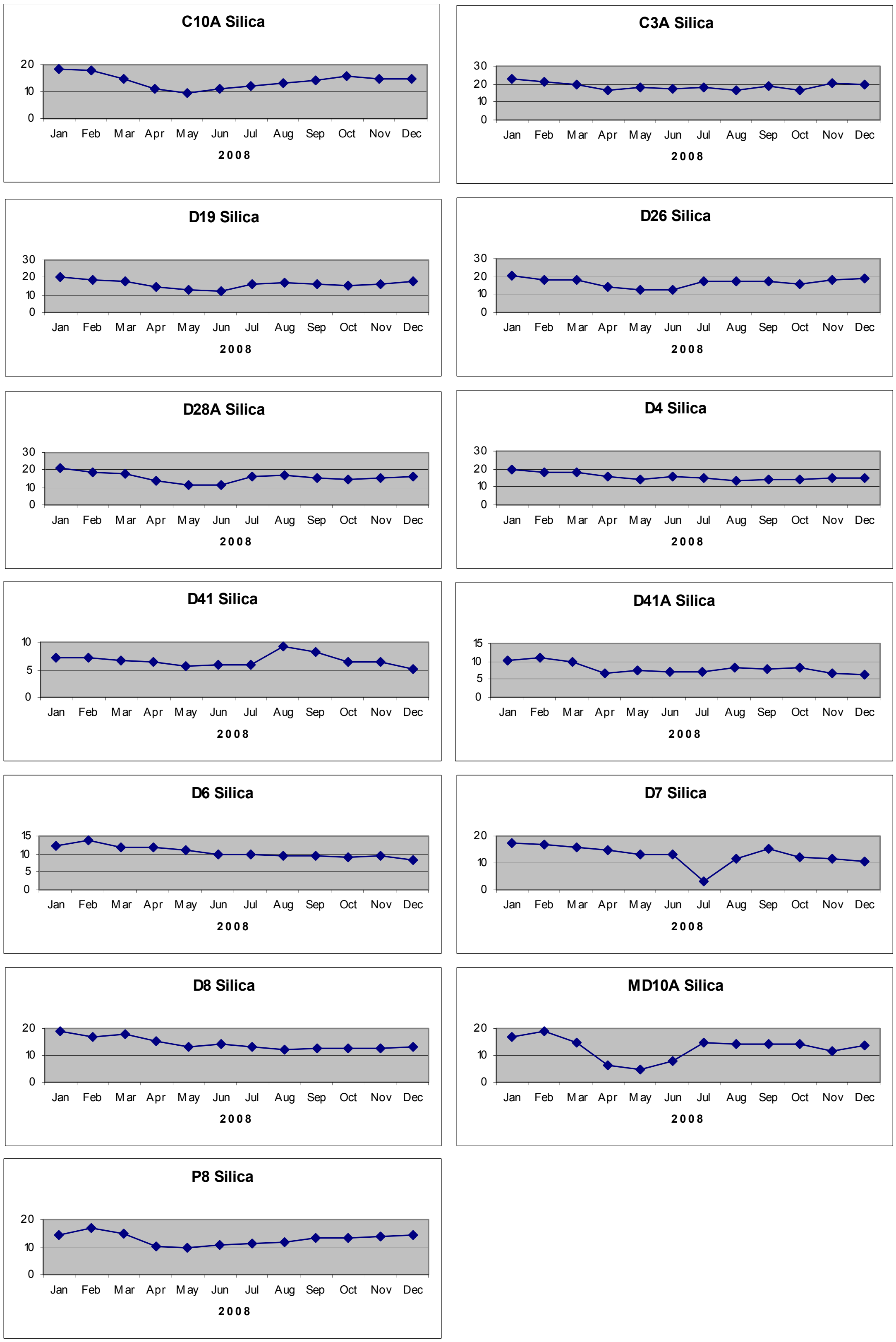

Figure 3-30 Chloride Comparisons, 2008

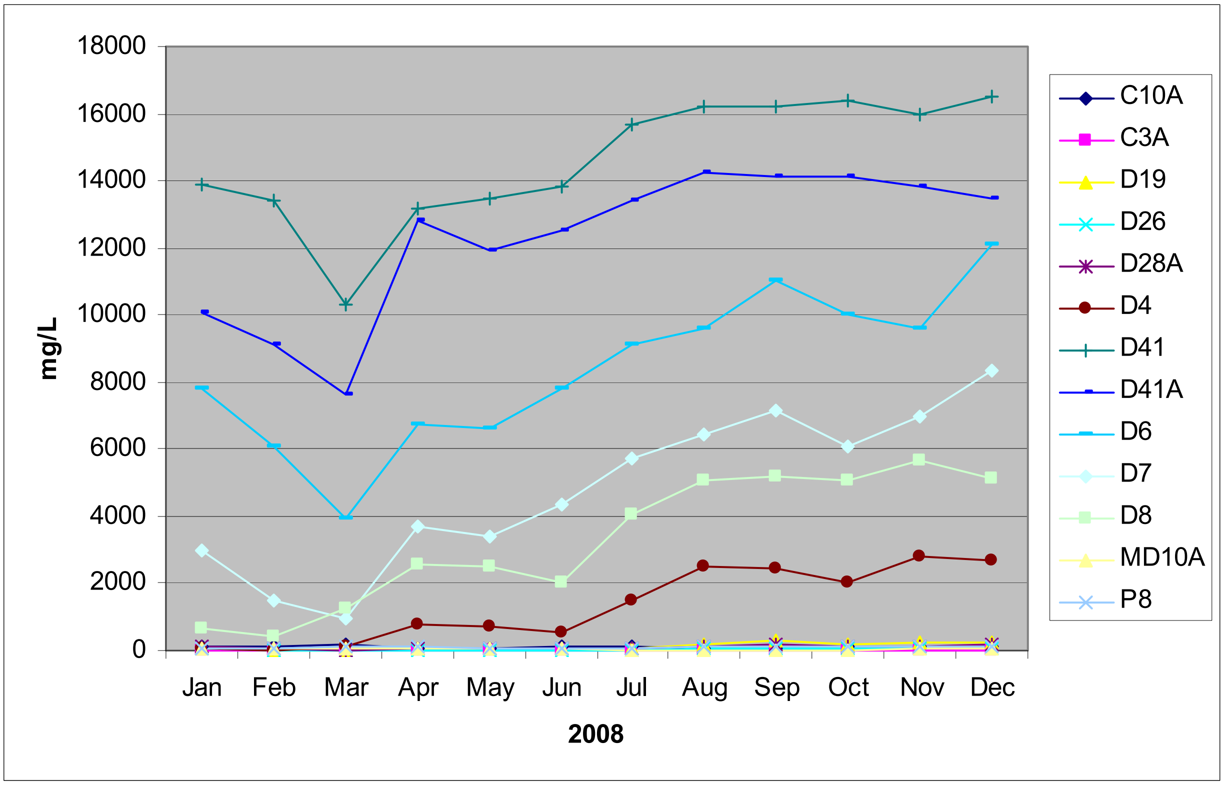

Figure 3-31 Chloride (mg/L) by Station, 2008

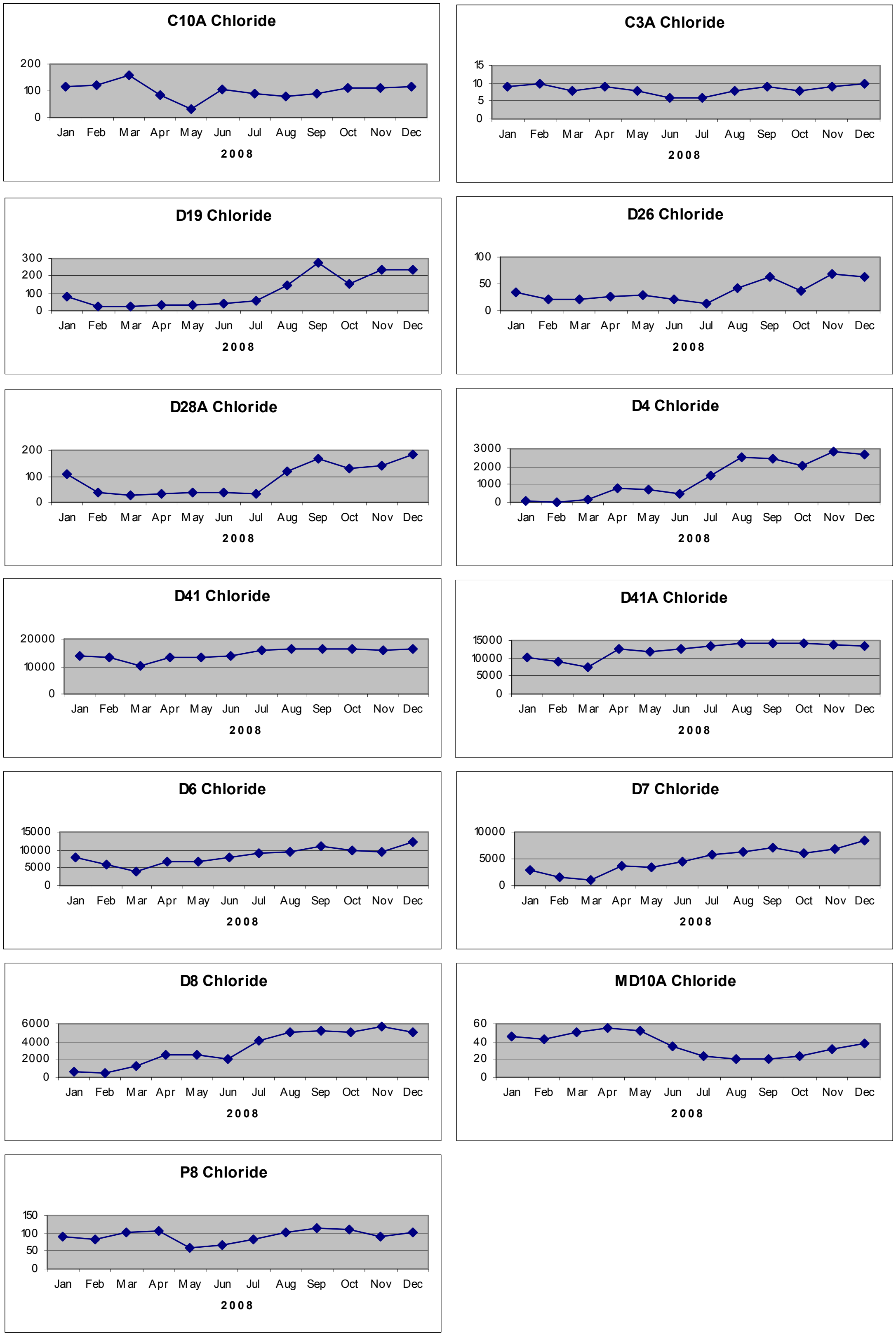

Table 3-1 Water Quality Parameters Measured

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

Table 3-2 Water Quality Sampling Sites and Regions

Region	Sampling Sites
Lower Sacramento River	D4
Lower San Joaquin River	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

Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll *a* samples in order to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (Estuary). The 13 sampling sites range from San Pablo Bay east to the lower 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 2008.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes which influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular, colonial or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect pH, dissolved oxygen, color, taste and odor, and under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael 1981). In freshwater, the cyanobacteria, or 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).

Carmichael, W., ed. 1981. The Water Environmental, Algal Toxins and Health. NY:Plenum Press

Van den Hoek, C., DG Mann and HM Jahns. 1995. Algae: an introduction to Phycology. UK: Cambridge 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).

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).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed. Phytoplankton identification and enumeration were performed at DWR's Bryte Laboratory from January through September and at EcoAnalyst, a private contractor, from October through December. Samples were analyzed 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 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and turbidity of the sample. Aliquots are enumerated at a magnification of 630X using a Leica DMIL inverted microscope. For each settled aliquot, phytoplankton in randomly chosen transects are counted. Taxa are enumerated as they appear along the transects. A minimum of 400 total algal units are counted, and a minimum of 100 algal units of the dominant taxon. For taxa that are in filaments or colonies, the number of cells per filament or colony is recorded. Organism counts for each sample can be converted to organisms/mL using the following formula:

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

where:

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

This simplifies to:

Organisms = C / cV

where:

cV = Counted volume (mL)

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

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

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1) using a submersible pump from 1 meter below the water's surface. Approximately 500 mL of water was passed through a 47-mm diameter glass-fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to the Standard Methods (APHA 1998) spectrophotometric procedure. Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1998).

Figure 4-1 Map of Chlorophyll and Phytoplankton Stations

Results

Phytoplankton Identification

- Of the twelve groups identified, unknown flagellates, cryptophyte flagellates, centric diatoms, pennate diatoms, chrysophyte flagellates, cyanobacteria and green algae constitued 98.67% of the organisms collected (Figure 4-2).

Figure 4-2 2008 Percent Phytoplankton Composition by Group

All organisms collected in 2008 fell into these twelve categories:

- Unknown flagellates
- Cryptophyte flagellates (class Cryptophyceae)
- Centric diatoms (class Coscinodiscophyceae)
- Pennate diatoms (classes Bacillariophyceae and Fragilariophyceae)
- Chrysophyte flagellates (class Chrysophyceae)
- Cyanobacteria (class Cyanophyceae)
- Green algae (classes Chlorophyceae, Ulvophyceae and Zygnematophyceae)
- Euglenoid flagellates (class Euglenophyceae)
- Unknown genus
- Dinoflagellates (class Dinophyceae)
- Ciliates (class Kinetofragminophora)
- Synurophyte flagellates (class Synurophyceae)

Table 4-1 2008 Phytoplankton Genera by Group

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

The 10 most common genera collected in 2008 were:

- Unknown flagellates
- Pyrenomonas (cryptophyte flagellate; class Cryptophyceae)
- Cyclotella (centric diatom; class Coscinodiscophyceae)
- Cryptomonas (cryptophyte flagellate; class Cryptophyceae)
- Unknown chrysophyte flagellates
- Aulacoseira (centric diatom; class Coscinodiscophyceae)
- Phormidium (cyanobacterium; class Cyanophyceae)
- Fragilaria (pennate diatom; class Fragilariophyceae)
- Cocconeis (pennate diatom; class Bacillariophyceae)
- Chroococcus (cyanobacterium; 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: http://www.iep.ca.gov/emp/Metadata/Phytoplankton/phytoplankton_dictionary.html

Pigment Concentrations

Table 4-2 2008 Chlorophyll a and Pheophytin a Concentrations

Chlorophyll *a* concentrations generally showed seasonal patterns. Most maxima occurred in spring and summer, while minima usually occurred in fall or winter. For some stations, however, peaks occurred in multiple seasons. All stations had one or more high peaks in chlorophyll *a* which skewed the mean values higher than the median values (Table 4-2 and Figures 4-3 through 4-15; note the different scales for each graph).

Monthly chlorophyll *a* concentrations throughout much of the Estuary were low. Of the 156 samples taken in 2008, 91.7% (143 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). Of the 13 samples with chlorophyll *a* concentrations above 10 µg/L, 11 were from the south Delta (C10A), one was from the central Delta (D19) in April, and one was from San Pablo Bay (D41A) in September.

The mean chlorophyll *a* concentration for all samples in 2008 was 6.52 µg/L, and the median value was 2.19 µg/L. The maximum chlorophyll *a* concentration in 2008 was 226.42 µg/L, recorded in June in the south Delta (C10A). Chlorophyll *a* maxima were recorded in spring and summer for all stations, except D41A (San Pablo Bay), which had its maximum value in September. The minimum chlorophyll *a* concentration was 0.76 µg/L, recorded in January in the south Delta (P8) and central Delta (MD10A), and in February in Suisun Bay (D8). Chlorophyll *a* minima were recorded in fall and winter at all stations.

Pheophytin *a* concentrations varied among stations, with some stations remaining relatively constant, while others had peaks during one or more months (Table 4-2 and Figures 4-3 through 4-15). The mean pheophytin *a* concentration for all samples in 2008 was 2.29 µg/L, and the median value was 1.17 µg/L. The maximum pheophytin *a* concentration was 32.08 µg/L, recorded at C10A (south Delta) in July. Pheophytin *a* maxima were recorded in spring and summer at all stations except P8 (south Delta), where the maximum was recorded in fall. At D8 (Suisun Bay) and D41 (San Pablo Bay), the maxiuma were recorded in winter. The minimum pheophytin *a* concentration was 0.27 µg/L, recorded at D6 (Suisun Bay) in November. Pheophytin *a* minima were recorded in fall and winter at all stations except D26 (lower San Joaquin River) and D4 (lower Sacramento River). At these stations, minima were recorded in summer and spring, respectively.

Table 4-2 shows the maximum and minimum values for chlorophyll *a* and pheophytin *a* for each station, as well as the median, mean, and standard deviation. Figures 4-3 through 4-15 show the results of chlorophyll *a* and pheophytin *a* analysis, and phytoplankton composition at each station. All chlorophyll *a* and pheophytin *a* data can be found at: http://www.water.ca.gov/bdma/.

Figure 4-3a 2008 Pigment Concentrations at C3A

Site C3A: North Delta

The highest chlorophyll *a* concentration was recorded in April (5.98 µg/L), and the lowest was recorded in December (0.81 µg/L) (Figure 4-3a, Table 4-2). The mean was 2.55 µg/L, and the median was 2.27 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 spring and summer (Figure 4-3a). The maximum (4.31 µg/L) was recorded in July, and the minimum (0.89 µg/L) was recorded in December (Table 4-2). The mean was 2.34 µg/L, and the median was 1.98 µg/L.

Phytoplankton was dominated by cryptophyte flagellates and pennate diatoms for most of the year, with blooms of centric diatoms in April and unknown flagellates in August (Figure 4-3b).

Figure 4-3b 2008 Phytoplankton Composition at C3A

Site C10A: South Delta

The maximum chlorophyll *a* concentration was recorded in June (226.42 µg/L), and the minimum was in November (9.93 µg/L) (Figure 4-4a, Table 4-2). The large peak in chlorophyll *a* in June skewed the mean (52.65 µg/L) much higher than the median (33.43 µg/L). Chlorophyll *a* still showed a seasonal pattern despite this large peak (Figure 4-4a).

The largest pheophytin *a* value for the year was recorded at this station in July (32.08 µg/L) (Figure 4-4a; Table 4-2). The minimum occurred in December (2.07 µg/L). As with chlorophyll, the large peak in July skewed the mean (13.35 µg/L) higher than the median (10.49 µg/L) (Table 4-2).

Figure 4-4a 2008 Pigment Concentrations at C10A

There was a slight seasonal pattern, with highest values in summer and fall (Figure 4-4a).

Centric diatoms dominated the phytoplankton all year, with significant contributions from pennate diatoms and cryptophyte flagellates in some months (Figure 4-4b).

Figure 4-4b 2008 Phytoplankton Composition at C10A

Site P8: South Delta

Chlorophyll *a* showed a strong seasonal pattern, with highest values recorded in spring and summer (Figure 4-5a). The maximum was recorded in April (6.62 µg/L), and the minimum in January (0.76 µg/L) (Table 4-2). The mean (2.72 µg/L) was slightly higher than the median (2.51 µg/L).

Pheophytin *a* was relatively stable throughout the year (Figure 4-5a). As a result, the mean and median were very close (1.90 µg/L and 1.88 µg/L, respectively) (Table 4-2). The maximum was 3.09 µg/L in October, and the minimum was 0.75 µg/L in November.

Figure 4-5a 2008 Pigment Concentrations at P8

Phytoplankton densities were low in the first half of the year. Blooms of unknown flagellates started in August, with cryptophyte flagellates contributing in the latter part of the year (Figure 4-5b).

Figure 4-5b 2008 Phytoplankton Composition at P8

Site MD10A: East Delta

Chlorophyll *a* showed a slight seasonal pattern; the highest values were recorded in spring, but were relatively stable the rest of the year (Figure 4-6a). The maximum (6.62 µg/L) occurred in April, and skewed the mean (2.48 µg/L) slightly higher than the median (2.26 µg/L) (Table 4-2). The minimum was recorded in December (0.84 µg/L).

Pheophytin *a* showed a pattern similar to chlorophyll *a*, with peaks in spring and lower (but stable) values after June (Figure 4-6a). This skewed the mean slightly higher than the median (1.47 µg/L and 1.20 µg/L, respectively) (Table 4-2). The maximum was recorded in March (2.94 µg/L). The minimum was recorded in November (0.65 µg/L).

Figure 4-6a 2008 Pigment Concentrations at MD10A

Like P8, phytoplankton densities were low in the beginning of the year, and saw blooms of unknown flagellates and cryptophyte flagellates starting in August (Figure 4-6b). There were small blooms of both centric and pennate diatoms in October.

Figure 4-6b 2008 Phytoplankton Composition at MD10A

Site D26: Lower San Joaquin River

With the exception of a peak in April, chlorophyll *a* values were very low (< 5 µg/L) all year (Figure 4-7a). The maximum was 9.61 µg/L in April, and the minimum was 0.80 µg/L in January (Table 4-2). The peak in April skewed the mean (2.30 µg/L) higher than the median (1.50 µg/L).

Figure 4-7a 2008 Pigment Concentrations at D26

Pheophytin *a* values were fairly low (< 3 µg/L) all year (Figure 4-7a). The maximum was 2.39 µg/L in June, and the minimum was 0.57 µg/L in August (Table 4-2). The mean (1.12 µg/L) was higher than the median (0.87 µg/L).

There was a large bloom of cyanobacteria in October; otherwise, phytoplankton were dominated by unknown flagellates and cryptophyte flagellates (Figure 4-7b).

Figure 4-7b 2008 Phytoplankton Composition at D26

Site D19: Central Delta

Chlorophyll *a* concentrations showed a seasonal pattern, but it was slightly obscured by a large peak in April (13.03 µg/L) that was the maximum for the year (Figure 4-8a, Table 4-2). The minimum was 0.82 µg/L in February. The peak in April skewed the mean (3.30 µg/L) much higher than the median (1.81 µg/L)

Figure 4-8a 2008 Pigment Concentrations at D19

Pheophytin *a* was similar to chlorophyll *a*, showing a seasonal pattern (Figure 4-8a). The maximum was recorded in June (3.28 µg/L), and the minimum was recorded in November (0.42 µg/L) (Table 4-2). The mean was slightly higher than the median (1.52 µg/L and 1.14 µg/L, respectively).

There were blooms of centric diatoms in April and May; unknown flagellates and cryptophyte flagellates dominated the rest of the year (Figure 4-8b).

Figure 4-8b 2008 Phytoplankton Composition at D19

Site D28A: Central Delta

Chlorophyll *a* showed a seasonal pattern with the maximum occurring in April (7.80 µg/L) (Figure 4-9a, Table 4-2). The minimum of 0.90 µg/L was recorded in February. The mean and median were similar (2.69 µg/L and 2.41 µg/L, respectively).

Figure 4-9a 2008 Pigment Concentrations at D28A

Pheophytin *a* values were low (< 3 µg/L) all year (Figure 4-9a). The mean and median were close (1.49 µg/L and 1.59 µg/L, respectively) (Table 4-2). The maximum of 2.82 µg/L was recorded in April; the minimum of 0.50 µg/L was recorded in February.

Again, phytoplankton were dominated by unknown flagellates and cryptophyte flagellates, with smaller contributions from centric and pennate diatoms (Figure 4-9b).

Figure 4-9b 2008 Phytoplankton Composition at D28A

Site D4: Lower Sacramento River

Chlorophyll *a* showed a seasonal pattern, with peaks in spring and summer, and declines in winter (Figure 4-10a). The maximum was 7.48 µg/L in April; the minimum was 1.03 µg/L in December (Table 4-2). The peak in April skewed the mean (2.19 µg/L) higher than the median (1.41 µg/L).

Figure 4-10a 2008 Pigment Concentrations at D4

Pheophytin *a* also showed a seasonal pattern, with peaks in spring and summer (Figure 4-10a). The maximum (4.00 µg/L) was recorded in May; the minimum (0.51 µg/L) was recorded in October (Table 4-2). The mean was 1.58 µg/L; the median was 0.89 µg/L.

Figure 4-10b 2008 Phytoplankton Composition at D4

Phytoplankton densities were very low until August, after which they were dominated by unknown flagellates and cryptophyte flagellates (Figure 4-10b).

Site D6: Suisun Bay

Chlorophyll *a* did not show a seasonal pattern, with peaks occurring throughout the year (Figure 4-11a). The maximum was 3.71 µg/L in April; the minimum was 1.07 µg/L in December (Table 4-2). The mean was 2.10 µg/L, and the median was 1.77 µg/L.

Figure 4-11a 2008 Pigment Concentrations at D6

Pheophytin *a* also did not show a seasonal pattern; peaks occurred throughout the year (Figure 4-11a). The maximum was recorded in April (1.33 µg/L) and the minimum was recorded in November (0.27 µg/) (Table 4-2). The mean and median were identical (0.66 µg/L).

Figure 4-11b 2008 Phytoplankton Composition at D6

Again, the dominant phytoplankton were unknown flagellates and cryptophyte flagellates (Figure 4-11b). Phytoplankton densities were very low from January thru March.

Site D7: Suisun Bay

Chlorophyll *a* did not show a seasonal pattern; there were peaks in April and August, and low values the rest of the year. The maximum was 4.83 µg/L in April, and the minimum was 0.85 µg/L in December (Figure 4-12a, Table 4-2). The mean was 2.00 µg/L, and the median was 1.60 µg/L.

Figure 4-12a 2008 Pigment Concentrations at D7

Pheophytin *a* showed a slight seasonal pattern; there were peaks in spring and summer (Figure 4-12a). The maximum (2.13 µg/L) was recorded in March; the minimum (0.37 µg/L) was recorded in September (Table 4-2). The mean was 1.17 µg/L; the median was 1.14 µg/L.

Figure 4-12b 2008 Phytoplankton Composition at D7

Like D6, phytoplankton densities were low during the first three months of the year, and then were dominated by unknown flagellates and cryptophyte flagellates (Figure 4-12b).

Site D8: Suisun Bay

Chlorophyll *a* showed a seasonal pattern, but it was slightly obscured by large peaks in April and August. The maximum was 4.26 µg/L in April, and the minimum was 0.76 µg/L in February (Figure 4-13a, Table 4-2). The mean was 1.71 µg/L, and the median was 1.48 µg/L.

Figure 4-13a 2008 Pigment Concentrations at D8

Pheophytin *a* showed no clear pattern; values were low for most of the year except in January (Figure 4-13a). The maximum (2.01 µg/L) was recorded in January; the minimum (0.52 µg/L) was recorded in October (Table 4-2). The mean was higher than the median (1.00 µg/L and 0.87 µg/L, respectively).

Figure 4-13b 2008 Phytoplankton Composition at D8

As with the other two Suisun Bay stations, phytoplankton densities were low January through March, and then dominated by the same groups (unknown flagellates and cryptophyte flagellates) (Figure 4-13b).

Site D41: San Pablo Bay

Chlorophyll *a* did not show a seasonal pattern; there were peaks throughout the year (Figure 4-14a). The maximum occurred in April (5.79 µg/L) (Table 4-2). The minimum of 1.69 µg/L was recorded in January. The mean (3.11 µg/L) was higher than the median (2.55 µg/L) (Table 4-2).

Pheophytin *a* also did not show a pattern; values were low all year (Figure 4-14a). The maximum of 1.59 µg/L was recorded in October; the minimum of 0.40 µg/L was recorded in February (Table 4-2). The mean and median were somewhat close (0.85 µg/L and 0.75 µg/L, respectively).

Phytoplankton densities were low until August, after which unknown flagellates and cryptophyte flagellates dominated (Figure 4-14b).

Figure 4-14a 2008 Pigment Concentrations at D41

Figure 4-14b 2008 Phytoplankton Composition at D41

Site D41A: San Pablo Bay

Chlorophyll *a* showed a slight seasonal pattern; there were peaks in spring and summer, and a very large peak in the fall. The maximum (21.57 µg/L) occurred in September (Figure 4-15a, Table 4-2). The minimum of 1.42 µg/L was recorded in January. The large peak in September skewed the mean (4.92 µg/L) higher than the median (3.24 µg/L) (Table 4-2).

Pheophytin *a* did not show a pattern; values were mostly low all year. The maximum of 3.10 µg/L was recorded in June, and the minimum of 0.34 µg/L was recorded in December (Figure 4-15a, Table 4-2). The mean was 1.32 µg/L; the median was 0.89 µg/L.

Unknown flagellates dominated all year; there was a bloom of cryptophyte flagellates in June (Figure 4-15b).

Figure 4-15a 2008 Pigment Concentrations at D41A

Figure 4-15b 2008 Phytoplankton Composition at D41A

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2007. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following twelve categories: unknown flagellates, cryptomonad flagellates, centric diatoms, pennate diatoms, chrysophyte flagellates, cyanobacteria, green algae, euglenoid flagellates, an unknown genus, dinoflagellates, ciliates, and synurophyte flagellates. The ten most common genera were unknown flagellates, *Pyrenomonas*, *Cyclotella*, *Cryptomonas*, unknown chrysophyte flagellates, *Aulacoseira*, *Phormidium, Fragilaria*, *Cocconeis*, and *Chroococcus*.

Chlorophyll *a* concentrations mostly showed a seasonal pattern; values ranged from 0.76 µg/L to 226.42 µg/L. Pheophytin *a* concentrations mainly did not show a seasonal pattern; values ranged from 0.27 µg/L to 32.08 µg/L. Despite sporadic peaks at some stations, chlorophyll *a* concentrations overall were relatively low when compared with the historical data.

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Chapter 4 Phytoplankton and Chlorophyll

Figure 4-1 Map of Chlorophyll and Phytoplankton

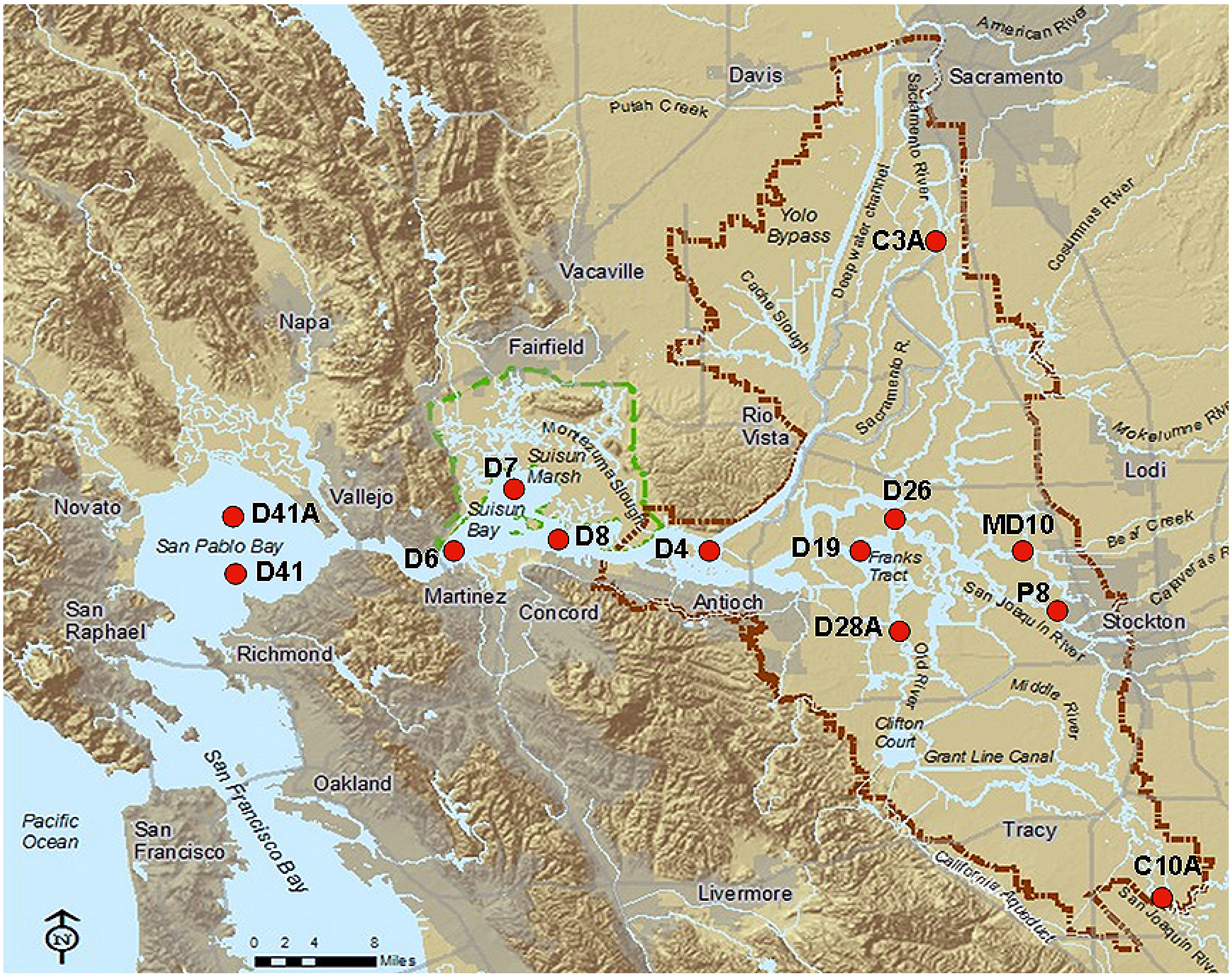


Figure 4-2 2008 Percent Phytoplankton Composition by Group

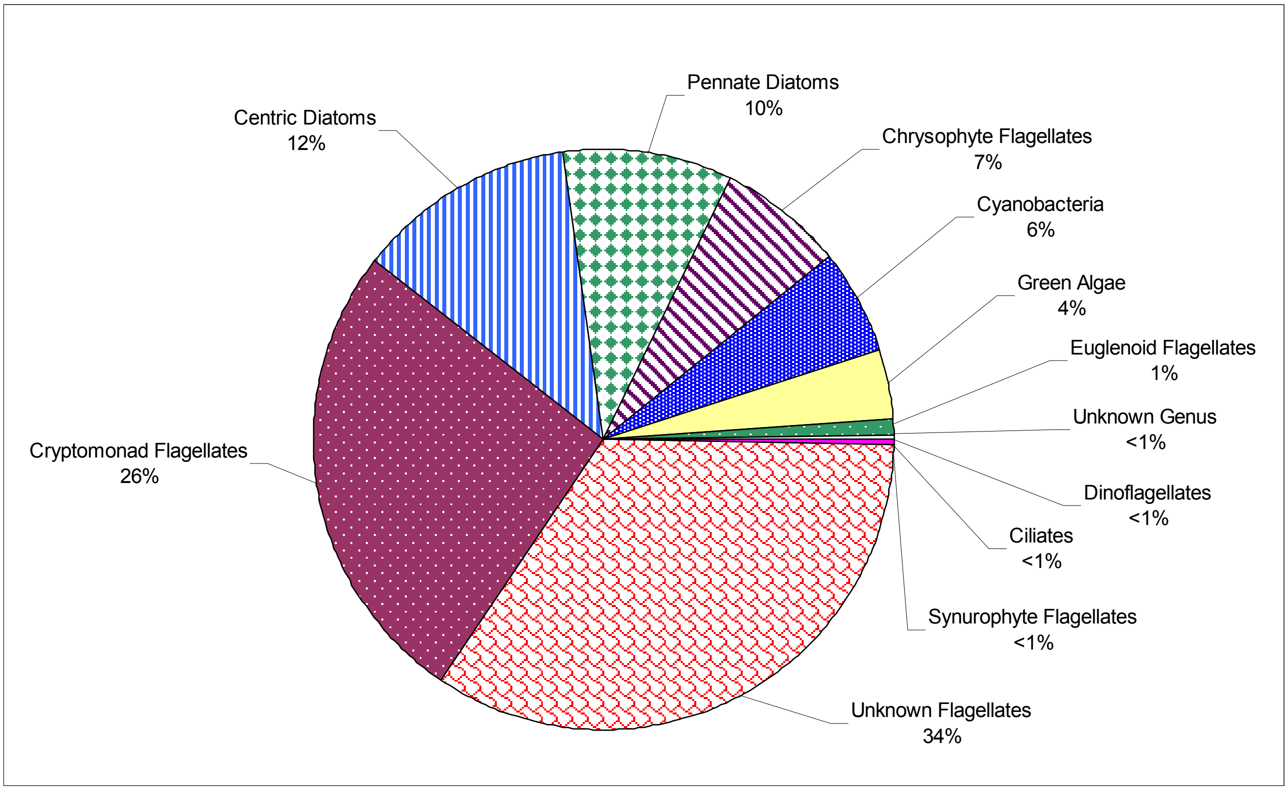


Figure 4-3a 2008 Pigment Concentrations at C3A

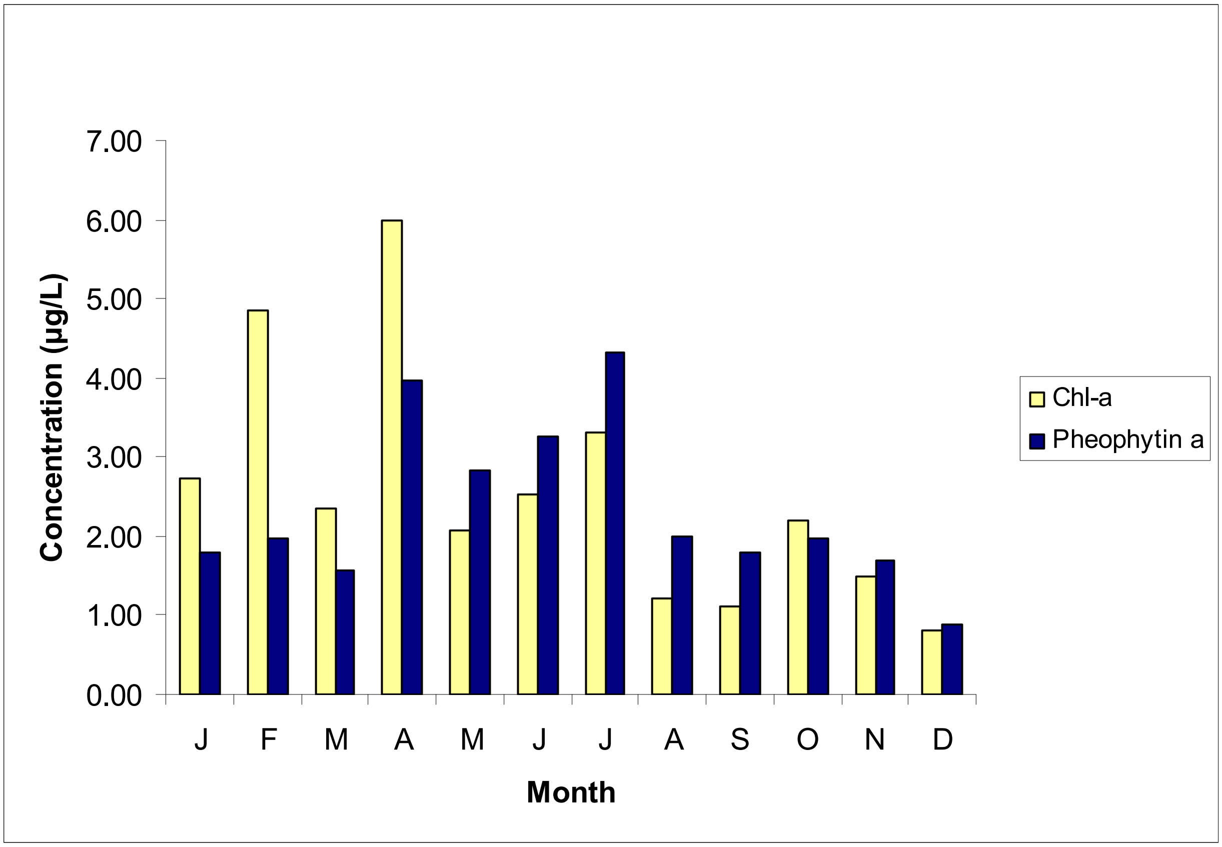


Figure 4-3b 2008 Phytoplankton Composition at C3A

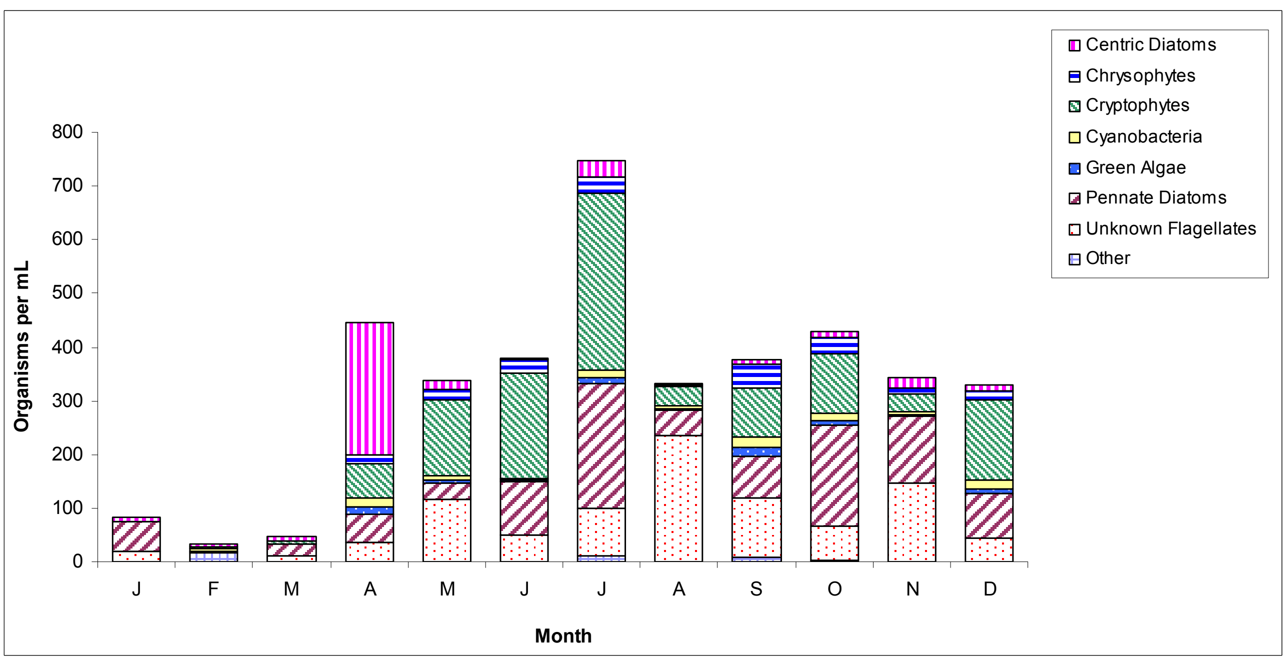


Figure 4-4a 2008 Pigment Concentrations at C10A

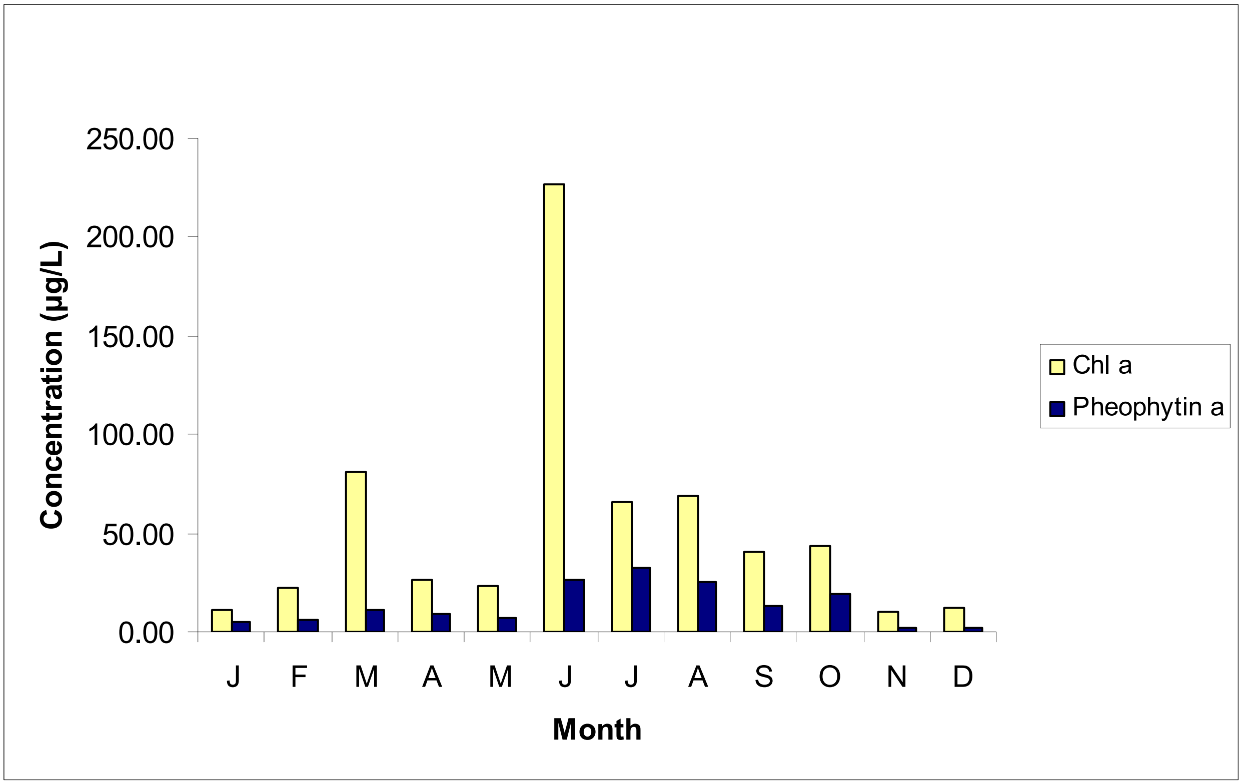


Figure 4-4b 2008 Phytoplankton Composition at C10A

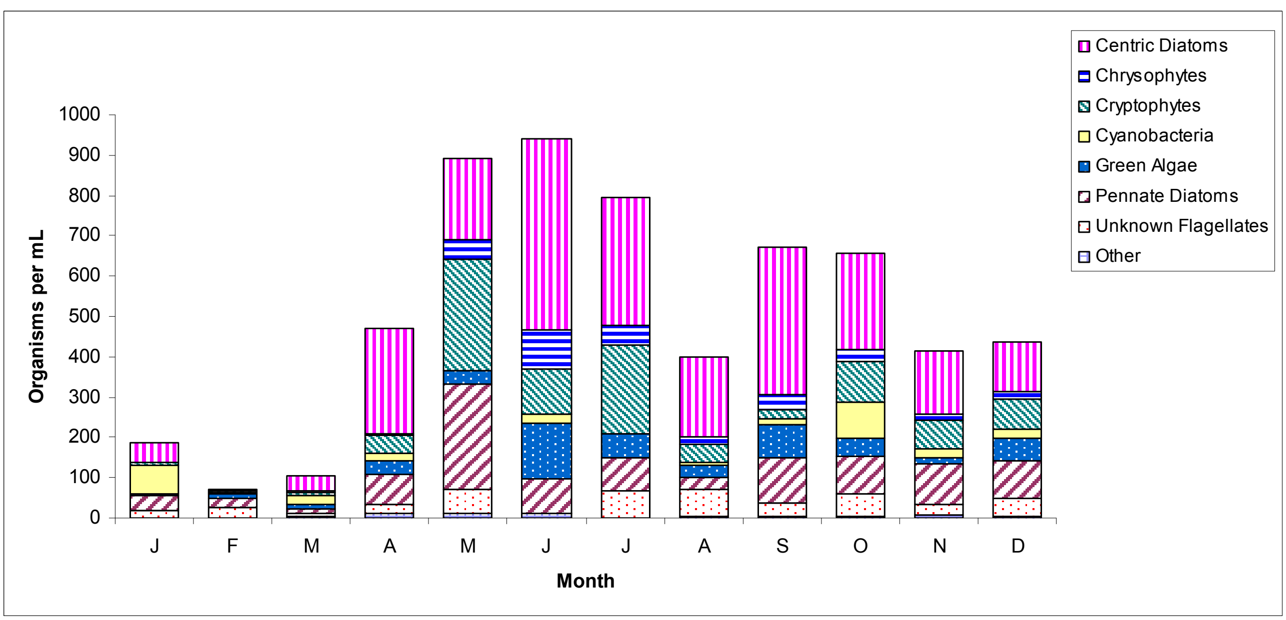


Figure 4-5a 2008 Pigment Concentrations at P8

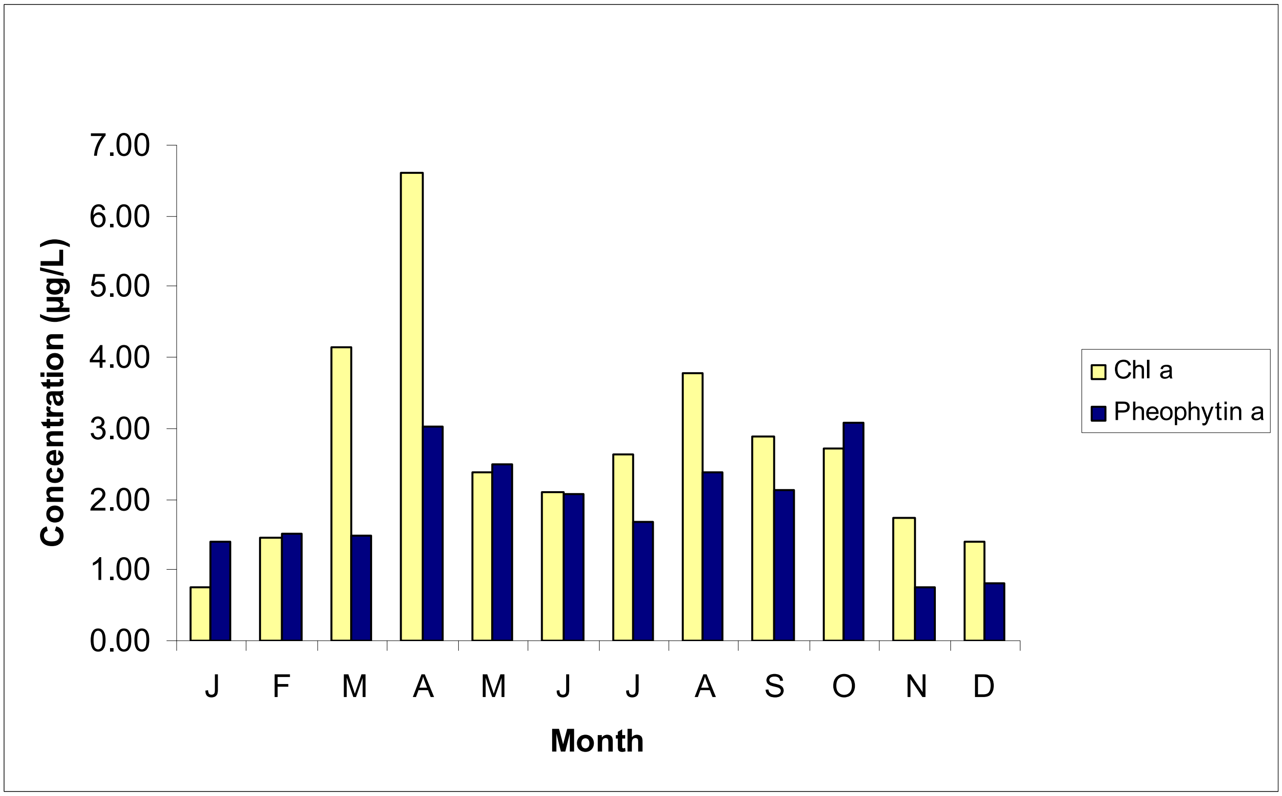


Figure 4-5b 2008 Phytoplankton Composition at P8

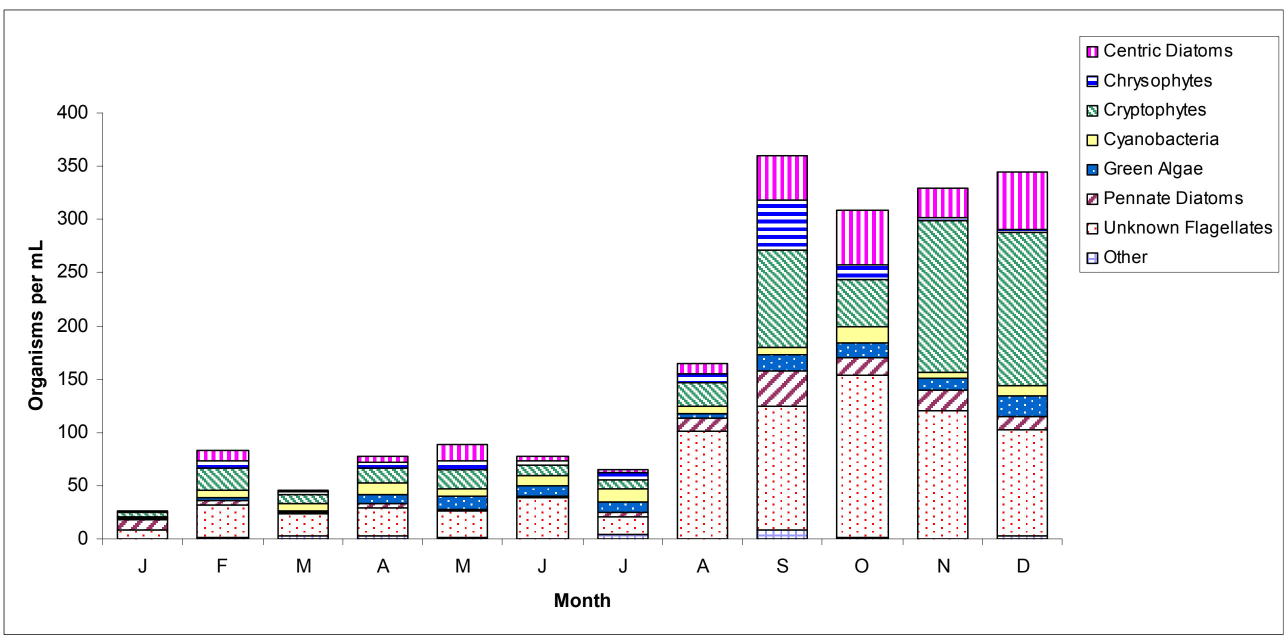


Figure 4-6a 2008 Pigment Concentrations at MD10A

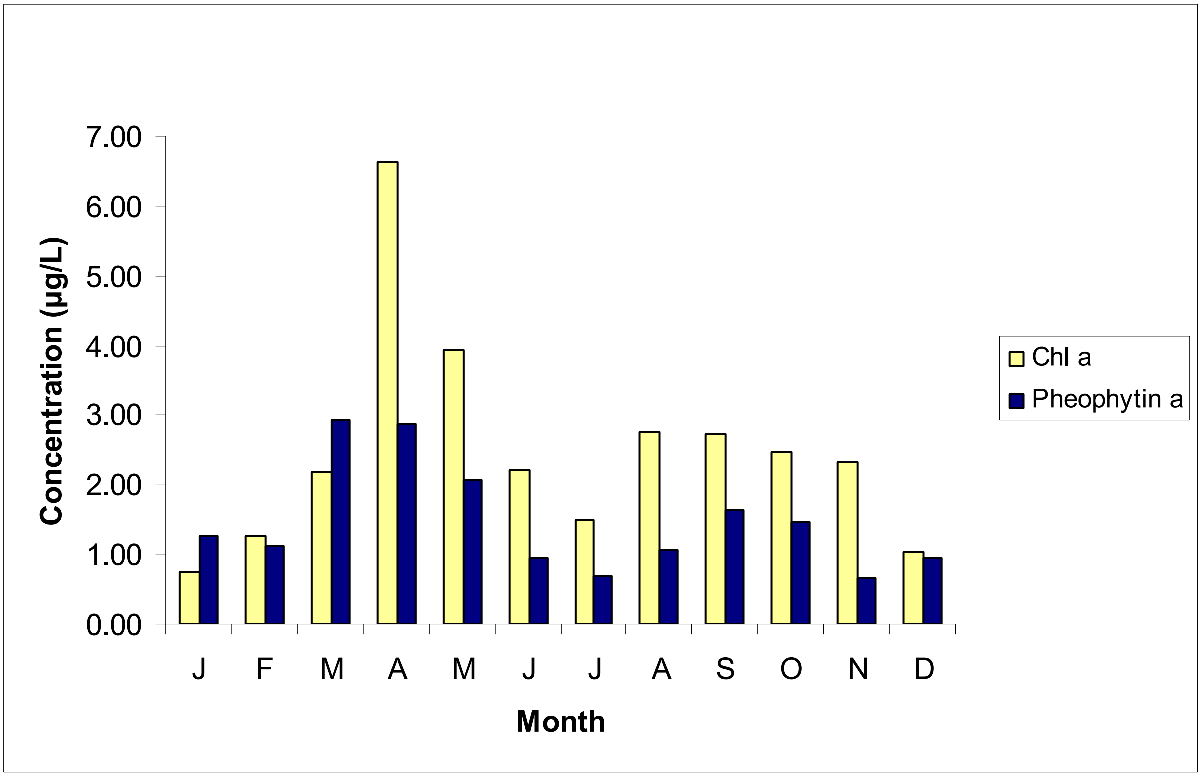


Figure 4-6b 2008 Phytoplankton Composition at MD10A

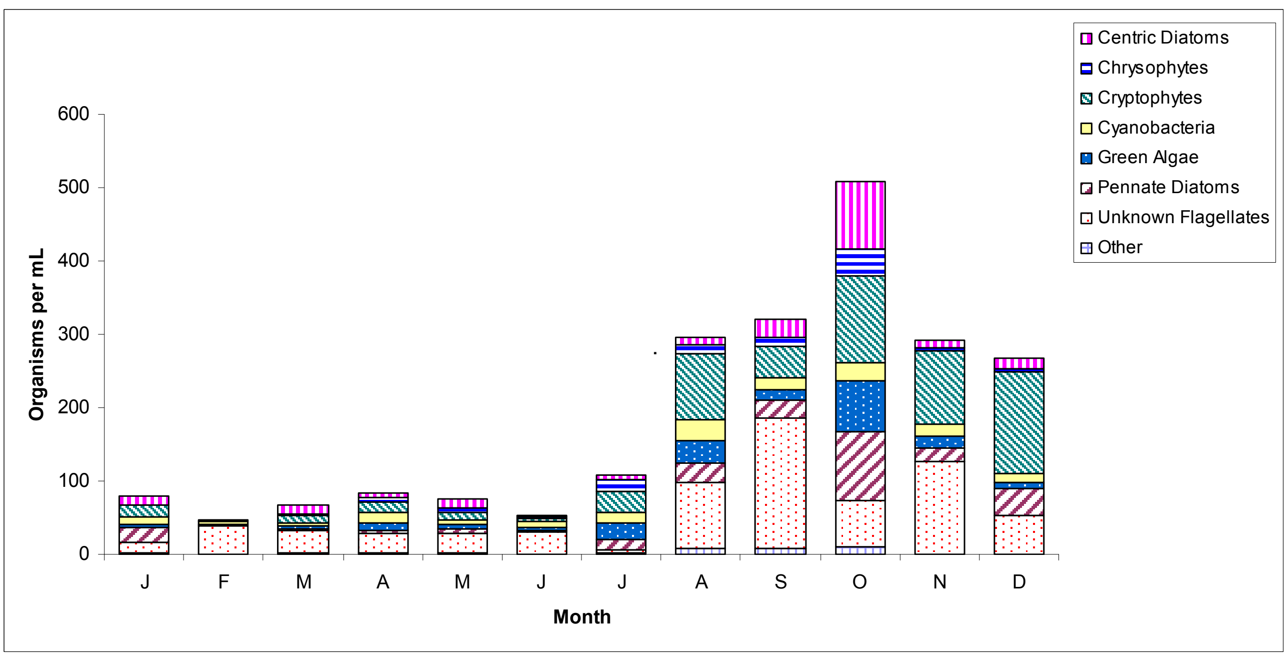


Figure 4-7a 2008 Pigment Concentrations at D26

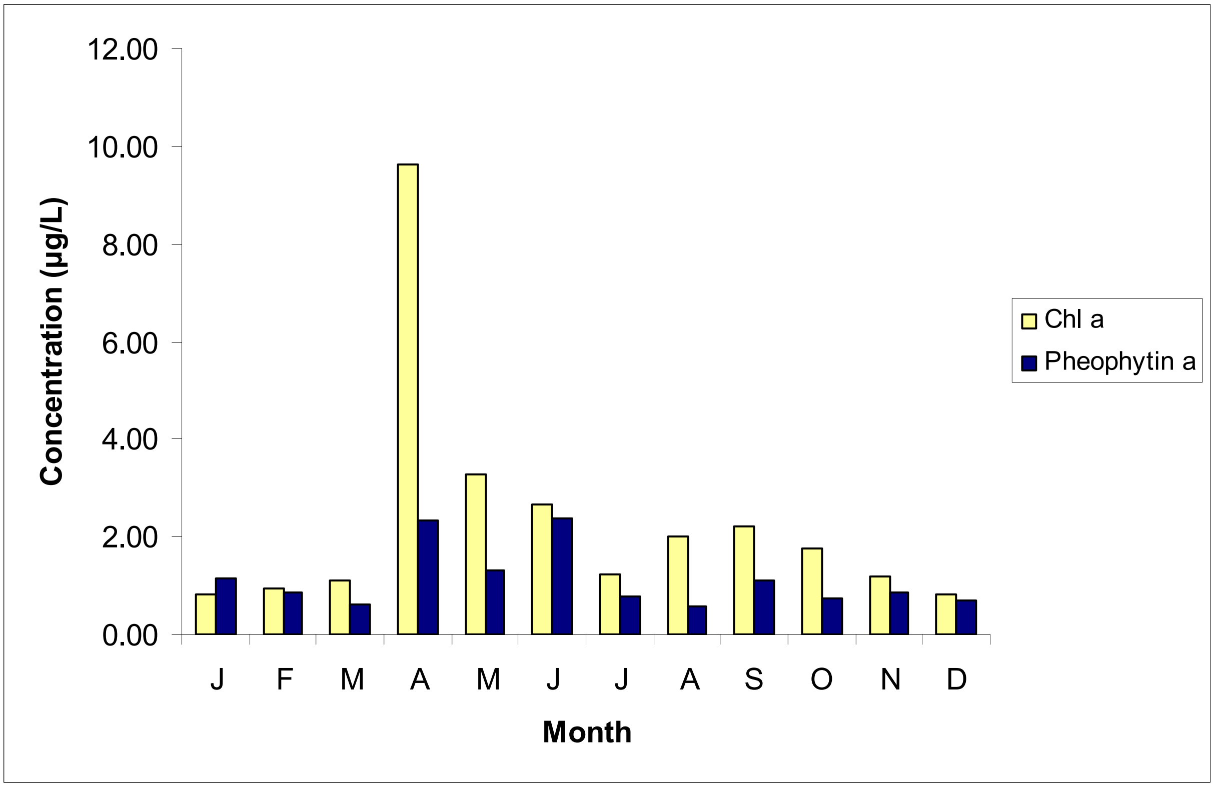


Figure 4-7b 2008 Phytoplankton Composition at D26

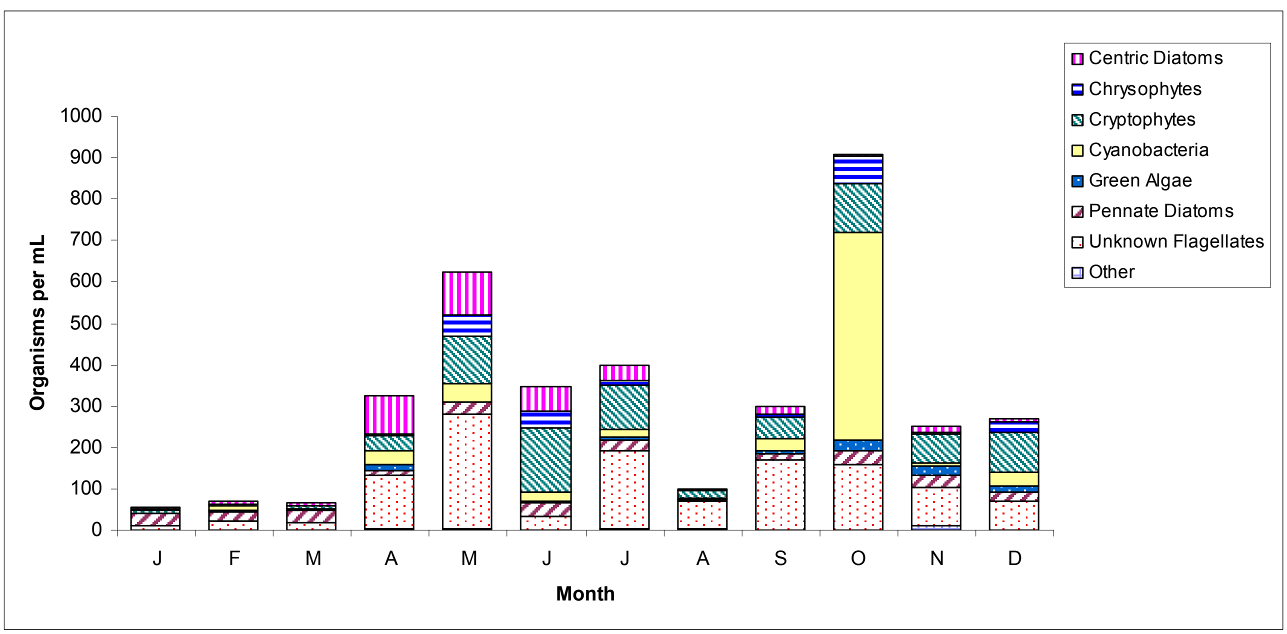


Figure 4-8a 2008 Pigment Concentrations at D19

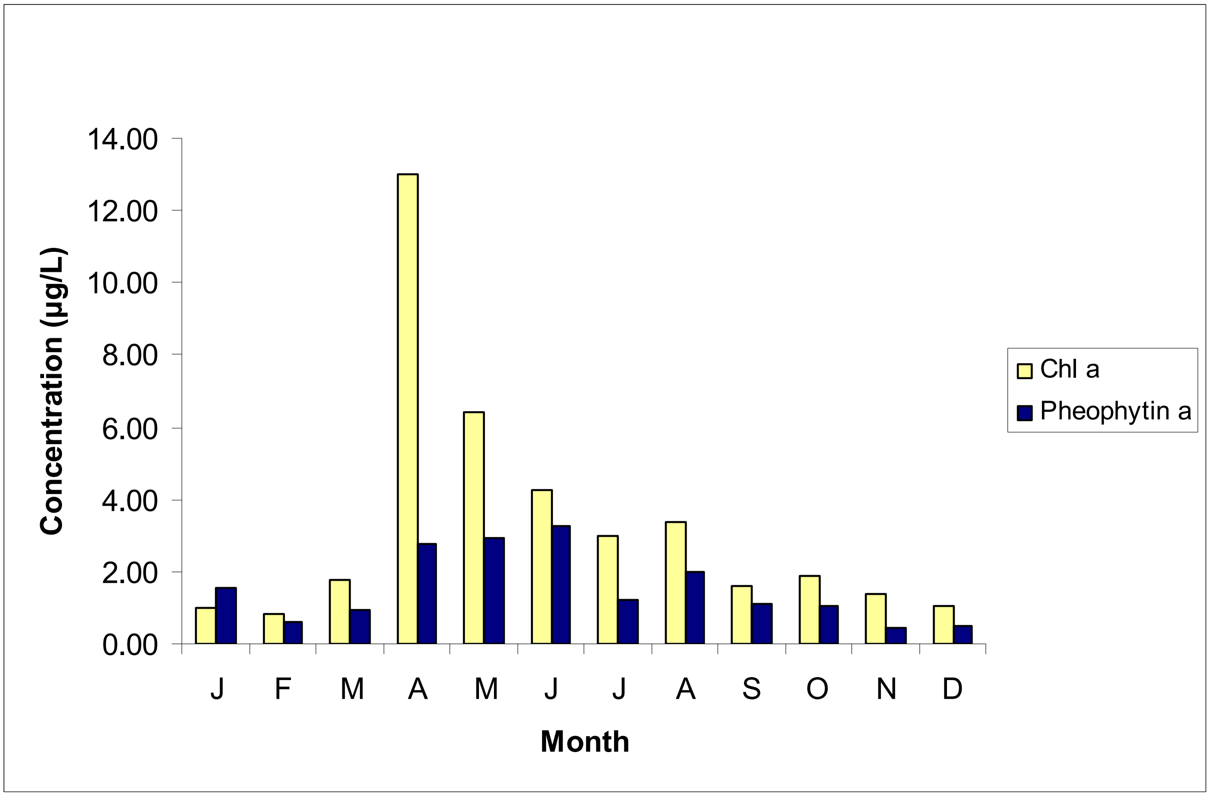


Figure 4-8b 2008 Phytoplankton Composition at D19

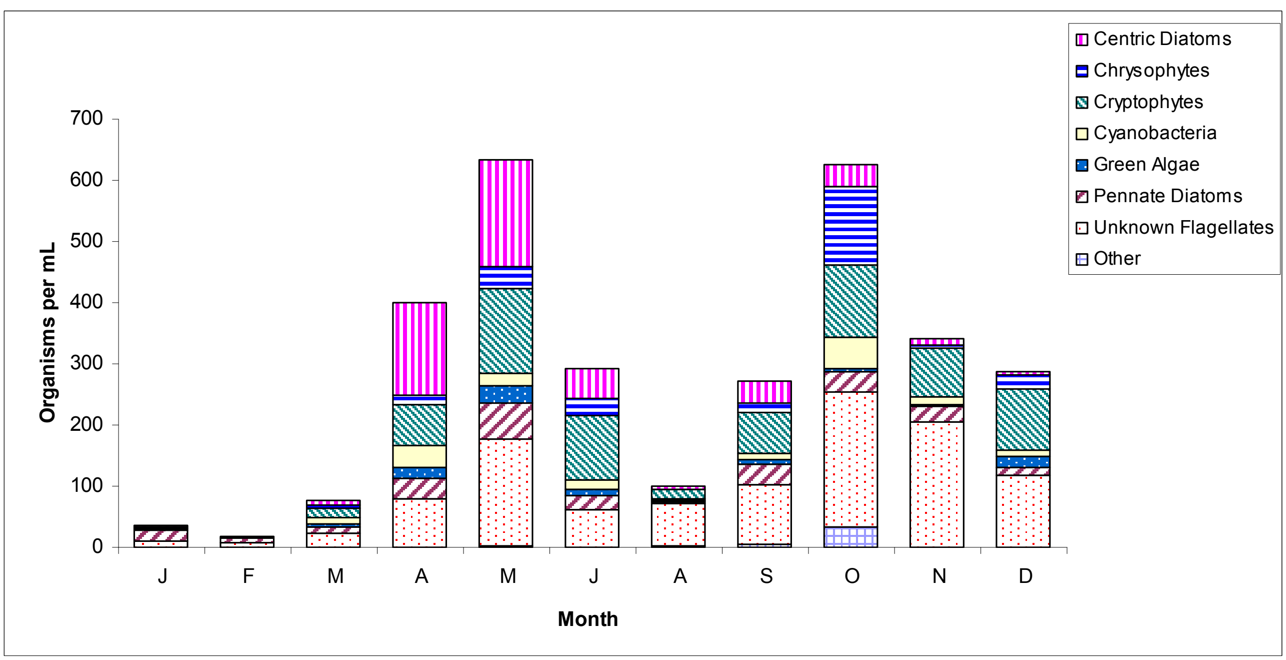


Figure 4-9a 2008 Pigment Concentrations at D28A

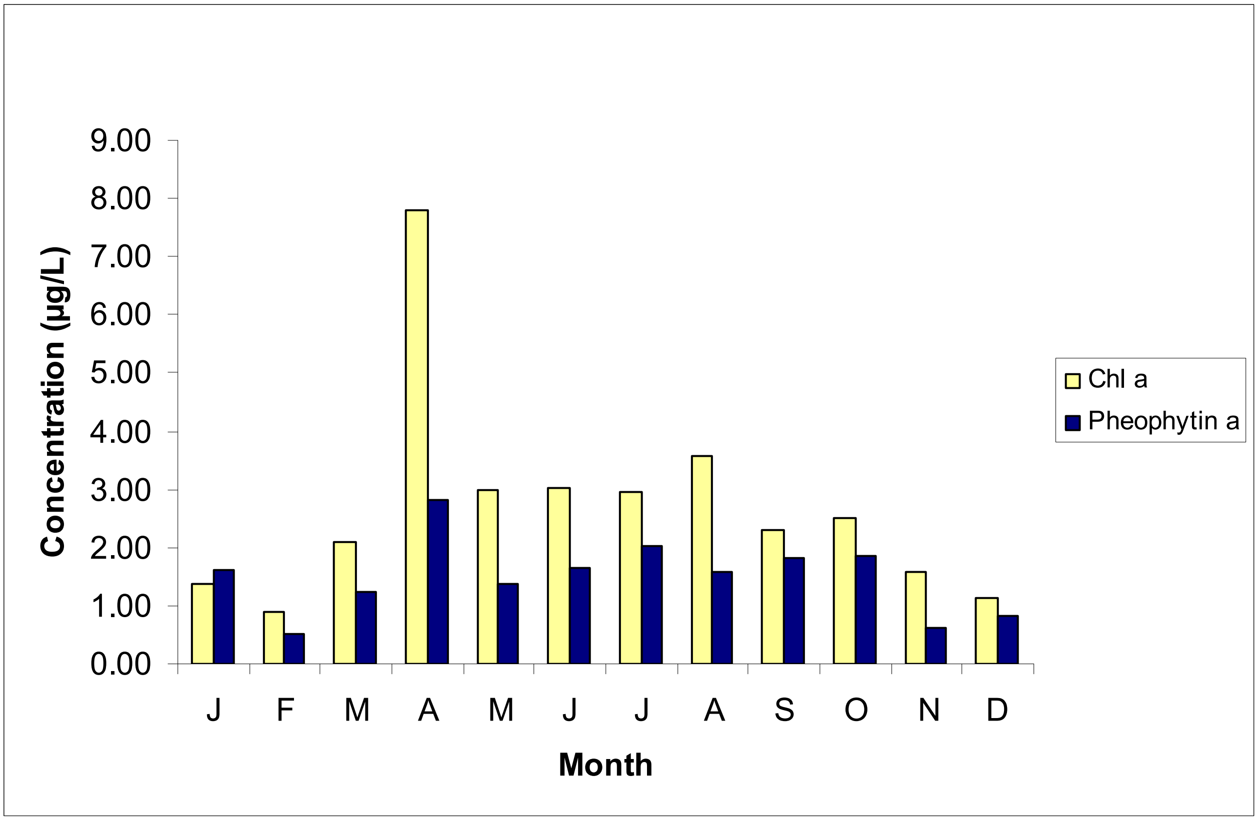


Figure 4-9b 2008 Phytoplankton Composition at D28A

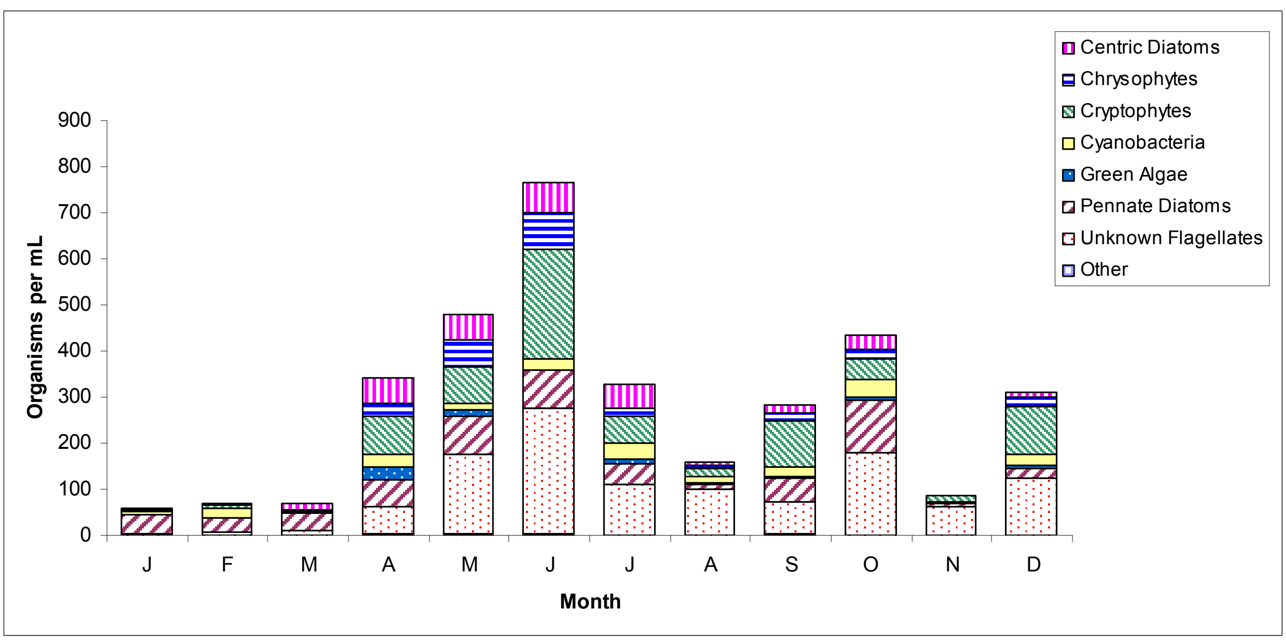


Figure 4-10a 2008 Pigment Concentrations at D4

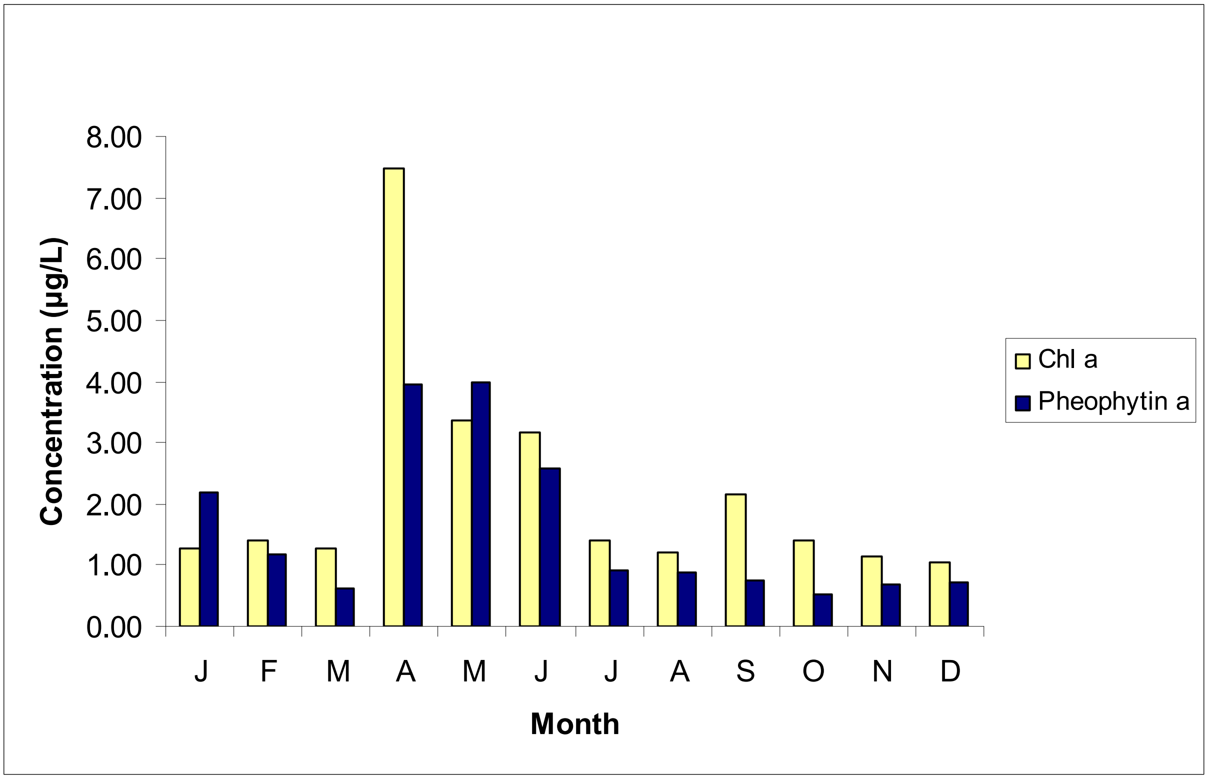


Figure 4-10b 2008 Phytoplankton Composition at D4

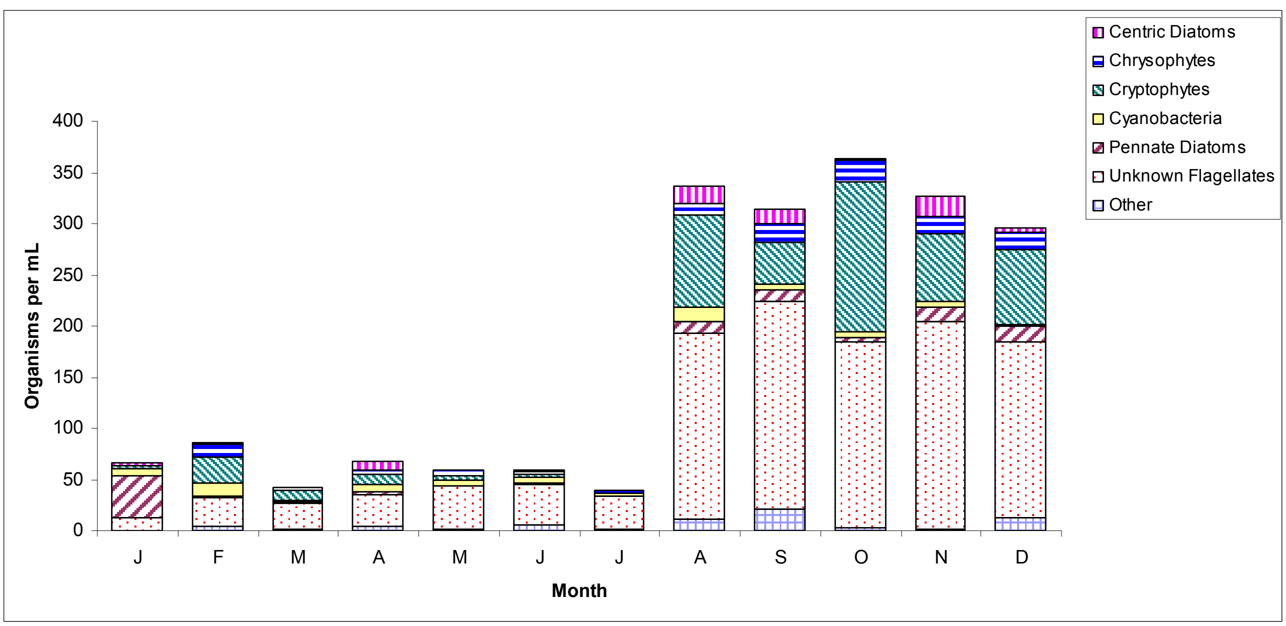


Figure 4-11a 2008 Pigment Concentrations at D6

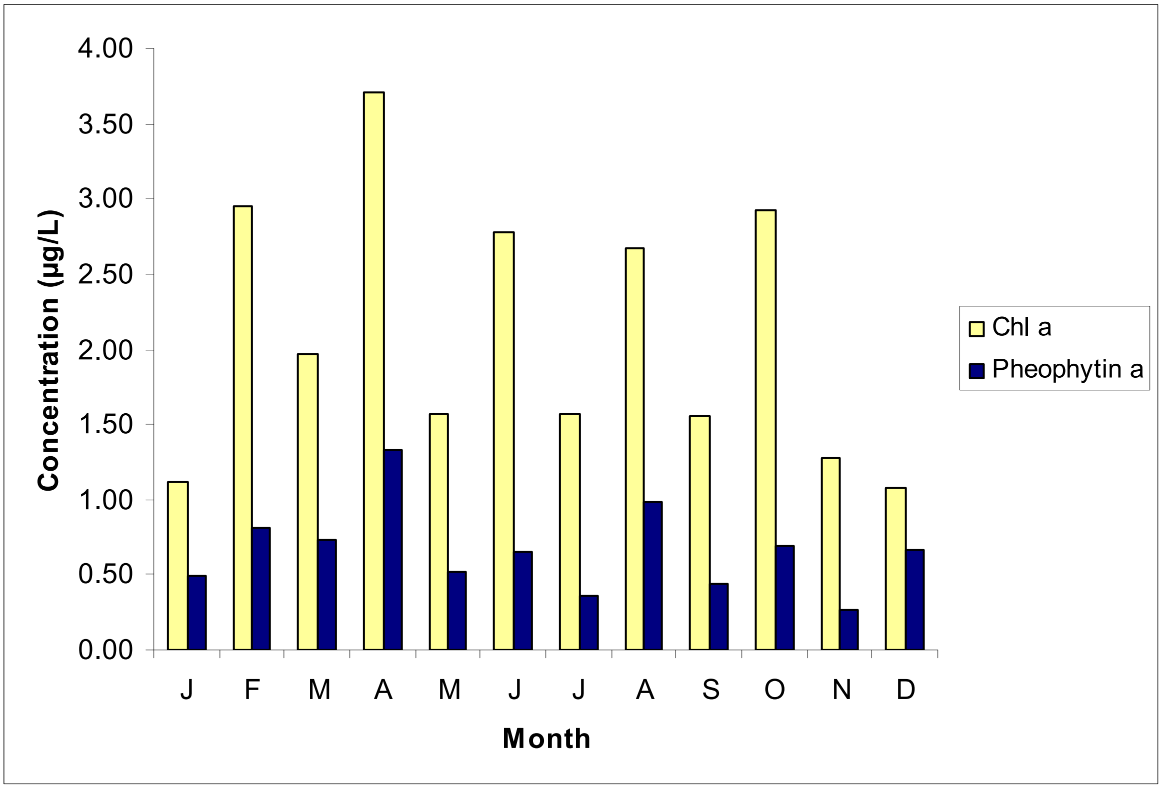


Figure 4-11b 2008 Phytoplankton Composition at D6

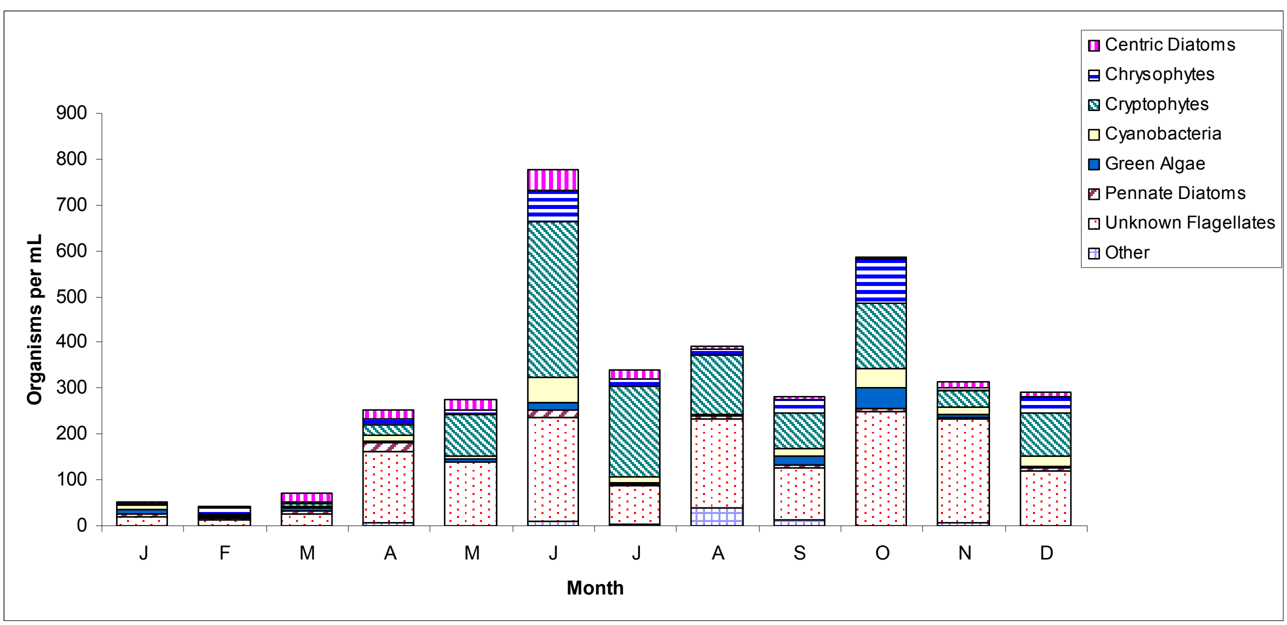


Figure 4-12a 2008 Pigment Concentrations at D7

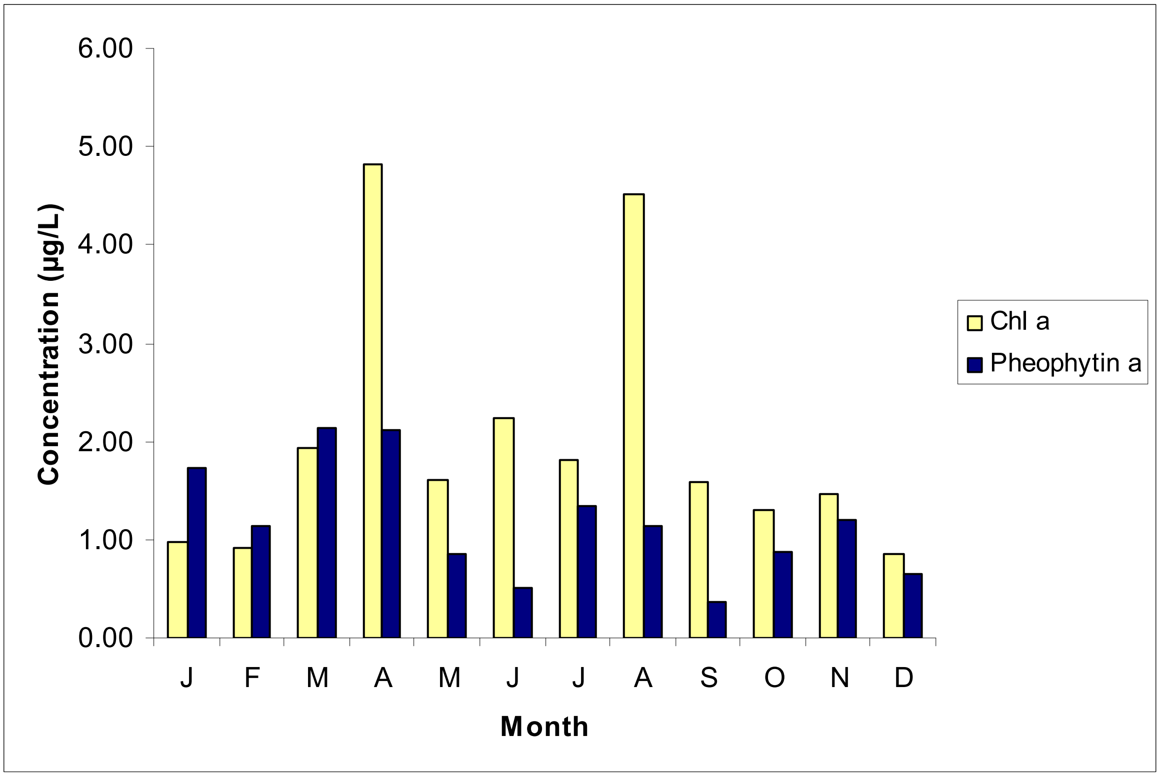


Figure 4-12b 2008 Phytoplankton Composition at D7

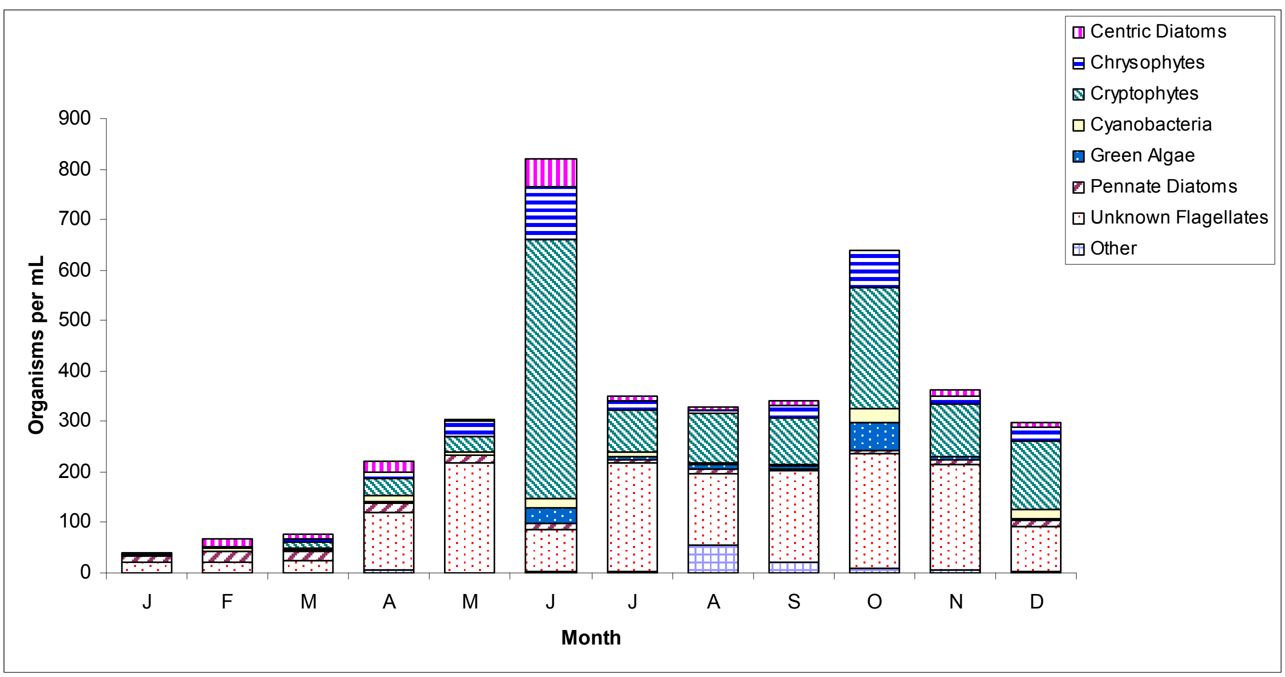


Figure 4-13a 2008 Pigment Concentrations at D8

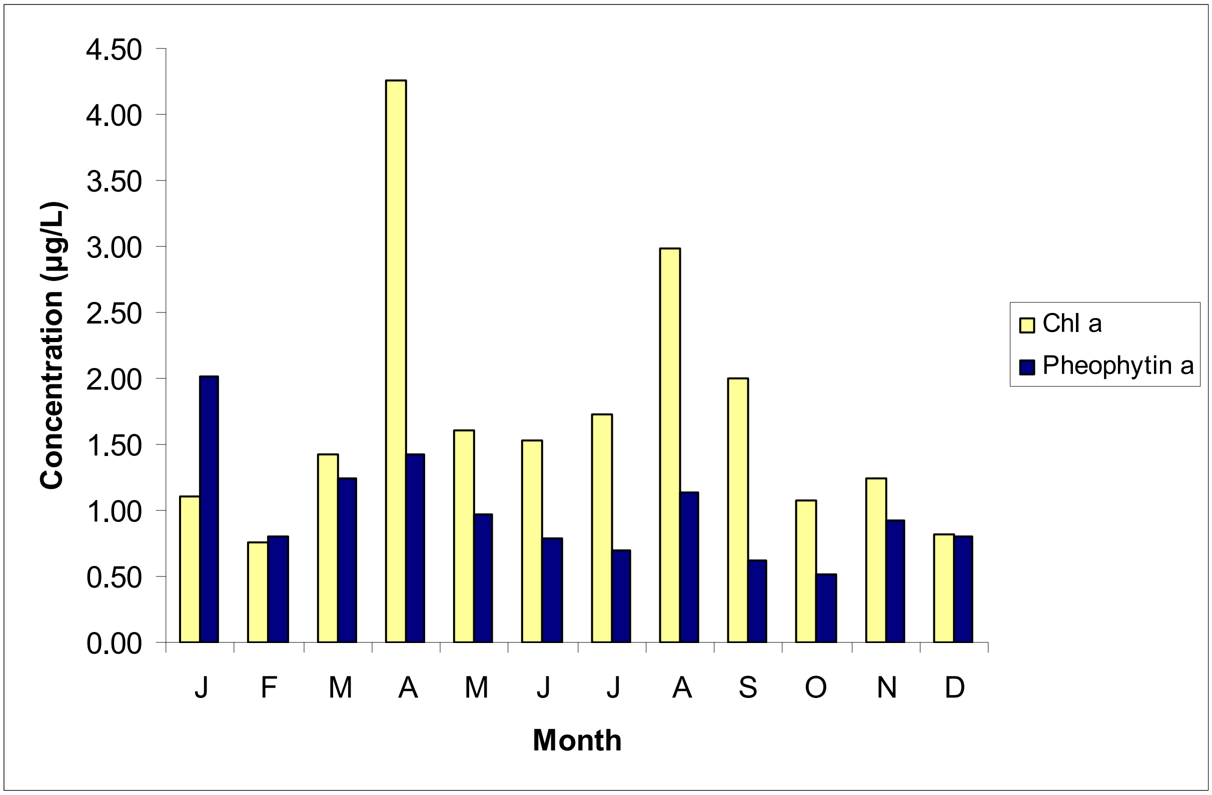


Figure 4-13b 2008 Phytoplankton Composition at D

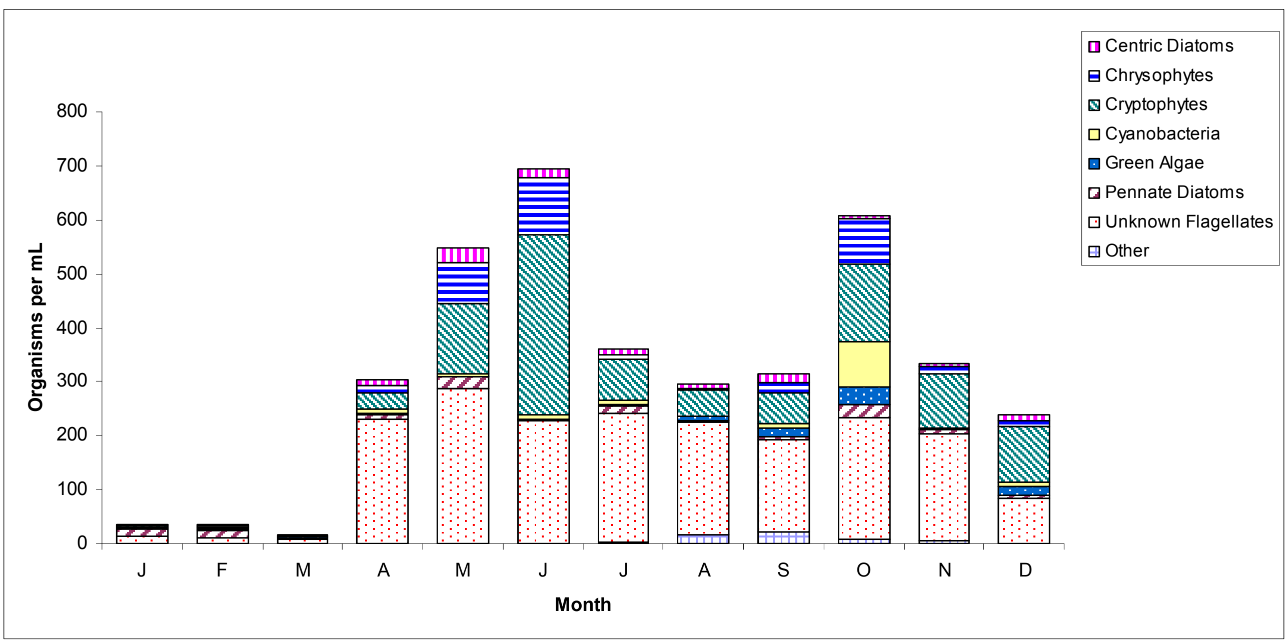


Figure 4-14a 2008 Pigment Concentrations at D41

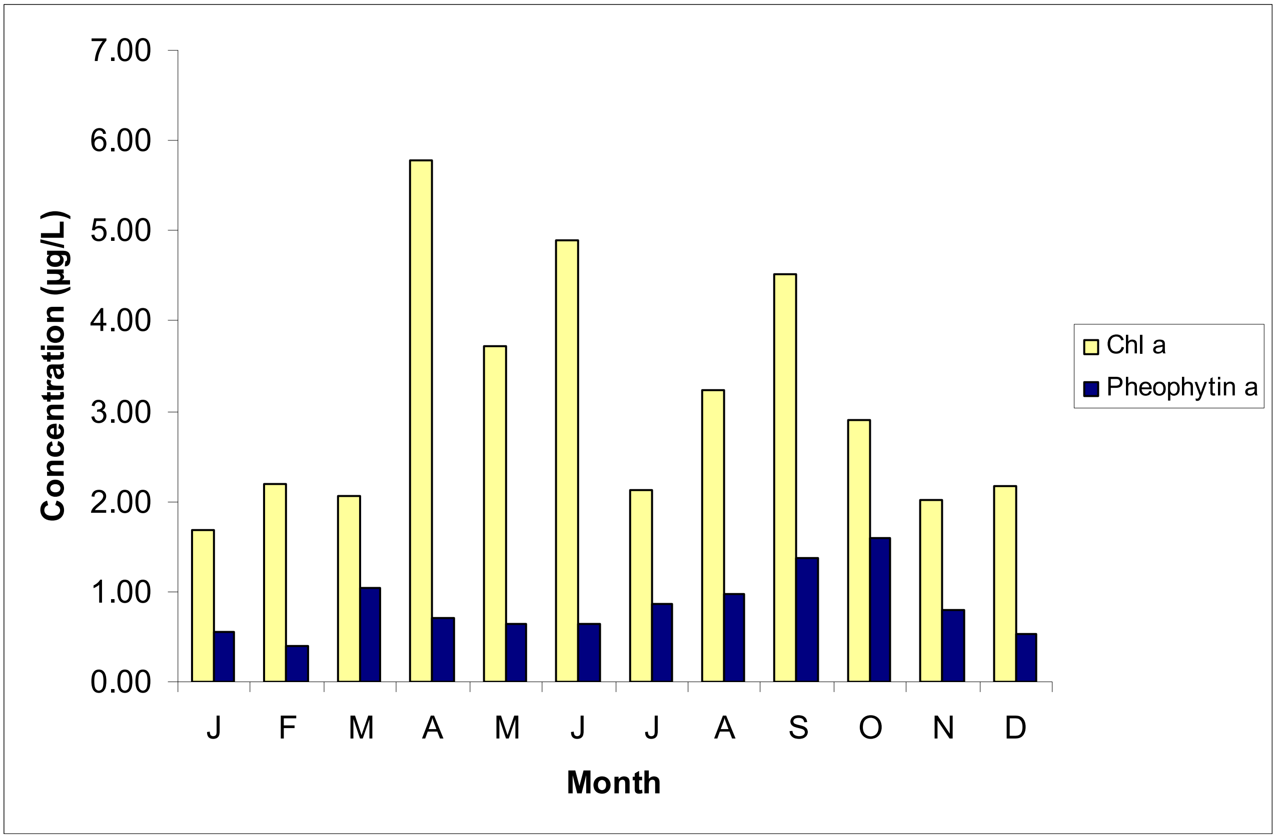


Figure 4-14b 2008 Phytoplankton Composition at D41

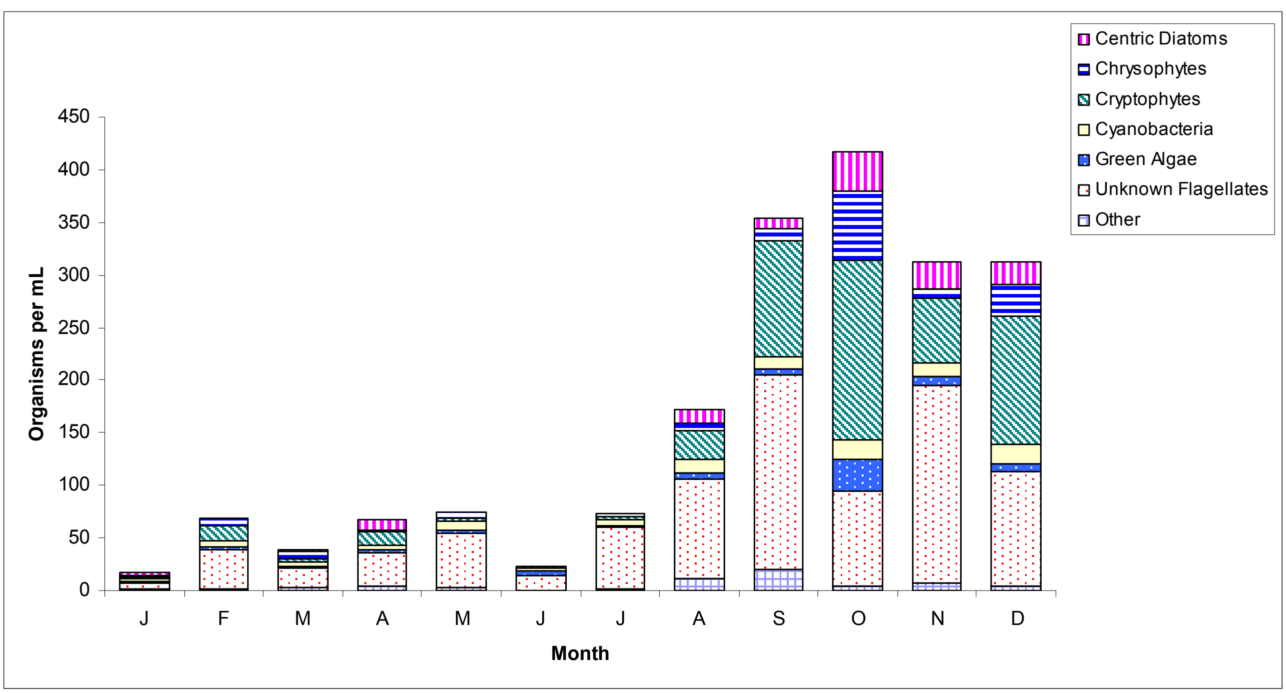


Figure 4-15a 2008 Pigment Concentrations at D41A

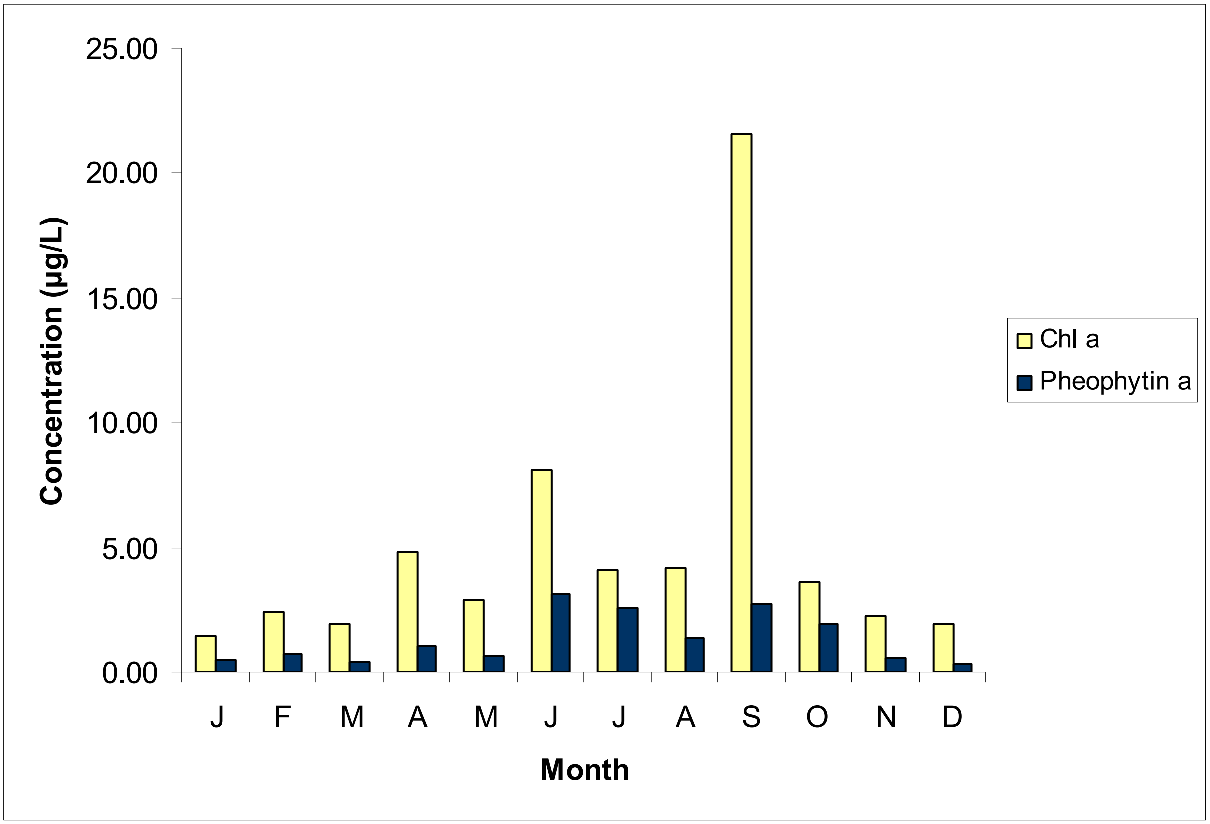


Figure 4-15b 2008 Phytoplankton Composition at D41A

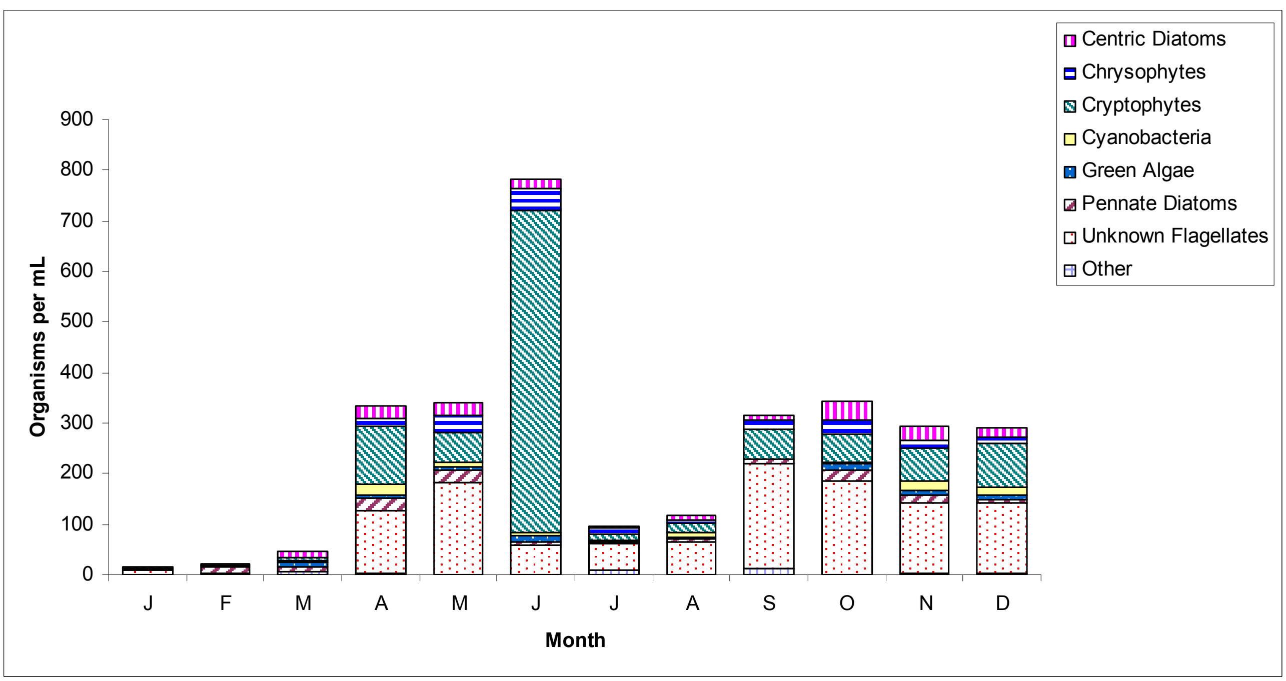


Table 4-1. 2008 Phytoplankton Genera by Group

Pennate Diatoms	**Green Algae**	**Cyanobacteria**	**Centric Diatoms**
Achnanthes	Actinastrum	Anabaena	Aulacoseira
Amphora	Ankistrodesmus	Aphanocapsa	Biddulphia
Asterionella	Chlamydomonas	Aphanothece	Coscinodiscus
Bacillaria	Chlorococcum	Chroococcus	Cyclotella
Caloneis	Cladophora	Coelosphaerium	Melosira
Campylodiscus	Closteriopsis	Eucapsis	Stephanodiscus
Cocconeis	Closterium	Gloeocapsa	Thalassiosira
Cymatopleura	Coelastrum	Gomphosphaeria	**Cryptophytes**
Cymbella	Cosmarium	Limnothrix	Chroomonas
Diatoma	Crucigenia	Merismopedia	Cryptomonas
Diploneis	Dictyosphaerium	Microcystis	Komma
Entomoneis	Gloeocystis	Oscillatoria	Pyrenomonas
Epithemia	Golenkinia	Phormidium	**Dinoflagellates**
Eunotia	Gonium	Planktolyngbya	Ceratium
Fragilaria	Kirchneriella	Pseudanabaena	Gonyaulax
Frustulia	Lagerheimia	Raphidiopsis	Peridiniopsis
Gomphoneis	Microspora	Synechococcus	Peridinium
Gomphonema	Mougeotia	Unknown cyanobacterium	
Gyrosigma	Nephrocytium	**Euglenoids**	
Hannaea	Oocystis	Euglena	
Mastogloia	Pandorina	Phacus	
Navicula	Pediastrum	Trachelomonas	
Neidium	Protoderma	**Chrysophytes**	
Nitzschia	Rhizoclonium	Ochromonas	
Pinnularia	Scenedesmus	Unknown chrysophyte	
Pleurosigma	Schroederia	**Synurophytes**	
Reimeria	Selenastrum	Mallomonas	
Rhoicosphenia	Sphaerocystis	Synura	
Rhopalodia	Stigeoclonium	**Ciliates**	
Stenopterobia	Tetraedron	Mesodinium	
Surirella	Tetrastrum	**Unknown**	
Synedra	Ulothrix	Unknown genus	
Tabellaria	Volvox	Unknown flagellates	

Table 4-2. 2008 Chlorophyll *a* and Pheophytin *a* Concentrations

Chlorophyll *a*(µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	5.98	0.81	2.27	2.55	1.54
C10A	226.42	9.93	33.43	52.65	59.78
P8	6.62	0.76	2.51	2.72	1.57
MD10A	6.62	0.76	2.26	2.48	1.57
D26	9.61	0.80	1.50	2.30	2.43
D19	13.03	0.82	1.81	3.30	3.47
D28A	7.80	0.90	2.41	2.69	1.82
D4	7.48	1.03	1.41	2.19	1.84
D6	3.71	1.07	1.77	2.10	0.87
D7	4.83	0.85	1.60	2.00	1.32
D8	4.26	0.76	1.48	1.71	1.00
D41	5.79	1.69	2.55	3.11	1.34
D41A	21.57	1.42	3.24	4.92	5.55

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	4.31	0.89	1.98	2.34	1.03
C10A	32.08	2.07	10.49	13.35	10.15
P8	3.09	0.75	1.88	1.90	0.77
MD10A	2.94	0.65	1.20	1.47	0.78
D26	2.39	0.57	0.87	1.12	0.63
D19	3.28	0.42	1.14	1.52	0.99
D28A	2.82	0.50	1.59	1.49	0.65
D4	4.00	0.51	0.89	1.58	1.29
D6	1.33	0.27	0.66	0.66	0.29
D7	2.13	0.37	1.14	1.17	0.58
D8	2.01	0.52	0.87	1.00	0.41
D41	1.59	0.40	0.75	0.85	0.35
D41A	3.10	0.34	0.89	1.32	1.00

Chapter 5 Zooplankton

Introduction

Zooplankton are important food organisms for larval and juvenile salmon, striped bass, and splittail, and for planktivorous fishes, such as delta smelt, longfin smelt, and threadfin shad, throughout their lives. The Department of Fish and Game's Zooplankton Study monitors the annual and seasonal abundance and distribution of the major zooplankton taxa to assess fish food resources in the San Francisco Estuary. This study also seeks to detect the presence of newly introduced species, monitor their distribution and abundance, and determine their effects 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 as well. Other mysid species were consistently identified and enumerated as of 1998, while newly introduced copepods, cladocerans and rotifers were identified and enumerated as they were detected.

Methods

Zooplankton were sampled monthly at 17 to 22 stations in the Delta and Suisun Bay (Figure 5-1). Twenty of these stations were at fixed locations and two were "floating" entrapment zone (EZ) stations located where bottom electrical conductance (EC) was 2 mS/cm and 6 mS/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 mS/cm. Monthly sampling was scheduled such that each station was sampled at approximately high slack tide.

Figure 5-1 Zooplankton monitoring stations

At each station three types of gear were deployed: 1) a mysid net for macrozooplankton; 2) a modified 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. A General Oceanics model 2030 flowmeter was mounted at the center of the net mouth. The net was attached to a ski-mounted towing frame made of steel tubing. 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 was a 19.1 cm long, clear acrylic pipe with an inside diameter of 12.0 cm with a General Oceanics model 2030 flowmeter suspended in the center. The CB net and frame were mounted on top of the mysid frame, and the nets were deployed together. The pump sampler consisted of a 15-liter/minute-capacity Teel marine pump connected to a 15 m intake hose that discharged into a 35 µm plankton net with a cod-end.

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, while the vessel was underway. Flowmeter readings from both nets were recorded before and after each tow to calculate the volume of water filtered through each net. At the end of this tow, after forward momentum had ceased, the pump was lowered to the bottom and turned on then raised slowly to the surface, following a retrieval schedule based on depth that ensured the entire water column was sampled evenly. Pumped water was discharged into a 35 µm plankton net suspended in a large plastic garbage can filled with water to alleviate damage to delicate organisms. Once 19.8 gallons were pumped, the pump was shut off, and the net was rinsed into the cod-end to concentrate the sample. All samples were fixed in 10% formalin and returned to the laboratory for identification (usually to genus or species level) and enumeration.

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

In this report, abundance is reported only for the gear that collects the taxon most efficiently: 1) the CB net for all calanoid copepods, the cyclopoid copepod *Acanthocyclops vernalis*, and all cladocerans; 2) the pump for all rotifers; and 3) both the CB and pump for the cyclopoid copepods *Limnoithona tetraspina* and *Oithona davisae*. Abundance for both gears is presented for the latter two species because larger adults are retained by the CB mesh, whereas smaller adults are more effectively sampled by the pump.

Zooplankton distribution within the estuary is determined more by salinity than geography. Therefore, samples were categorized into three EC zones: 1) upstream of the entrapment zone (where bottom EC < 1.8 mS/cm); 2) the entrapment zone (where bottom EC ranged from 1.8 mS/cm to 6.6 mS/cm); and 3) downstream of the entrapment zone (where bottom EC > 6.6 mS/cm).

Monthly and annual abundance indices for each taxon were calculated as the mean number per cubic meter (catch-per-unit-effort or CPUE) for each gear type and EC zone. The number of stations in each zone varied monthly due to upstream and downstream shifts in salinity caused by variations in outflow. Averaging the abundance for each zone provided a common basis for comparisons.

To depict seasonal changes in abundance, data were log transformed ($\log_{10}$ (CPUE+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 2008 CPUE for all stations sampled. Monthly abundance trends are presented for the top three to five ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Results

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*) is an introduced mysid that was first collected in the upper estuary in 1993, and has been the most abundant mysid in the upper estuary since 1995. In 2008, *H. longirostris* was again the most abundant mysid in all zones (Table 5-1). Abundance was highest downstream of the entrapment zone, entrapment zone abundance was similar at 79% of the downstream abundance (Figure 5-2). Upstream abundance was much lower at only 8% of downstream abundance. Seasonality was similar among zones, with abundance peaks May through July upstream and downstream of the entrapment zone, while abundance in the entrapment zone peaked in May and July but dipped in June. Abundance declined in fall in all of the zones, except a small peak in the entrapment zone in November. Although abundance typically peaks during summer, late summer and early fall abundance was lower than usual.

Table 5-1 Mysid abundance upstream, within, and downstream of the entrapment zone in 2008

Figure 5-2 Monthly *Hyperacanthomysis longirostris* (*Acanthomysis* bowmani) abundance upstream, within, and downstream of the entrapment zone in 2008

The native brackish-water mysid *Neomysis kadiakensis* is very similar to *Neomysis japonica,* a freshwater mysid that may be present in the estuary. Until we are able to distinguish between the two species, they will be grouped together as *Neomysis kadiakensis/japonica*. *N. kadiakensis/japonica* was again the second most abundant mysid overall in 2008, although numbers were very low (Table 5-1). Upstream of the entrapment zone *N. kadiakensis/japonica* was only present in January and March and in very low abundance, indicating that if *N. japonica* is present in the estuary, abundance was very low in 2008 (Figure 5-3). Entrapment zone abundance was only 34% of downstream abundance. Downstream abundance was highest in spring and summer with peaks in April and July.

Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, within, and downstream of the entrapment zone in 2008

Alienacanthomysis macropsis is a native brackish-water mysid that was again the third most abundant mysid in 2008 (Table 5-1). *A. macropsis* was not collected upstream of the entrapment zone in 2008, and was only collected from 1 station in the entrapment zone in December (Figure 5-4). Downstream of the entrapment zone, *A. macropsis* was collected in low numbers during every month of 2008, except July through September when none were caught. *A. macropsis* abundance peaked downstream of the entrapment zone January through March, and again in November and December.

Figure 5-4 Monthly *Alienacanthomysis macropsis* abundance upstream, within, and downstream of the entrapment zone in 2008

Neomysis mercedis was again the fourth most abundant mysid in 2008, and was collected mainly within and upstream of the entrapment zone (Table 5-1). Until the mid-1990s, this native species had been the most common mysid in the estuary. Since 1993 however, *N. mercedis* abundance has been very low. *N. mercedis* abundance was highest upstream of the entrapment zone in 2008, (Figure 5-5). Entrapment zone abundance was much lower at only 38% of upstream abundance and was highest in spring and summer with a peak in July. Downstream of the entrapment zone, abundance was very low in 2008 with a small peak in June. In 2008, abundance peaked in June

Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, within, and downstream of the entrapment zone in 2008

upstream of the entrapment zone, but was very low in all zones in every month. After July no *N. mercedis* were caught at any stations sampled.

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in 2008, switching ranks with the genus *Acartia* which was the most abundant in 2007 (Table 5-2). *P. forbesi* was most abundant upstream of the entrapment zone, with the highest abundance during summer and fall (Figure 5-6). Entrapment zone abundance was much lower at only 34% of upstream abundance. Downstream abundance was even lower at only 4% of upstream abundance. Seasonality was similar among the zones with lower abundances January through March, after which abundance gradually increased and was higher for the remainder of the year.

Table 5-2 Calanoid copepod abundance upstream, within, and downstream of the entrapment zone in 2008

Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, within, and downstream of the entrapment zone in 2008

The genus *Acartia* consists of three native brackish water species and was the second most abundant calanoid copepod in 2008 (Table 5-2). *Acartia* spp. was the most common calanoid copepod collected downstream of the entrapment zone. Upstream of the entrapment zone *Acartia* spp. was only collected in May from a single station and in very low numbers (Figure 5-7). Within the entrapment zone, it was collected March through May in very low numbers. Downstream abundance was highest January through March and lowest during the summer, after which abundance increased again in the fall.

Figure 5-7 Monthly *Acartia* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

The introduced *Acartiella sinensis* was the third most abundant calanoid copepod for the second year in a row (Table 5-2). *A. sinensis* abundance was highest within the entrapment zone in fall (Figure 5-8). Upstream abundance was very low January through June, with no catch during February, April, and May. Late summer and early fall upstream abundance increased, before declining again in late fall and early winter. Downstream abundance was lowest in March when none were collected, then steadily increased until abundance peaked in October.

Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, within, and downstream of the entrapment zone in 2008

Sinocalanus doerrii was the fourth most abundant calanoid copepod in 2008 (Table 5-2), switching ranks with *Eurytemora affinis* which was the fourth most abundant in 2007. It was most common upstream of the entrapment zone, where abundance peaked in late fall and early summer (Figure 5-9). A similar seasonal trend was seen in the entrapment zone and downstream of the entrapment zone.

Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, within, and downstream of the entrapment zone in 2008

Eurytemora affinis was the fifth most abundant calanoid copepod in 2008 (Table 5-2). *E. affinis* was most common in the entrapment zone, where abundance peaked from January through May and declined sharply thereafter (Figure 5-10). Upstream of the entrapment zone, abundance peaked in April and May, and then again in November and December. Downstream of the entrapment zone, abundance also peaked in April and May.

Figure 5-10 Monthly *Eurytemora affinis* abundance upstream, within, and downstream of the entrapment zone in 2008

Cyclopoid Copepods

Since it was first detected in 1993, *Limnoithona tetraspina* has become the most abundant cyclopoid copepod in the study area. It also continues to be the most abundant zooplankton species in the delta. It was abundant in all three EC zones in 2008, with the highest CPUE in and downstream of the entrapment zone (Table 5-3). Abundance was highest throughout the year in the pump samples, except February through April upstream of the entrapment zone where there was no catch in the pump samples and very low numbers in the CB samples (Figure 5-11). Within and downstream of the entrapment zone, abundance trends between the CB and pump were similar until after May when CB abundance declined while pump abundance continued to increase. This indicated that the abundance of large adults was much higher during the first part of the year, while the abundance of small adults was much higher during the latter part of the year. Upstream of the entrapment zone, pump abundance increased throughout the summer and peaked in September. Entrapment zone abundance peaked in the pump samples in August and September, with lows occurring in January and March. Downstream CB abundance peaked in April while pump abundance peaked much later in August.

Table 5-3 Cyclopoid copepod abundance upstream, within, and downstream of the entrapment zone in 2008

Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, within, and downstream of the entrapment zone in 2008.

Another introduced species, *Oithona davisae*, was the most abundant cyclopoid copepod in the CB samples again in 2008 and was the second most abundant cyclopoid copepod in the pump samples (Table 5-3). It was most common downstream of the entrapment zone in both the CB and pump samples from late summer through fall (Figure 5-12). Within and upstream of the entrapment zone, abundance was low for both gears all year, with a small peak in January in the entrapment zone and another in October upstream of the entrapment zone.

Figure 5-12 Monthly *Oithona davisae* abundance upstream, within, and downstream of the entrapment zone in 2008. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod in 2008, for the third year in a row, and was most abundant in and upstream of the entrapment zone (Table 5-3). In all zones abundance was highest during the first half of the year and then declined in late summer and early fall (Figure 5-13).

Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, within, and downstream of the entrapment zone in 2008

Cladocerans

The cladocerans most commonly collected by this study are freshwater, and therefore are found upstream of the entrapment zone. *Bosmina* were again the most abundant cladoceran genera, whereas *Diaphanosoma* and *Daphnia* switched ranks from 2007 to 2008.

Figure 5-14 Monthly *Bosmina* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

Bosmina spp. was the most abundant cladoceran in 2008 (Table 5-4). Upstream abundance was relatively high all year with a lot of fluctuation (Figure 5-14). Upstream abundance peaked in April, May, and December, with lows in July and August. Within and downstream of the entrapment zone, abundance was much lower and these zones showed similar seasonal trends. Abundance peaked in January and February in the entrapment zone and downstream. In the entrapment zone, none were caught June through August, or in October. Downstream of the entrapment zone there were none caught in March, April, July, August, or October.

Table 5-4 Cladoceran abundance upstream, within, and downstream of the entrapment zone in 2008

Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

The second most abundant cladoceran in 2008 was *Diaphanosoma* spp. (Table 5-4). It was most common upstream of the entrapment zone where abundance peaked in summer and early fall, then declined thereafter (Figure 5-15). Within and downstream of the entrapment zone, abundance was very low all year with a small increase June through September.

Daphnia spp. was the third most abundant cladoceran in 2008 (Table 5-4). As with *Bosmina* and *Diaphanosoma*, it was most common upstream. Upstream abundance was relatively high most of the year, with a peak in late spring and early summer followed by a sharp decline in July that lead to a crash in August (Figure 5-16). Within and downstream of the entrapment zone, abundance was much lower. In the entrapment zone abundance peaked in February, whereas downstream abundance peaked later in June.

Figure 5-16 Monthly *Daphnia* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

Rotifers

Rotifers are primarily freshwater organisms, except the brackish-water species *Synchaeta bicornis.* Therefore, rotifer abundance is highest upstream of the entrapment zone, except during high-flow events when they are washed downstream into the entrapment zone and beyond. Although the same taxa were most common in both 2008 and 2007, their relative rankings changed.

Table 5-5 Rotifer abundance upstream, within, and downstream of the entrapment zone in 2008

Synchaeta spp., which includes the brackish-water species *Synchaeta bicornis*, was the most common rotifer in 2008 (Table 5-5). *Synchaeta* spp. was the third most abundant rotifer in 2007, switching rankings in 2008 with *Keratella* spp. which was the most abundant in 2007. It was most abundant downstream of the entrapment zone, where abundance was relatively stable most of the year except the sharp drop in May (Figure 5-17). Upstream and within the entrapment zone abundance was also relatively stable with lows in June and September.

Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

Polyarthra spp. was again the second most abundant rotifer in 2008, as it was in 2007 (Table 5-5). It was most abundant upstream of the entrapment zone, where abundance was stable most of the year with a small drop in June (Figure 5-18). Within and downstream of the entrapment zone abundance was highest in January and February, after which abundance was highly variable and for several months abundance was zero. In July, August, and October, none were collected in the entrapment zone. Downstream of the entrapment zone none were collected in March, June, or October.

Figure 5-18 Monthly *Polyarthra* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

Keratella spp. was the third most abundant rotifer in 2008, after falling from most abundant in 2007 (Table 5-5). It was most abundant upstream of the entrapment zone, but was relatively abundant in the other zones most of the year as well (Figure 5-19). Upstream of the entrapment zone, abundance was fairly stable throughout the year with a slight dip in June before steadily rising to a peak in December. In the entrapment zone, abundance was highest in January and February and was lower thereafter before declining to zero in December. Downstream of the entrapment zone, abundance was highest January through April before declining slightly in May. In June,

Figure 5-19 Monthly *Keratella* spp. abundance upstream, within, and downstream of the entrapment zone in 2008

July, and August, none were caught downstream of the entrapment zone. Fall abundance rebounded and remained fairly stable through December.

Summary

In 2008, the most common zooplankton taxa were the same as 2007, although their relative rankings changed. Monthly abundance patterns in 2007 and 2008 were similar. Mysid and copepod abundances were generally higher in 2008 than 2007, while cladoceran and rotifer abundances were generally lower. As in 2007, the introduced *H. longirsotris* and the *N. kadiakensis/japonica* complex remained the two most abundant mysids in 2008, followed by the native *A. macropsis* and *N. mercedis*. The introduced *P. forbesi* replaced the native *Acartia* spp. as the most abundant calanoid copepod in 2008. *Acartia* spp., ranked first in 2007, was second, followed by *A. sinensis*, *S. doerrii*, and *E. affinis*. *S. doerrii* and *E. affinis* also switched ranks from 2007 to 2008. The three most common cyclopoid copepods remained the introduced *O. davisae*, *L.tetraspina*, and *A. vernalis*. In 2008, as in 2007, *O. davisae* was more abundant in CB samples, while *L. tetraspina* was more abundant in pump samples. *Bosmina* spp. was again the most abundant cladoceran in 2008, as it was in 2007. However *Diaphanosoma* spp. was the second most abundant cladoceran in 2008, switching ranks with *Daphnia* spp., the second most abundant in 2007, which was the third most abundant cladoceran in 2008. The rotifers switched ranks from 2007 to 2008, with *Synchaeta* spp. moving from third most abundant in 2007 to most abundant in 2008. *Polyarthra* spp. was again the second most abundant in 2008, as it was in 2007. *Keratella* spp. moved from most abundant in 2007 to third most abundant in 2008.

Chapter 5 Zooplankton

Figure 5-1 Zooplankton monitoring stations

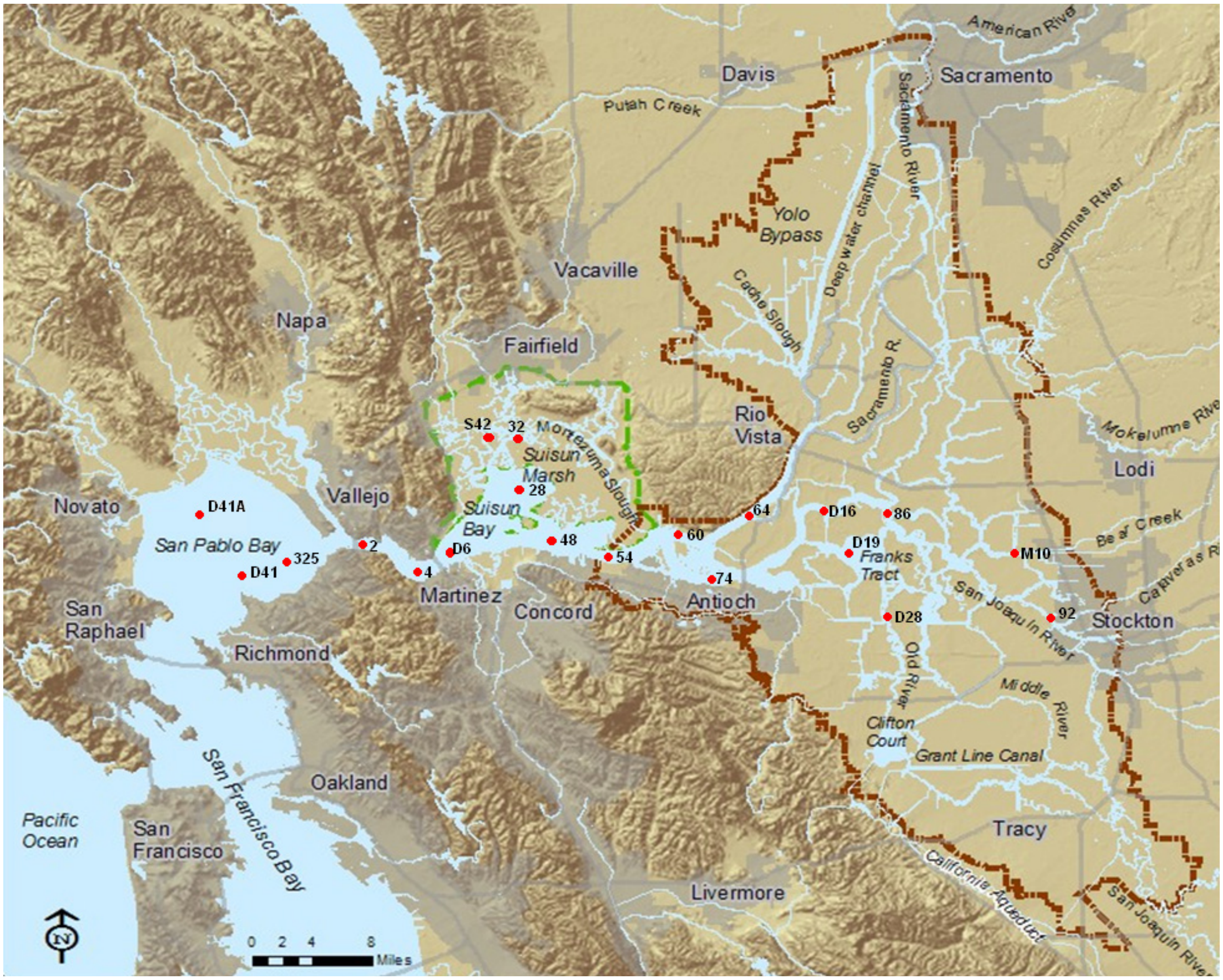


Figure 5-2 Monthly *Hyperacanthomysis longirostris* (*Acanthomysis* bowmani) abundance upstream, within, and downstream of the entrapment zone, 2008

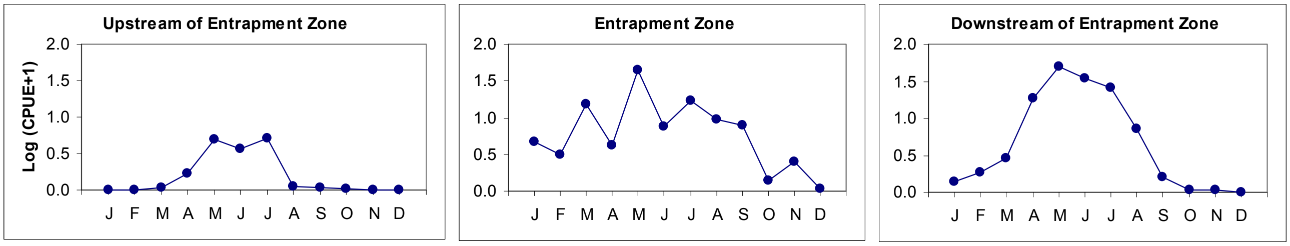


Figure 5-3 Monthly *Neomysis kadiakensis/japonica* abundance upstream, within, and downstream of the entrapment zone, 2008

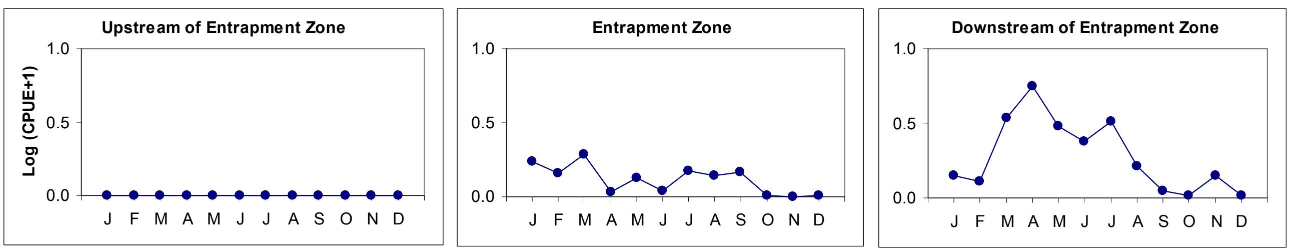


Figure 5-4 Monthly *Alienacanthomysis macropsis* abundance upstream, within, and downstream of the entrapment zone, 2008

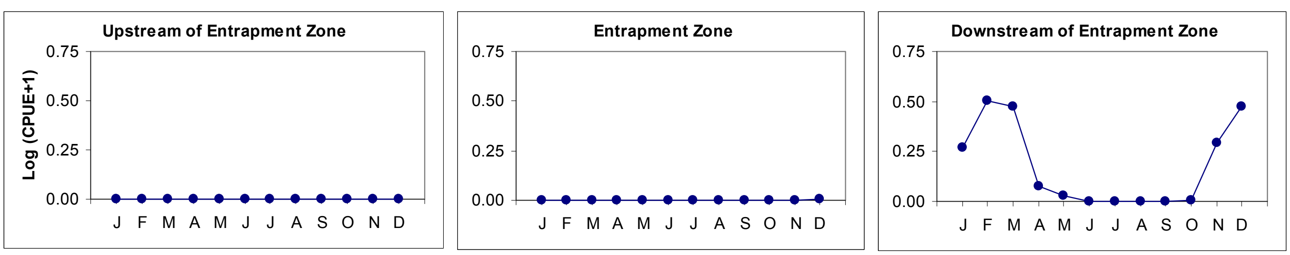


Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, within, and downstream of the entrapment zone, 2008

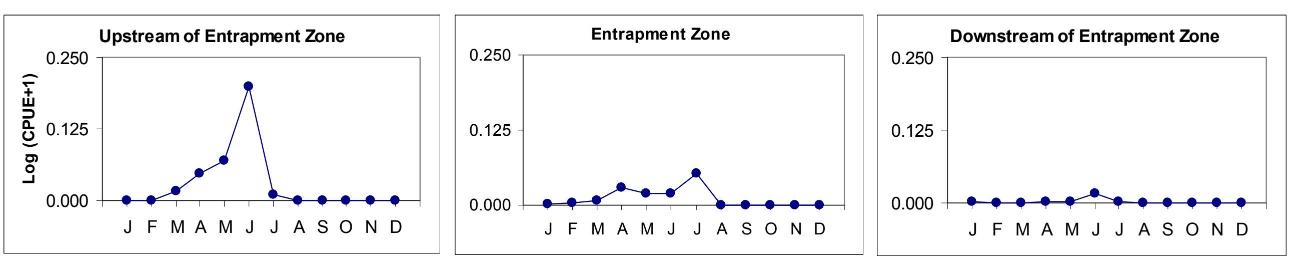


Figure 5-6 Monthly *Pseudodiaptomus forbesi* abundance upstream, within, and downstream of the entrapment zone, 2008

Figure 5-7 Monthly *Acartia* spp. abundance upstream, within, and downstream of the entrapment zone, 2008

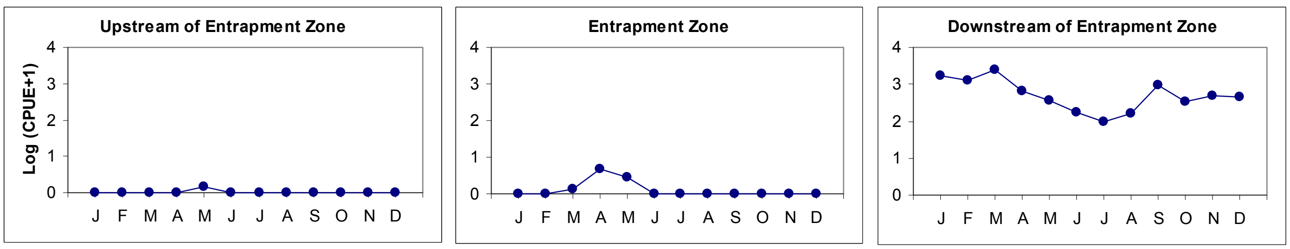


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, within, and downstream of the entrapment zone, 2008

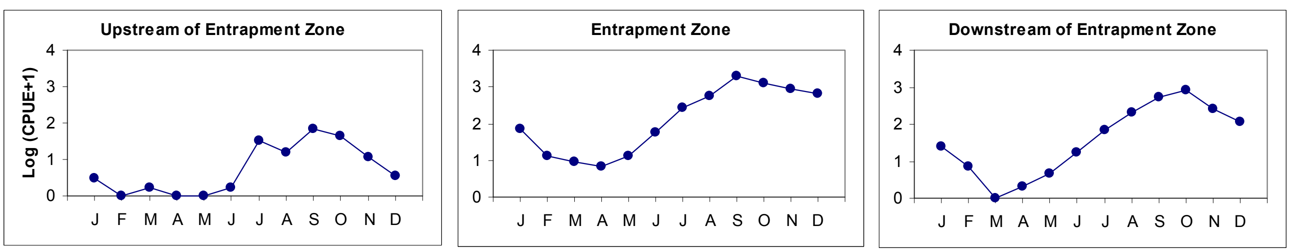


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, within, and downstream of the entrapment zone, 2008

Figure 5-10 Monthly *Eurytemora affinis* abundance upstream, within, and downstream of the entrapment zone, 2008

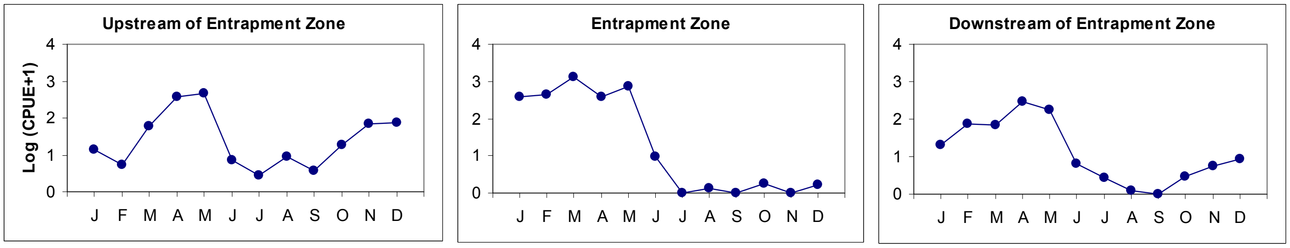


Figure 5-11 Monthly *Limnoithona tetraspina* abundance upstream, within, and downstream of the entrapment zone, 2008. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

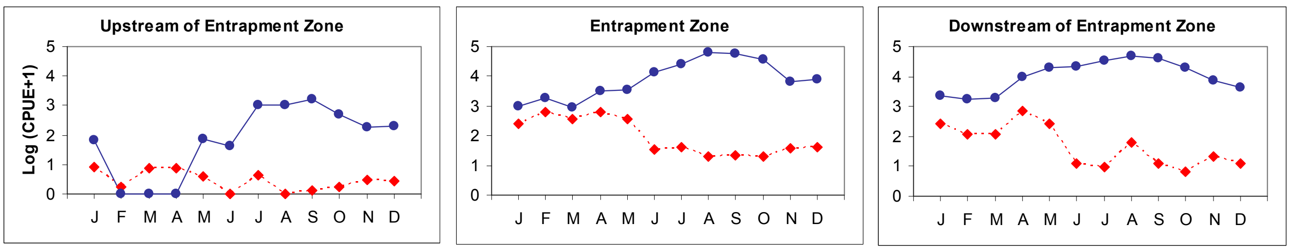


Figure 5-12 Monthly *Oithona davisae* abundance upstream, within, and downstream of the entrapment zone, 2008. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

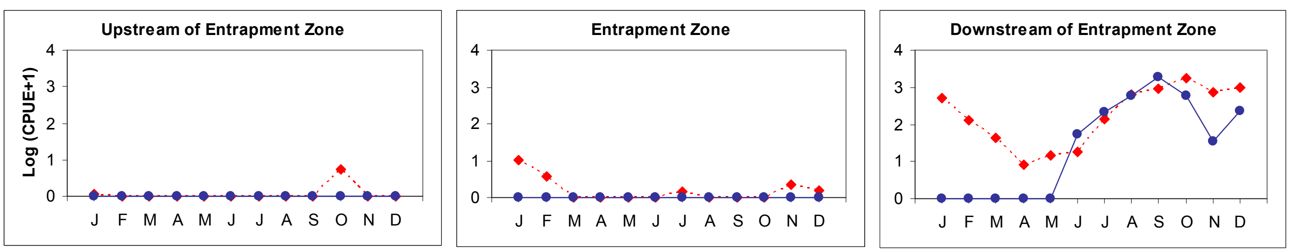


Figure 5-13 Monthly *Acanthocyclops vernalis* abundance upstream, within, and downstream of the entrapment zone, 2008

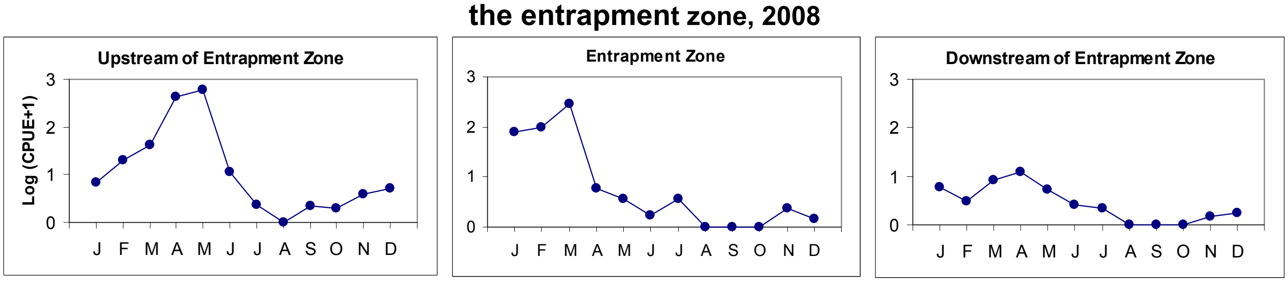
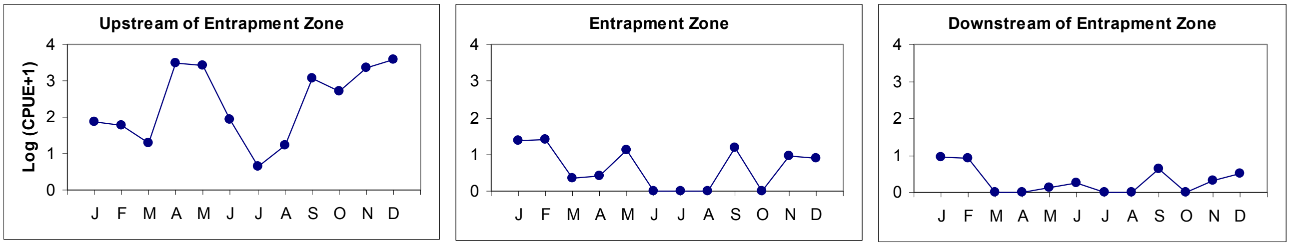


Figure 5-14 Monthly *Bosmina* spp. abundance upstream, within, and downstream of the entrapment zone, 2008



Monthly *Diaphanosoma* spp. abundance upstream, within, and downstream of the entrapment zone, 2008

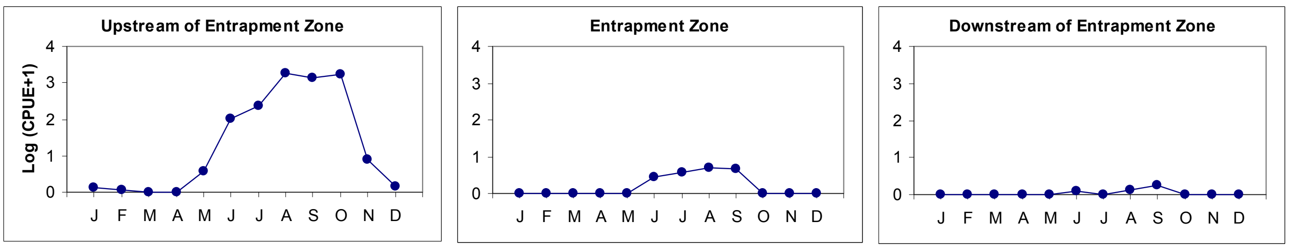


Figure 5-16 Monthly *Daphnia* spp. abundance upstream, within, and downstream of the entrapment zone, 2008

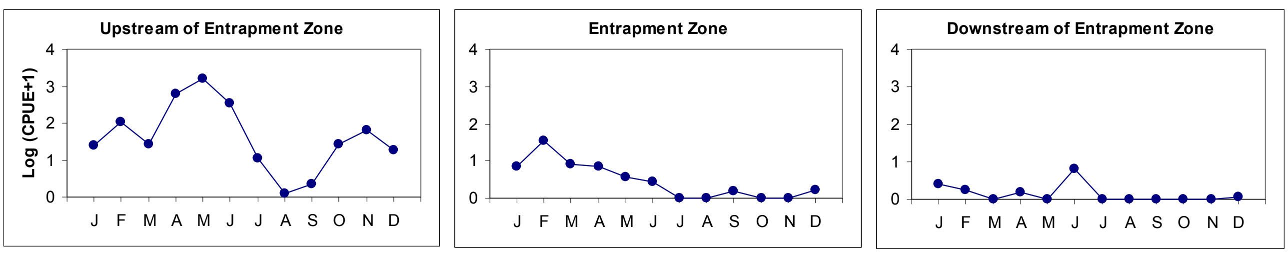


Figure 5-17 Monthly *Synchaeta* spp. abundance upstream, within, and downstream of the entrapment zone, 2008

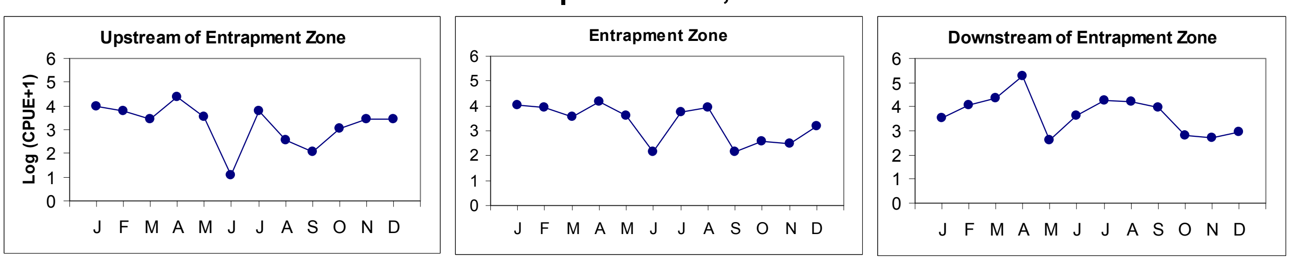


Figure 5-18 Monthly *Polyarthra* spp. abundance upstream, within, and downstream of the entrapment zone, 2008.

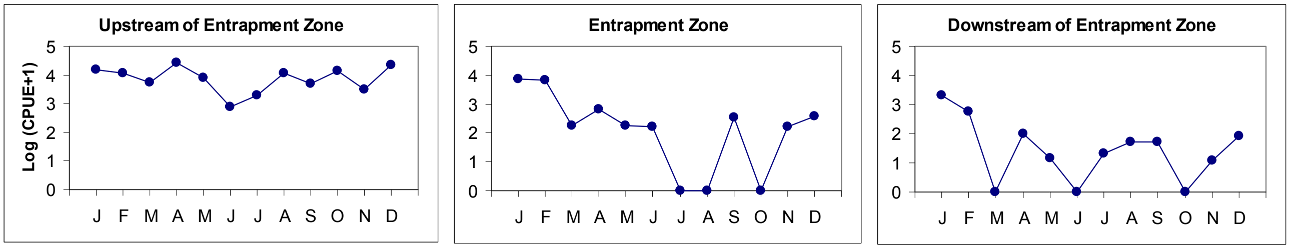


Figure 5-19 Monthly *Keratella* spp. abundance upstream, within, and downstream of the entrapment zone, 2008

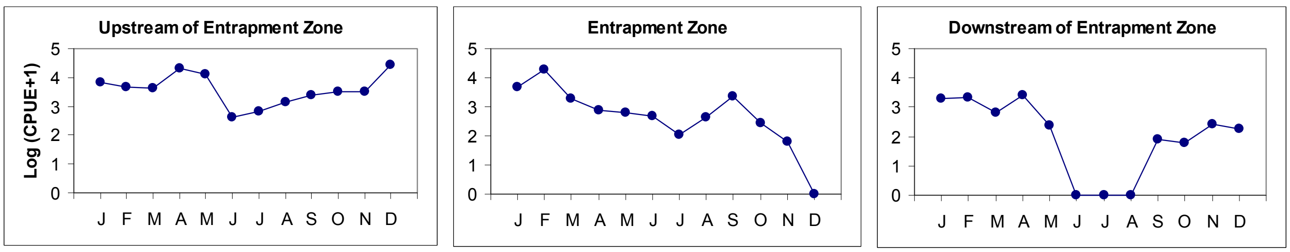


Table 5-1 Mysid abundance upstream, within, and downstream of the entrapment zone, 2008

Mysids	Upstream	Entrapment Zone	Downstream	All Zones
Hyperacanthomysis longirostris	0.96	9.07	11.49	7.05
Neomysis kadiakensis/japonica	<0.01	0.39	1.16	0.56
Alienacanthomysis macropsis	0.00	<0.01	0.60	0.25
Neomysis mercedis	0.08	0.03	<0.01	0.04

Table 5-2 Calanoid copepod abundance upstream, within, and downstream of the entrapment zone, 2008

Calanoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
Pseudodiaptomus forbesi	1182.2	401.5	49.5	545.9
Acartia spp.	<0.1	0.5	644.2	268.5
Acartiella sinensis	12.7	387.0	202.8	170.7
Sinocalanus doerrii	344.5	94.5	15.7	154.9
Eurytemora affinis	89.8	354.3	49.4	128.7

Table 5-3 Cyclopoid copepod abundance upstream, within, and downstream of the entrapment zone, 2008

Cyclopoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
CB net:				
Oithona davisae	0.3	1.5	553.5	231.0
Limnoithona tetraspina	2.9	246.7	119.6	102.9
Acanthocyclops vernalis	91.9	56.9	2.4	47.3
Pump:				
Limnoithona tetraspina	352	16406	19365	11585
Oithona davisae	0	0	346	142

Table 5-4 Cladoceran abundance upstream, within, and downstream of the entrapment zone, 2008

Cladocerans	Upstream	Entrapment Zone	Downstream	All Zones
Bosmina spp.	1035.6	8.5	1.6	388.5
Diaphanosoma spp.	370.9	0.9	0.1	138.5
Daphnia spp.	242.7	6.8	0.6	92.2

Table 5-5 Rotifer abundance upstream, within, and downstream of the entrapment zone, 2008

Rotifers	Upstream	Entrapment Zone	Downstream	All Zones
Synchaeta spp.	5123	5534	23058	12591
Polyarthra spp.	10597	1789	178	4439
Keratella spp.	7142	3447	563	3650

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 lower 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 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, 2008

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 2008, 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 *San Carlos*, *Endeavor* and *Whaler*, all 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 formaldehyde 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 / 0.053 m^2 and 0.053 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* and the *Whaler* 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 176 species collected, 10 represented 82.8% of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods

Ampelisca abdita

Monocorophium acherusicum

Americorophium stimpsoni

Corophium alienense

Americorophium spinicorne

Gammarus daiberi

Sabellidae Polychaete

Laonome sp. A

Tubificidae Worms

Varichaetadrilus angustipenis

Asian Clams

Corbula amurensis

Corbicula fluminea

Of the 10 dominant species, *Corbula amurensis, Ampelisca abdita* and *Monocorophium acherusicum* represent 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,* 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 upon request.

All organisms collected during 2008 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 99.1% 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 6-12 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 2008

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 6-12). Sediment composition is also discussed for each site (Figures 6-13 through 6-22).

org/m^2 = organisms per square meter

Benthic Abundance

Maximum abundances in 2008 ranged from 58,406 organisms per square meter in July at D41 to 5,486 organisms per square meter in August at D24. Minimum abundances ranged from 6,726 organisms per square meter in December at D4 to 57 organisms per square meter in November at D16.

Site C9: South Delta

Maximum abundance in 2008 occurred in May with a total of 38,632 organisms per square meter (Figure 6-3). *Americorophium stimpsoni* (32,319 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in November with a total of 1,240 organisms per square meter. *Varichaetadrilus angustipenis* (565 org/m^2) and *Limnodrilus hoffmeisteri* (380 org/m^2) were the dominant species.

Figure 6-3 Total abundance at Station C9, 2008

Site P8: South Delta

The maximum abundance in 2008 was in April with a total of 11,376 organisms per square meter (Figure 6-4). *Manayunkia speciosa* (7,363 org/m^2) was the dominant species. The minimum abundance in 2008 was in October with a total of 1,929 organisms per square meter. *Varichaetadrilus angustipenis* (741 org/m2) and *Laonome sp. A* (475 org/m2) were the dominant species.

Figure 6-4 Total abundance at P8, 2008

Site D28A: Central Delta

Maximum abundance in 2008 occurred in May with a total of 13,452 organisms per square meter (Figure 6-5). *Gammarus daiberi* (4,418 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in September with a total of 1,007 organisms per square meter. *Varichaetadrilus angustipenis* (570 org/m^2) was the dominant species.

Figure 6-5 Total abundance at Station D28A, 2008

Site D16: Lower San Joaquin River

Maximum abundance in 2008 occurred in August with a total of 5,733 organisms per square meter (Figure 6-6). *Americorophium stimpsoni* (3,278 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in November with a total of 57 organisms per square meter. *Corbicula fluminea* (38 org/m^2) was the dominant species.

Figure 6-6 Total abundance at Station D16, 2008

Site D24: Lower Sacramento River

Maximum abundance in 2008 occurred in August with a total of 5,486 organisms per square meter (Figure 6-7). *Corbicula fluminea* (3,016 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in February with a total of 803 organisms per square meter. *Corbicula fluminea* (494 org/m^2) was the dominant species.

Figure 6-7 Total abundance at Station D24, 2008

Site D4: Lower Sacramento River

Maximum abundance in 2008 occurred in May with a total of 19,765 organisms per square meter (Figure 6-8). *Americorophium spinicorne* (7,491 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in December with a total of 6,726 organisms per square meter. *Laonome sp. A* (2,095 org/m^2) was the dominant species.

Figure 6-8 Total abundance at Station D4, 2008

Site D6: Suisun Bay

Maximum abundance in 2008 occurred in October with a total of 29,360 organisms per square meter (Figure 6-9). *Corbula amurensis* (28,942 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in January with a total of 1,458 organisms per square meter. *Corbula amurensis* (1,036 org/m^2) was the dominant species.

Figure 6-9 Total abundance at Station D6, 2008

Site D7: Suisun Bay

Maximum abundance in 2008 occurred in October with a total of 21,038 organisms per square meter (Figure 6-10). *Corbula amurensis* (14,098 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in April with a total of 4,109 organisms per square meter. *Corophium alienense* (1,577 org/m^2) and *Nippoleucon hinumensis* (1,283 org/m^2) were the dominant species.

Figure 6-10 Total abundance at Station D7, 2008

Site D41: San Pablo Bay

Maximum abundance in 2008 occurred in July with a total of 58,406 organisms per square meter (Figure 6-11). *Ampelisca abdita* (33,773 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in December with a total of 1,316 organisms per square meter. *Neanthes limnicola* (508 org/m^2) was the dominant species.

Figure 6-11 Total abundance at Station D41, 2008

Site D41A: San Pablo Bay

Maximum abundance in 2008 occurred in June with a total of 37,748 organisms per square meter (Figure 6-12). *Monocorophium*

Figure 6-12 Total abundance Station D41A, 2008

acherusicum (21,689 org/m^2) was the dominant species. The minimum abundance in 2008 occurred in August with a total of 4,475 organisms per square meter. *Ampelisca abdita* (3,734 org/m^2) was the dominant species.

Sediment Analysis

Sediment organic content was determined using ash-free dry weight and is given as a percent of the total sample mass. In 2008, organic content ranged from 0.3% at site D16 to 50.4% at site D4. Sediment grain size ranged from 100% fines in July at site D7 to 100% sand at D24 in December.

Site C9: South Delta

Sandy clay dominated the sediment content at C9 in May through November of 2008, while the rest of the year was mainly silty sand (Figure 6-13). The percentage of organic content ranged from 0.5% 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 2008

Site P8: South Delta

All through 2008 the sediment at P8 was consistently about 2/3 sand with silt, with a slight dip in August when the sand and silt was evenly distributed (Figure 6-14). The organic matter ranged from 1.3% to 3.2%, with the higher organic values typically coinciding with finer sediments.

Figure 6-14 Sediment grain size and organic content at Station P8 during 2008

Site D28A: Central Delta

Sandy sediment was dominant most months at site D28A for 2008 with the exception of November when there was about half sand, half fine sediment at the site (Figure 6-15). The organic matter ranged from 1.3% to 8.5%. Larger quantities of organic matter coincided with an abundance of fine sediment.

Figure 6-15 Sediment grain size and organic content at Station D28A during 2008

Site D16: Lower San Joaquin River

Sand dominated the sediment type at site D16 for 2008 with the exception of August when silt dominated (Figure 6-16). The amount of organic matter at this site ranged from 0.3% to 2.9% with higher values coinciding with higher percentages of fine sediment.

Figure 6-16 Sediment grain size and organic content at Station D16 during 2008

Site D24: Lower Sacramento River

Sand dominated the sediment at site D24 during 2008 (Figure 6-17). The amount of organic matter ranged from 0.5% to 2.2%. August had a higher organic content but seemed to have no affect on sediment content.

Figure 6-17 Sediment grain size and organic content at Station D24 during 2008

Site D4: Lower Sacramento River

Peat with sand dominated the sediment at site D4 during the months of April through November. December through March was mostly described as silty sand (Figure 6-18). The percent of organic matter at this site was high for most of the year and ranged from 3.5% to 50.4%.

Figure 6-18 Sediment grain size and organic content at Station D4 during 2008

Site D6: Suisun Bay

Silty clay dominated site D6 throughout 2008 (Figure 6-19). Organic matter at this site remained quite constant ranging from 3.2% to 5.4%.

Figure 6-19 Sediment grain size and organic content at Station D6 during 2008

Site D7: Suisun Bay

Silty clay dominated site D7 for all of 2008 (Figure 6-20). The organic matter at this site was stable throughout the year ranging from 2.6% to 4.8%.

Figure 6-20 Sediment grain size and organic content at Station D7 during 2008

Site D41: San Pablo Bay

The majority of the months at site D41 in 2008 contained higher percentages of silty fine sediment with the exception of May, September, October and December which contained a slightly higher percent of sand (Figure 6-21). The organic matter at this site ranged from 1.2% to 4.8% with higher values coinciding with higher percentages of fine sediment.

Figure 6-21 Sediment grain size and organic content at Station D41 during 2008

Site D41A: San Pablo Bay

Fine clay and silt sediments dominated site D41A for all of 2008 (Figure 6-22). The percent organic matter at this site evenly ranged from 2.1% to 4.2%.

Figure 6-22 Sediment grain size and organic content at Station D41A during 2008

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 2008 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda and Mollusca constituted 99.1% of the organisms collected during the study period. Ten species represent 82.8% of all organisms collected during this period. These species are: (1) the amphipods—*Ampelisca abdita*, *Monocorophium acherusicum, Americorophium stimpsoni, Corophium alienense, Americorophium spinicorne, and Gammarus daiberi*; (2) the Sabellidae polychaete— *Laonome sp A.* ; (3) the Tubificidae worm— *Varichaetadrilus angustipenis*; and (4) the Asian clams—*Corbula amurensis* and *Corbicula fluminea*.

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, 10.60-10.74.

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

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

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

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

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

Thompson, J. 2005. "*Potamocorbula amurensis* is, for now, *Corbula amurensis*". Interagency Ecological Program Newsletter. Spring;18(2). California Department of Water Resources.

Figure 6-1 Location of macrobenthic monitoring stations

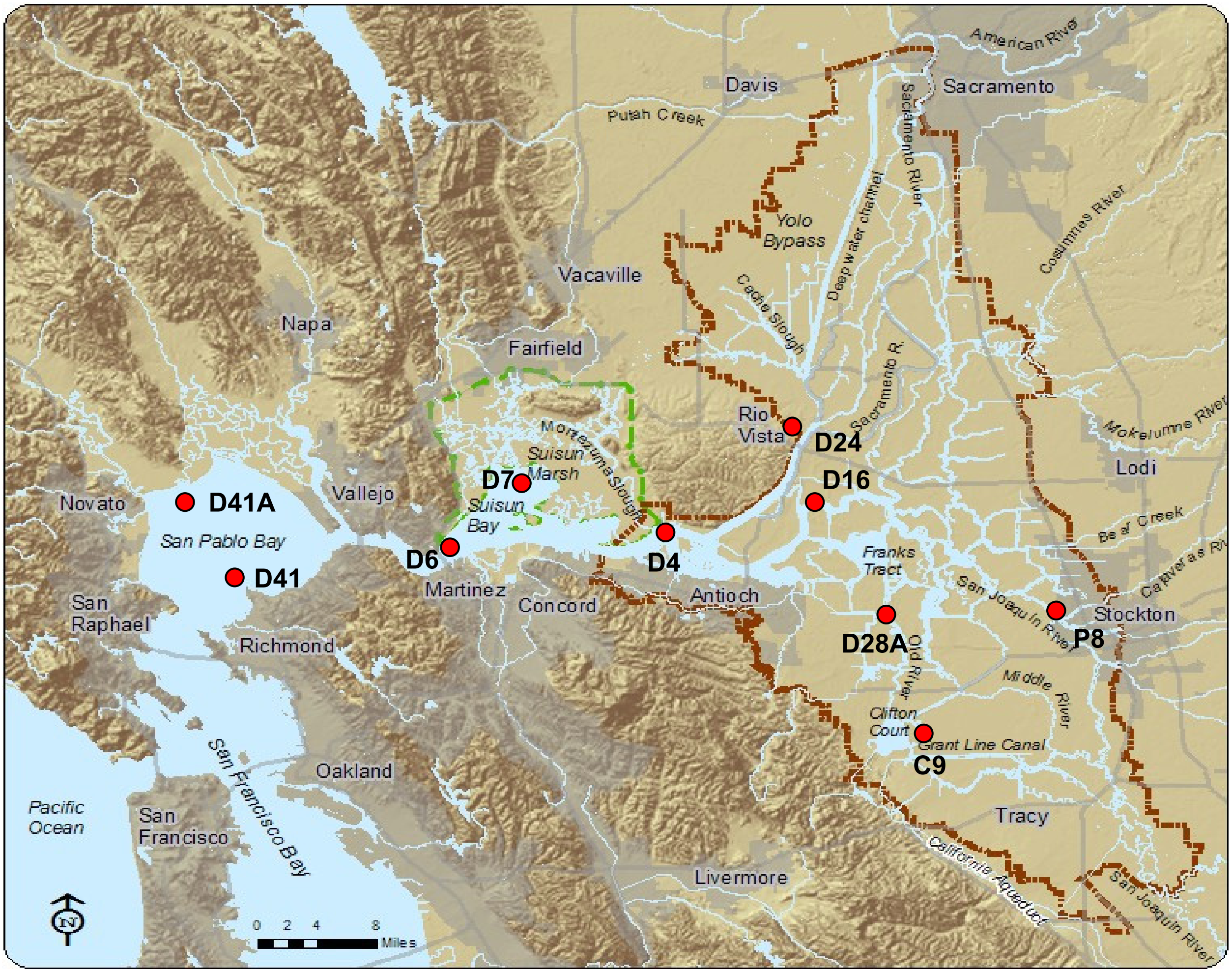


Figure 6-2 Total contribution by phyla for all stations during 2008

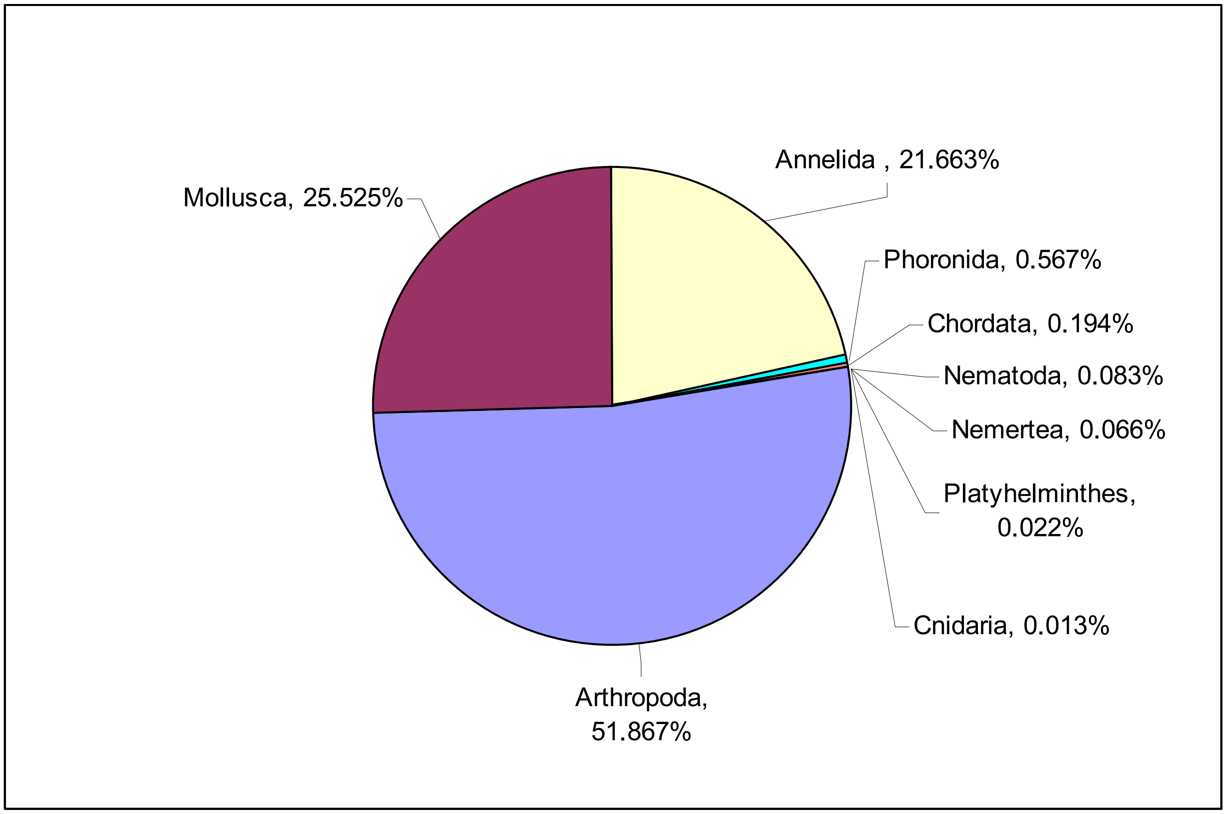


Figure 6-3 Total abundance at Station C9, 2008

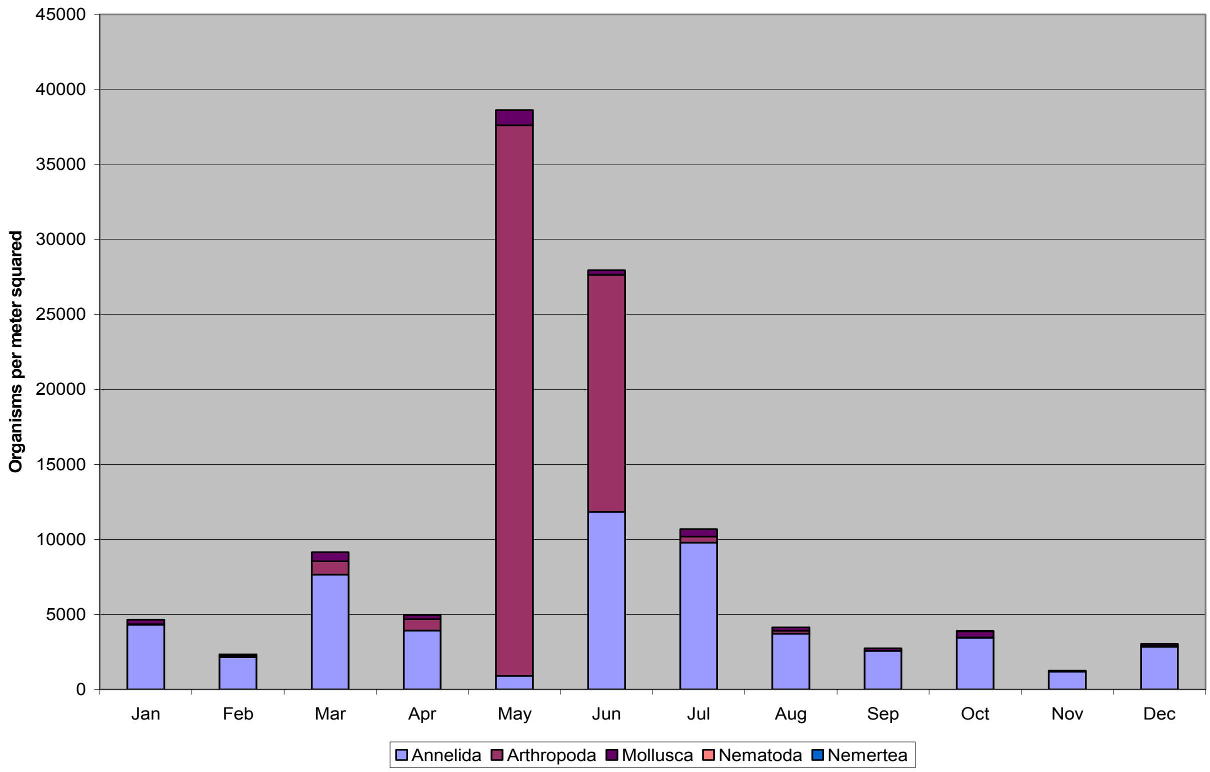


Figure 6-4 Total abundance at Station P8, 2008

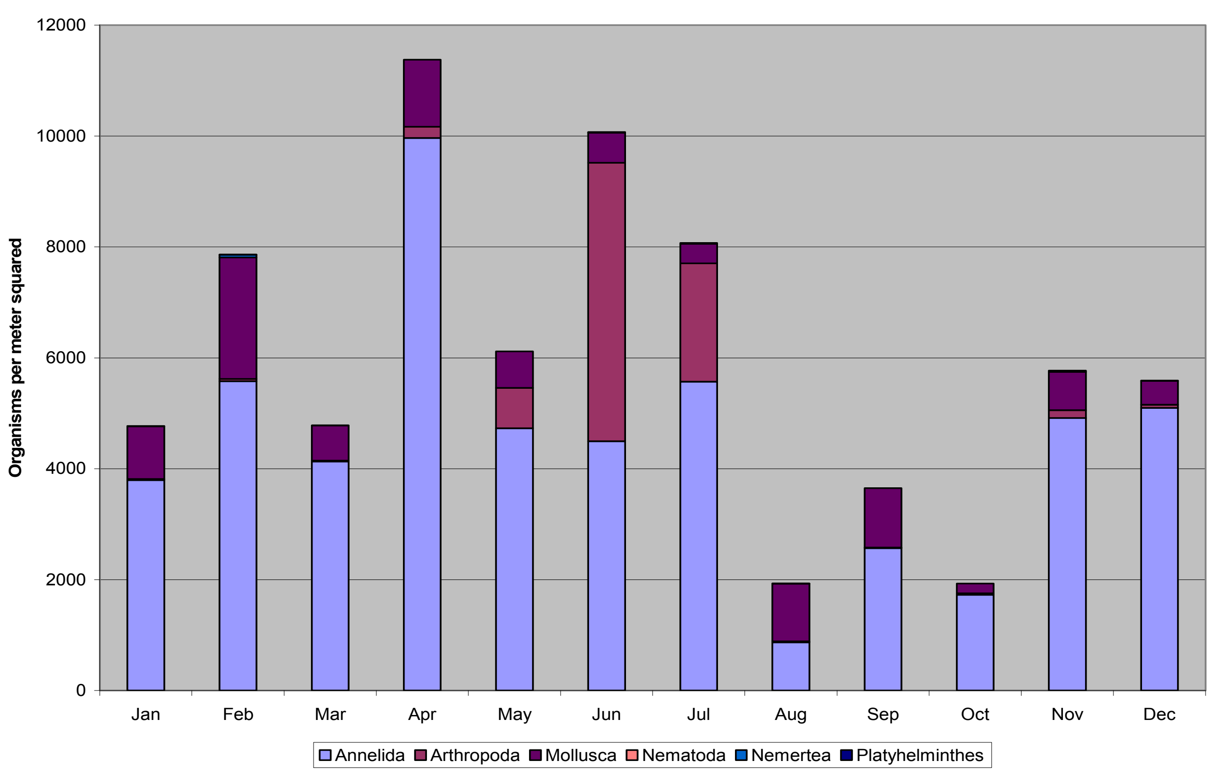


Figure 6-5 Total abundance at Station D28A, 2008

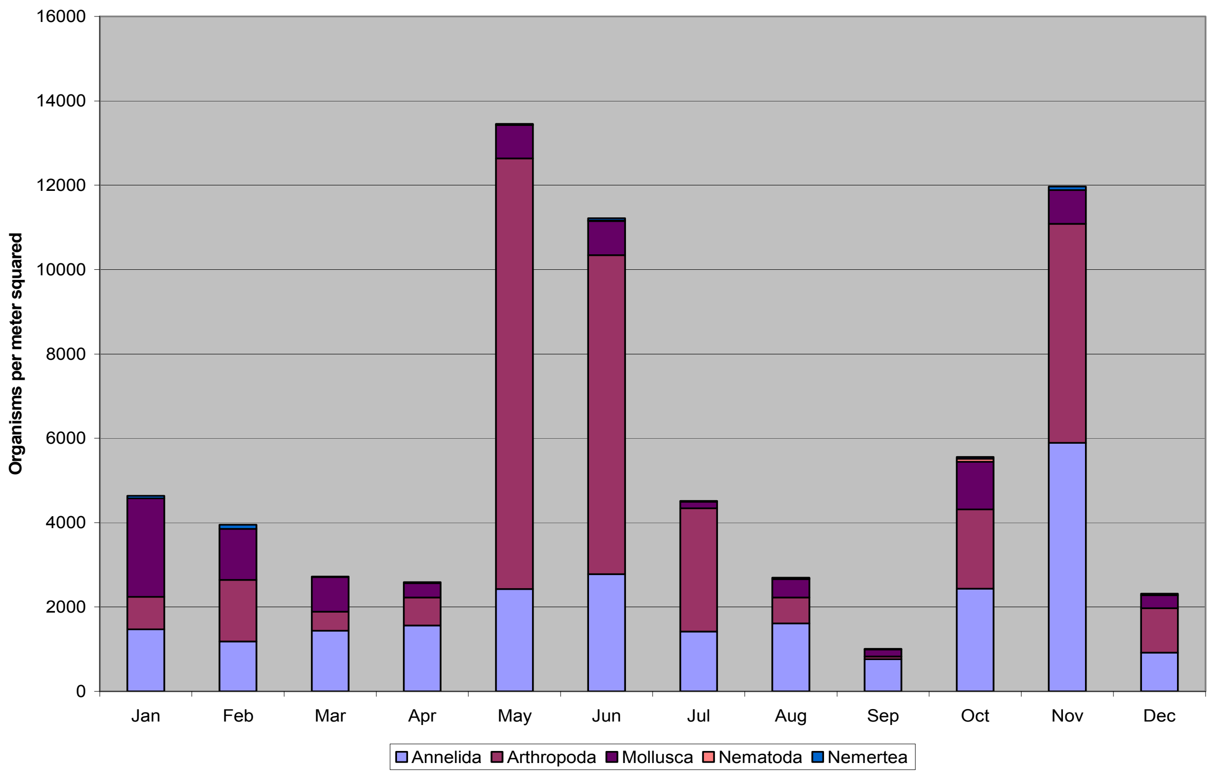


Figure 6-6 Total abundance at Station D16, 2008

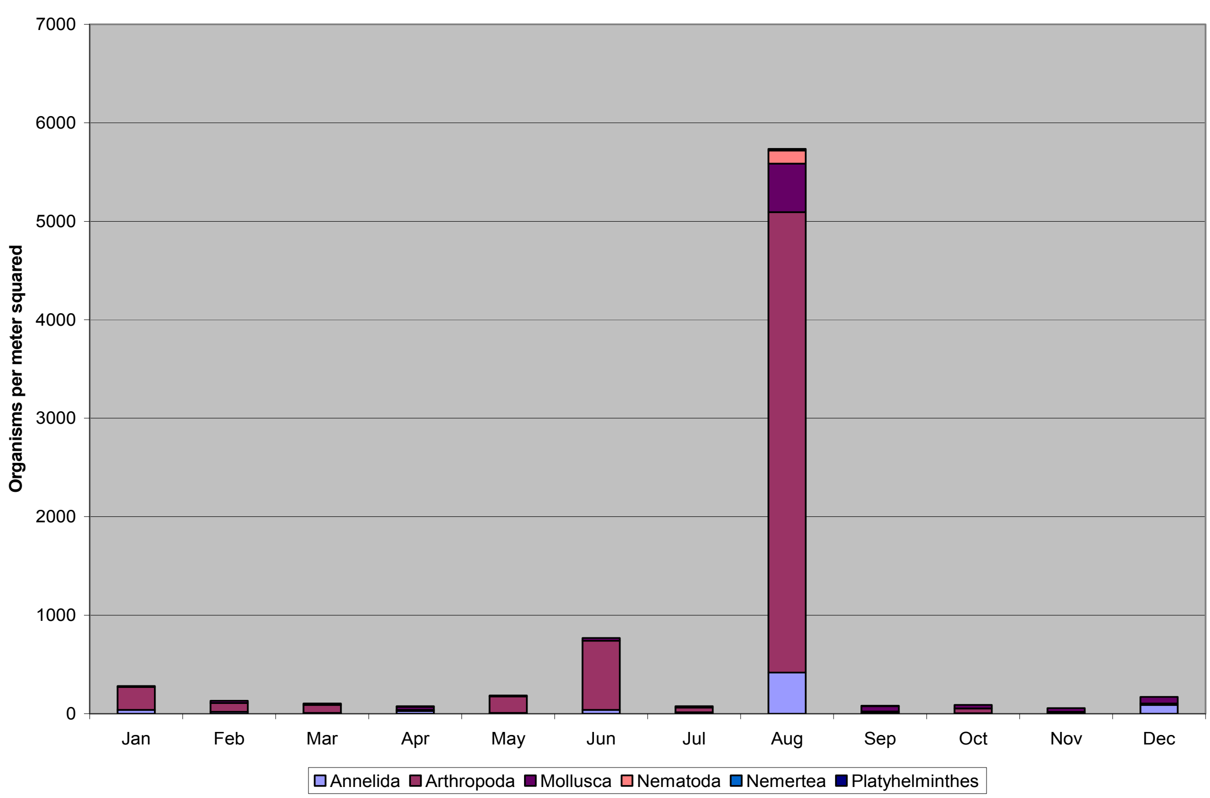


Figure 6-7 Total abundance at Station D24, 2008

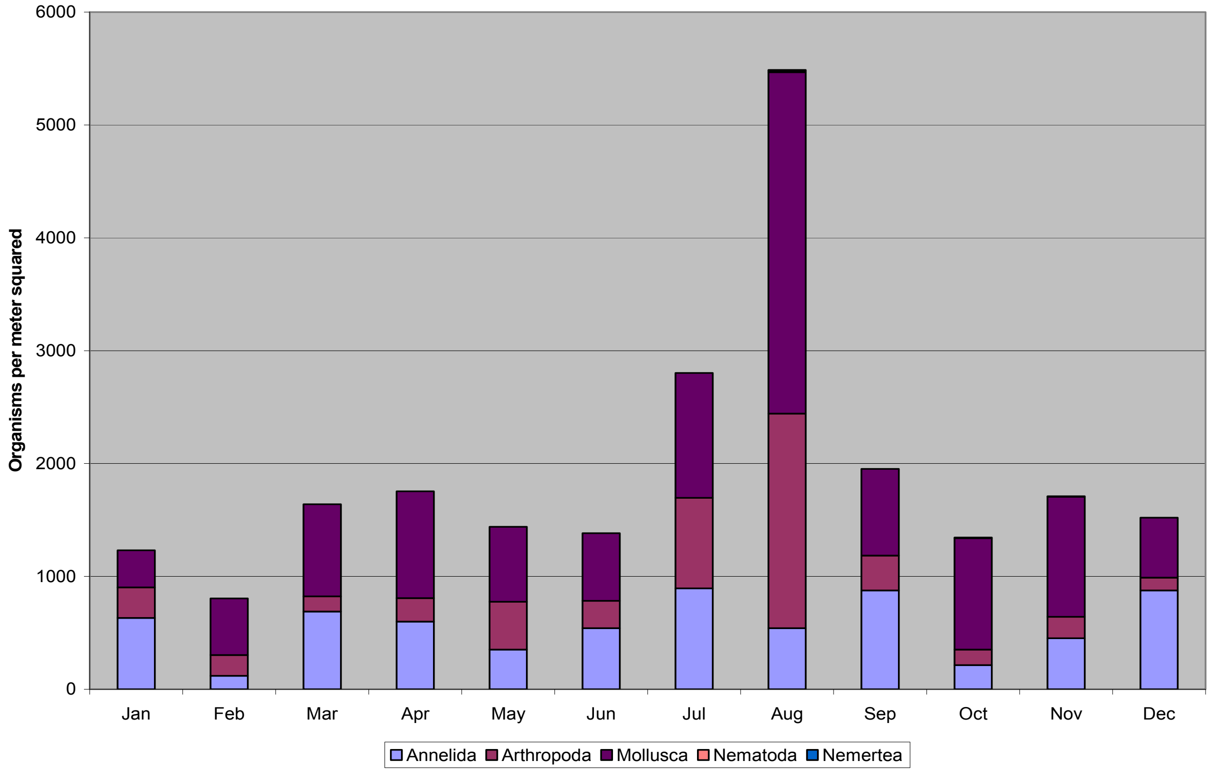


Figure 6-8 Total abundance at Station D4, 2008

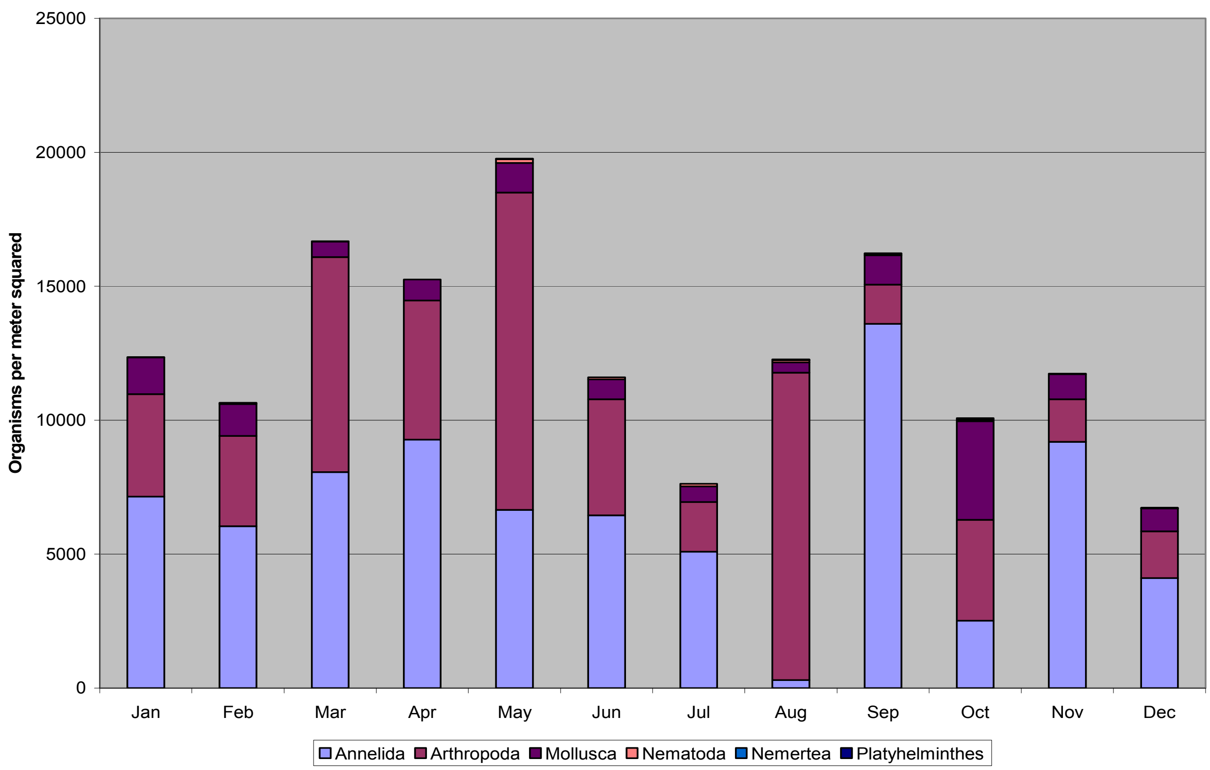


Figure 6-9 Total abundance at Station D6, 2008

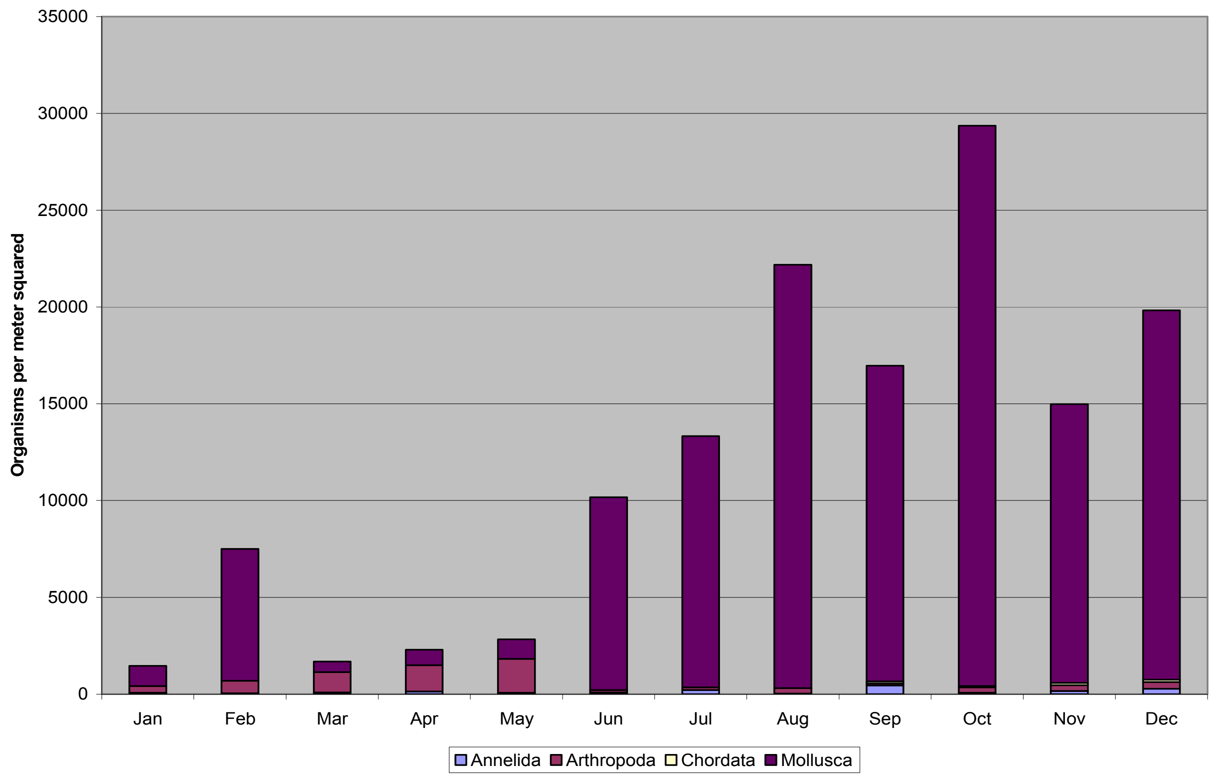


Figure 6-10 Total abundance at Station D7, 2008

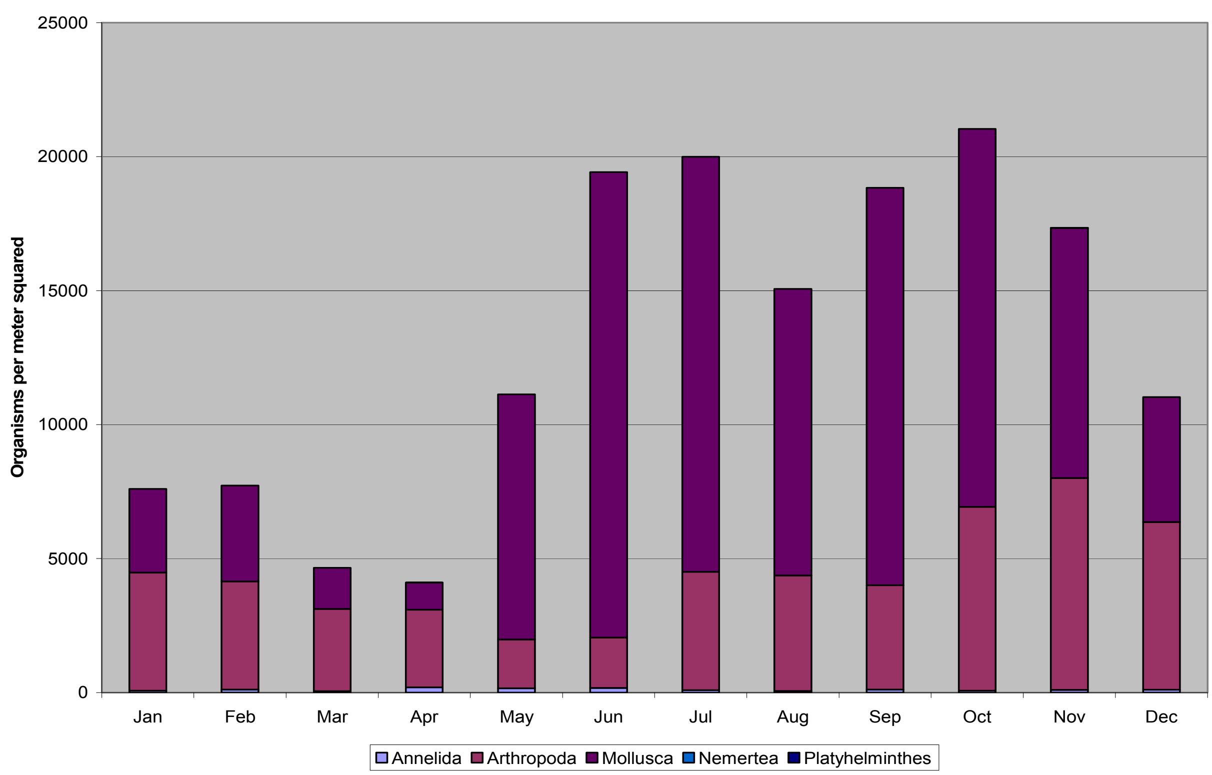


Figure 6-11 Total abundance at Station D41, 2008

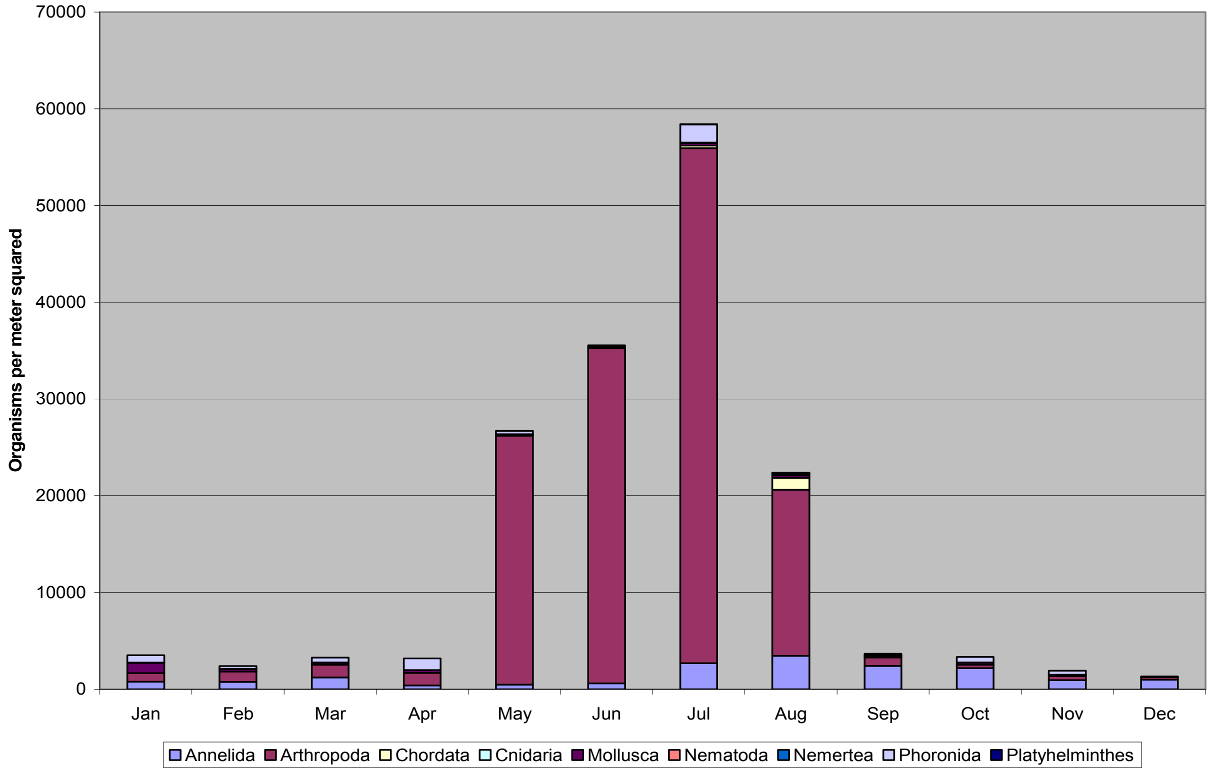


Figure 6-12 Total abundance at Station D41A, 2008

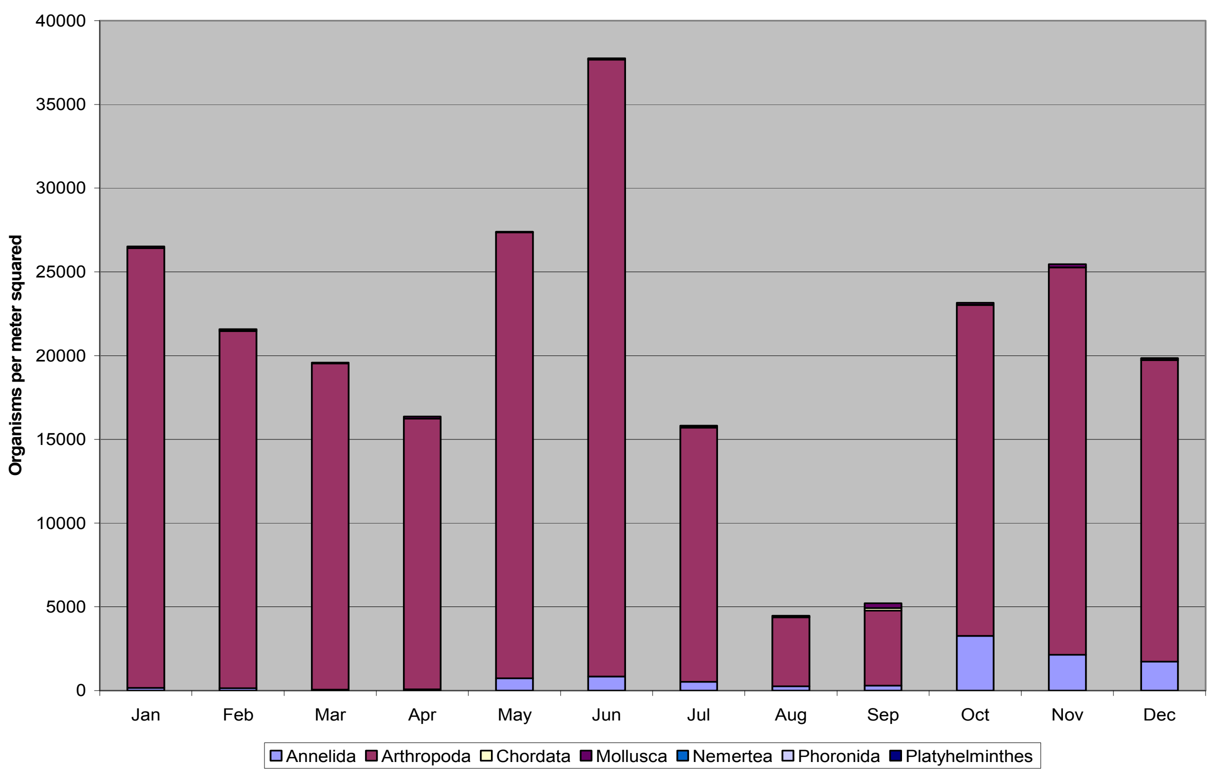


Figure 6-13 Sediment grain size and organic content at Station C9 during 2008

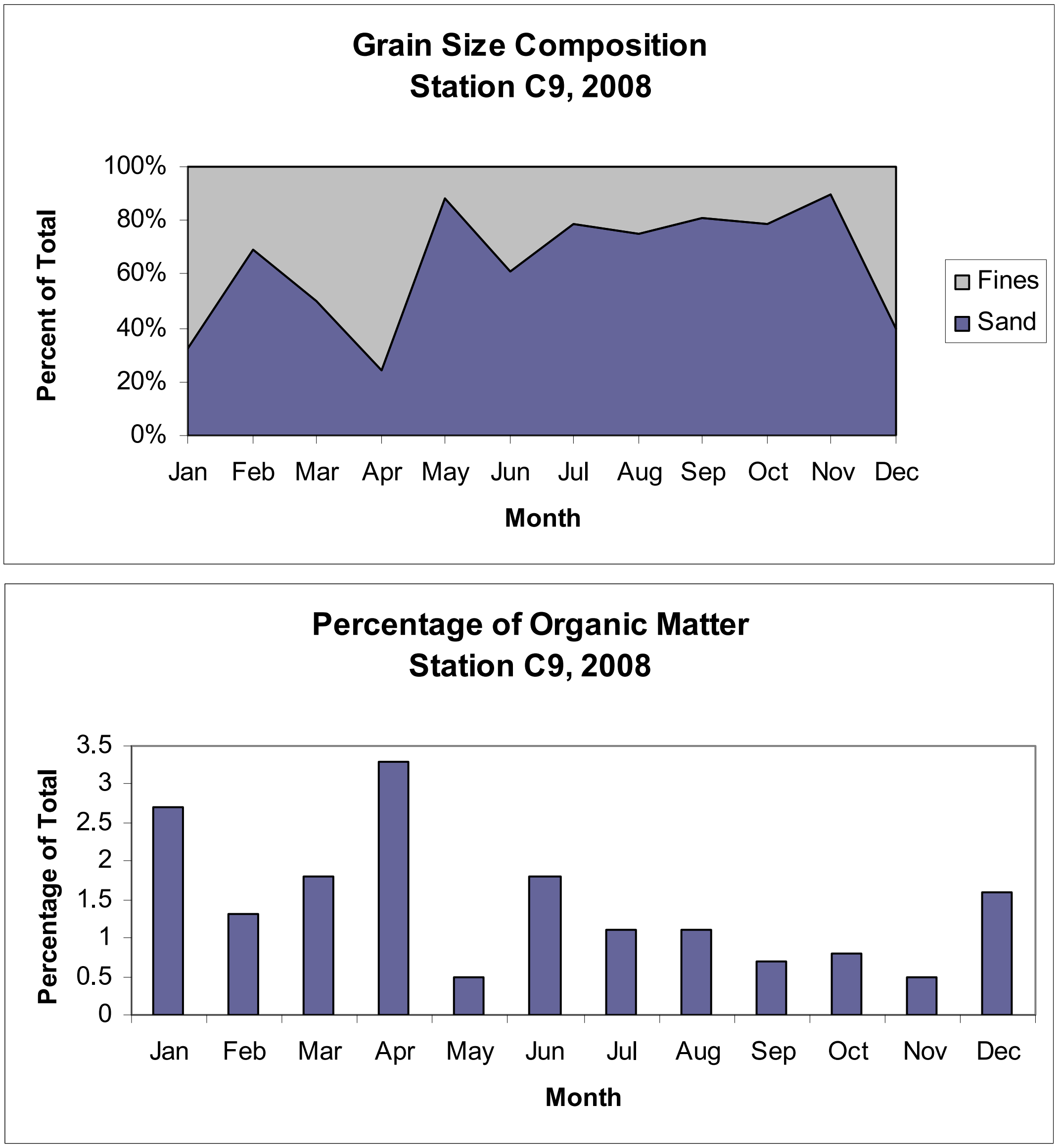
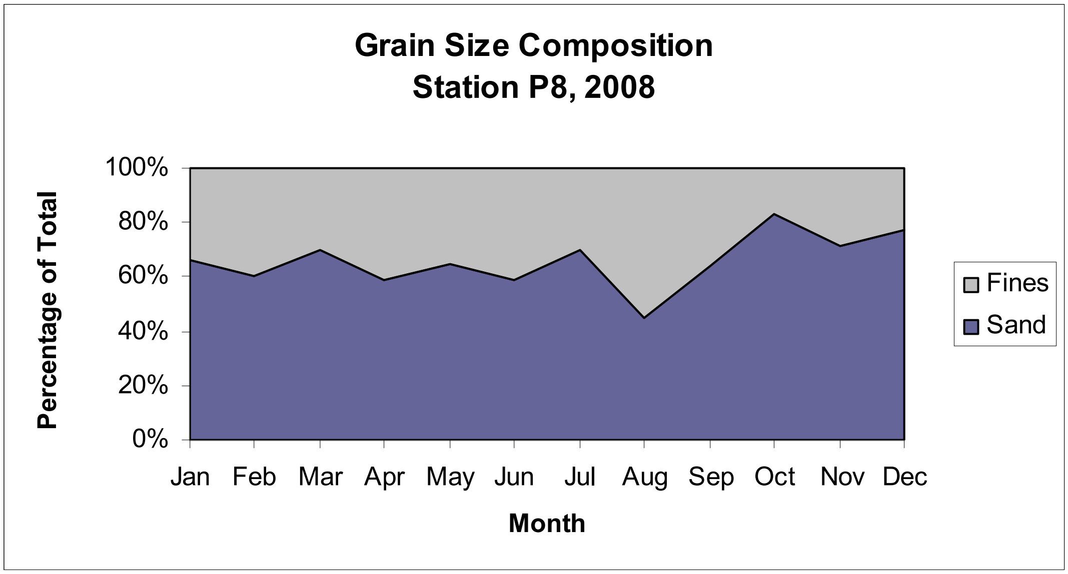


Figure 6-14 Sediment grain size and organic content at Station P8 during 2008



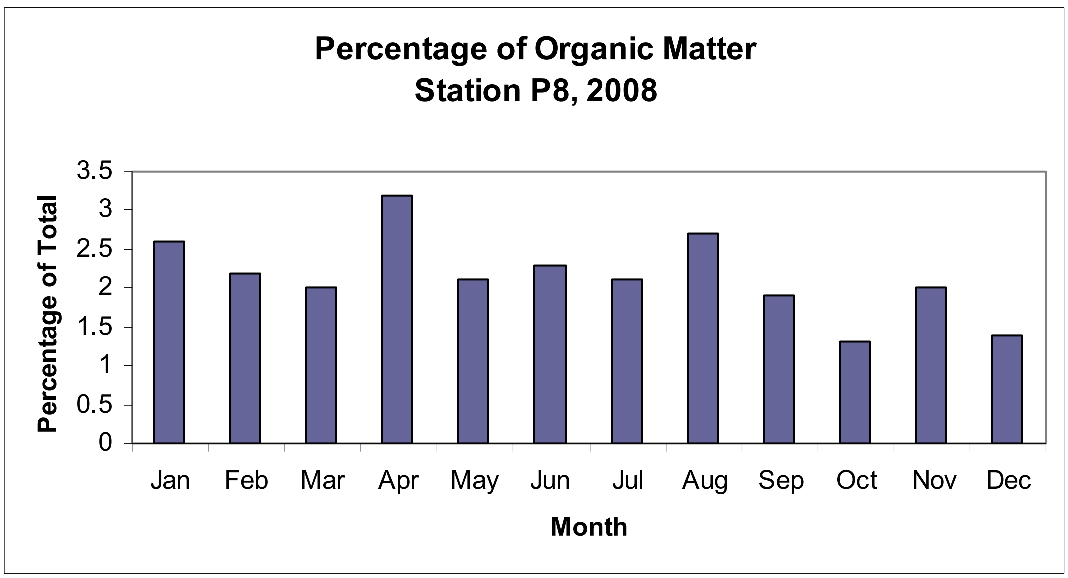
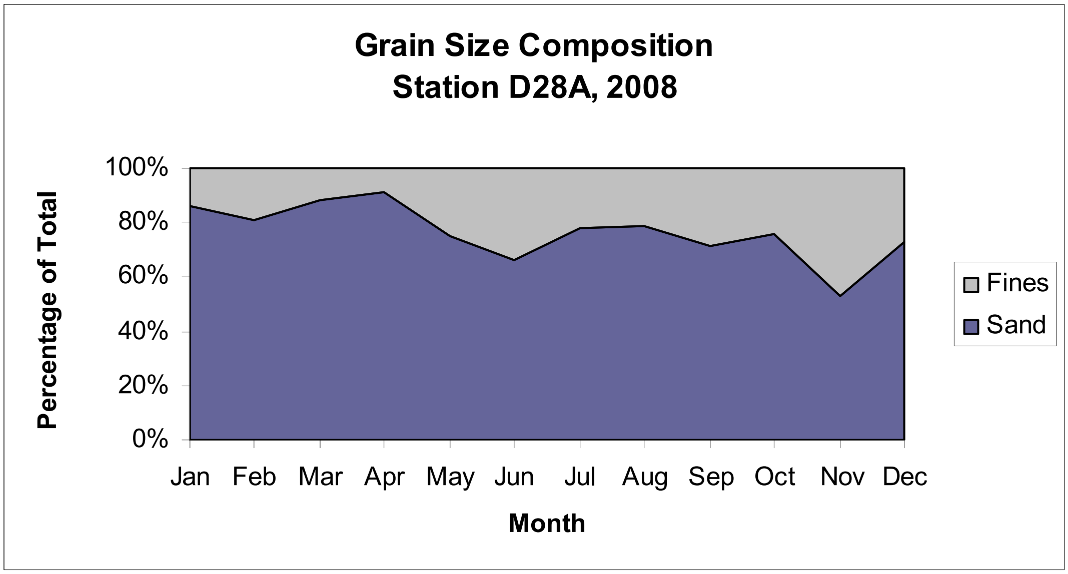


Figure 6-15 Sediment grain size and organic content at Station D28A during 2008



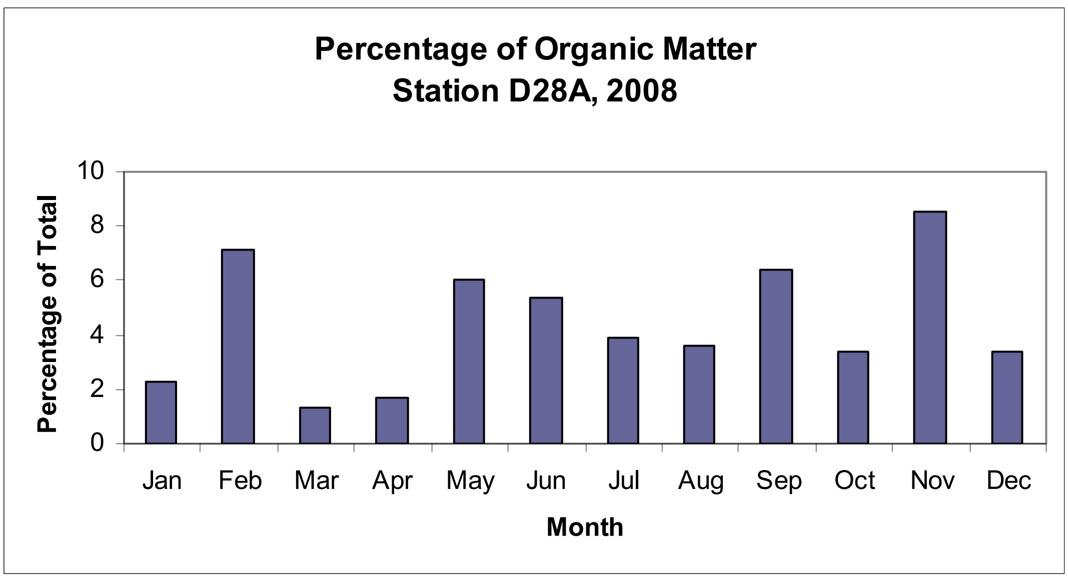
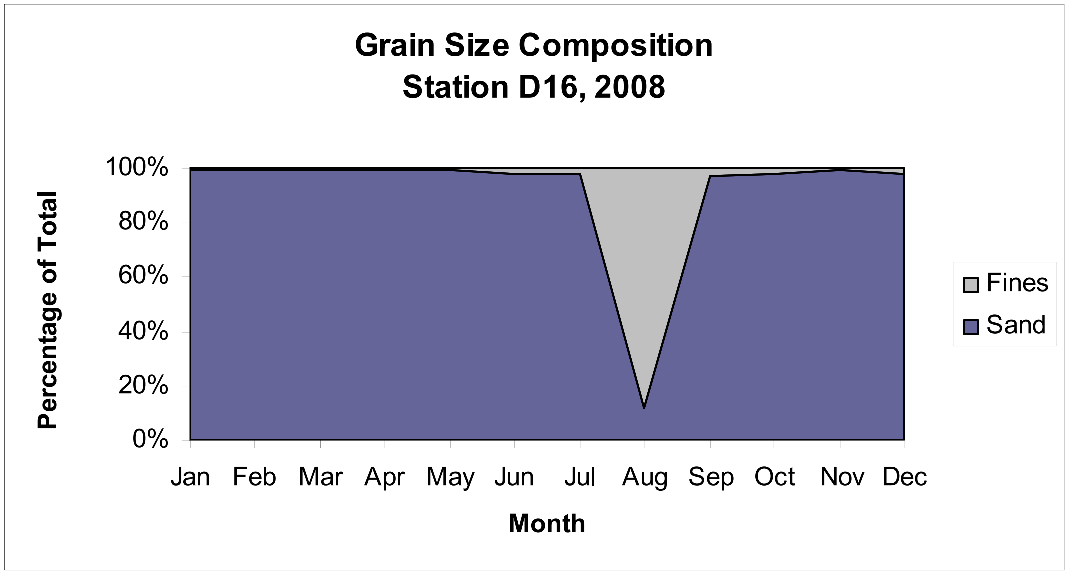


Figure 6-16 Sediment grain size and organic content at Station D16 during 2008



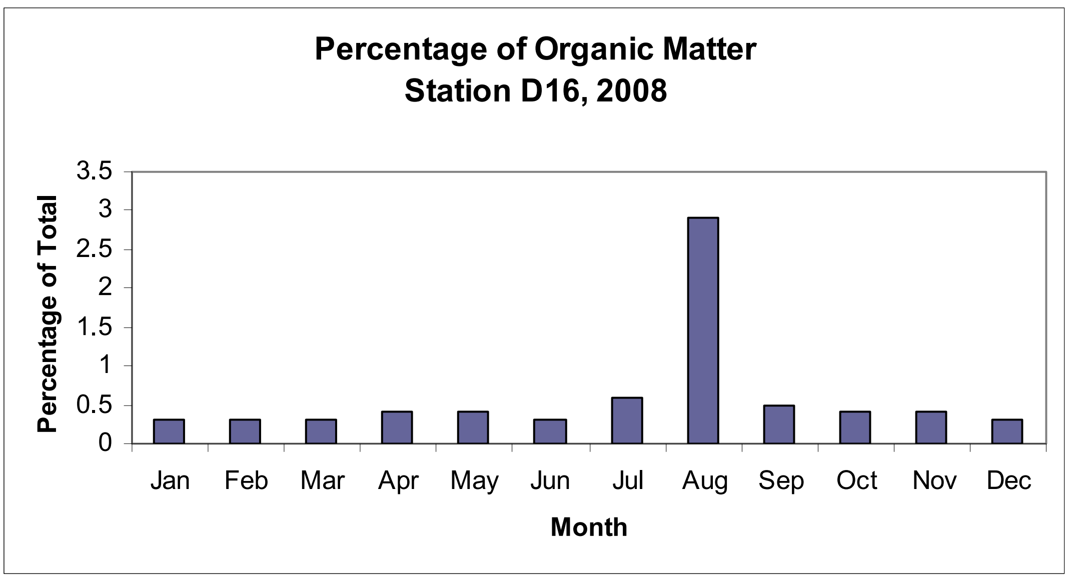
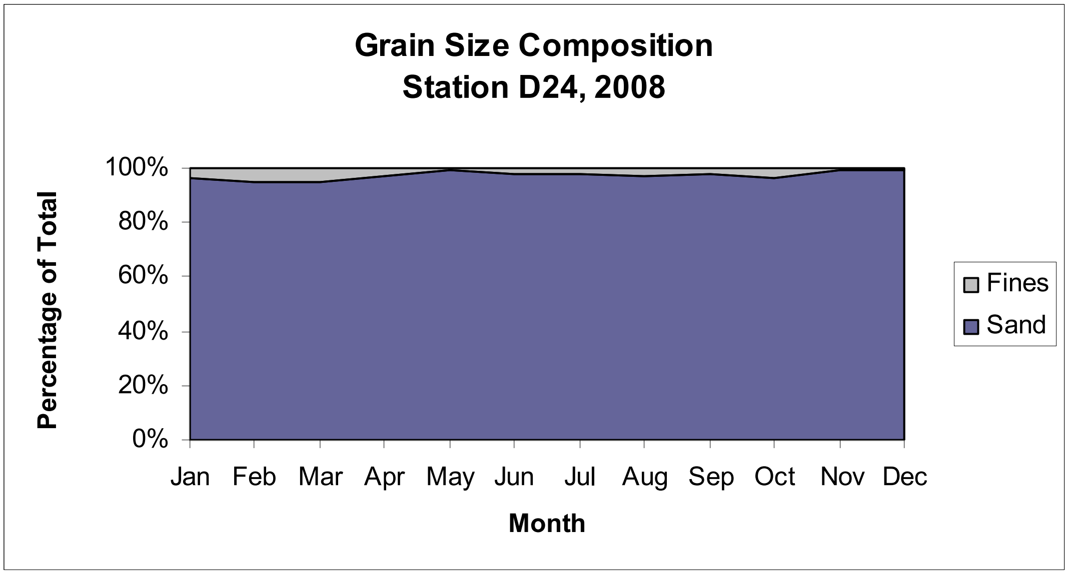


Figure 6-17 Sediment grain size and organic content at Station D24 during 2008



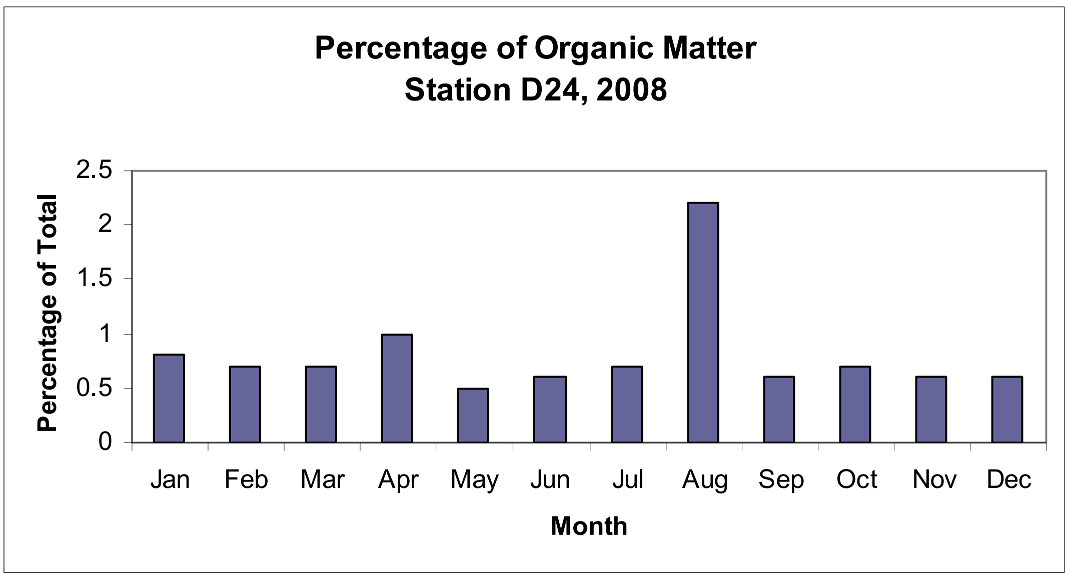
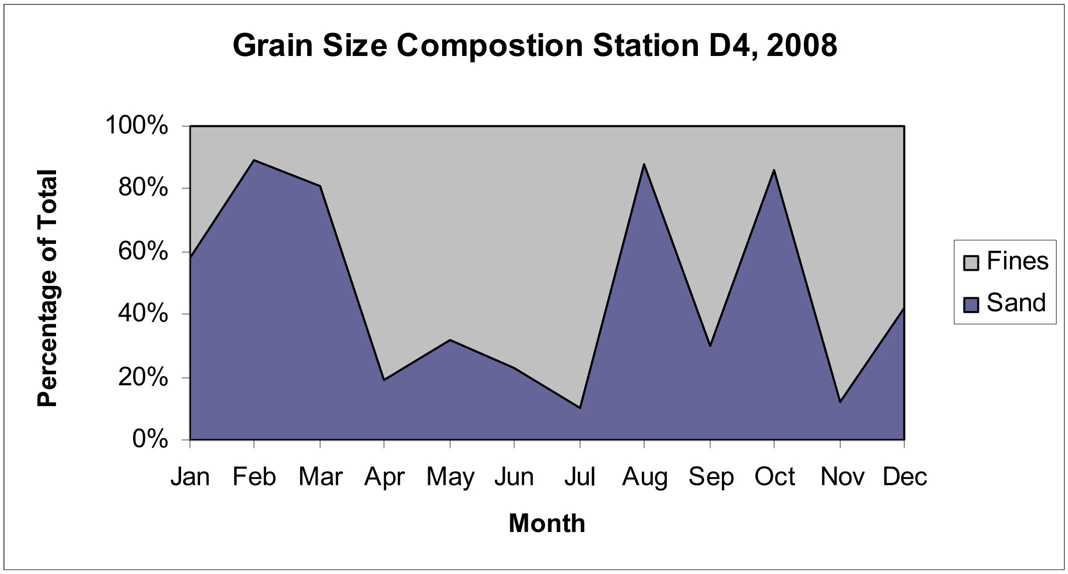


Figure 6-18 Sediment grain size and organic content at Station D4 during 2008



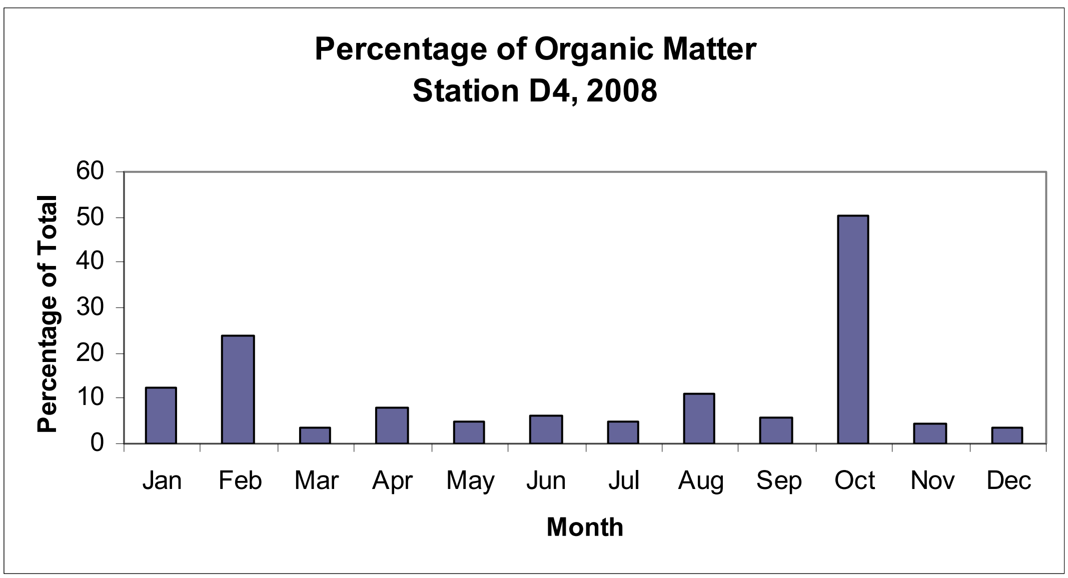
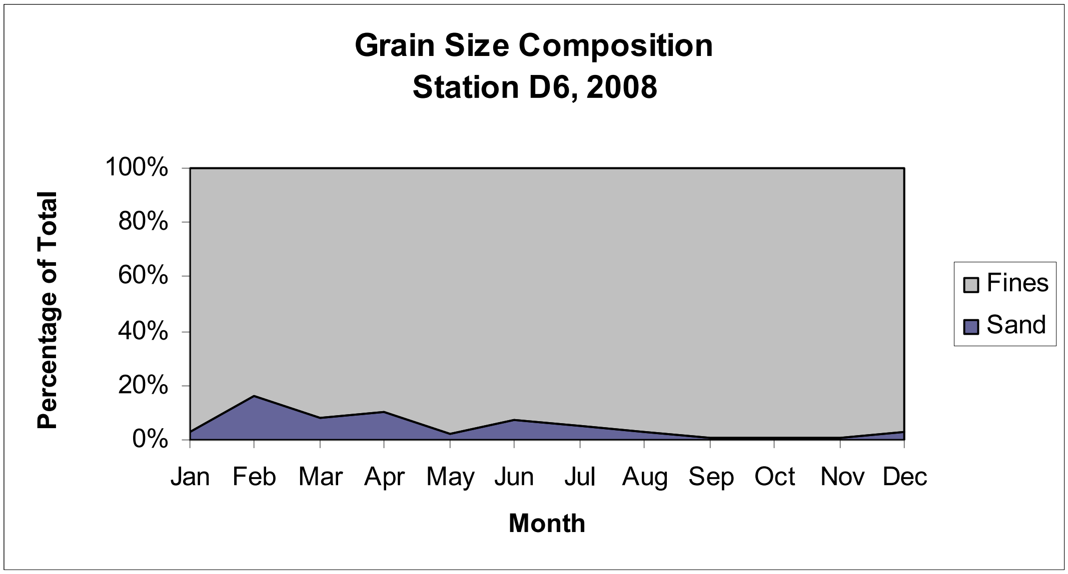


Figure 6-19 Sediment grain size and organic content at Station D6 during 2008



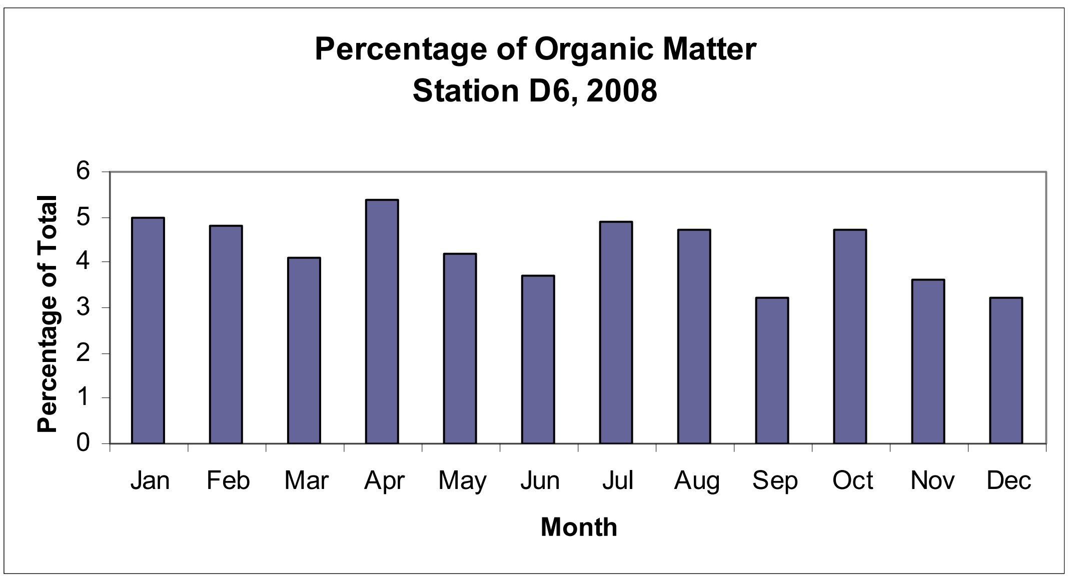
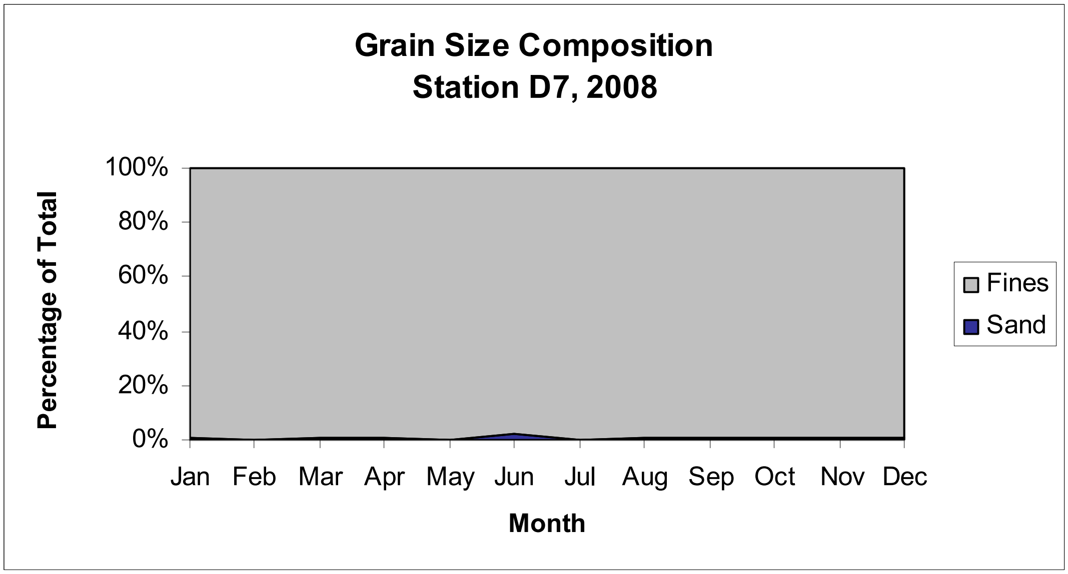


Figure 6-20 Sediment grain size and organic content at Station D7 during 2008



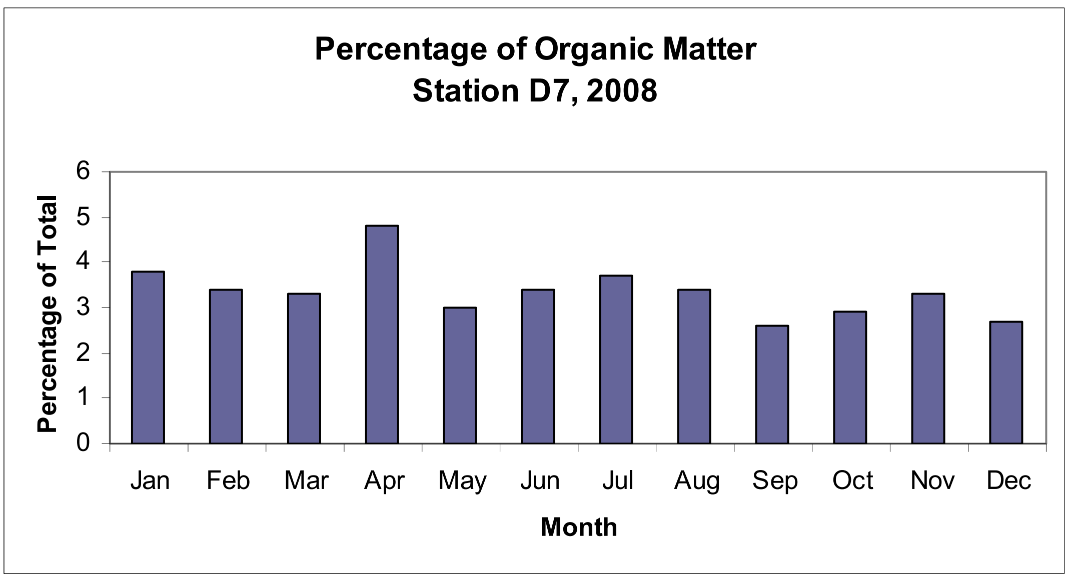
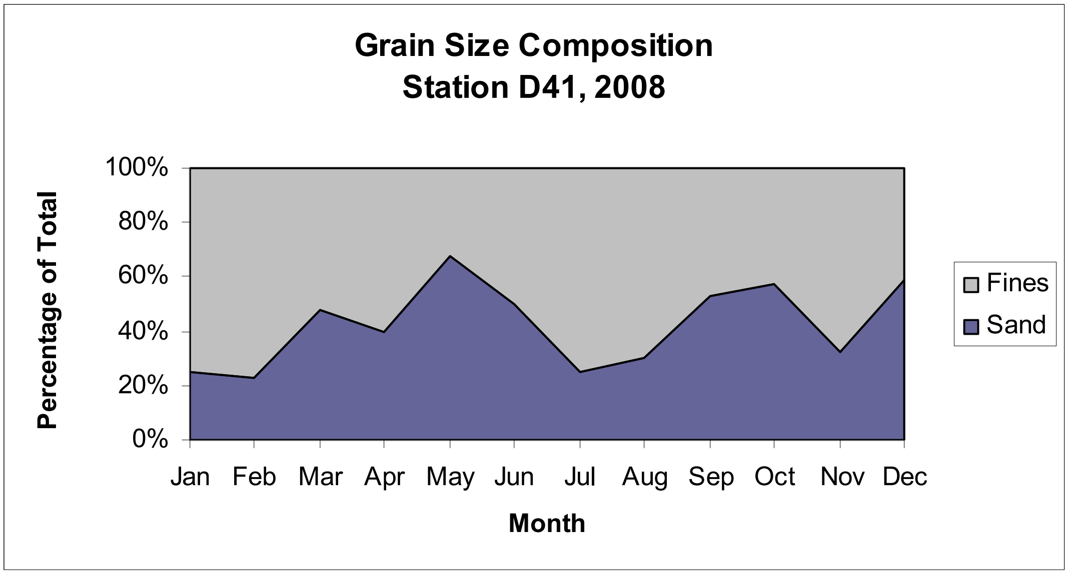


Figure 6-21 Sediment grain size and organic content at Station D41 during 2008



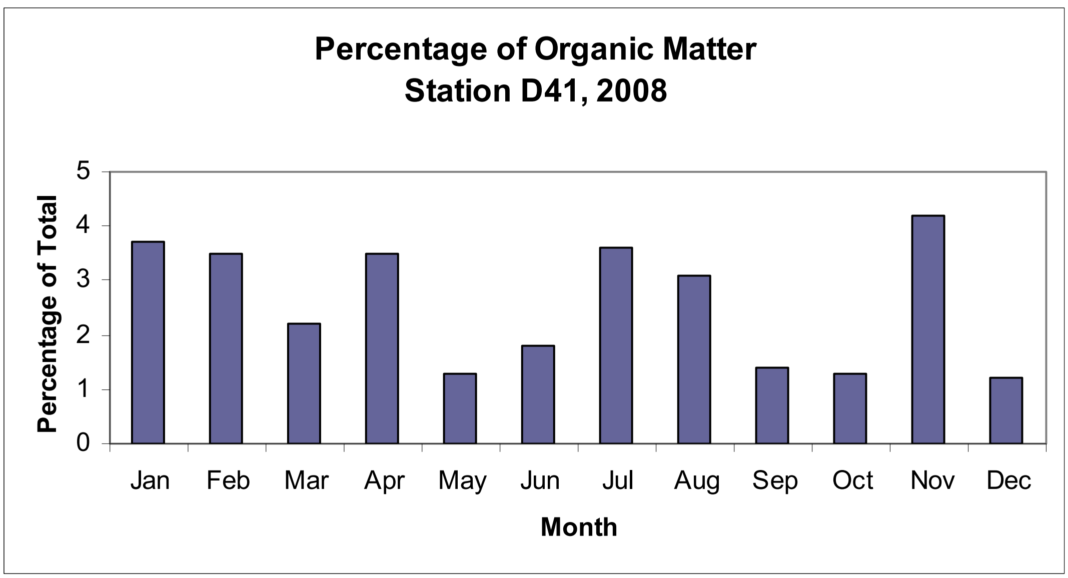
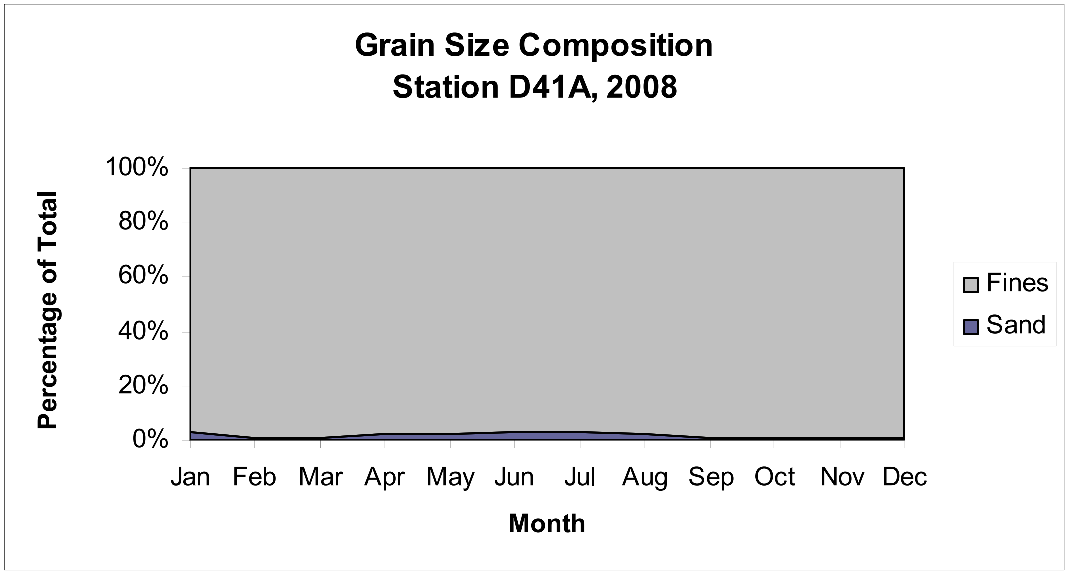


Figure 6-22 Sediment grain size and organic content at Station D41A during 2008



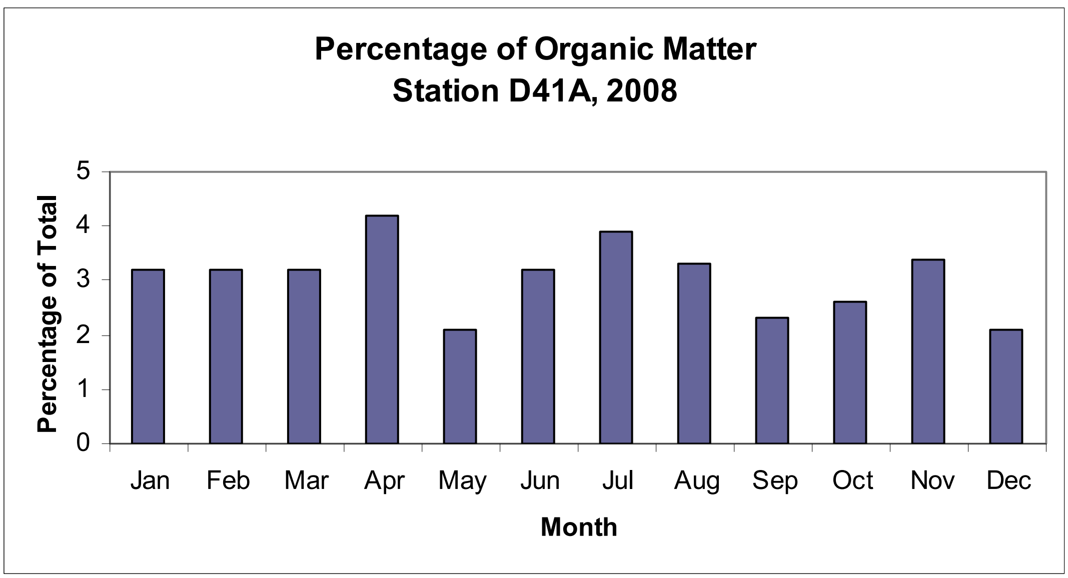


Table 6-1 Macrobenthic monitoring station characteristics, 2008

Station Region	Latitude Longitude	Substrate composition	Approx. salinity range (uS/cm)
C9 Delta-Old River	37° 49' 50" 121° 33' 09"	Mostly sand in spring and summer. Fall and winter add silty clay.	272 - 907
P8 Delta San Joaquin River	37° 58' 42" 121° 22' 55"	Consistent. High sand content (≈60%).	436 - 754
D28A Delta Old River	37° 58' 14" 121° 34' 19"	Consistent. High sand content (≈70%).	283 - 851
D16 Delta San Joaquin River	38° 05' 50" 121° 40' 05"	Consistent. High sand content except aug.	263 - 1,190
D24 Delta Sacramento River	38° 09' 27" 121° 41' 01"	Consistent. High sand content (≈97%).	150 - 1,155
D4 Delta Sacramento River	38° 03' 45" 121° 49' 10"	Mixed composition of sand, fines, and organic materials.	280 - 9,625
D6 Suisun Bay	38° 02' 40" 122° 07' 00"	Consistent. High fines content (≈95%)	16,305 - 33,870
D7 Grizzly Bay	38° 07' 02" 122° 02' 19"	Consistent. High Fines content (≈99%)	4,095 - 24,535
D41 San Pablo Bay	38° 01' 50" 122° 22' 15"	Mixed composition of sand, fines, and organic material.	33,305 - 45,179
D41A San Pablo Bay	38° 03' 75" 122° 24' 40"	Consistent. High fines content (≈98%)	24,605 - 39,929

Chapter 7 Dissolved Oxygen Monitoring in the Stockton Ship Channel

Introduction

The Department of Water Resources (DWR) Bay-Delta Monitoring and Analysis Section has been monitoring dissolved oxygen (DO) levels in the Stockton Ship Channel (channel) during the late summer and fall since 1968. Due to a variety of factors, DO levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River at Stockton.

Because low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the State Water Resources Control Board (SWRCB) established specific water quality objectives to protect these uses. Within the channel, two separate DO objectives have been established. The most recent Basin Plan (1998) of the Central Valley Regional Water Quality Control Board establishes a baseline objective of 5.0 mg/L DO 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.

As part of a 1969 Memorandum of Understanding between DWR, the U.S. Fish and Wildlife Service, the U.S. Bureau of Reclamation, and the Department of Fish and Game, DWR has installed a rock barrier across the upstream entrance (head) to 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 temporarily 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.

This report describes DO monitoring results during the period of June through November 2008, which includes an instance when San Joaquin River net flow at Stockton reached a minimum of -79 cfs. Installation of the barrier began on October 1 and was completed on October 16. Barrier removal began on November 3 and was completed by November 9, 2008.

Methods

Monitoring was conducted approximately every two weeks by vessel on 12 monitoring cruises from June 16 to November 25, 2008. During each of the monitoring cruises, 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; Figure 7-1). For geographic reference and simplicity of reporting, the sampling stations are keyed to channel light markers. Because monitoring results differ along the channel, sampling stations are grouped into western, central, and eastern regions. These regions are highlighted in Figure 7-1.

Figure 7-1 Monitoring sites in the Stockton Ship Channel

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.

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. Average daily flows on the San Joaquin River near 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.

Flows of the San Joaquin River past Stockton used in this report were obtained from data recorded by the USGS flow monitoring station northeast of Rough and Ready Island. 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[1]. 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 July 2008, net flow at Stockton reached a minimum of -79 cfs.

Results

During the period of this study, DO levels varied by season and between regions within the channel (excluding the turning basin). Overall study

[1] 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.

period range was 4.5 to 10.3 mg/L at the surface and 4.3 to 9.8 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 6.9 to 8.5 mg/L at the surface and 6.7 to 8.4 mg/L at the bottom. In the central portion of the channel, DO concentrations were variable, ranging from 5.5 to 8.4 mg/L at the surface and 5.4 to 8.2 mg/L at the bottom. In the eastern channel, DO levels were the lowest and tended to be more stratified than the other stations, ranging from 4.5 to 10.3 mg/L at the surface and 4.3 to 9.8 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 1,325 cfs in October to a low of 584 cfs in September. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 1,070 cfs in October to a low of -79 cfs in July (Figure 7-2).

The findings for the summer and fall of 2008 are briefly summarized by month as follows. Because of the unique hydro-morphology of station 14 (the Stockton Turning Basin), the findings for this station are discussed separately from those of the other channel stations.

June

Monitoring was conducted on June 16th. Surface DO levels ranged from 4.5 mg/L at station 13 to 7.4 mg/L at station 1. Bottom DO levels ranged from 4.3 mg/L at station 12 to 7.2 mg/L at station 1. Dissolved oxygen values fell below the 5.0 mg/L objective at station 13 at the surface and stations 11-13 at the bottom (Figure 7-3).

Figure 7-3 DO and water temperature during one monitoring cruise in June, 2008

Water temperatures ranged from 21.3 ^oC (station 1) to 24.2 ^oC (station 12) at the surface and 21.1 ^oC (station 1) to 23.2 ^oC (station 13) at the bottom (Figure 7-3).

Flows on the San Joaquin River near Vernalis during the month of June ranged from 875 to 1,502 cfs. Net flow in the San Joaquin River near Stockton during June ranged from 4.1 to 435 cfs (Figure 7-2).

July

Monitoring cruises were conducted on July 1, 16 and 30. Surface DO levels ranged from 5.1 mg/L at station 13 to 7.6 mg/L at station 1. Bottom DO levels ranged from 5.1 mg/L at stations 12 and 13 to 7.4 mg/L at station 1 (Figure 7-4).

Figure 7-4 DO and water temperature during three monitoring cruises in July, 2008

Water temperatures ranged from 21.6 ^oC (station 1) to 26.7 ^oC (station 12) at the surface and 21.6 ^oC (station 1) to 26.1 ^oC (station 13) at the bottom (Figure7-4).

Flows on the San Joaquin River near Vernalis during the month of July ranged from 737 to 1,035 cfs. Net flow in the San Joaquin River near Stockton during July ranged from -79 to 379 cfs (Figure 7-2).

August

Monitoring cruises were conducted on August 14 and 28. Surface DO levels ranged from 5.5 mg/L at station 9 to 7.6 mg/L at station 12. Bottom DO levels ranged from 5.1 mg/L at station 12 to 7.3 mg/L at station 1 (Figure 7-5).

Figure 7-5: DO and water temperature during two monitoring cruises in August, 2008

Water temperatures ranged from 23.7 ^{o}C (station 1) to 26.5 ^{o}C (station 12) at the surface and 23.5 ^{o}C (station 1) to 25.9 ^{o}C (station 13) at the bottom (Figure 7-5).

Flows on the San Joaquin River near Vernalis during the month of August ranged from 771 to 987 cfs. Net flow in the San Joaquin River near Stockton during August ranged from 40 to 508 cfs (Figure 7-2).

September

Monitoring cruises were conducted on September 12 and 29. Surface DO levels ranged from 5.7 mg/L at station 9 to 7.8 mg/L at station 1. Bottom DO levels ranged from 5.2 mg/L at station 12 to 8.0 mg/L at station 2 (Figure 7-6). However, the DO objective increased to 6 mg/L and six stations fell below the objective on September 12, but all met the objective on September 29.

Figure 7-6 DO and water temperature during two monitoring cruises in September, 2008

Water temperatures ranged from 21.3 ^{o}C (station 1) to 24.7 ^{o}C (station 12) at the surface and 21.3 ^{o}C (station 1) to 24.5 ^{o}C (station 12) at the bottom (Figure 7-6).

Flows on the San Joaquin River near Vernalis during the month of September ranged from 584 to 1,011 cfs. Net flow in the San Joaquin River near Stockton during September ranged from 188 to 524 cfs (Figure 7-2).

October

Monitoring cruises were conducted on October 10 and 24. Surface DO levels ranged from 6.2 mg/L at station 9 to 10.3 mg/L at station 13. Bottom DO levels ranged from 6.3 mg/L at stations 9 and 10 to 9.8 mg/L at station 13 (Figure 7-7).

Figure 7-7: DO and water temperature during two monitoring cruises in October 2008

Water temperatures ranged from 17.0 ^{o}C (stations 1 and 8) to 20.5 ^{o}C (stations 9 -12) at the surface and 17.0 ^{o}C (stations 1, 8 and 9) to 20.4 ^{o}C (stations 10 and 11) at the bottom (Figure 7-7).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 635 to 1,325 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 406 to 1,070 cfs (Figure 7-2).

November

Monitoring cruises were conducted on November 11 and 25. Surface DO levels ranged from 7.2 mg/L at station 10 to 8.4 mg/L at station 7. Bottom DO levels ranged from 7.0 mg/L at station 11 to 8.3 mg/L at station 13 (Figure 7-8).

Water temperatures ranged from 14.4 °C (stations 1 - 5) to 16.1 °C (station 12) at the surface and 14.4 °C (stations 1, 8 and 9) to 15.6 °C (station 8) at the bottom (Figure 7-8).

Figure 7-8 DO and water temperature during two monitoring cruises in November, 2008

Flows on the San Joaquin River near Vernalis during the month of October ranged from 976 to 1,245 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 15 to 936 cfs (Figure 7-2).

Stockton Turning Basin (Station 14)

DO levels at the surface in the Stockton turning basin were below SWRCB objectives on only one occasion in October during the study period, and bottom DO levels dropped below the SWRCB standards during eight of ten monitoring cruises from June through October. DO levels in June ranged from 12.4 mg/L at the surface to 4.9 mg/L at the bottom (Figure 9). DO levels in July ranged from 10.3 mg/L at the surface to 2.3 mg/L at the bottom. DO levels in August ranged from 12.7 mg/L at the surface to 1.7 mg/L at the bottom. September DO levels at the surface and bottom ranged from 10.7 to 3.7 mg/L, respectively. DO levels in October ranged from 9.6 mg/L at the surface to 5.9 mg/L at the bottom. November DO readings ranged from 9.5 mg/L at the surface to 7.5 mg/L at the bottom (Figure 7-9).

Figure 7-9 DO and water temperature in the Stockton Turning Basin from June through November, 2008

Summary

DO concentrations in the Stockton Ship Channel fell below the SWRCB's 5.0 mg/L and 6.0 mg/L objectives at six stations (excluding the Stockton turning basin) during two of ten monitoring cruises during the study period. The Stockton turning basin was below DO objectives during eight of ten monitoring cruises.

Flows on the San Joaquin River near Vernalis ranged from a low of 584 cfs in July to a high of 1,325 cfs in September. Net daily flow on the San Joaquin River past Stockton ranged from a low of -79 cfs in July to a high of 1,070 cfs in October. The head of Old River barrier was installed by October 16th and completely removed by November 9th.

Further monitoring operations for the summer and fall 2008 special study were suspended after November 25, 2008.

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

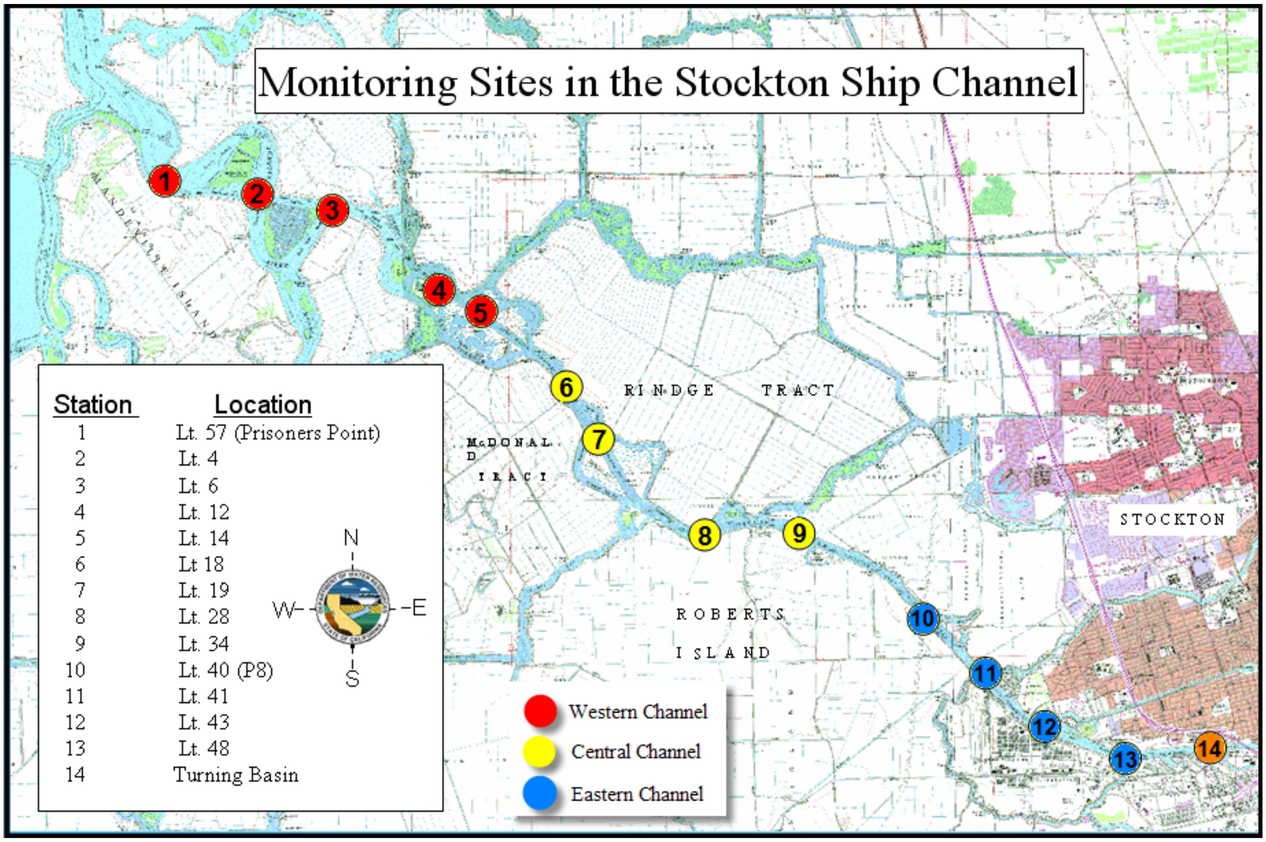


Figure 7-2 San Joaquin River mean daily flow, summer/fall 2008

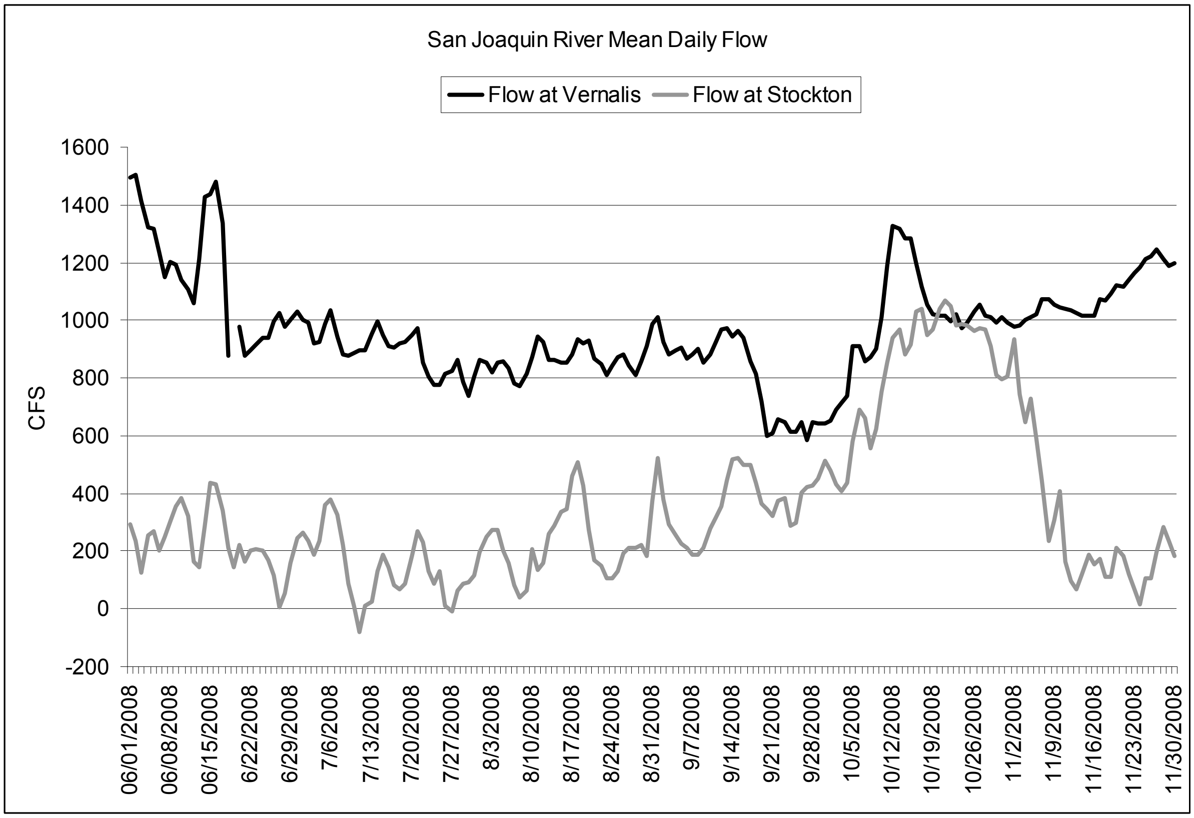


Figure 7-3 DO and water temperature during one monitoring cruise in June 2008

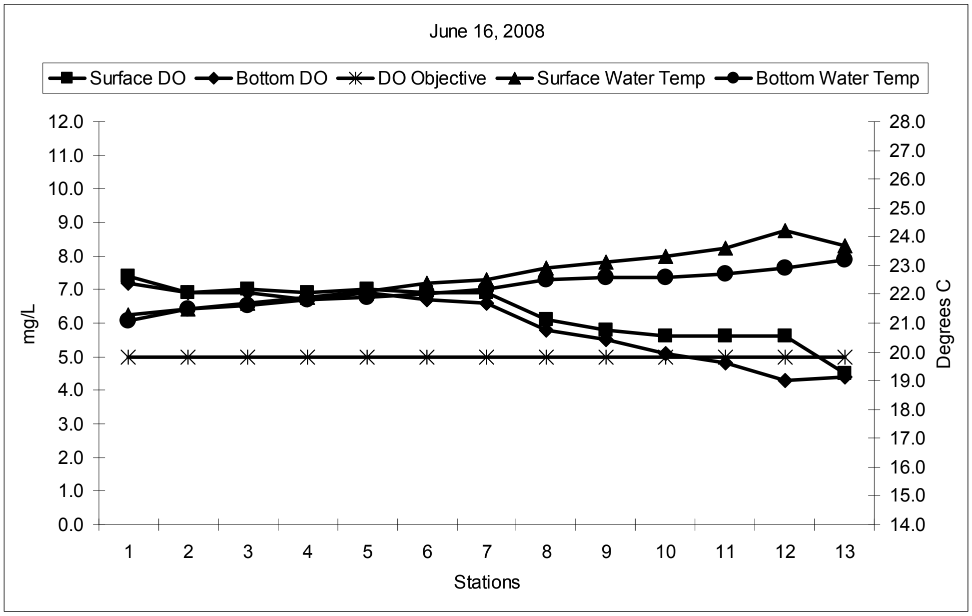
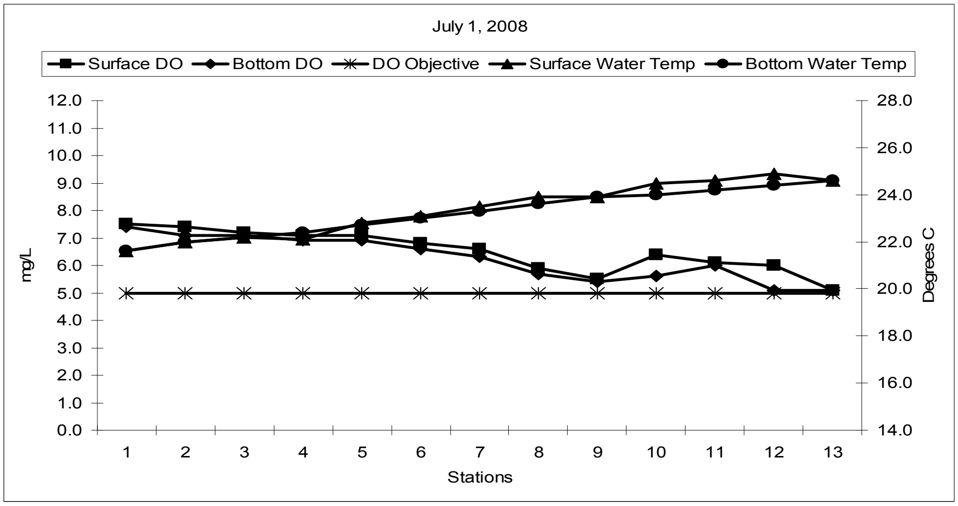
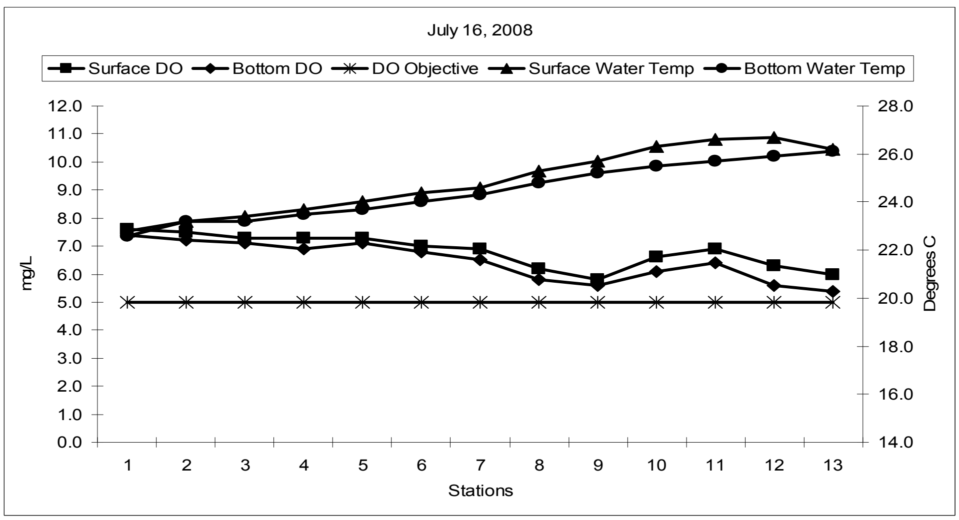


Figure 7-4 DO and water temperature during three monitoring cruises in July 2008





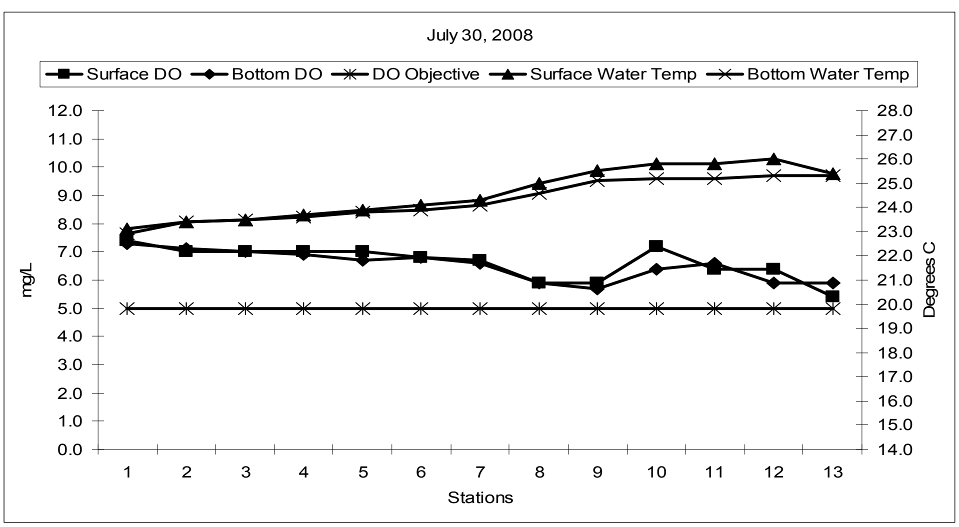
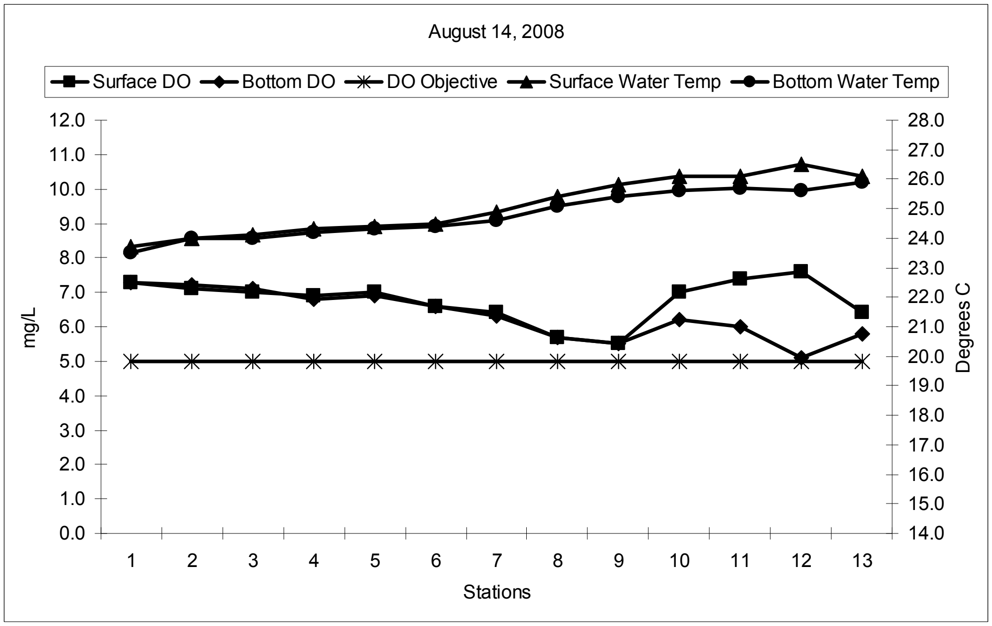


Figure 7-5 DO and water temperature during two monitoring cruises in August 2008



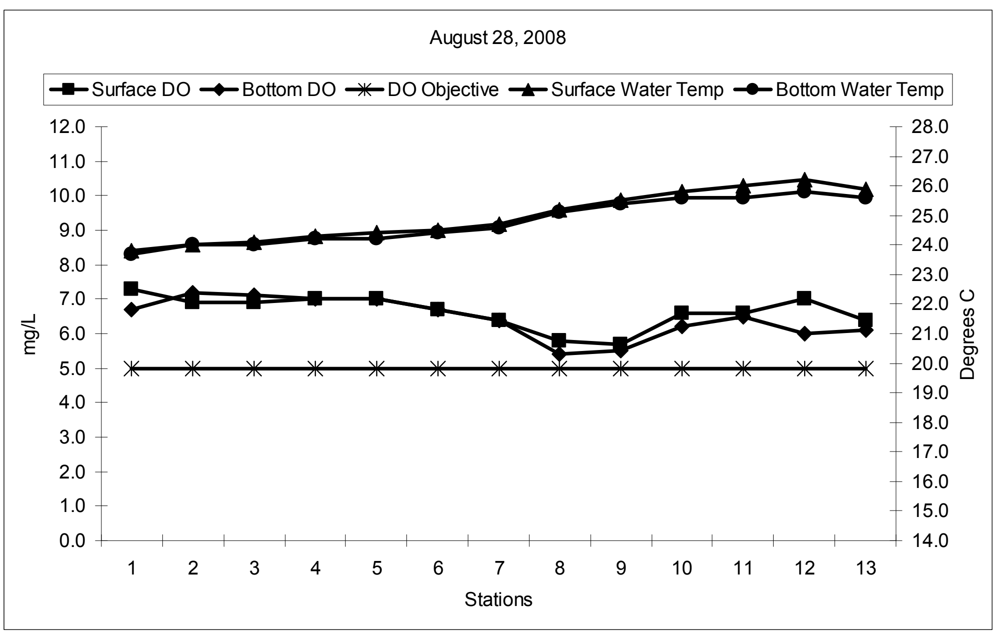
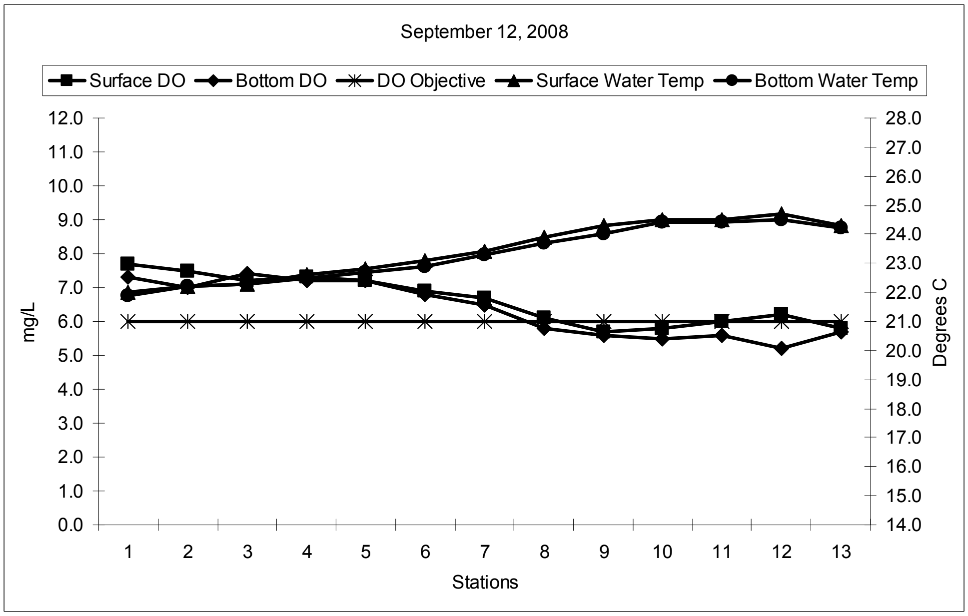


Figure 7-6 DO and water temperature during two monitoring cruises in September 2008



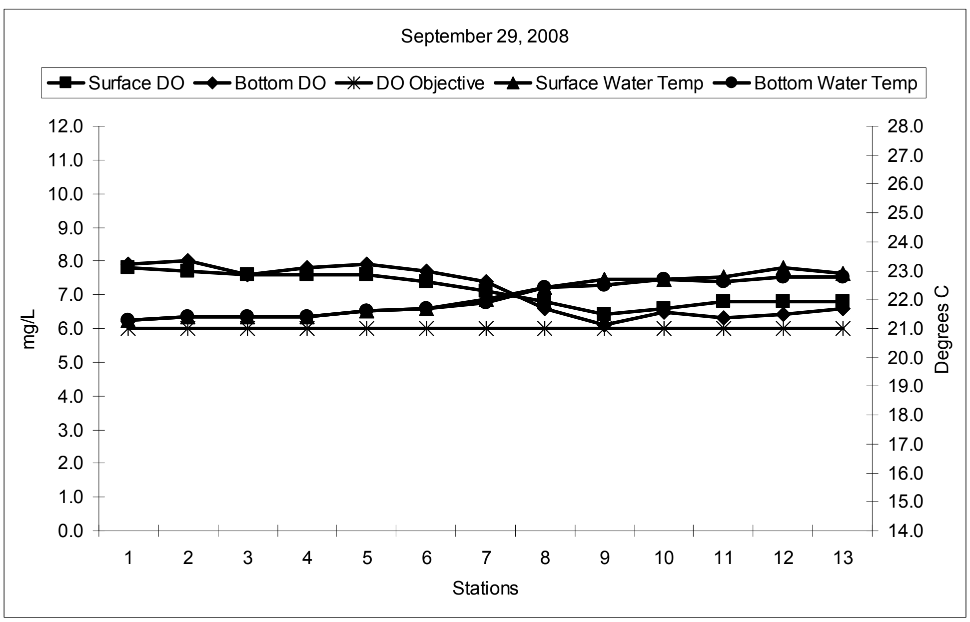
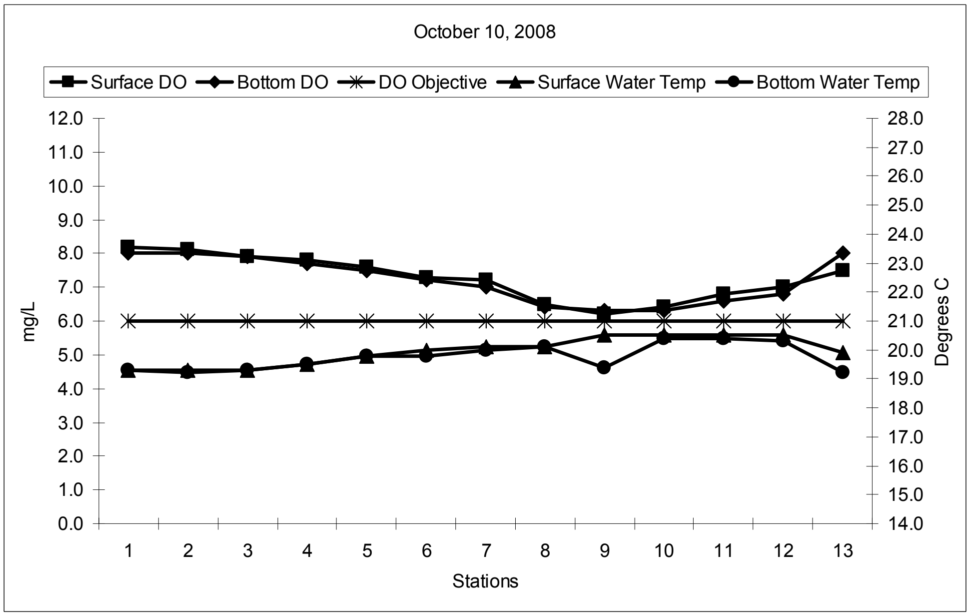


Figure 7-7 DO and water temperature during two monitoring cruises in October 2008



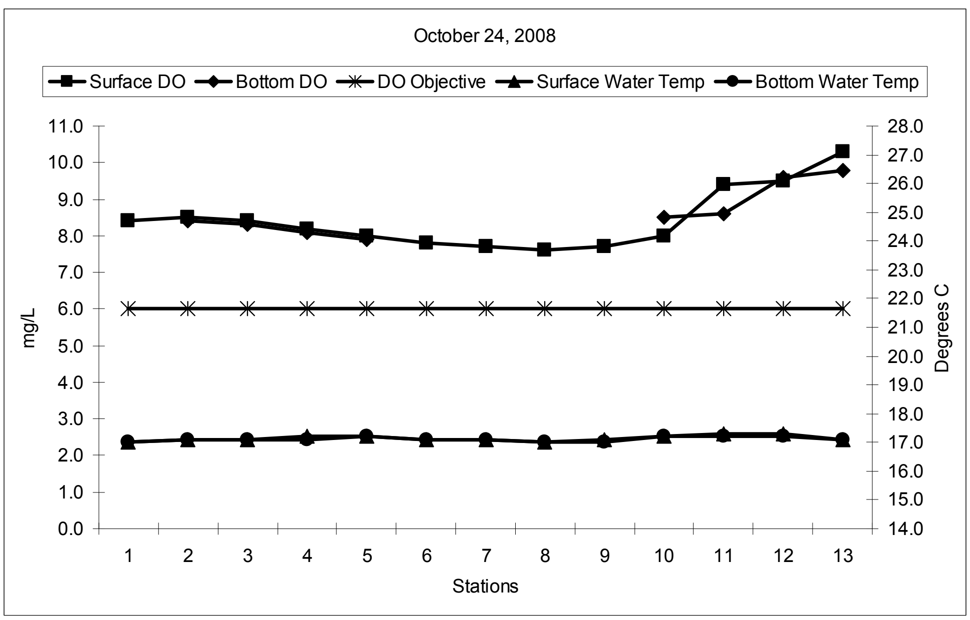
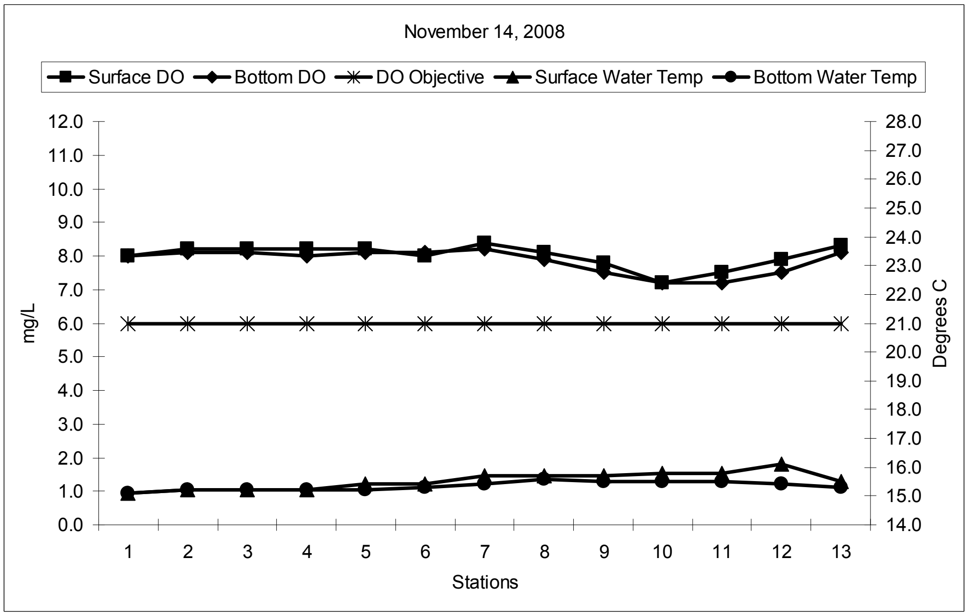


Figure 7-8 DO and water temperature during two monitoring cruises in November 2008



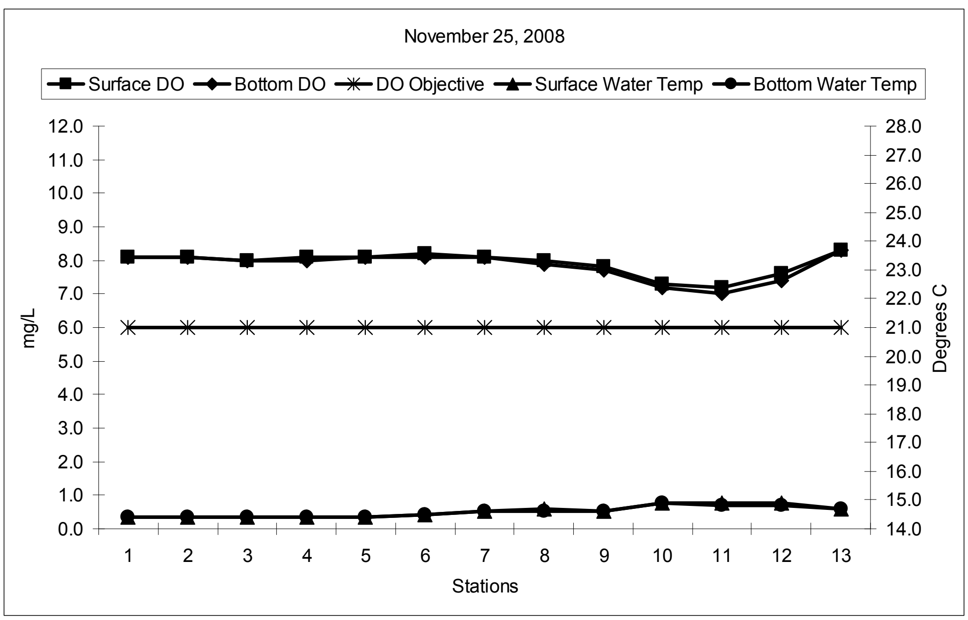
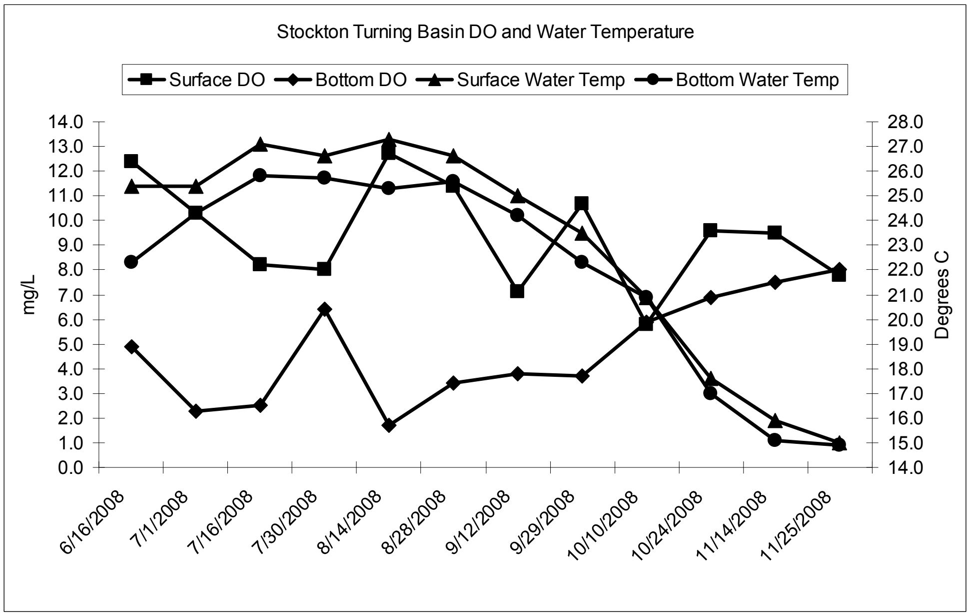


Figure 7-9 DO and water temperature in the Stockton Turning Basin from June through November 2008



Chapter 8 Continuous Monitoring

Introduction

The Department of Water Resource's Continuous Monitoring Program supplements the DWR's monthly discrete Compliance Monitoring Program by providing real-time hourly and quarter-hourly water quality and environmental data from nine shore-based automated sampling stations in the upper San Francisco Estuary (Figure 8-1). These stations provide continuous measurements of seven water quality parameters and four environmental parameters. These measurements are used by operators of the State Water Project and the Central Valley Project to assess the impacts of the project operations and to adjust project operations to comply with mandated water quality standards. The Continuous Monitoring Program has been in operation since 1983. This chapter summarizes the results of continuous water quality monitoring at nine sites for calendar year 2008. The stations were divided into three regions to allow for detail in the plots:

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

Methods

Continuous data are collected for the water quality and environmental parameters shown in Table 8-1. Each of the nine monitoring stations collects continuous data for water temperature, pH, dissolved oxygen, surface specific conductance, chlorophyll fluorescence, and turbidity. Additional sensors are installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom specific conductance, 1.5 meters above the channel bottom. These measurements, along with river stage data measured at the Mallard and Martinez stations, are needed to determine compliance with the salinity standard (also known as X2) mandated by the Bay-Delta Plan (SWRCB 1995). Environmental data—such as air temperature, solar radiation, wind speed, and direction—are measured at all stations except Mossdale (only air temperature), Prisoners Point, Vernalis, and Hood stations (none). as part of Water Right Decision 1641's Table 3 objectives (SWRCB 1999).

Except for bottom specific conductivity, all water samples are collected at 1 meter below the water surface using a float-mounted multi-parameter water quality sonde. Water quality data and environmental data are recorded at 15-minute intervals.

Complete quarter-hourly data for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, chlorophyll florescence, turbidity, wind velocity, wind direction, solar radiation intensity and river stage are available by request to the Chief of the Real Time Monitoring and Support Section[1].

Results

The monthly averages of the continuous 15-minute collected for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, chlorophyll fluorescence, and turbidity for calendar year 2008 are shown in Figures 8-2 to 8-10.

Water Temperature

Water temperature was measured in degrees Centigrade (°C) using a YSI 6600 multi-parameter water quality sonde.

Average monthly water temperatures in the San Francisco Estuary (Estuary) ranged from 7.9 °C in January 2008 at the Prisoners Point station on the San Joaquin River to 26.2 °C in July 2008 at the Stockton station on the San Joaquin River (Figure 8-2). Maximum water temperature values are similar to the same time period in 2007.

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 July through September at the San Joaquin River stations of Stockton, Mossdale and Vernalis.

Dissolved Oxygen

Dissolved oxygen was measured using a YSI 6600 multi-parameter water quality sonde utilizing new technology optical DO sensor.

Average monthly dissolved oxygen values for the nine monitoring stations ranged from 5.8 mg/L to 12.8 mg/L (Figure 8-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton, Mossdale and Vernalis. A monthly average of 5.8 mg/L was calculated for the Stockton station in June 2008, and a value of 12.8 mg/L was calculated for the Mossdale station for June 2008. All other stations showed monthly averages between 8.0 mg/L and 10.9 mg/L with the Stockton station recording lower values starting in June 2008. The Hood station showed a decrease in the measured values starting in May 2008 and not recovering until December 2008. All compliance monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the Central Valley Water Resources Control Board in the Basin Plan. Monthly average dissolved-oxygen values at the Stockton station were highly variable and ranged from 4.5 mg/L to 14.1 mg/L. The Stockton station, located in the Stockton Deep Water Ship Channel, showed a DO sag to 5.8 mg/L in June 2008 similar to 2007. The operation of the new Department aeration facility

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[1] Chief Real-Time Monitoring and Support Section, Division of Environmental Services, Office of Water Quality, Environmental Water Quality and Estuarine Studies Branch, 3500 Industrial Blvd., West Sacramento CA 95619

located near the Stockton station produced an increase in the DO values by July 2008. The recovery in 2007 did not occur until October 2007. The San Joaquin River stations at Mossdale and Vernalis showed a significant rise in DO for the same time period. The pattern of winter sag was first identified in 2000 was not evident in 2008.

During summer and fall 2008, monthly average dissolved oxygen values at the Mossdale and Vernalis stations showed a familiar pattern of increase for July and August. Monthly average dissolved oxygen values in previous years showed a similar pattern from June to September. The June increase to 12.8 mg/L at the Mossdale station in 2008 showed a drop in summer DO levels from the high of 13.5 mg/L in 2007. The high average summer DO levels seen at the Mossdale and Vernalis stations coincided with high chlorophyll fluorescence during the same period (Figure 8-9).

Specific Conductance

Specific conductance was measured using a YSI 6600 multi-parameter water quality sonde.

Monthly average surface specific conductance for the San Francisco Estuary ranged from 155 µS/cm to 28,781 µS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 8-4). The 2008 data are very similar to the 2007 data range. Data collected at the Mossdale and Stockton stations on the San Joaquin River upstream of the confluence of the Sacramento and San Joaquin rivers show a higher average specific conductance than the data collected from Hood and Rio Vista stations on the Sacramento River upstream of the confluence of the Sacramento and San Joaquin rivers (Figure 8-4a).

Bottom specific conductance measured at the Antioch, Mallard Island, and Martinez stations exhibited seasonal patterns and ranges similar to the surface specific conductance (Figure 8-5).

pH

pH was measured using a YSI 6600 multi-parameter water quality sonde.

Monthly average pH levels for the Estuary for all stations ranged from 7.3 to 9.2 pH units (Figure 8-6). Unlike 2007—where the stations on the San Joaquin River showed a decrease in pH for the months April thru June, the Mossdale and Vernalis stations showed a significant increase in pH values during the same time period in 2008. The Stockton station showed an increase n pH starting in July 2008 and peaking August 2008.

Air Temperature

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

Monthly average air temperatures in the Estuary ranged from 6.0 °C in December 2008 at the Rio Vista station on the Sacramento River to 25.2 °C August 2008 at the Mossdale station on the San Joaquin River. (Figure 8-7). The maxima and minima monthly average air temperatures for 2008 were within 0.3 °C from 2007 values.

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured using a.YSI 6600 multi-parameter water quality sonde .

Monthly average chlorophyll fluorescence recorded at the stations in the Estuary ranged from minima of 1.01 fluorescence units (FU) in October 2008 at the Rio Vista station on the Sacramento River to maxima of 67.8 FU in June 2008 at the Mossdale station on the San Joaquin River (Figure 8-9, a-c).

Turbidity

Turbidity was measured using a YSI 6600 multi-parameter water quality sonde.

Monthly average turbidity was recorded at the stations in the Estuary ranged from minima of 1 Nephelometric Turbidity Units (NTU) at the Prisoners Point station on the San Joaquin River in September 2008 to maxima of 68 NTU at the Hood station on the Sacramento River in February 2008 (Figure 8-10, a-c).

Stockton Ship Channel Dissolved Oxygen

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

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

Monthly average DO values in 2008 ranged from 5.8 to 9.5 mg/L. The lowest DO value occurred in June 2008 at the Stockton station on the San Joaquin River while the highest value of 9.5 mg/L occurred in April 2008 .

Monthly average DO values did not drop below the state-mandated standards of 5.0mg/L for 2008 at the Stockton station on the San Joaquin River in the Stockton Deep Water Ship Channel. The quarter hourly values for the Stockton station ranged from 4.5 to 14.1 mg/L. The minimum value of 4.5 mg/L was recorded in June 2008 with the maxima value recorded in April 2008. As seen in previous years, the DO levels drop during the summer months of May and June and recovered in July. This may be due to the operation of the Department's oxygen aeration station. The pattern of falling DO levels in the winter, first observed in 2000, was not observed in 2008 and remained above the 5.0 mg/L standard.

For 2008, average monthly DO values at the Stockton station did not drop below the standard 6.0 mg/L for the period September through November 2008. (Figure 8-8).

The box plots (Figure 8-8) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal "whiskers" indicate the range of hourly DO values for each month. Boxes represent monthly medians and averages. Open boxes indicate that the monthly median is greater than the monthly average, with the top of the box indicating the median, and the bottom of the box indicating the average. Filled boxes indicate that the monthly average is greater than the median, with the top of the box indicating the average and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the average are equal.

Summary

Water quality conditions in the upper San Francisco Estuary for calendar year 2008 were almost always in the expected range of values for water temperature, dissolved oxygen, specific conductance, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. The exceptions continue to be found on the San Joaquin River.

The upper San Joaquin River stations at Mossdale and Vernalis showed higher chlorophyll *a* fluorescence values in July, than any other station in the Estuary. the San Joaquin station at Mossdale showed higher dissolved oxygen values in July and August, than any other station in the Estuary with the Stockton station showing the lowest values for dissolved oxygen in June and July. As in 2007, the pH values at the Mossdale and Vernalis stations on the San Joaquin River increased during the months of June through September and returned near or lower than pH values measured at the other Estuary stations end of the year.

The San Joaquin River station at Stockton did not below the 5.0 mg/L standard, which was set by the CVRWQCB (1998),. The dissolved oxygen 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 Channel for September through November 2008 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*. Fourth Edition.

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

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

Chapter 8 Continuous Monitoring

Figure 8-1 Location of 9 shore-based automated sampling stations in the upper San Francisco Estuary

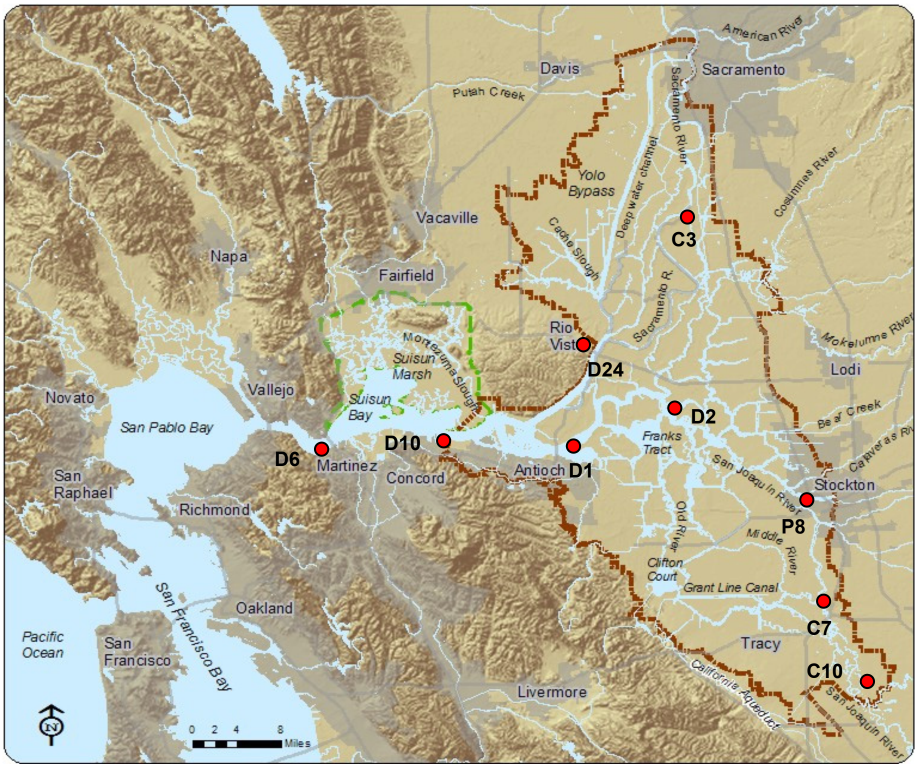

Fig 8-2 Average Monthly Water Temperature at Nine Stations 2008

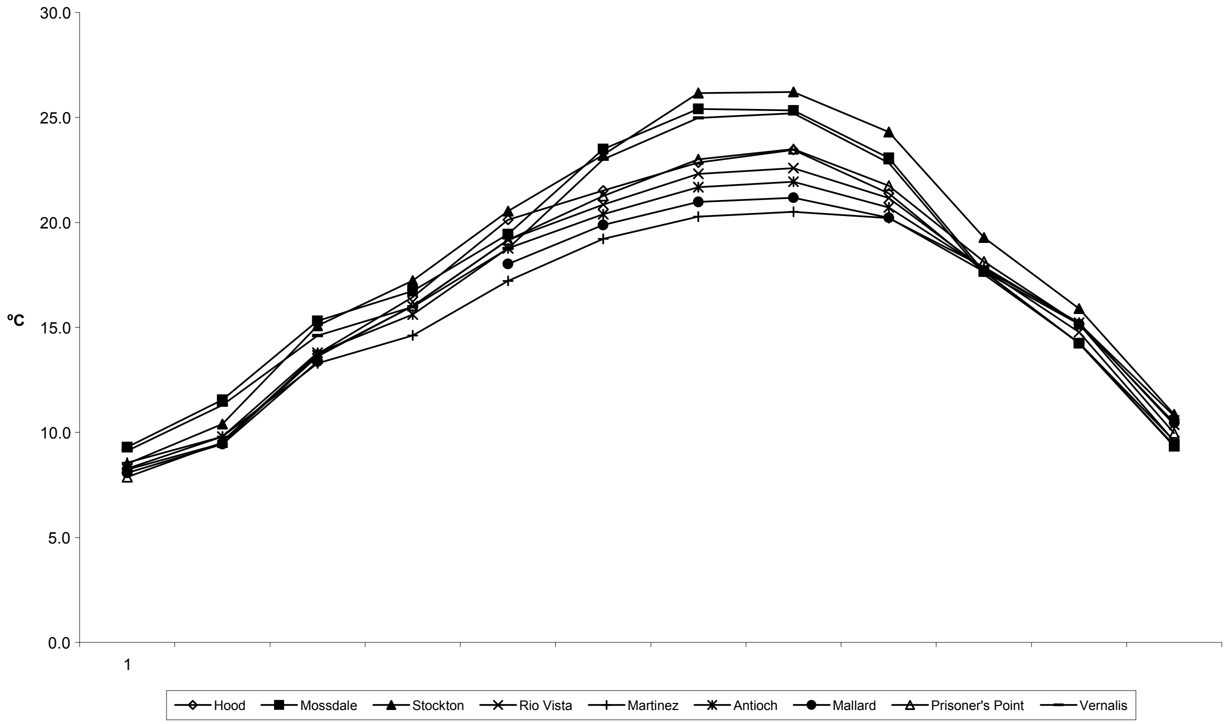

Fig 8-3 Average Monthly Dissolved Oxygen at Nine Statons 2008

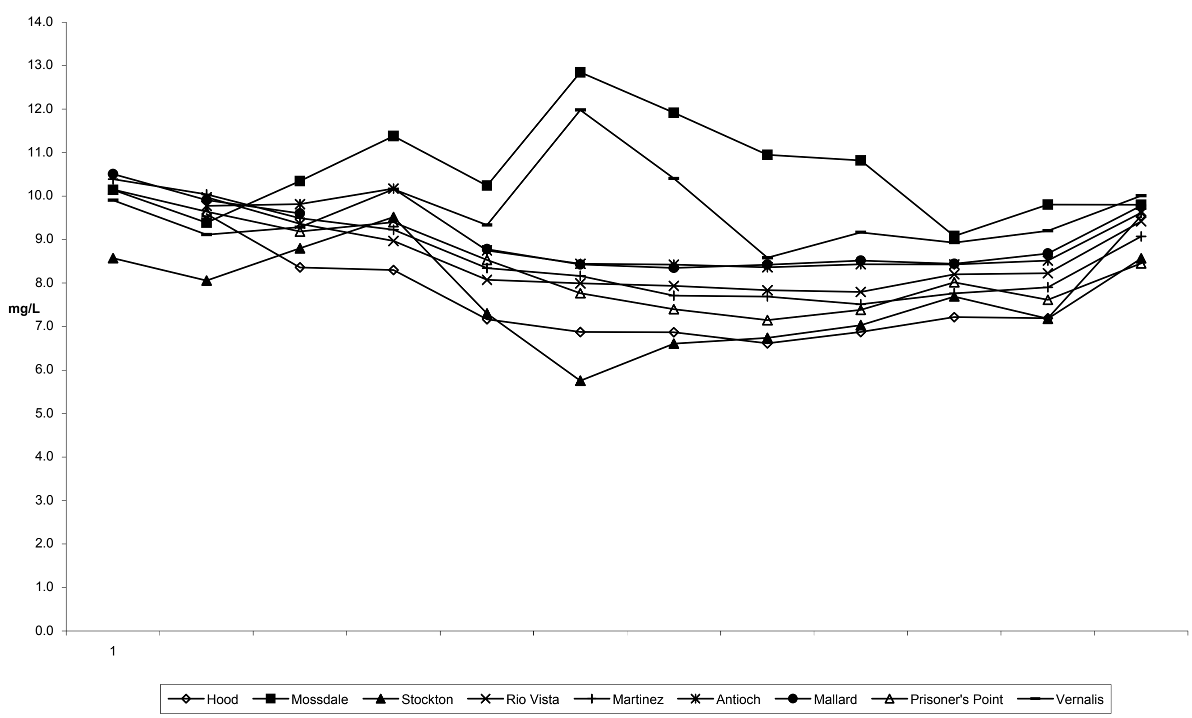

Fig 8-4 Average Monthly Specific Conductance at Nine Statons 2008

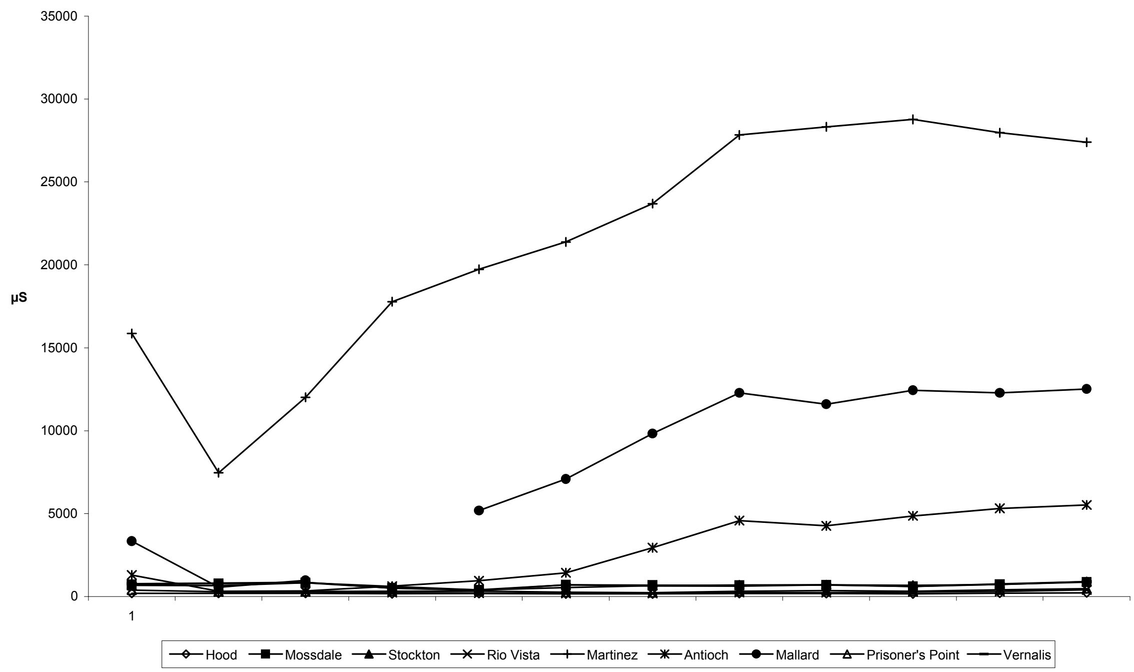

Fig 8-4A Average Monthly Specific Conductance at Six Stations 2008

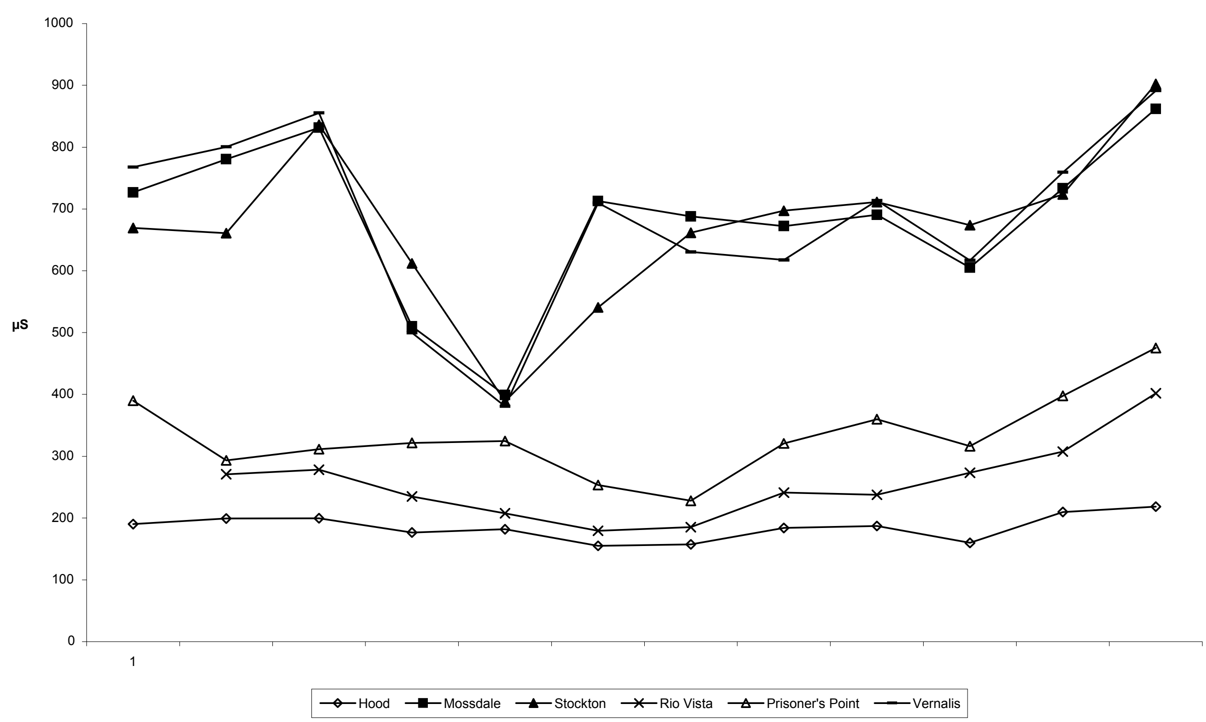

Fig 8-5 Average Monthly Surface and Bottom Specific Conductance at Three Tidally influenced Stations 2008

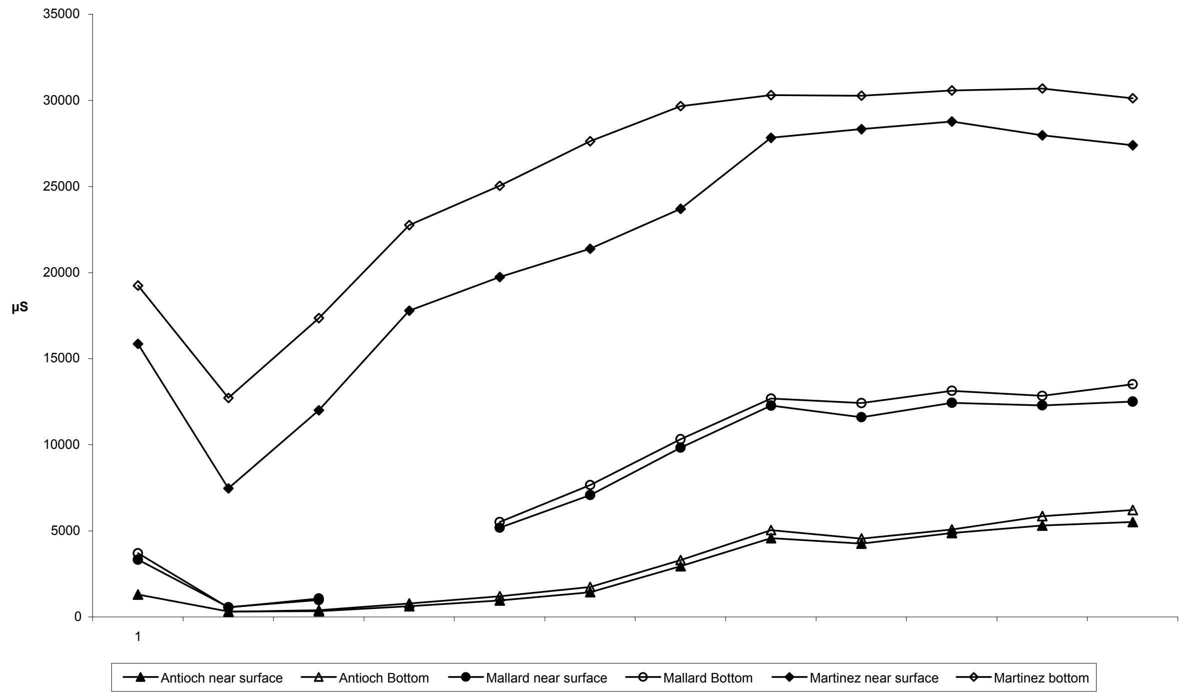

Fig 8-6 Average Monthly pH at Nine Stations 2008

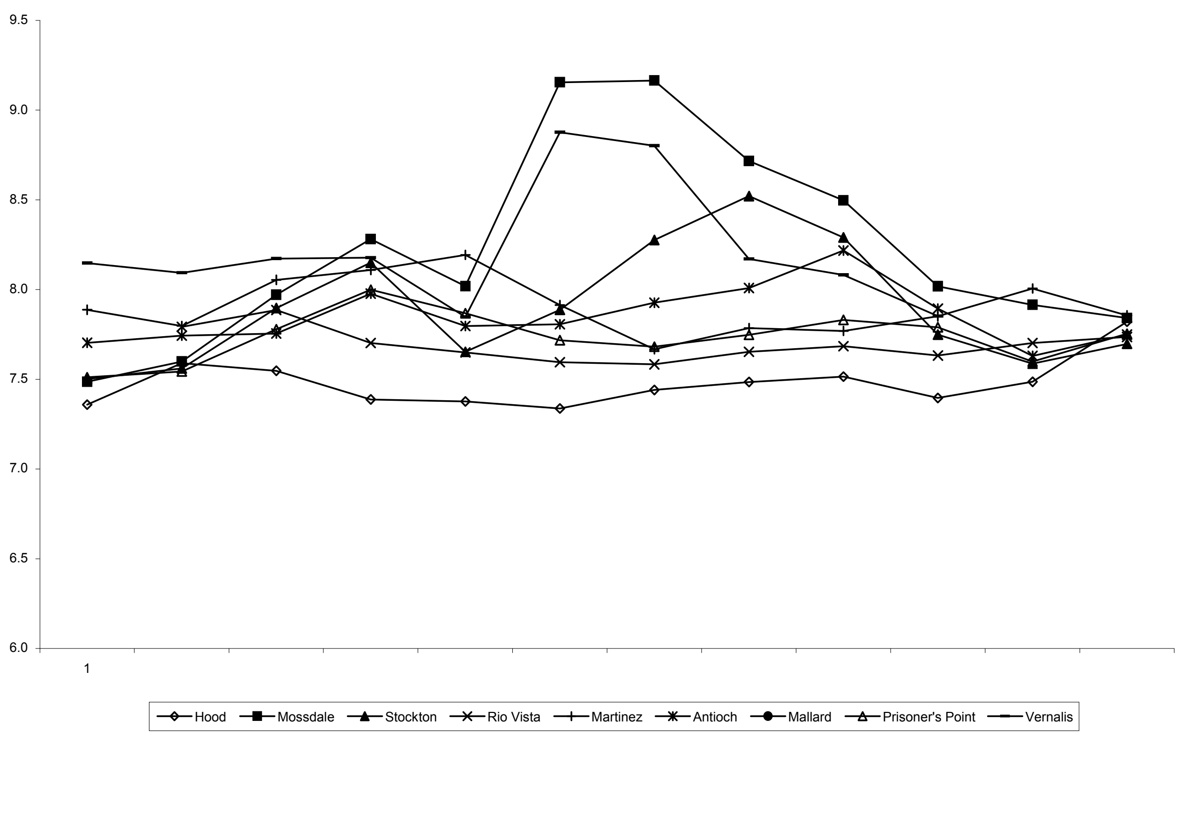

Fig 8-7 Monthly Average Air Temperature at Six Stations 2008

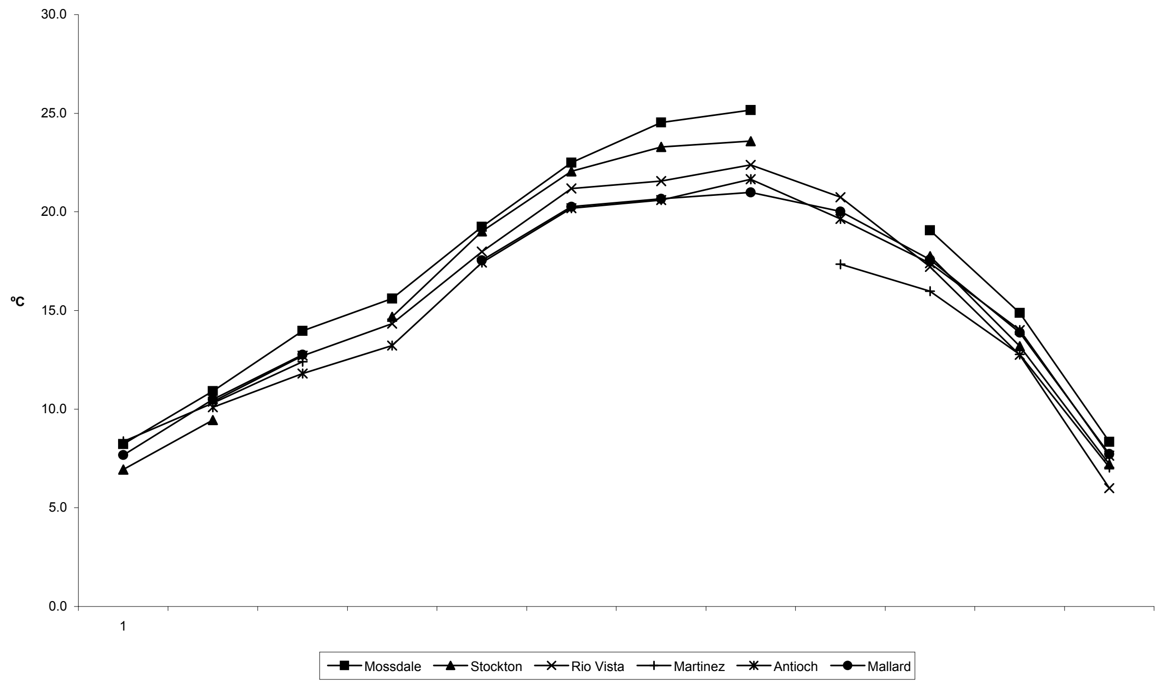

Fig 8-8 San Joaquin River @ Rough and Ready Island Range of Monthly Dissolved Oxygen Values 2008 * Solid Boxes when Monthly average higher than Monthly median

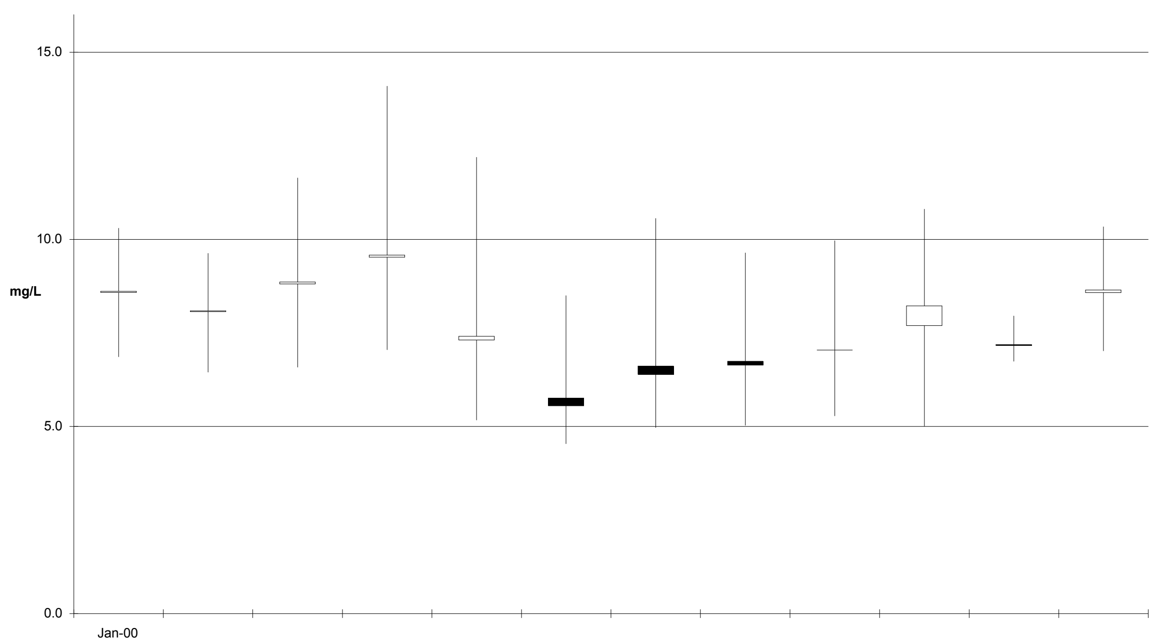

Fig 8-9 Average Monthly Cholorophyll at Nine Stations 2008

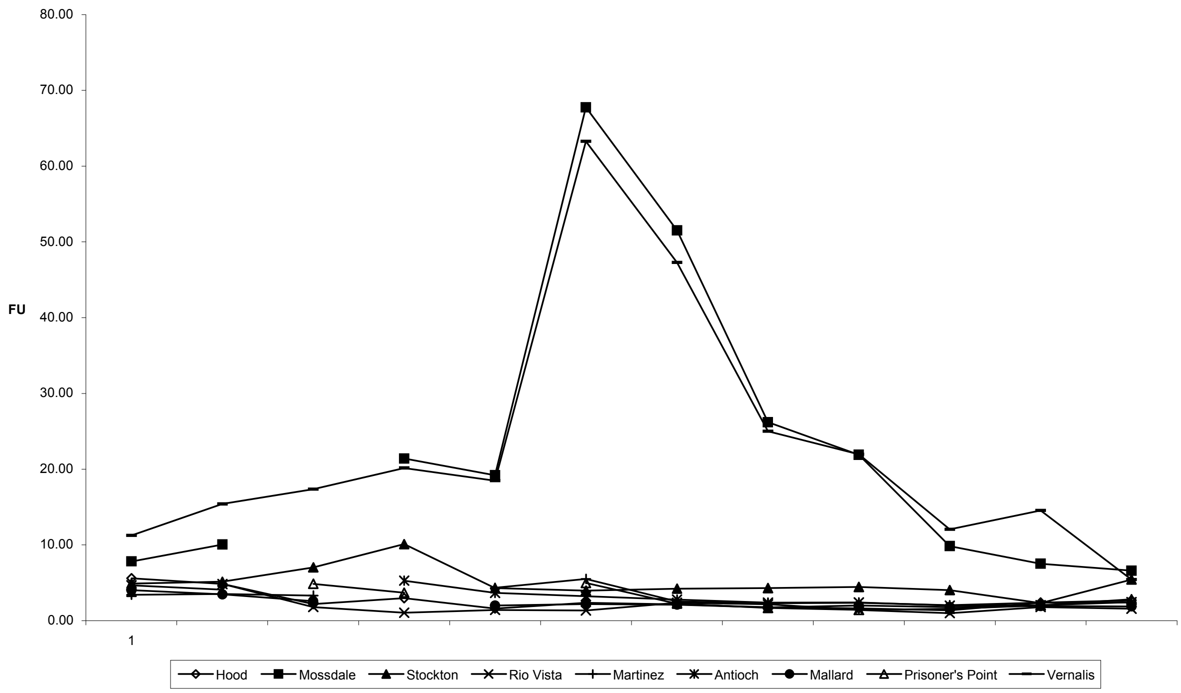

Fig 8-9A Average Monthly Cholorophyll at Two Sacramento River Stations 2008

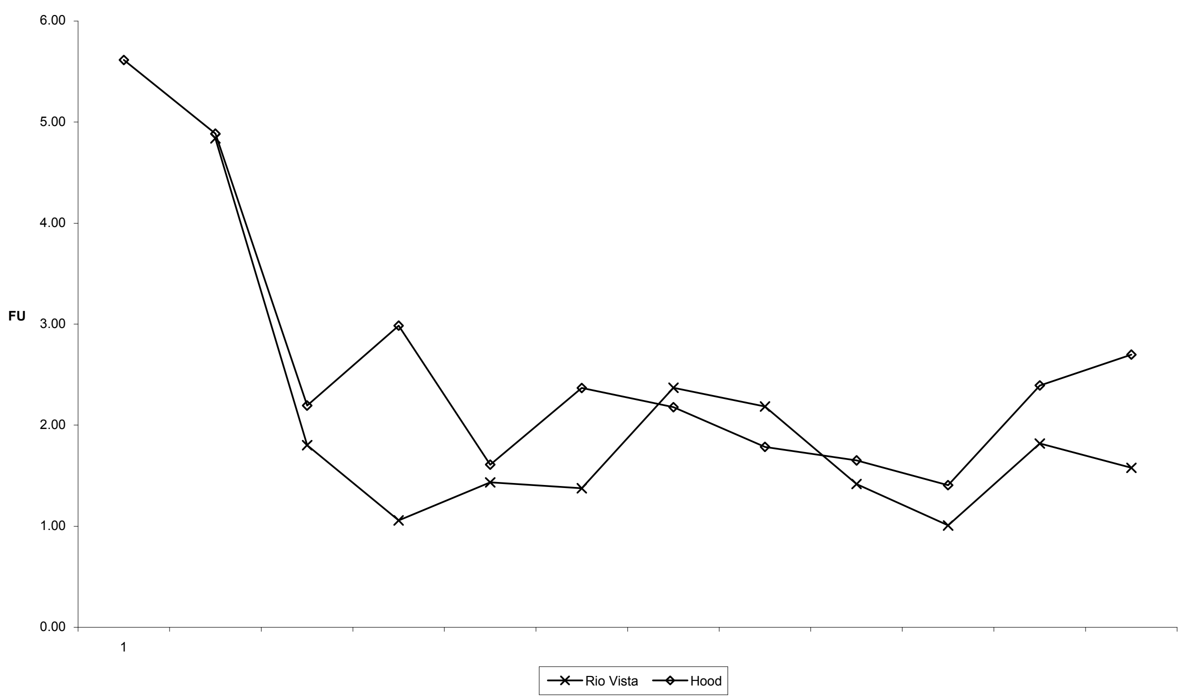

Fig 8-9B Average Monthly Chlorophyll at Four San Joaquin River Stations 2008

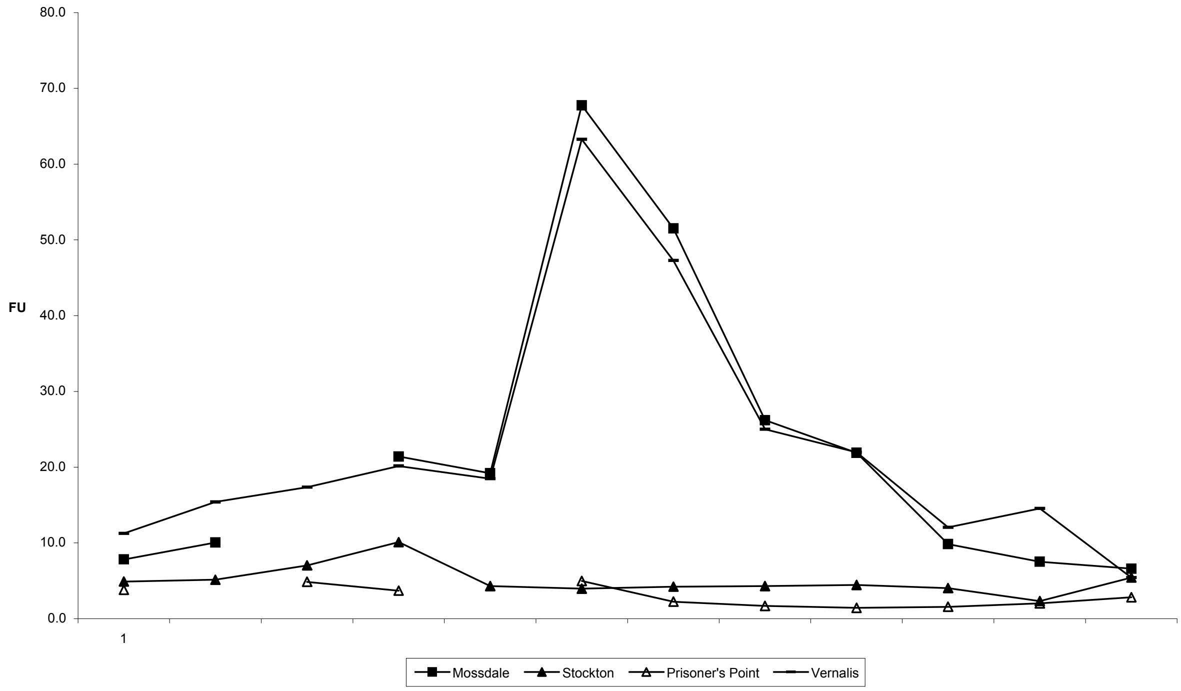

Fig 8-9C Average Monthly Cholorophyll at Three Tidally influenced Stations 2007

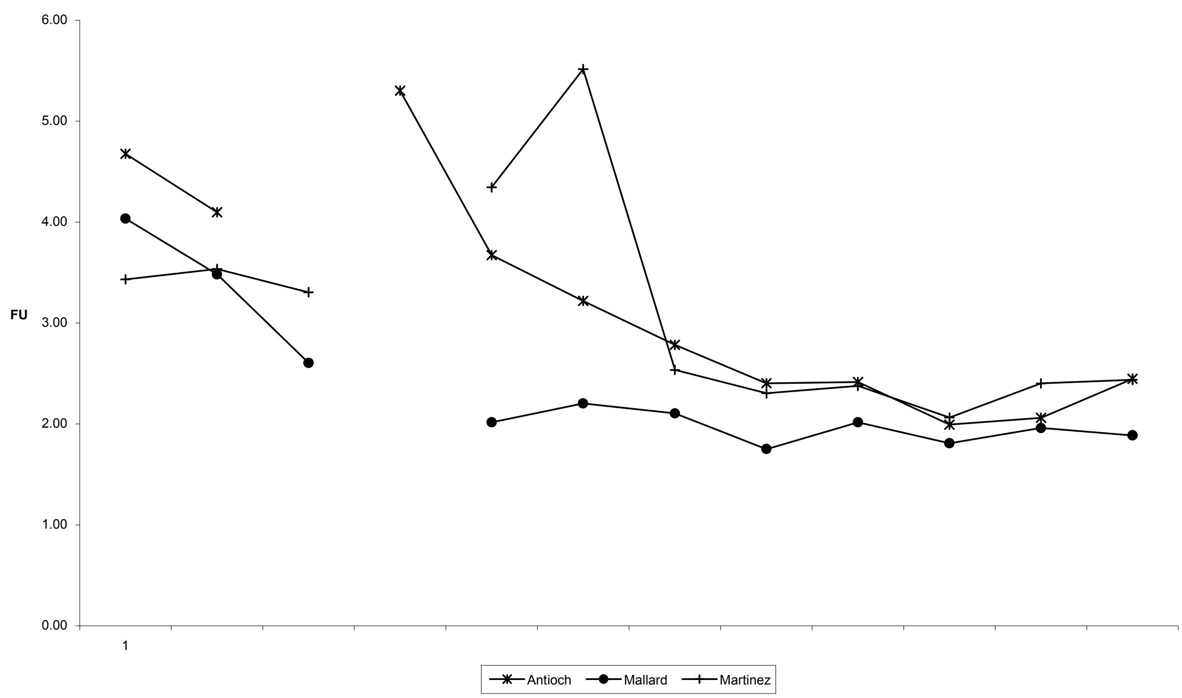

Fig 8-10 Average Monthly Turbidity at Nine Stations 2008

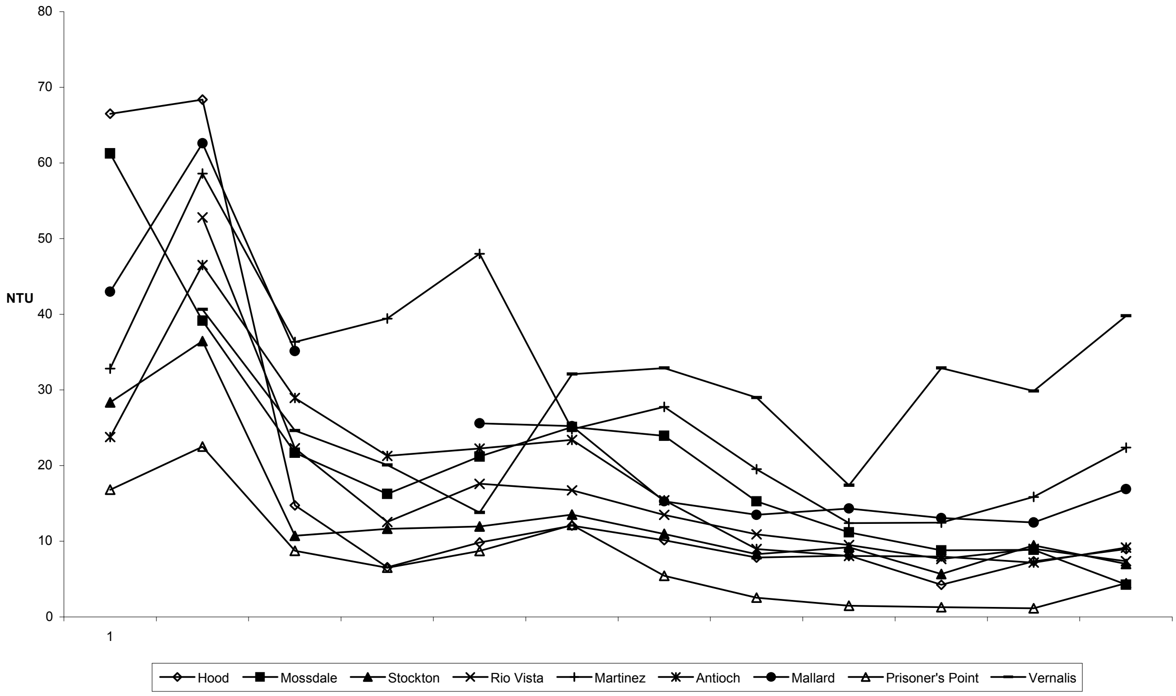

Fig 8-10A Average Monthly Turbidity at Two Sacramento River Stations 2008

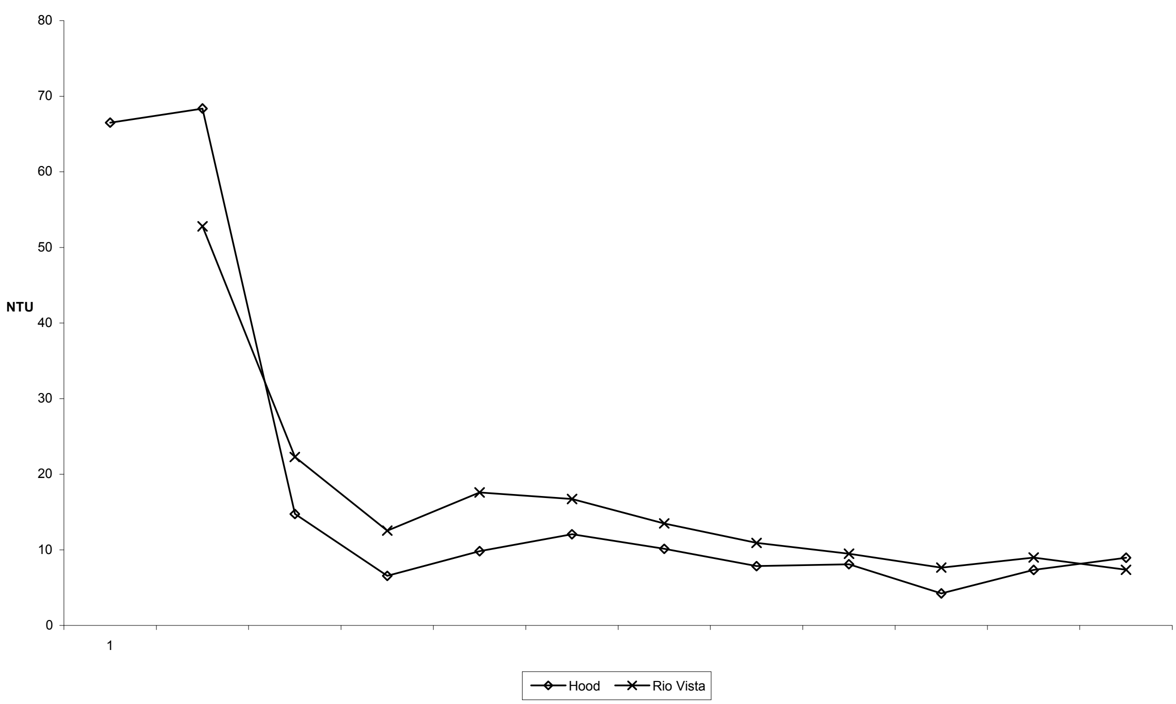

Fig 8-10B Average Monthly Turbidity
at Four San Joaquin River Stations 2008

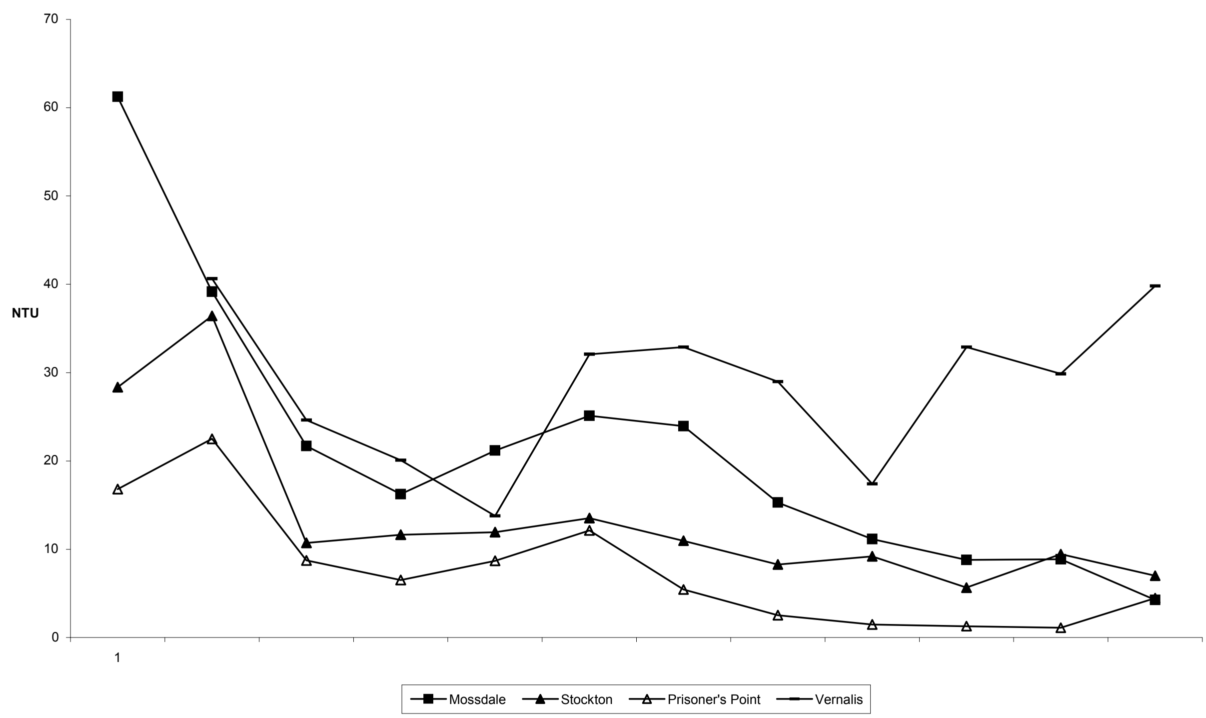

Fig 8-10C Average Monthly Turbidity
at Three Tidally influenced Stations 2008

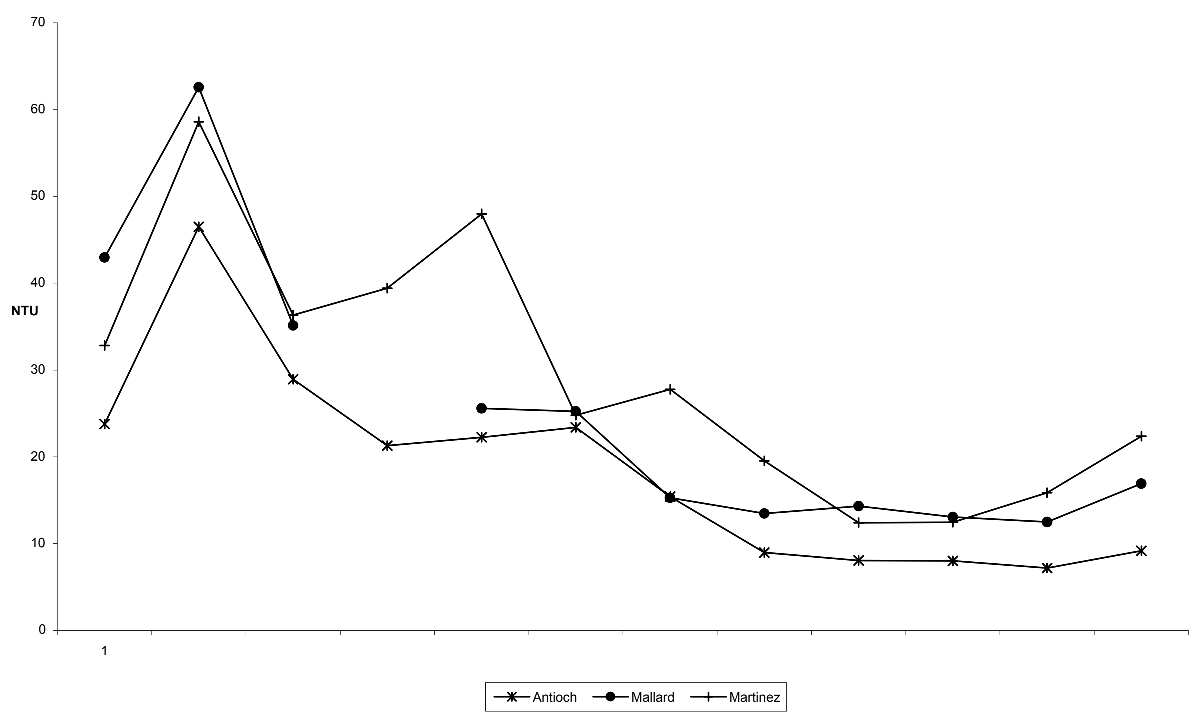

Table 8-1 Parameters

Parameter	Units	Frequency
Water Temperature	°C	15 minute instantaneous
Air Temperature	°C	15 minute instantaneous
Dissolved Oxygen	mg/L	15 minute instantaneous
pH	unitless	15 minute instantaneous
Chlorophyll Fluorescence	fluorescence units	15 minute instantaneous
Turbidity	NTU	15 minute instantaneous
Surface Specific Conductance	µS/cm	15 minute instantaneous
Bottom Specific Conductance	µS/cm	15 minute instantaneous
River Stage	feet (from mean sea level NGVD88)	15 minute instantaneous
Wind Speed	kilometers/hr	15 minute instantaneous
Wind Direction	degrees	15 minute instantaneous
Solar Radiation	cal/min/cm^2	15 minute instantaneous

Chapter 9 Data Management

Content

Chapter 9 Data Management

Introduction

All data collected by the EMP are stored in digital format for data management and dissemination. Each monitoring element has a particular process for data entry, quality control, management and dissemination. All data is available to the public.

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

Metadata information describing sampling site locations, sampling methodology, and field and laboratory processing for all the data variables can be found at http://www.water.ca.gov/bdma/meta/.

EMP = Environmental Monitoring Program

BDAT = Bay Delta and Tributaries database

IEP = Interagency Ecological Program

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.

Discrete Water Quality Data

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.

DWR = California Department of Water Resources

FLIMS = Field and Laboratory Information Management System

Discrete water quality data from 1975 to present are available upon request. 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 sent by telemetery to an EMP server. Data are then loaded into a database and reviewed for accuracy, completeness, and consistency using probe verification and calibration records.

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

Continuous water quality data from 1983 to present are available upon request. For more information regarding management and access to continuous water quality data, contact Mike Dempsey at mdempsey@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.

Benthic and Sediment data from 1975 to present are available upon request. For more information regarding benthic or sediment data, contact Heather Fuller at hlfuller@water.ca.gov.

Phytoplankton Data

Phytoplankton sampling sites are surveyed monthly, primarily by vessel. EcoAnalyst, a private contractor, identified, enumerated and measured the size of phytoplankton. These data are entered into the EMP phytoplankton database using Microsoft Access software. EMP staff periodically review the data for accuracy, completeness and consistency.

Phytoplankton data from 1975 to present are available upon request. 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.

DFG = California Department of Fish and Game

Zooplankton data are available upon request. For more information regarding zooplankton data, contact April Hennessy at ahennessy@dfg.ca.gov.