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 2009

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

December 2010

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Executive Summary 2009

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 (Delta) and Suisun and San Pablo bays (the upper San Francisco estuary) during calendar year 2009. 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 (DO) concentration, specific conductance, dissolved inorganic nitrogen, orthophosphate, and volatile suspended solids were within their historical range. Measured parameters exhibited seasonal variation as well as changes in response to significant rainfall events and 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 2009 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 m below the water's surface. All organisms collected in 2009 fell into 12 categories: centric diatoms, cyanobacteria, unidentified flagellates, green algae, pennate diatoms, cryptomonads, euglenoids, haptophytes, chrysophytes, unknown genus, dinoflagellates, and synurophytes. Of the 12 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 monitoring sites in the estuary. The introduced *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) and the *Neomysis kadiakensis/japonica* complex remained the 2 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 3 most common cyclopoid copepods remained the introduced *Limnoithona tetraspina* and *Oithona davisae*, followed by the native *Acanthocyclops vernalis*. The 3 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. 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 2009 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 in these phyla represent 82.8% of all organisms collected during this period.

The EMP also conducted a series of special studies to monitor DO levels within the Stockton Ship Channel during the late summer and early fall of 2009. 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

°C	degrees Celsius
ac-ft	acre-feet
BOD	biochemical oxygen demand
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
D-1641	Water Right Decision 1641
DFG	California Department of Fish and Game
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
DON	dissolved organic nitrogen
DWR	California Department of Water Resources
EMP	Environmental Monitoring Program
FLIMS	Field and Laboratory Information Management System
ft	feet
FU	fluorescence units
IEP	Interagency Ecological Program
km	kilometers
L	liter
m	meter
MAF	million acre feet
mg/L	milligrams per liter
mL	milliliters
mS/cm	millisiemens per centimeter
NH_3	total ammonia
NH_4^+	total ammonium
NO_2	nitrite
NO_3	nitrate
NTU	nephelometric turbidity units
Org/grab	organisms per grab sample
Org/m^2	organisms per square meter

org/mL	organisms per milliliter
psu	practical salinity units
SC	specific conductance
SWP	State Water Project
SWRCB	State Water Resources Control Board
TDS	total dissolved solids
TSS	total suspended solids
µg/L	micrograms per liter
µg/mL	micrograms per milliliter
µm	micrometer
µS/cm	micro Siemens per cm
USBR	US Bureau of Reclamation
USEPA	US Environmental Protection Agency
USFS	US Fish and Wildlife Service
USGS	US Geological Survey
VAMP	Vernalis Adaptive Management Plan
VSS	volatile suspended solids
WR 2000-02	Water Right Decision 2000-2002

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

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Chapter 1 Introduction

The SWRCB establishes water quality objectives and monitoring plans to protect the variety of beneficial uses of the water within the upper San Francisco estuary (estuary). The SWRCB ensures that these objectives are met, in part, by inclusion of water quality monitoring requirements into water rights decisions issued to DWR and USBR as conditions for operating the SWP and 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 D-1641 (SWRCB, 1999) and revised by order WR 2000-02 in March 2000.

Data collected since 1975 by the EMP are stored and managed by DWR and 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.

This report, titled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2009*, summarizes the findings of the EMP for calendar year 2009. 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.

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[SWRCB] State Water Resources Control Board. (1999). *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh* (Adopted December 29, 1999, Revised in Accordance with order WR2000-02 March 15, 2000). Sacramento, CA.

Chapter 2 Hydrologic Conditions

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Chapter 2 Hydrologic Conditions

Introduction

The Sacramento-San Joaquin Delta (Delta) is a unique source of freshwater and is one of the few inverted river deltas found worldwide. The waterways of the Delta are subject to ocean tidal action from the San Francisco Bay, which sometimes can reverse flow. The variation in these flows and their interaction with the salt water of the San Francisco Bay has resulted in the formation of a unique and diverse ecosystem.

The Delta receives runoff from about 40% of the land area of California and consists of about 50% of California's total stream flow (DWR, n.d.). At least 20 million people get their water supply from the Delta (Delta Protection Commission, 1995). State and Federal contracts provide for export of up to 7.5 MAF per year from the 2 pumping stations in the southern Delta and about 83% of this water is used for agribusiness and urban use throughout the state (DWR, n.d.).

Seasonal water supply forecasts are important tools for water management. They are used by farmers, municipalities, and reservoir managers to predict the availability of expected water for the coming year. Hydrologic conditions are typically discussed using water years and provide a brief overview of historic and current conditions in Sacramento River and San Joaquin River watersheds. Water year 2009 covered by this report comprises the period October 1, 2008 to September 30, 2009.

Methods

Water Year Classification

Water years are classified for the Sacramento Valley by using the Sacramento Valley 40-30-30 Water Year Hydrological Classification Index[1],[2] (the Sacramento Valley Index). The San Joaquin Valley water year is classified using the San Joaquin Valley 60-20-20 Water Year Hydrological Classification Index[3], [4](the San Joaquin Valley Index) (SWRCB, 1999). The official year types are based on the forecasts of future runoff on May 1 (CDEC, 2010b). The Sacramento Valley Index is used to characterize water years statewide because the majority of California's precipitation falls within the northern half of the state and flows down the Sacramento River through the estuary. The Sacramento Valley Index is also used because the Sacramento River watershed provides the majority of water to the SWP and the CVP (SWRCB, 1999). The San Joaquin Valley Index is used predominately for regional applications; however, the index also provides supporting information concerning water conditions within the San Joaquin Valley.

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

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

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

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

Outflow and Runoff

The freshwater outflow of the estuary is determined by using the Net Delta Outflow Index [5] (Figure 2-1). Much of this outflow occurs during late winter and early spring. An estimate of net Delta outflow at Chipps Island is derived by performing a water balance about the boundary of the Delta, taking Chipps Island as the western limit (Dayflow, n.d.). Total tidal flow is much larger and should not be confused with the Net Delta Outflow Index (Dayflow, n.d.).

Indices are based on flow in MAF. Unimpaired runoff represents the natural water production of a river basin, unaltered by upstream diversions, storage, and export of water to or import of water from other basins measured in MAF (Dayflow, 2009). Figures 2-1 and 2-2 show the monthly average Delta outflow and the yearly unimpaired runoff. Dissolved materials are carried into the Delta from runoff and the salinity distribution is an important source that drives water circulation and the transport of dissolved solids in the San Francisco Bay (Kimmerer et al., 2009).

X2[6] is currently used as the primary indicator in managing Delta outflows. Above X2, water becomes progressively fresher and below X2, water becomes more and more brackish until reaching the ocean. Benthic macroinvertebrates, phytoplankton, mysids and shrimp, larval fish, and many of the Delta's fish species have a direct statistical relationship to higher Delta outflow (Kimmerer et al., 2009).

Summary

Tidal influence and subsequent saltwater intrusion is important throughout the Delta. Variation in these flows and their unique interaction with the salt water of the San Francisco Bay has resulted in the creation of a rich and diverse wetland estuary. The Delta provides about two-thirds of California's freshwater for urban and agricultural use, and sustains many diverse habitats for biological species.

Water year 2009 was classified as below normal for the San Joaquin Valley[7] and a dry year for the Sacramento Valley[8] in precipitation, seasonal runoff, reservoir storage, and snowpack water content. Figures 2-3 and 2-4 summarize these findings and includes the previous 13 years for reference.

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[5] The Net Delta Outflow Index (NDOI) is a calculation of freshwater outflow from the Delta past Chipps Island. The NDOI includes a factor dependent upon inflows of the Yolo Bypass System, the eastside stream system (the Mokelumne, Cosumnes, and Calaveras rivers), the San Joaquin River at Vernalis, the Sacramento Regional Treatment Plant, and miscellaneous Delta inflows (Bear Creek, Dry Creek, Stockton Diverting Canal, French Camp Slough, Marsh Creek, and Morrison Creek).
NDOI formula: QOUT = QTOT + QPREC – QGCD – QEXPORTS – QMISDV
(1) Q- Flow
QOUT- Net Delta outflow at Chipps Island
QTOT- Total Delta inflow
QPREC- Delta precipitation runoff estimate
QGCD- Deltawide gross channel depletion estimate (consumptive use)
QEXPORTS- Total Delta exports and diversions/transfers; QMISDV-flooded island and island storage diversion

[6] The meeting of the ocean and the river creates a dynamic balance between freshwater and saltwater which creates the biologically rich "mixing zone" (Kimmerer, 2002). In the Delta, this mixing zone is referred to as X2. The location of X2 is the distance in kilometers (km) from the Golden Gate Bridge to the 2 psu isohaline (Jassby et al., 1995; Kimmerer, 2002).

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

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

Statewide water conditions for May 1 are summarized in Table 2-1 and include the previous 13 years for reference. Table 2-2 summarizes these conditions and includes the previous 13 years for reference. Maximum Delta outflow indices exceeded 105,682 ac-ft/day (53,294 cfs) in March and minimum outflow indices approached 2,419 ac-ft/day (1,220 cfs) in October (Kate Le, personal communication, 2009). The figures cited in this summary may not match that published in DWR *Bulletin 120* due to changes in averages, course selection, and reported preliminary data (CDEC, 2010a).

The Delta region had very dry climate conditions between January and February. January 2009 was the eighth driest January on record for California statewide. Hydrological conditions in the Delta changed greatly in the middle of February. Storm events in the northern reach of the Delta contributed to high outflows coming down from Sacramento (Le & Chu, 2010). Very little change occurred for San Joaquin flows through the entire period of January to March. The largest peak flows for both Sacramento and the Net Delta Outflow Index occurred in March, surpassing 53,000 cfs. Project operations in the Delta from January through March 2009 were restricted by the drier hydrological conditions and the fishery protections (Le & Chu, 2010).

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Chapter 2 Appendix

Figure 2-1 Net Delta Outflow Indices, water year 2009

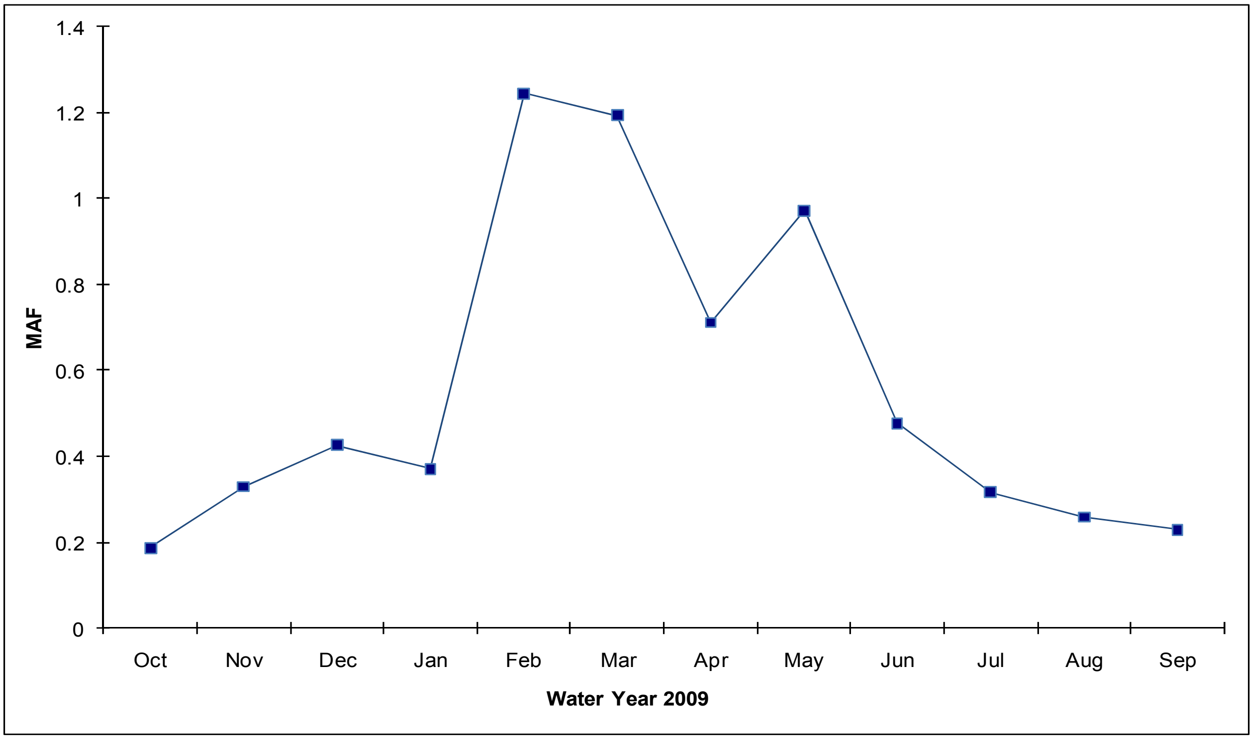

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, water years 1996–2009

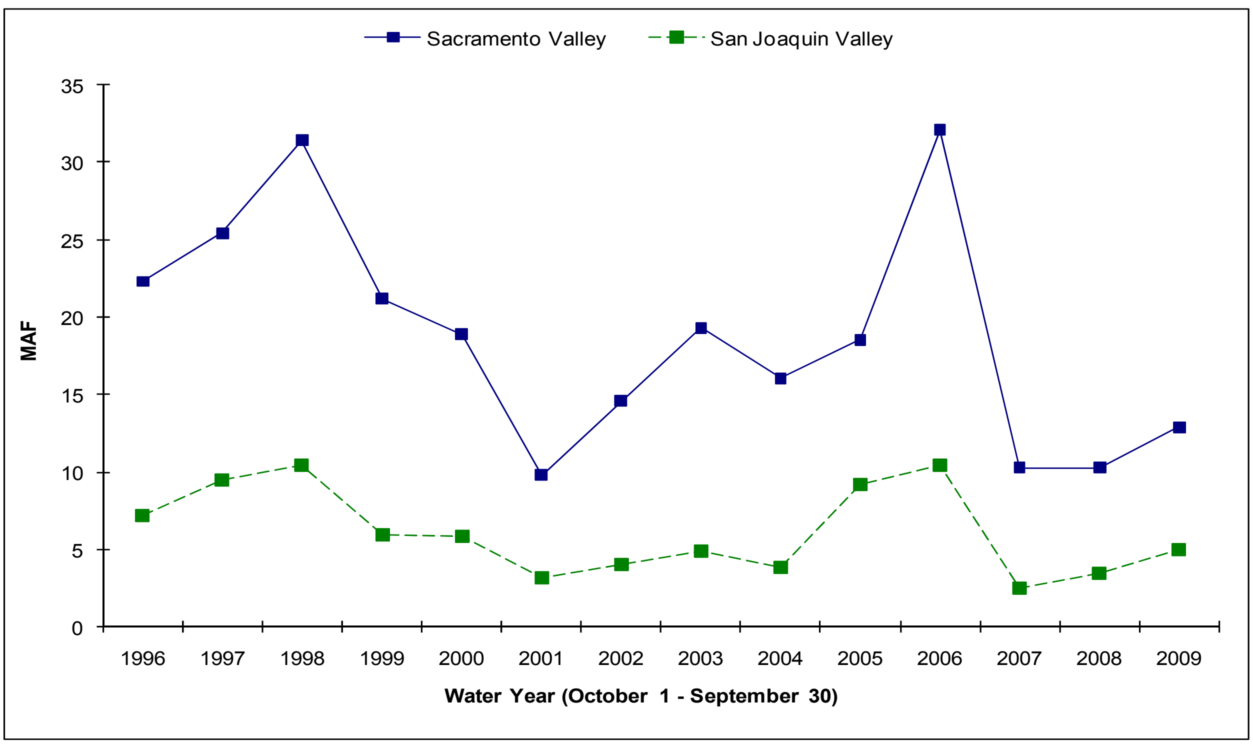

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, water years 1996–2009

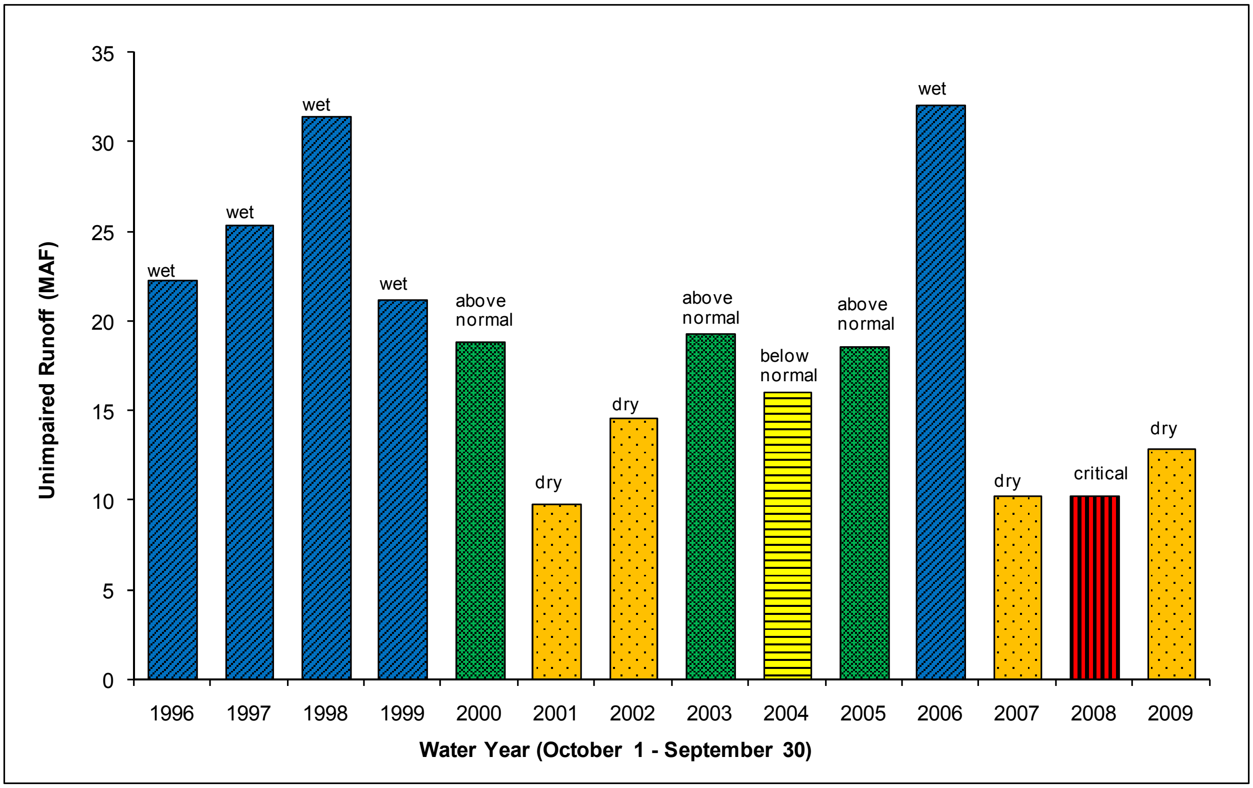

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, water years 1996–2009

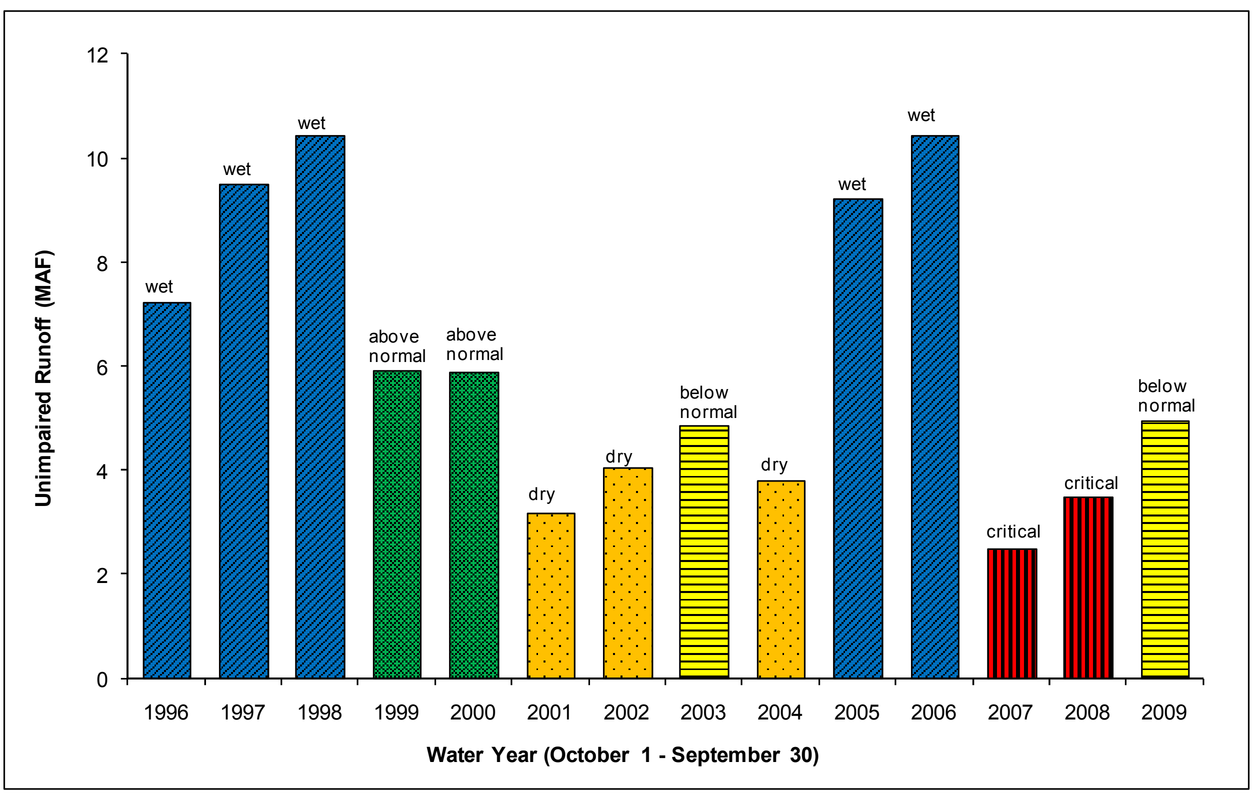

Table 2-1 Summary of statewide major hydrologic characteristics on May 1, water years 1996–2009

Water year	Precipitation (% of historic average)	Seasonal runoff (% of historic average)	Reservoir storage (% of historic average)	Snow water content (% of historic average)
1996	110	115	120	95
1997	120	175	110	55
1998	160	155	115	190
1999	100	115	115	120
2000	95	100	115	75
2001	75	55	100	65
2002	80	80	100	60
2003	110	100	105	105
2004	90	90	100	50
2005	135	108	105	150
2006	140	170	115	185
2007	65	55	85*	39*
2008	78	60	72	102
2009	80	70	80	60

Note: Measurements made May 1 in each water year denote conditions from October 1 through April 30 of the respective water year.
*Numbers different from those reported in previous EMP reports.

Table 2-2 Unimpaired runoff for Sacramento and San Joaquin rivers, water years 1996–2009

Sacramento River				San Joaquin River			
Year	Oct 1- Mar 30 (MAF)	Apr 1- Jul 30 (MAF)	Whole year (MAF)	Year	Oct 1- Mar 30 (MAF)	Apr 1- Jul 30 (MAF)	Whole year (MAF)
1996	13.05	8.37	22.29	1996	2.57	4.51	7.22
1997	20.22	4.39	25.42	1997	5.75	3.59	9.51
1998	17.65	12.54	31.4	1998	2.82	7.11	10.43
1999	12.97	7.26	21.19	1999	1.9	3.85	5.91
2000	12.06	5.96	18.9	2000	1.98	3.78	5.9
2001	5.64	3.46	9.81	2001	0.92	2.23	3.18
2002	9.32	4.57	14.6	2002	1.27	2.75	4.06
2003	10.71	7.74	19.31	2003	1.25	3.49	4.87
2004	10.95	4.4	16.04	2004	1.51	2.25	3.81
2005	8.4	9.28	18.55	2005	2.73	6.28	9.21
2006	18.06*	13.09*	32.09*	2006	2.86*	7.37	10.44*
2007	6.59*	3.04*	10.28*	2007	0.99*	1.46*	2.51*
2008	5.9	3.82	10.28	2008	0.99	2.45	3.49
2009	7.05	5.22	12.91	2009	1.51	3.36	4.97

Note: *Numbers different from those reported in previous EMP reports.

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Chapter 3 Water Quality Monitoring

Introduction

Water quality monitoring in 2009 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), and stations C3A and C10A. C3A replaced station C3 in 2004 and C10A replaced station C10 in 2005. Discrete samples were taken monthly at each site (Figure 3-1). Data were recorded within 1 hour of high slack tide and the time of each sample was recorded to the nearest 5 minutes of the 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.

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

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 ft above the water's surface.

Water Temperature

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

A water temperature minimum of 8.3°C was recorded in January 2009 at station D19 on the lower San Joaquin River and at station D28A in the central Delta (Figures 3-2 and 3-3). This minimum temperature represents a decrease of 0.1 °C from the previously recorded minima in 2008 (Riordan et al., 2010).

Temperature minima at all sites during 2009 occurred during the months of January or December. The timing of these temperature minima is similar to the 2008 study period, where all temperature minima occurred during January (Riordan et al., 2010).

A water temperature maximum of 26.1 °C was recorded in August at station P8 in the south Delta. This maximum is a 0.2 °C decrease over the temperature maximum reported for 2008 (Riordan et al., 2010). Recorded temperatures exhibited strong seasonal variability, with cooling during the winter and warming during the summer.

Dissolved Oxygen

DO was measured using the modified Winkler iodometric method as 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 1 m. The samples were collected in 300 mL glass-stoppered bottles and immediately analyzed.

During 2009, DO concentrations ranged from 5.8 mg/L at site P8 in September to 11.2 mg/L at site MD10A in January (Figures 3-4 and 3-5). Seasonal trends were evident in most regions, with DO concentrations decreasing during the summer and rising in the winter. Reduced summer DO levels coincided with warmer water temperatures. This suggests that DO levels at many sites may be influenced primarily by physical processes (temperature and saturation capacity) rather than biological processes (respiration and primary production).

Specific Conductance

SC, 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 m depth. The samples were analyzed for SC using a Seabird model CTD 911+ data logger, or a YSI 85 (sites C3A and C10A) with temperature compensation to 25 °C.

SC varied greatly between sites monitored, ranging from 101.3 µS/cm at site C3A in May to 45,634 µS/cm at site D41 in October (Figures 3-6 and 3-7). This range of SC was broader than the range of 77.4 - 45,179 µS/cm reported for 2008 (Riordan et al., 2010).

SC 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 SC, such as D4, D6, D7, D8, D41, and D41A, tended to show stronger seasonal variations, with SC varying from lows in the spring to highs in winter. At sites with lower SC, this seasonal trend was less apparent.

Secchi Disk Depth

Water transparency was measured to the nearest cm 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.

A minimum Secchi depth of 10 cm was recorded at site D7 in Suisun Bay in May. (Figures 3-8 and 3-9). A maximum Secchi depth of 228 cm was recorded at sampling site MD10A (east Delta) in December. Secchi values during 2008 were similar, ranging from 16 to 215 cm (Riordan et al., 2010). In October, Secchi depth data for 2 sites were missing due to unfavorable sampling conditions.

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 m depth. The samples were pumped through a Turner Model 10 flow-through nephelometer and calibrated with a reference sample of formazin suspension at 40 NTU according to Standard Reference 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.

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 2.5 NTU at site MD10A (east Delta) in January to 299 NTU at site C3A (north Delta) in February. This range of turbidity was greater than the 1.5 to 60.5 NTU range reported for 2008 (Riordan et al., 2010). In October, data for 2 interior Delta sites are missing due to an equipment failure.

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 m depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory[1] for analysis according to the USEPA (1983) Method 365.4. The minimum reporting limit for orthophosphate is 0.01 mg/L.

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest orthophosphate value was 0.01 mg/L at station MD10A in December. The 2008 study period showed the lowest value (0.02 mg/L) of orthophosphate occurring at site C10A in June (Riordan et al., 2010).

The highest value of orthophosphate was 0.12 mg/L at site C10A in March and at site P8 in May and June. During 2008, site P8 also had the highest orthophosphate concentration (0.25 mg/L) in January (Riordan et al., 2010).

Total Phosphorus

Total phosphorus is the sum of all phosphorus compounds in a sample. This parameter includes phosphorus compounds that are bioavailable as well as those that are not. Phosphorus that is unavailable for bioassimilation includes phosphorus compounds incorporated into biological tissue and insoluble mineral particles.

Total phosphorus concentrations were measured by first collecting sample aliquots from a 1 m depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) Method 365.4. The minimum reporting limit for total phosphorus is 0.01 mg/L.

Values for total phosphorus varied considerably between sites and across seasons (Figures 3-14 and 3-15) and showed distributions similar to those reported for orthophosphate. The lowest value of 0.02 mg/L was recorded at site C3A during August. This value is slightly lower than the minimum value of 0.04 mg/L recorded during 2008 at site MD10A in November (Riordan et

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

al., 2009). A maximum value of 0.29 mg/L was recorded at site C3A in February. This value is lower than the maximum value of 0.5 mg/L recorded during 2008 at site MD10A in January (Riordan et al., 2010).

Site C10A had the highest average total phosphorus concentrations during 2009. Site MD10A had the lowest average total phosphorus concentrations.

Kjeldahl Nitrogen

Kjeldahl nitrogen is nitrogen in the form of organic proteins or their decomposition product, NH_3, as measured by the Kjeldahl method (APHA, 1992).

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

Kjeldahl nitrogen concentrations ranged from lows below the minimum reporting limit at sites D19, D26, and D28A in September to 1.3 mg/L at site C3A in January (Figures 3-16 and 3-17). During 2008, Kjeldahl nitrogen levels peaked at sites C10A in June and P8 in January with a high of 1.5 mg/L (Riordan et al., 2010).

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

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

DIN concentrations ranged from a minimum of 0.03 mg/L at site MD10A in September to a maximum of 3.77 mg/L at site P8 in February. (Figures 3-18 and 3-9). This range is similar to the values observed during 2008, which recorded a minimum value of 0.09 mg/L at site MD10A in September and a maximum of 3.74 mg/L at station P8 in December (Riordan et al., 2010). Unlike the other Delta stations, the majority of the DIN concentrations in the Sacramento River below Freeport (C3A) were in the form of NH_3 rather than NO_3 and NO_2 (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).

DON was measured by first pumping water samples from a 1 m depth into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) Method 351.2. The minimum reporting limit for DON is 0.1 mg/L.

DON concentrations were below the minimum reporting limit at station C3A in March, June, August, September, October and December, stations D19, D28A and D8 in September, and station D26 in August and September. A maximum concentration of 1.1 mg/L was recorded at station C3A in February (Figures 3-20 and 3-21). Peak DON during 2008 was similar, reaching 1.2 mg/L at station MD10A in January (Riordan et al., 2010).

Most sites showed peak DON concentrations during February.

Total Dissolved Solids

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

TDS were measured by first pumping water samples from a 1 m depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45 µm pore size. 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 D19 in June to 29,400 mg/L at site D41 in September (Figures 3-22 and 3-23). The values were similar during 2008, which had a range of 63 mg/L to 29,260 mg/L (Riordan et al., 2010). 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.

TSS may increase in surface waters due to increases in flow rate, as higher velocities increase the 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, concentrations of suspended solids can vary significantly over relatively short time periods.

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

TSS in the Delta varied over a wide range, from below the minimum reporting limit (<1.0 mg/L) at site D28A in March and June and at MD10A in March to 232 mg/L at site C3A in February (Figures 3-24 and 3-25). These results are different from the 2008 study period, where the highest TSS value was recorded at site D41A (124 mg/L) in July and the lowest TSS value was below the minimum reporting limit at site D19 in September and site MD10A in November (Riordan et al., 2010).

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

Volatile Suspended Solids

The measurement of 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 m, stored in polyethylene bottles and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for VSS according to USEPA (1983) Method 160.4. The minimum reporting level for VSS in these analyses was 1.0 mg/L.

VSS levels fell below minimum reporting levels (<1 mg/L) in most regions, and reached a high of 33.0 mg/L at site D41A in October (Figures 3-26 and 3-27). These results were similar to those observed in 2008, which had a maximum value of 31.0 mg/L at site D41A in July (Riordan et al., 2010). 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 m into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45 µm pore size and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for silica according to USEPA (1983) Method 200.7. The minimum reporting level for silica in these analyses was 0.1 mg/L.

Silica concentrations ranged from a low of 1.5 mg/L at site D6 in February to a high of 22.0 mg/L at site C3A in January (Figures 3-28 and 3-29). Values during 2008 exhibited a similar range, from 3.1 mg/L at site D7 in July to 22.9 mg/L at site C3A in January (Riordan et al., 2010). 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 m into new, rinsed polyethylene bottles. The water samples were then passed through a pre-washed membrane filter with a 0.45 µm pore size and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for chloride according to USEPA (1983) Method 300.0.

Chloride concentrations in the estuary varied over a wide range from 4 mg/L at site C3A in July and August to 16,600 mg/L at site D41 in August and October (Figures 3-30 and 3-31). These results are very similar to those observed during 2008, which recorded a low of 6 mg/L at site C3A in June and July and a high of 16,500 mg/L at site D41 in December (Riordan et al., 2010).

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 chloride concentrations are closely correlated to values reported for SC and TDS reported earlier in this chapter.

Summary

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

References

[APHA] American Public Health Association, American Water Works Association, and Water Environmental Federation. (1992). *Standard Methods for the Examination of Water and Wastewater* [*Standard Methods*] (20th Edition ed.). Washington DC.

Riordan, D., Brown, T., Dempsey, M., Evans, J., Hennessy, A., & Noble, B. (2010). *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2008*. Sacramento, CA: Department of Water Resources.

Lehman, P., Hayes, S., Marsh, G., Messer, C., Ralston, C., Gehrts, K. & Lee, J. (2001). *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1996* [*1996 Water Quality Report*]. Sacramento, CA: Department of Water Resources.

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

Chapter 3 Appendix

Figure 3-1 Discrete water quality sampling stations

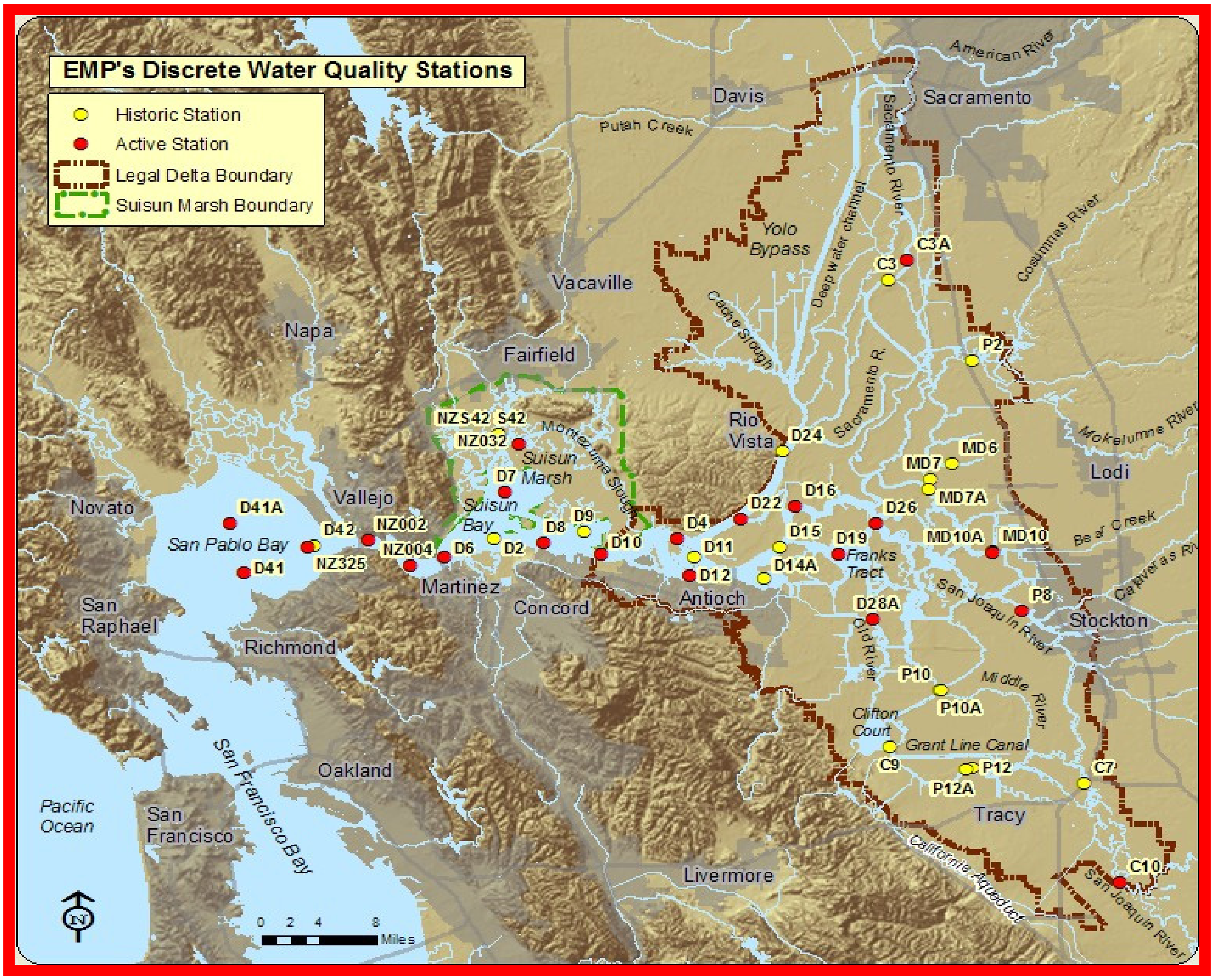


Figure 3-2 Water temperature comparisons, 2009

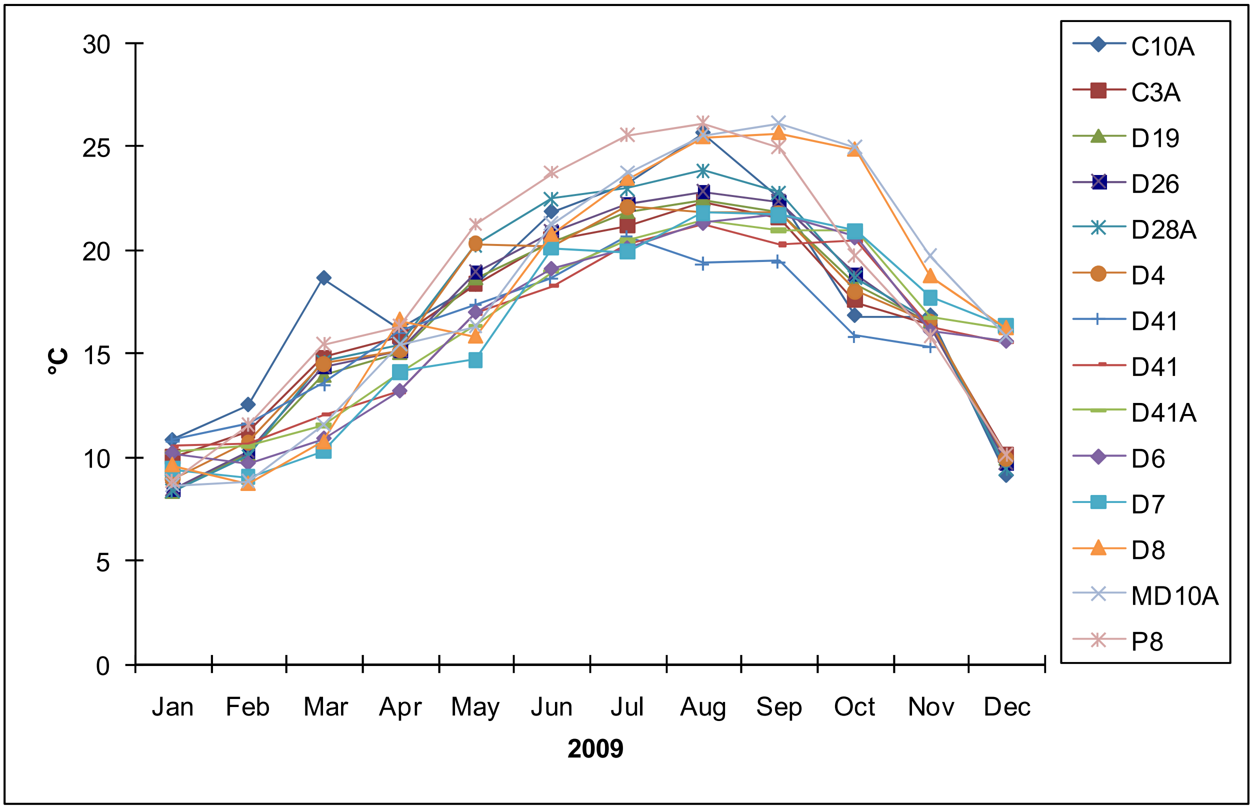


Figure 3-3 Water temperature by station, 2009

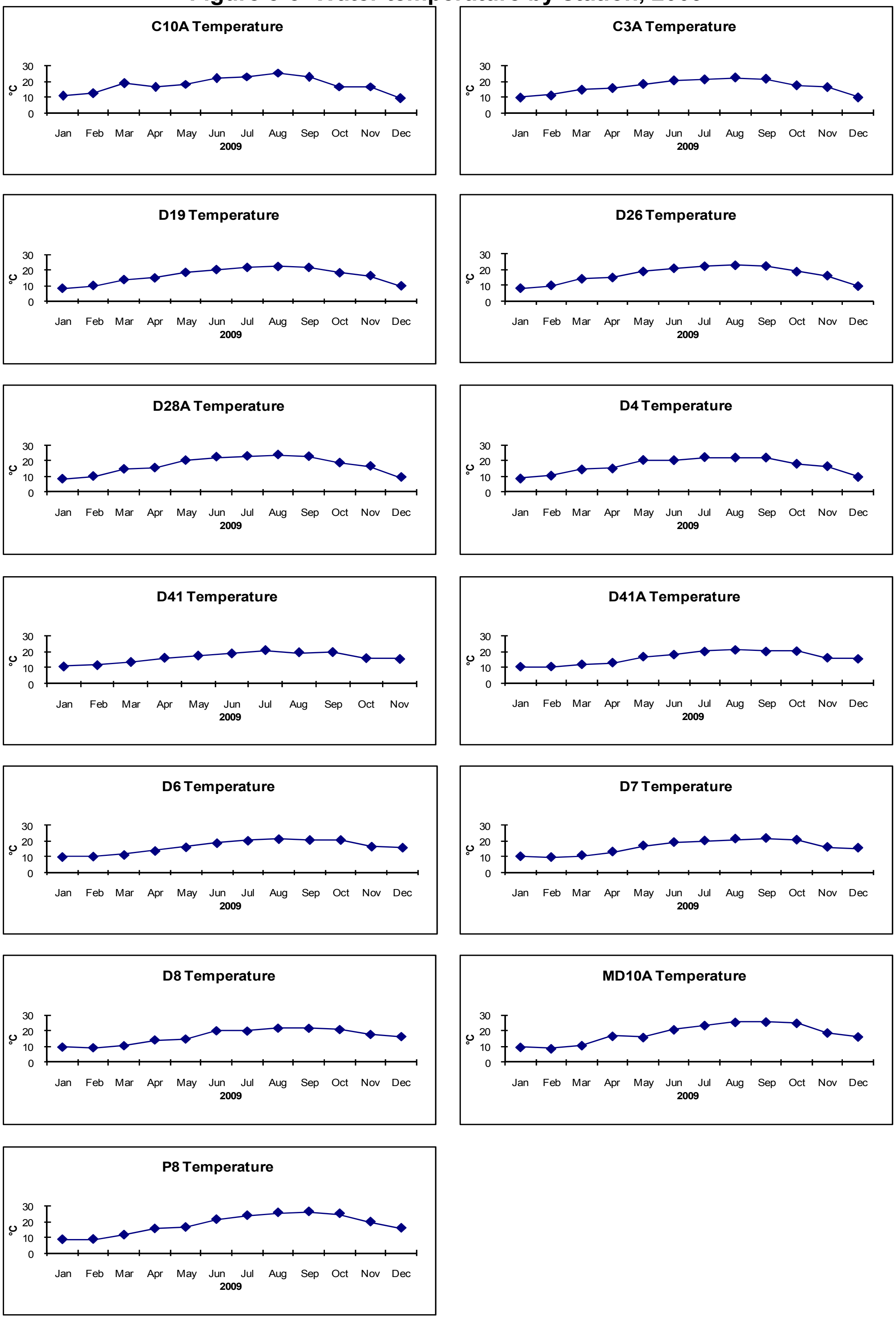


Figure 3-4 DO comparisons, 2009

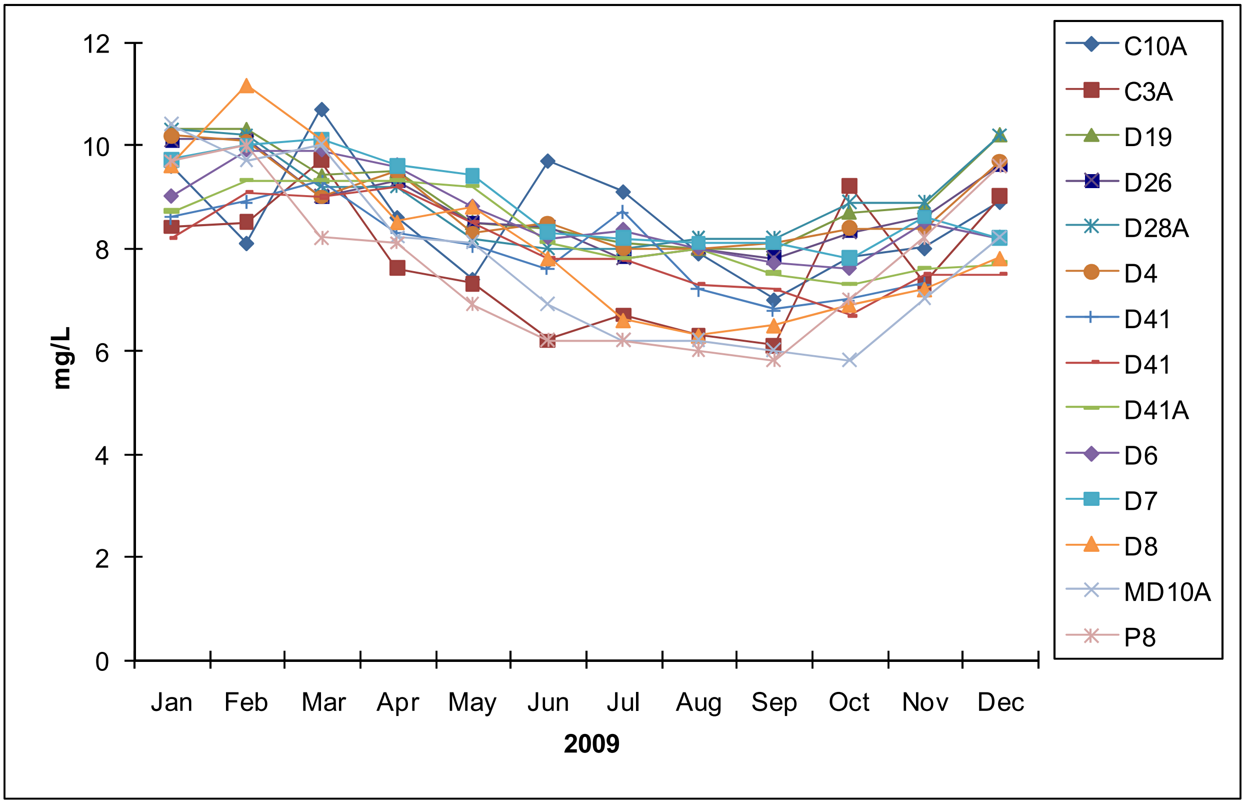


Figure 3-5 DO by station, 2009

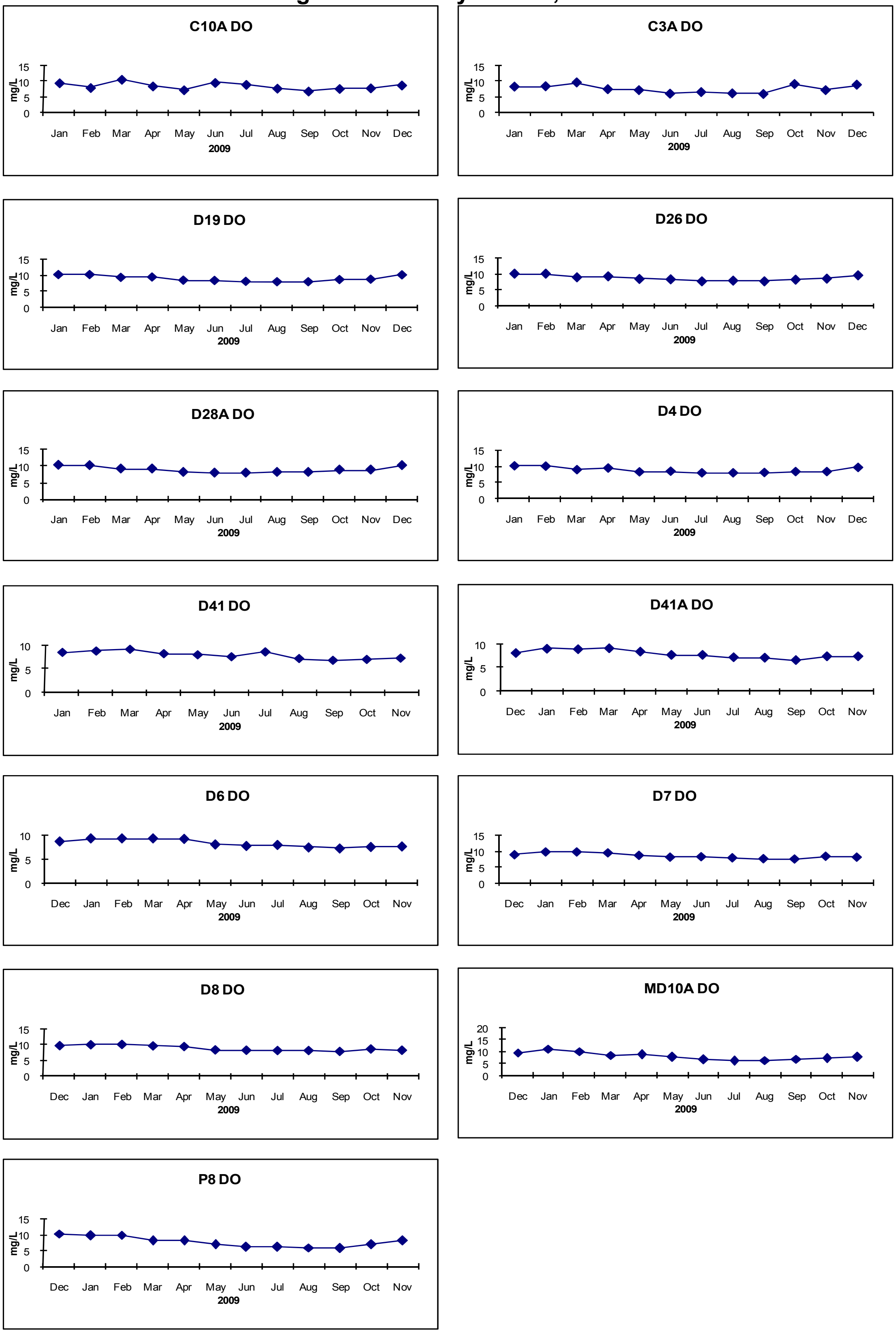


Figure 3-6 SC comparisons, 2009

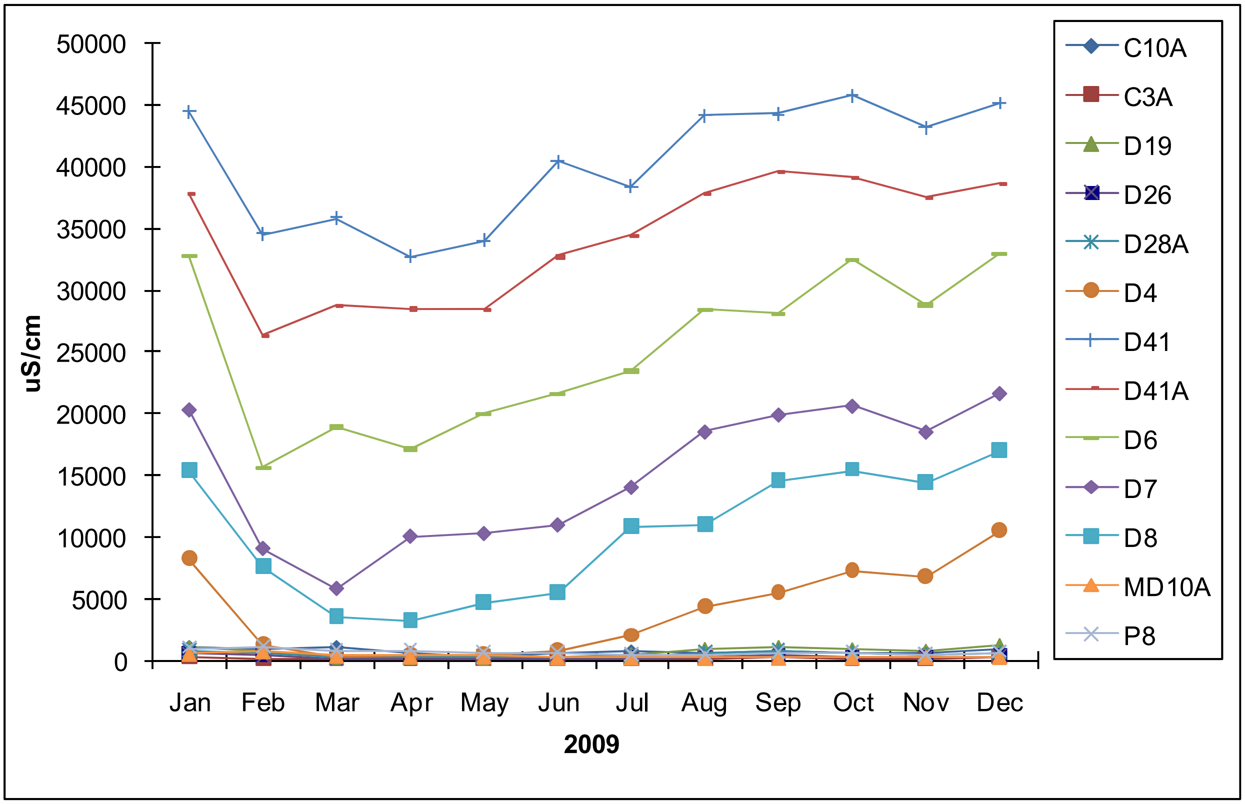


Figure 3-7 SC by station, 2009

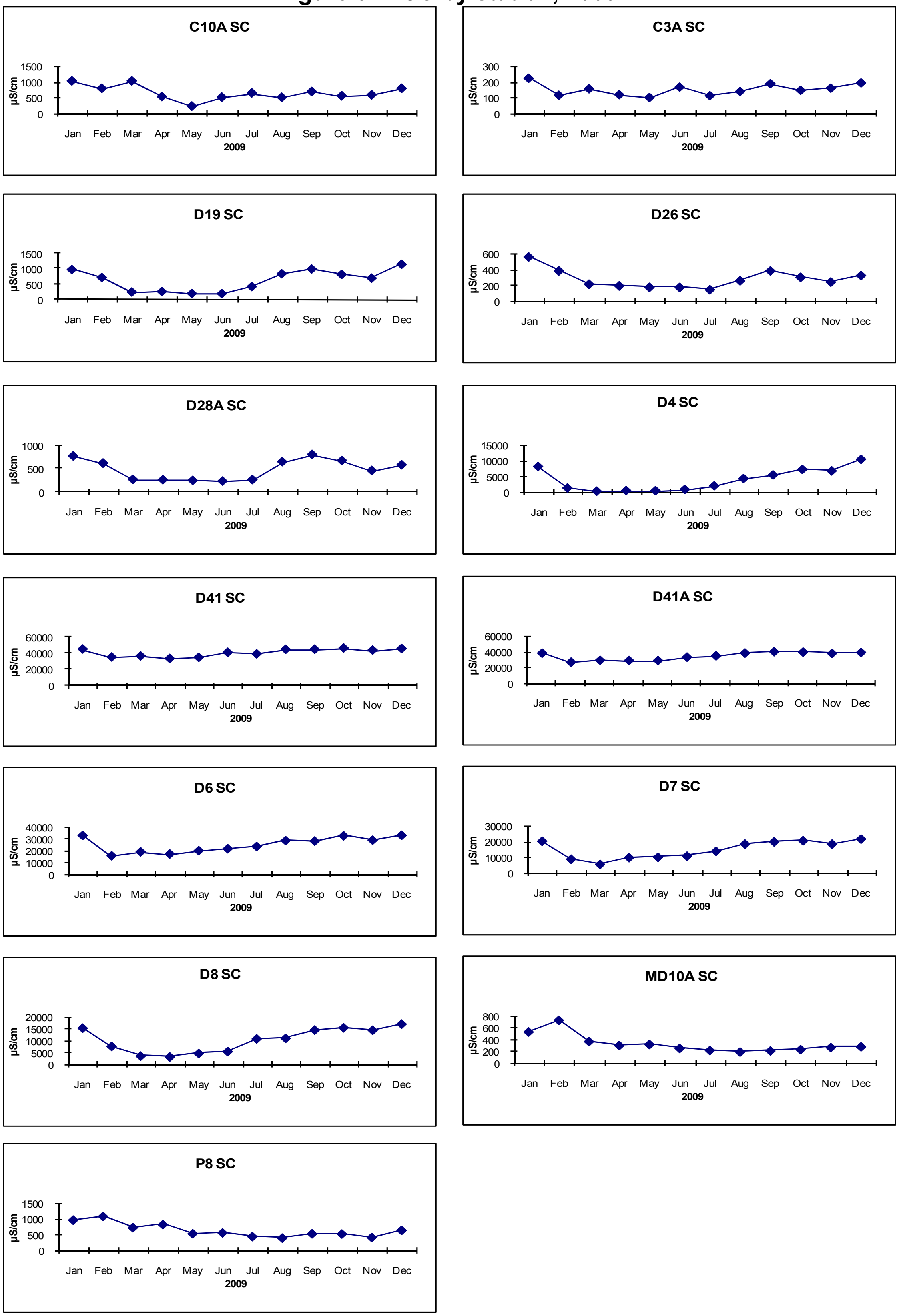


Figure 3-8 Secchi disk depth comparisons, 2009

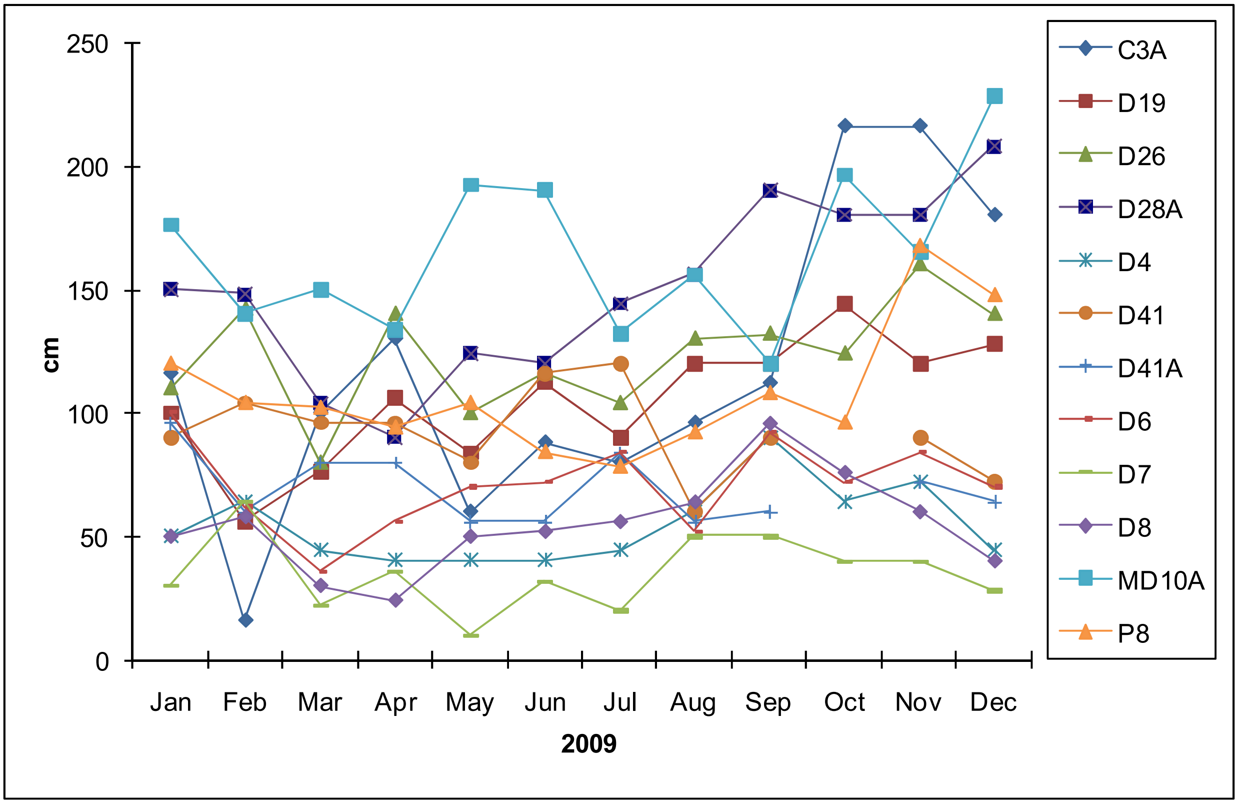
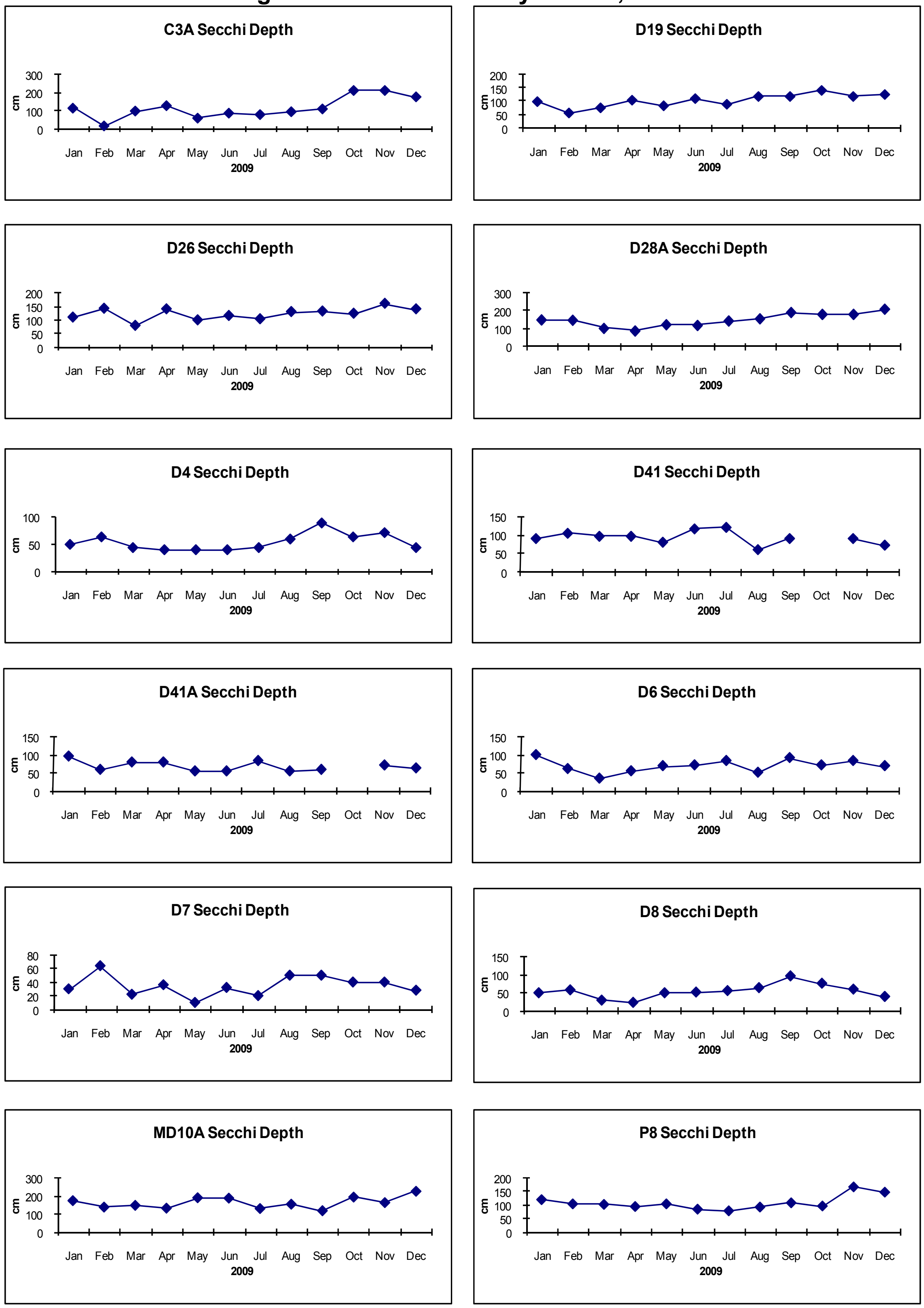


Figure 3-9 Secchi disk by station, 2009



Note: Some values are missing during October due to dangerous sampling conditions.

Figure 3-10 Turbidity comparisons, 2009

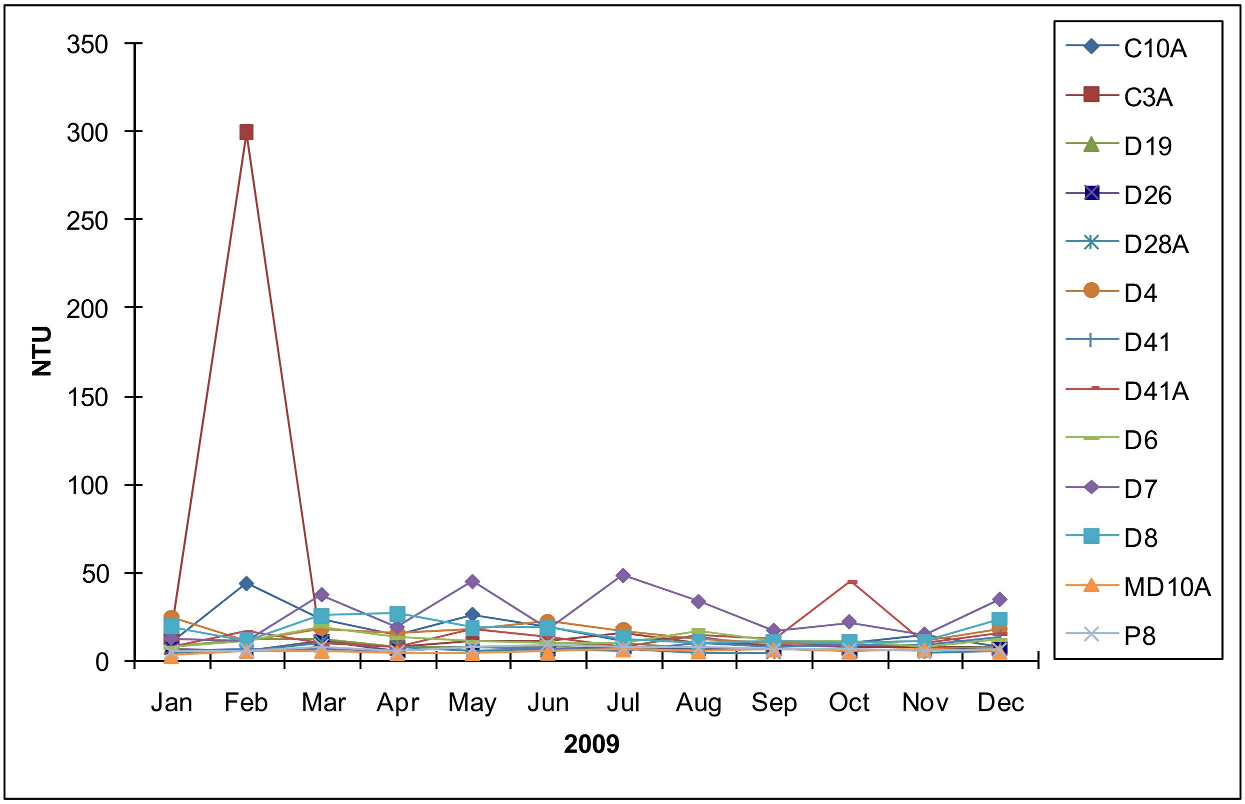
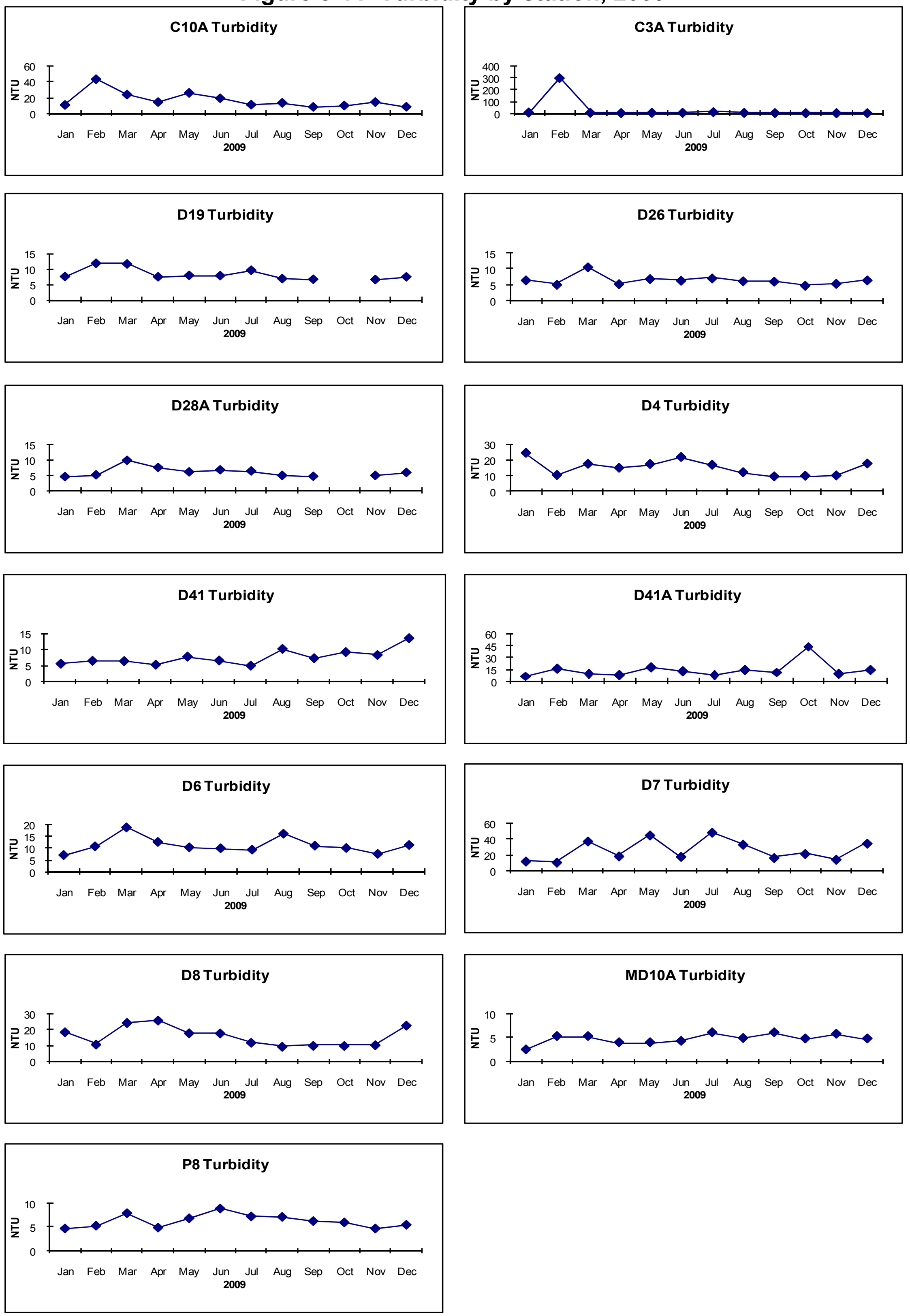


Figure 3-11 Turbidity by station, 2009



Note: Some values are missing in October due to a malfunctioning turbidimeter

Figure 3-12 Orthophosphate comparisons, 2009

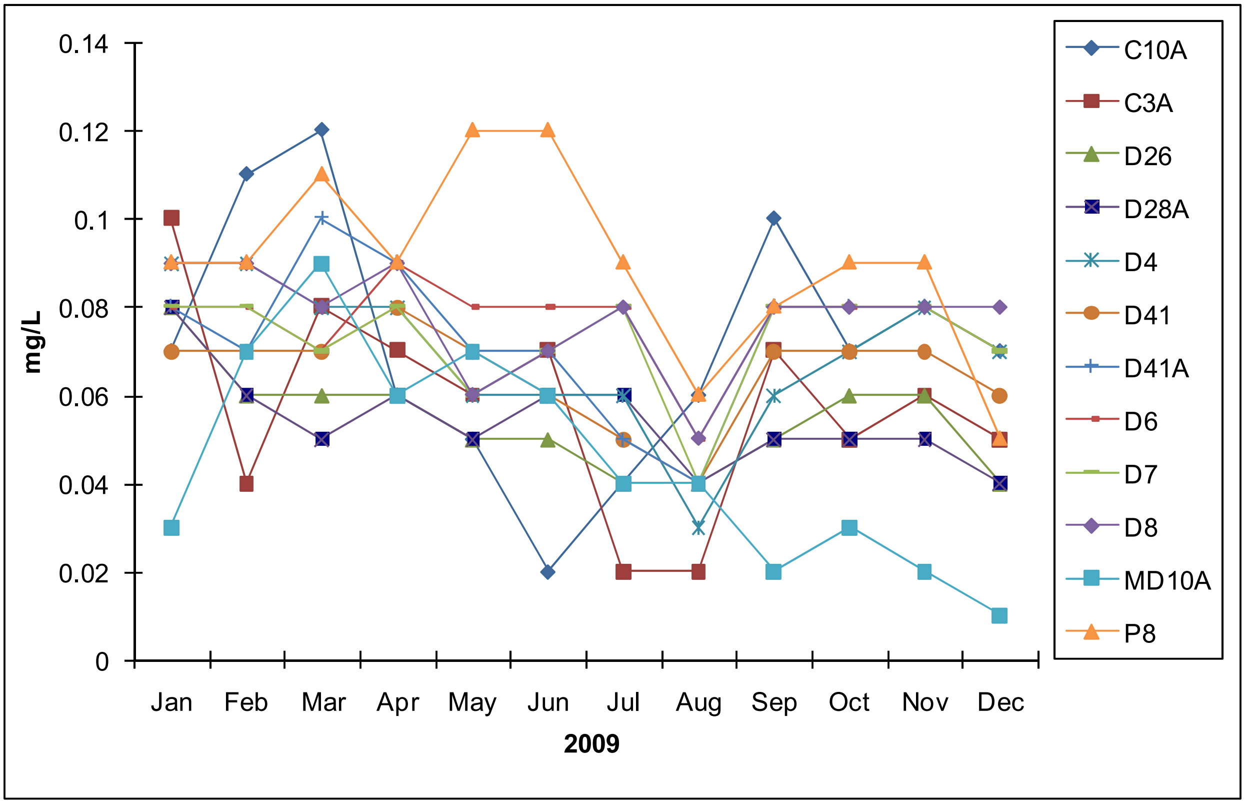


Figure 3-13 Orthophosphate by station, 2009

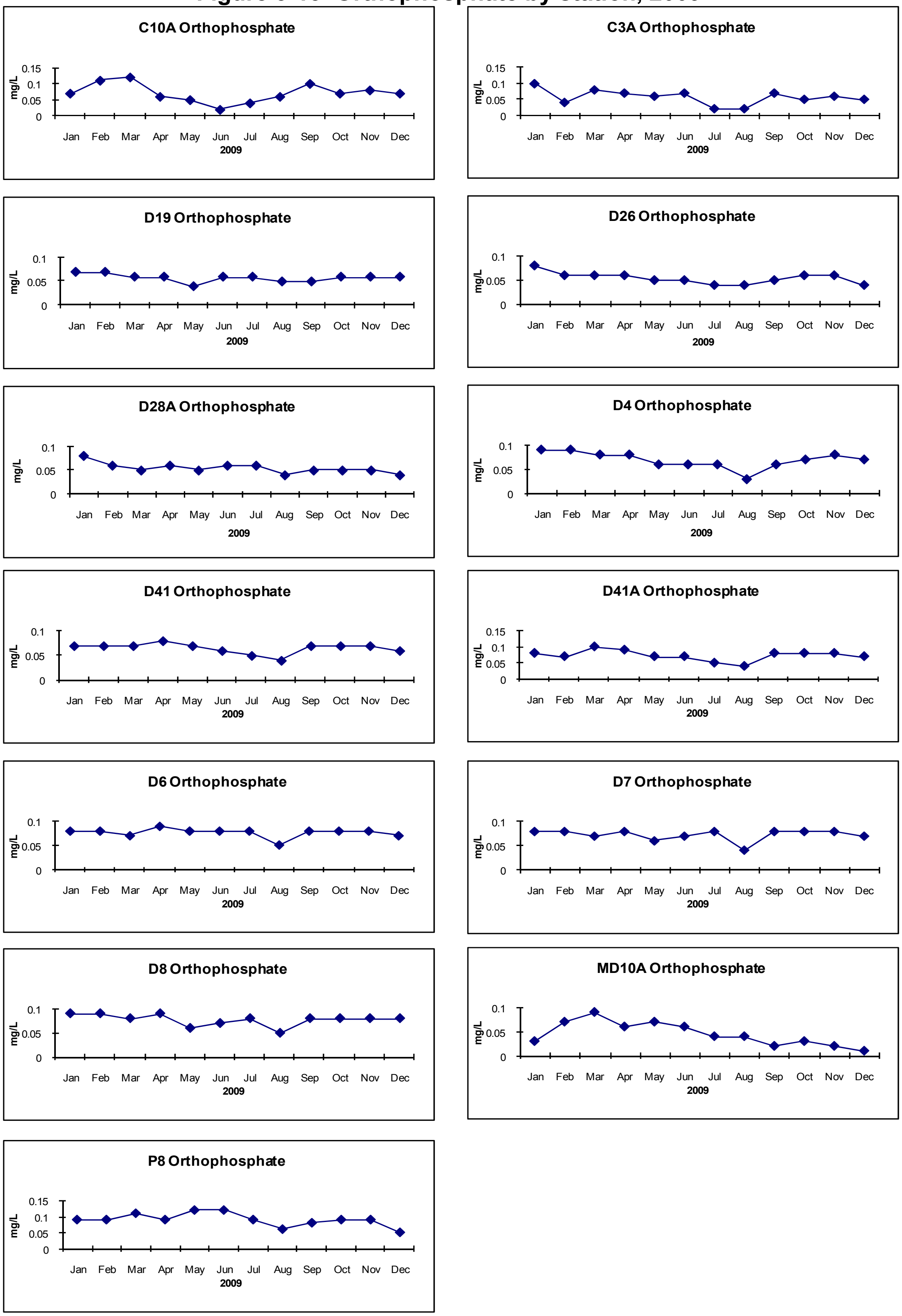


Figure 3-14 Total phosphorus comparisons, 2009

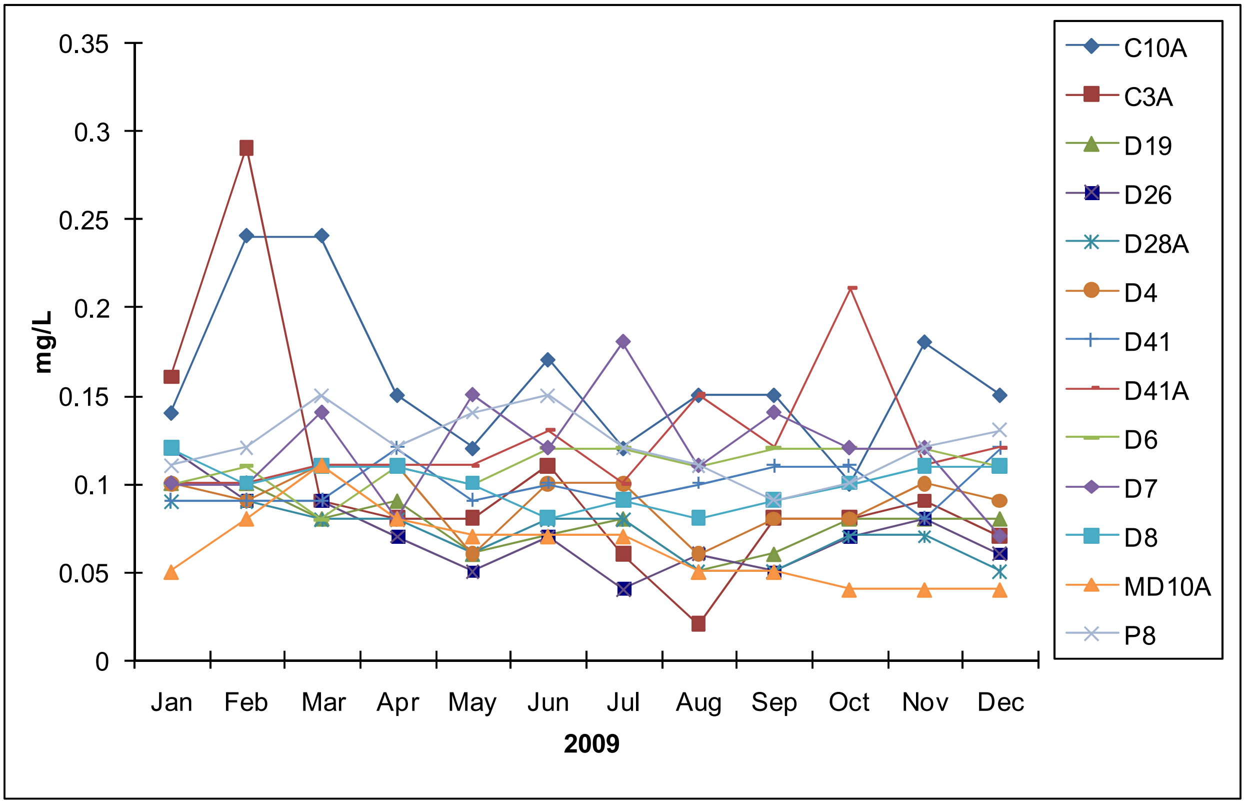


Figure 3-15 Total phosphorus by station, 2009

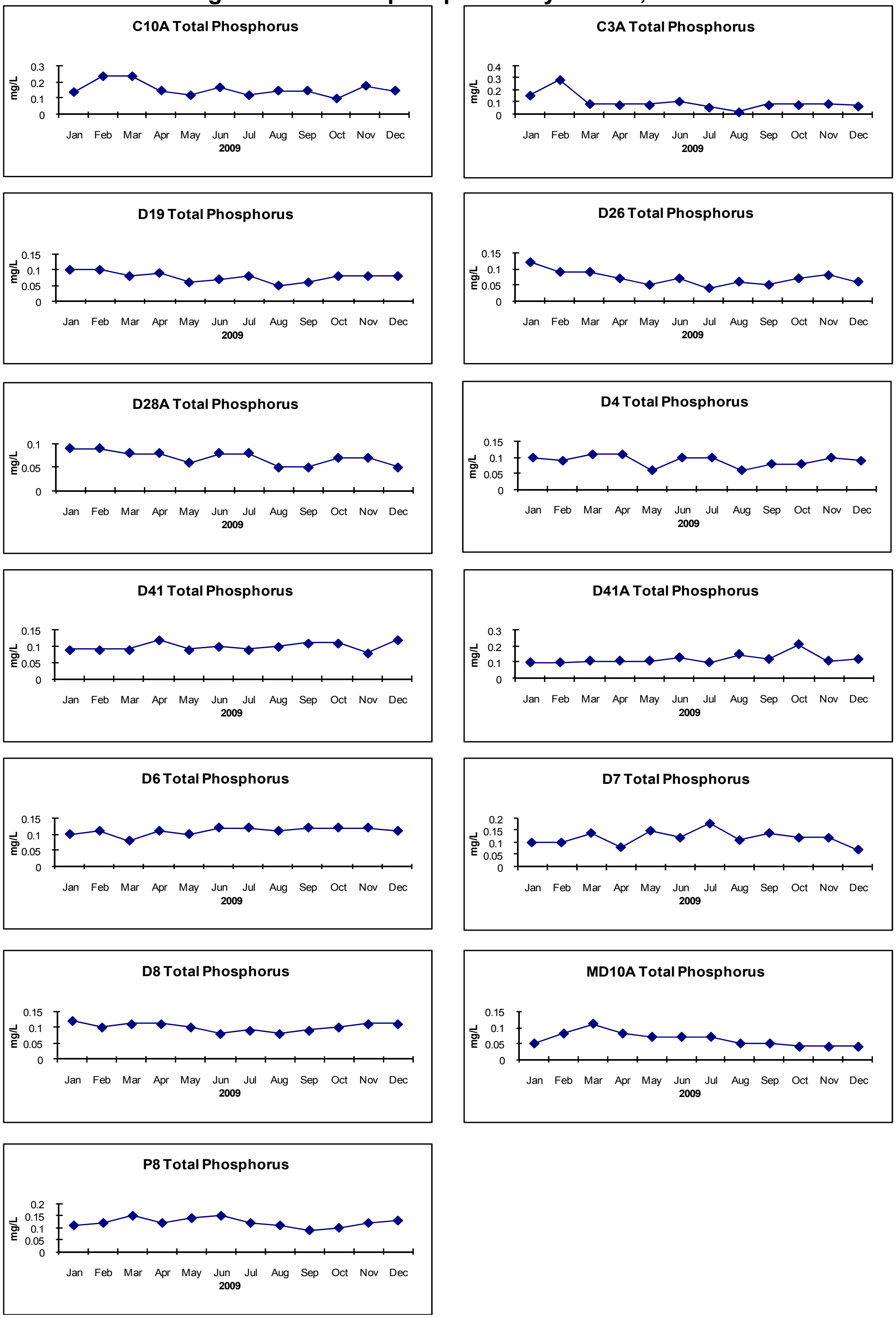


Figure 3-16 Kjeldahl nitrogen comparisons, 2009

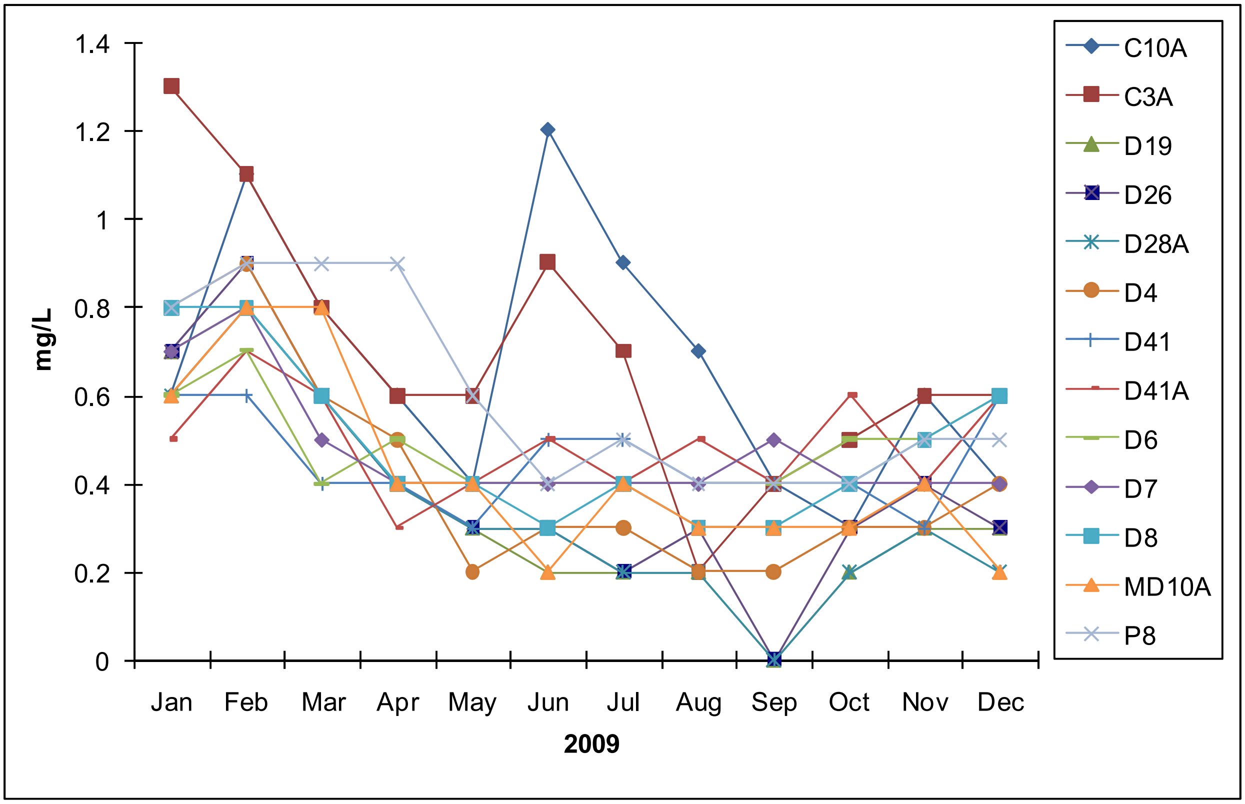


Figure 3-17 Kjeldahl nitrogen by station, 2009

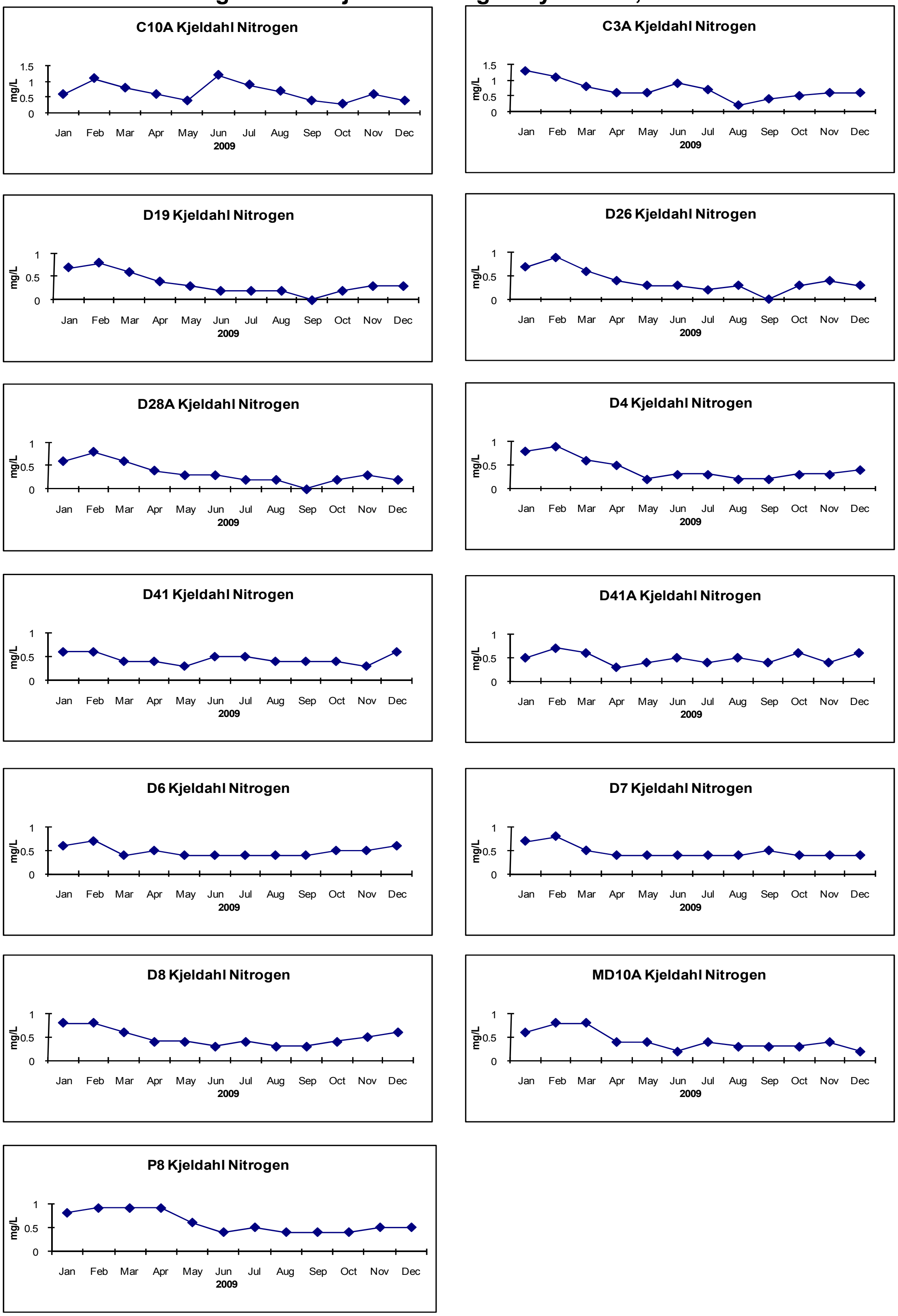


Figure 3-18 DIN comparisons, 2009

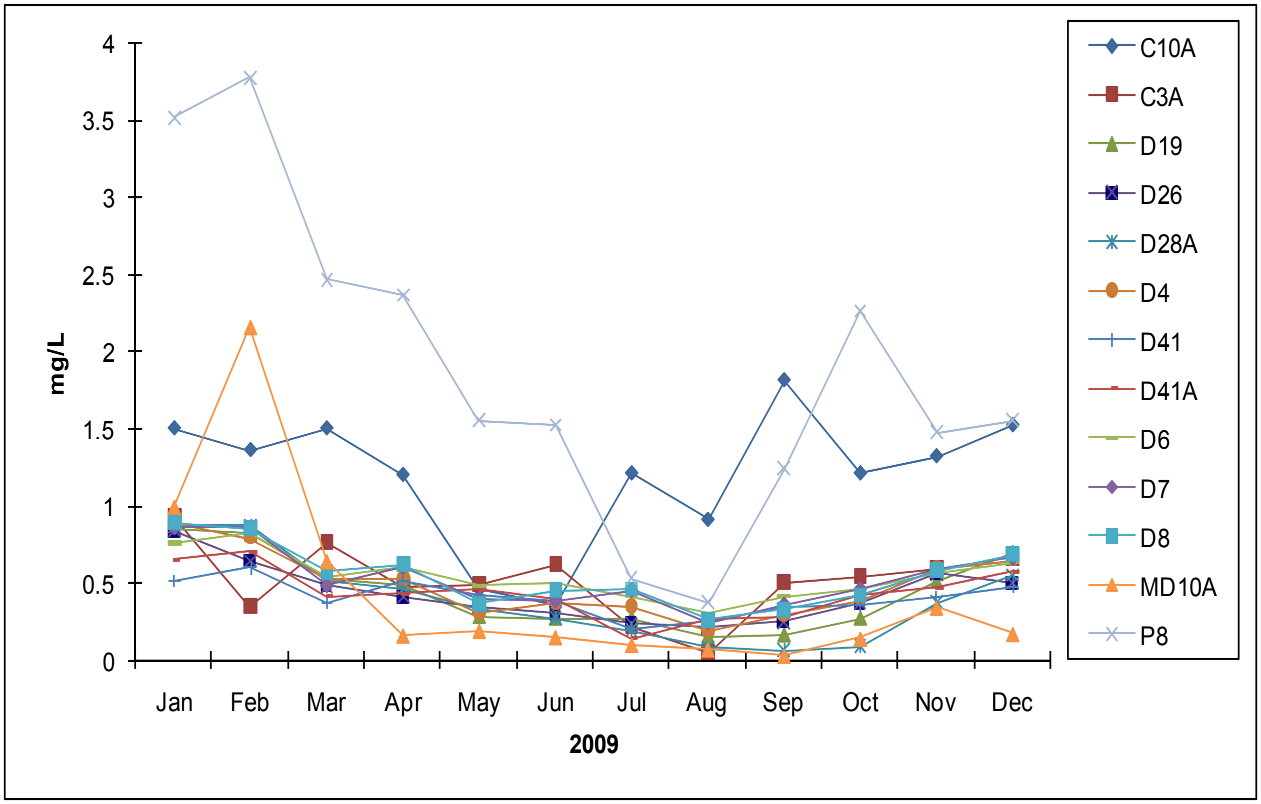


Figure 3-19 DIN by station, 2009

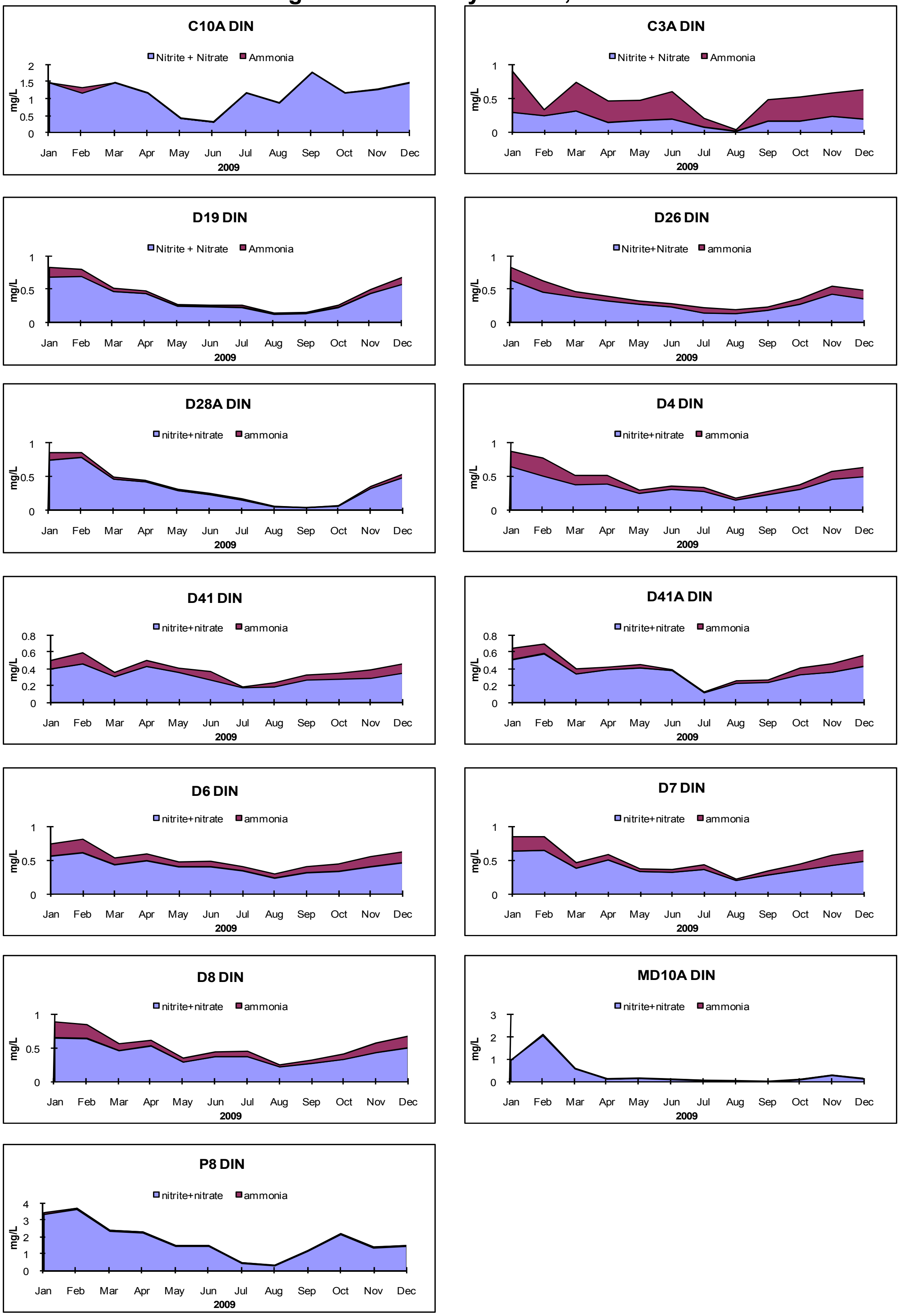


Figure 3-20 DON comparisons, 2009

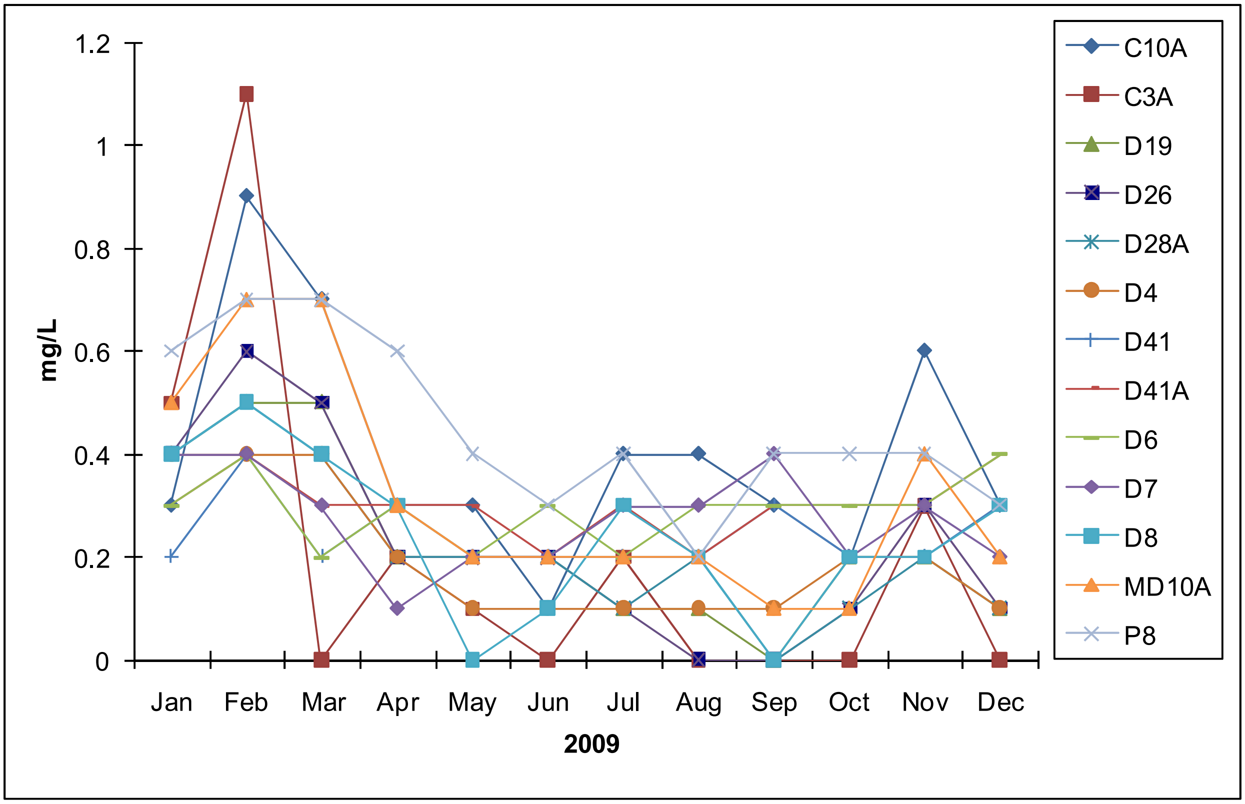


Figure 3-21 DON by station, 2009

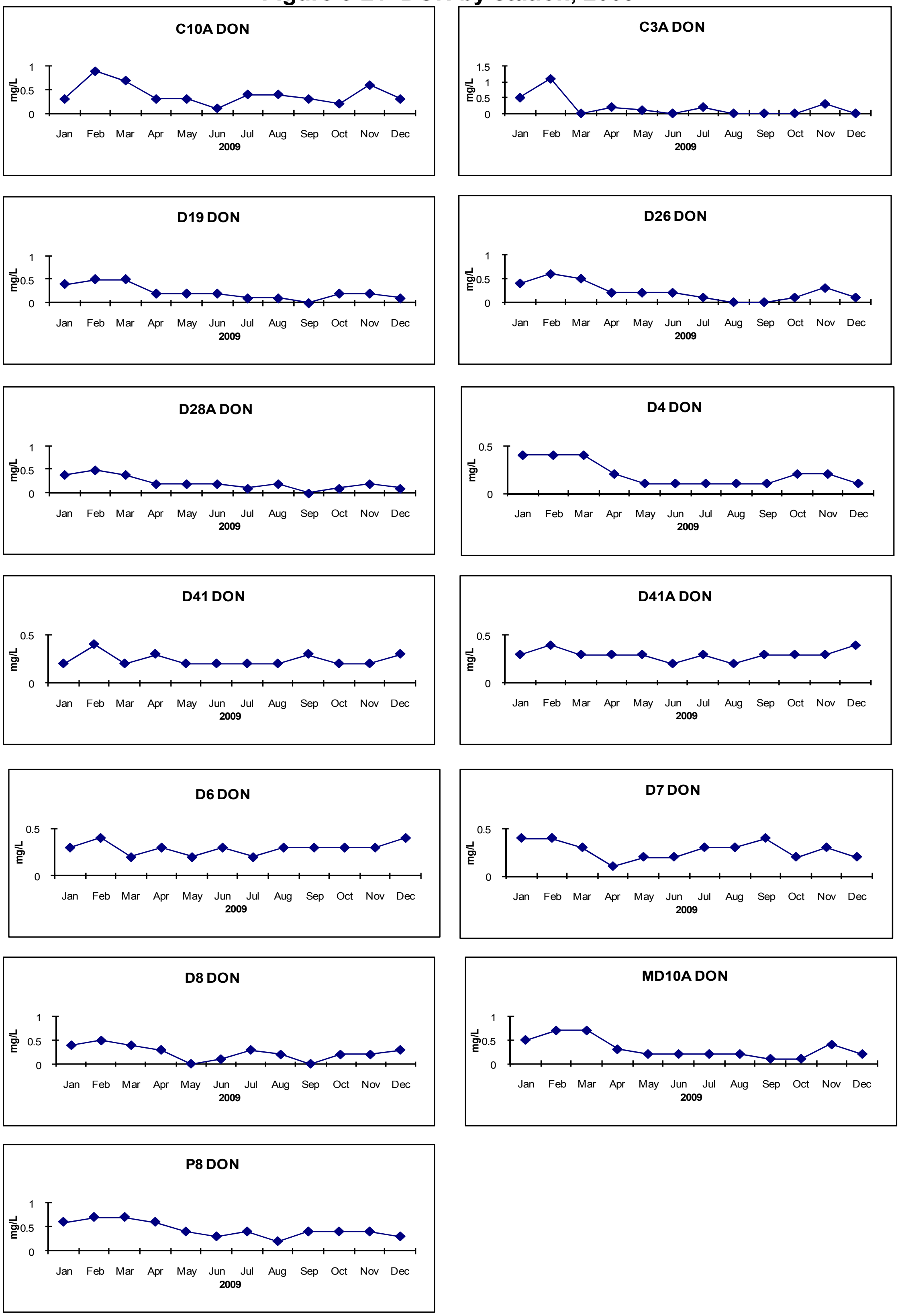


Figure 3-22 TDS comparisons, 2009

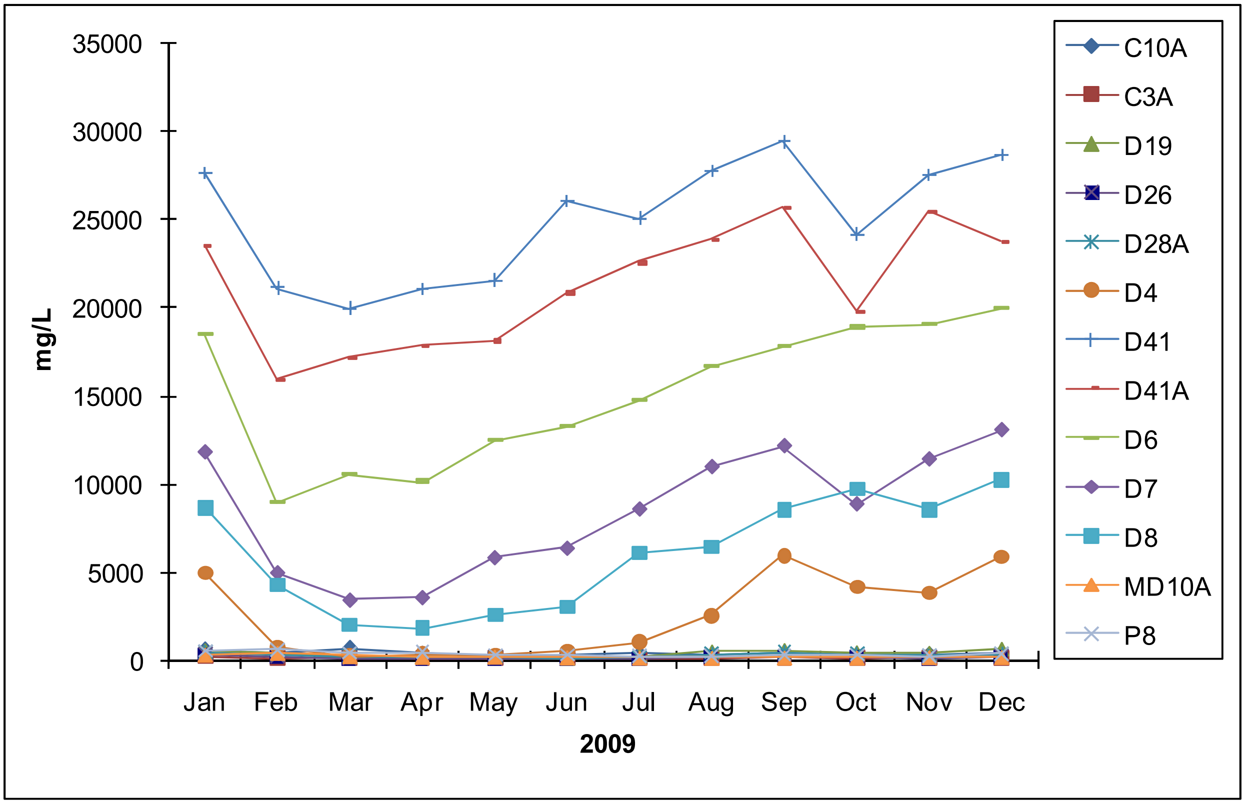


Figure 3-23 TDS by station, 2009

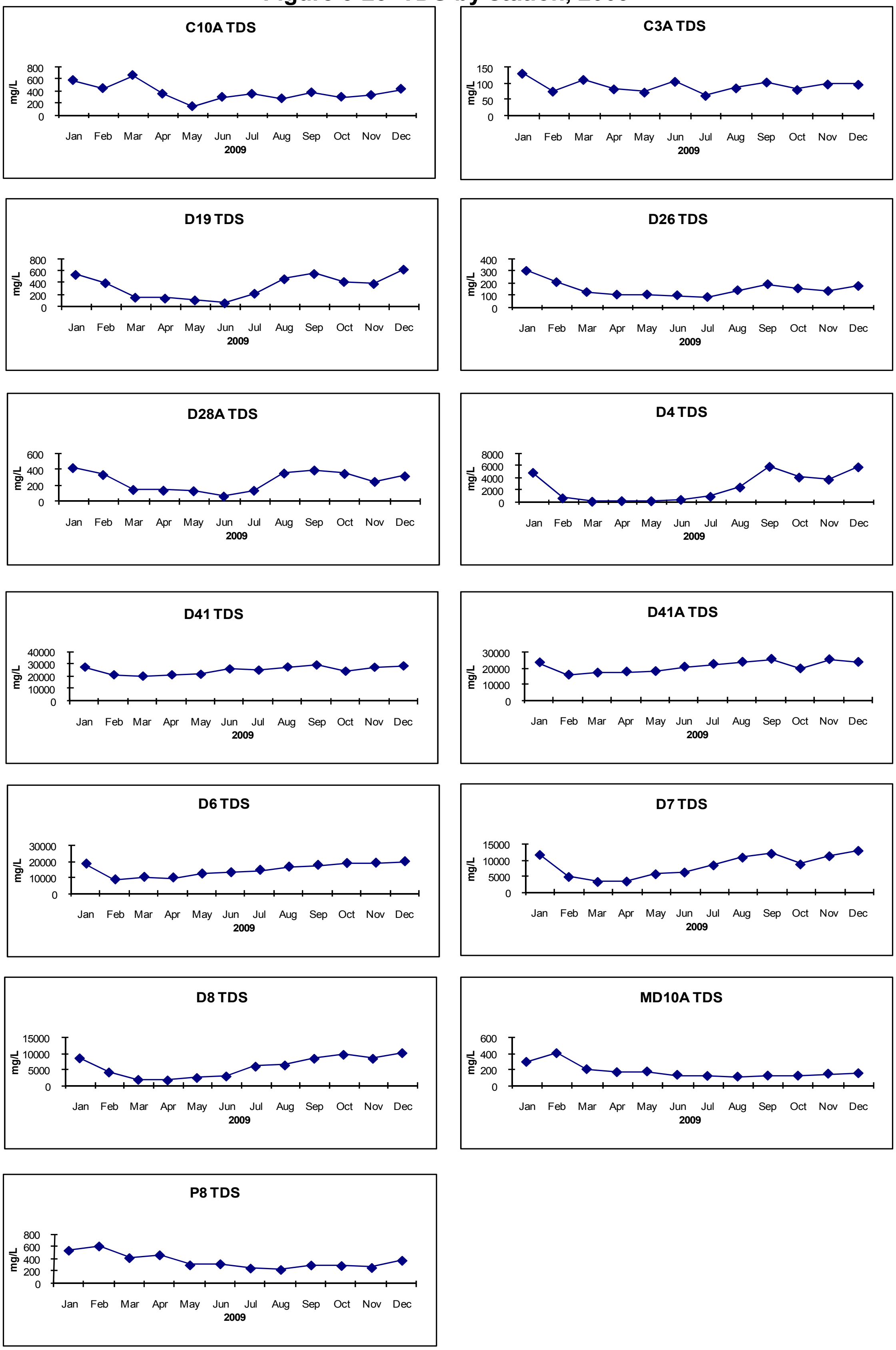


Figure 3-24 TSS comparisons, 2009

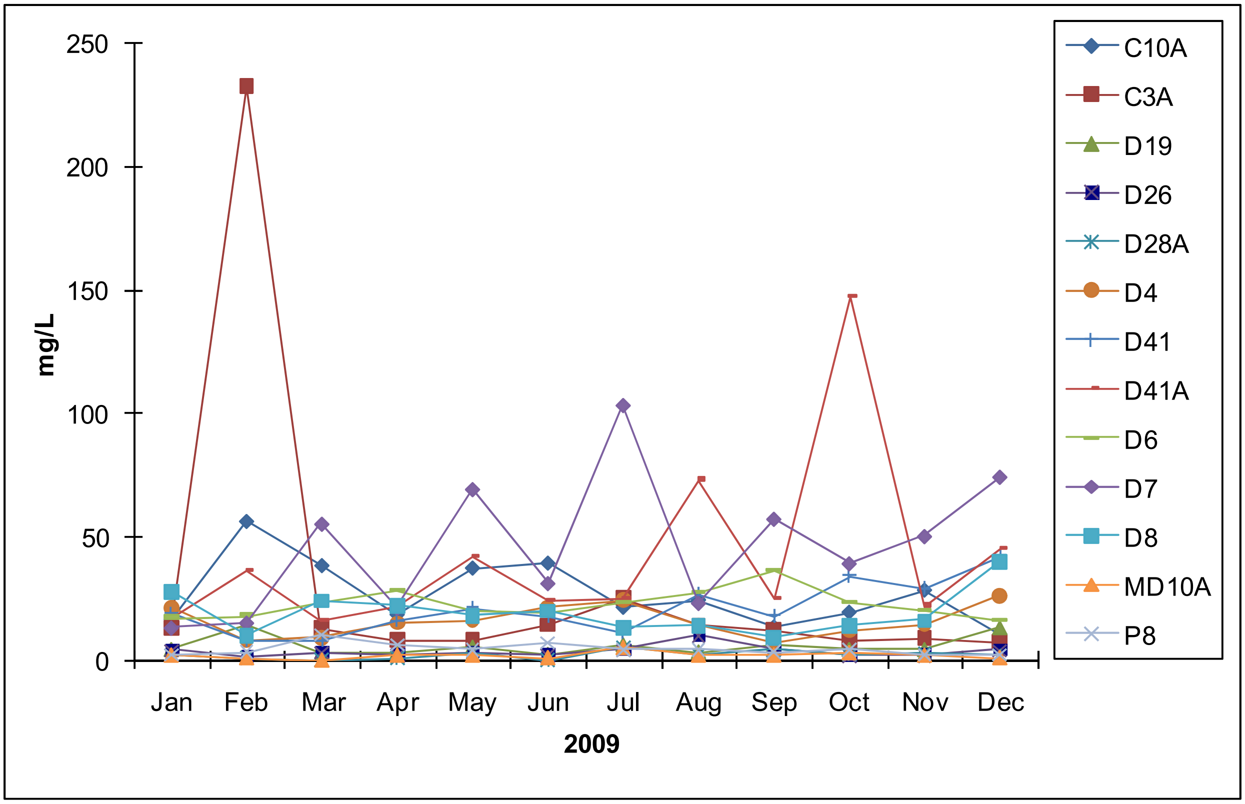


Figure 3-25 TSS by station, 2009

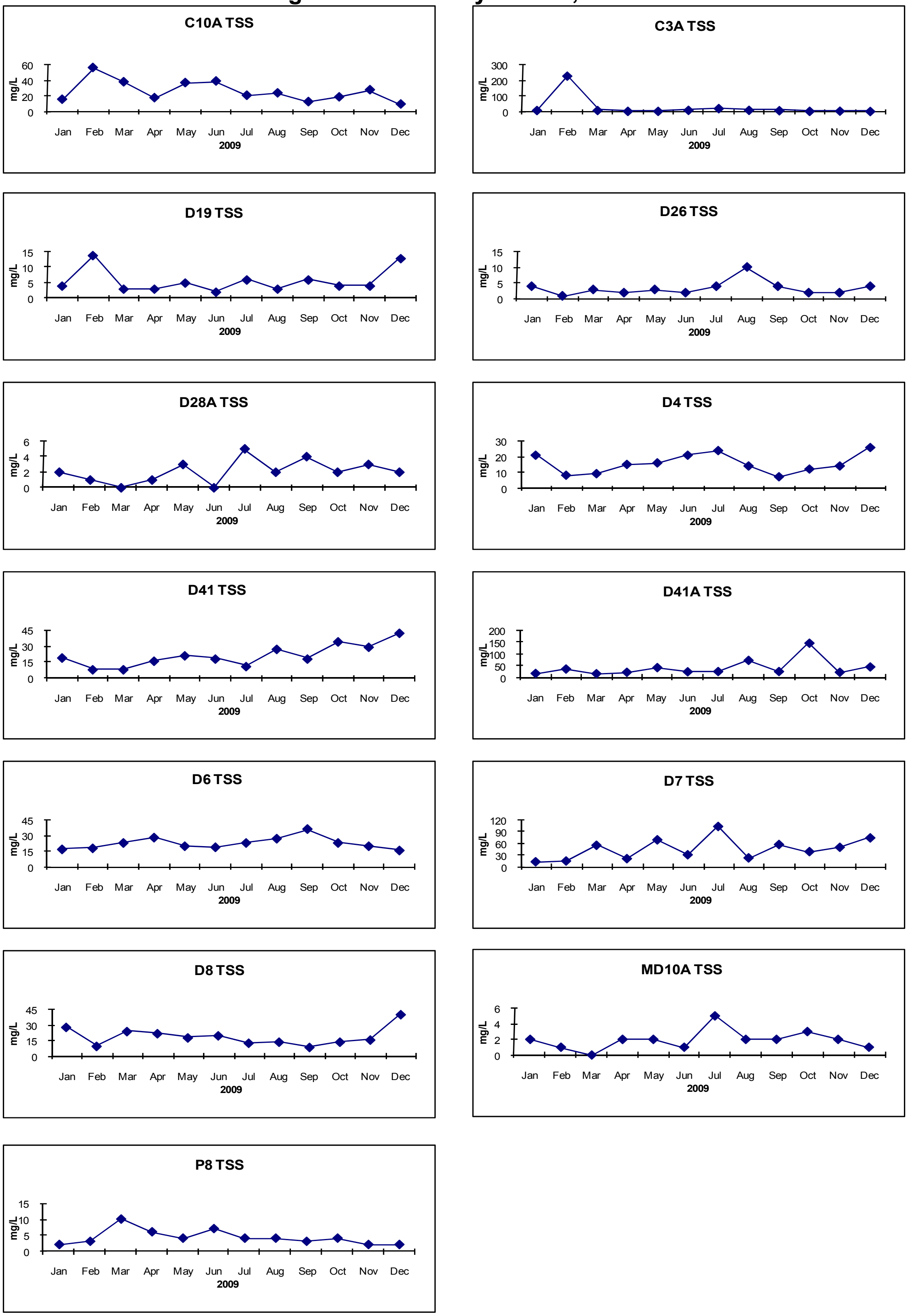


Figure 3-26 VSS comparisons, 2009

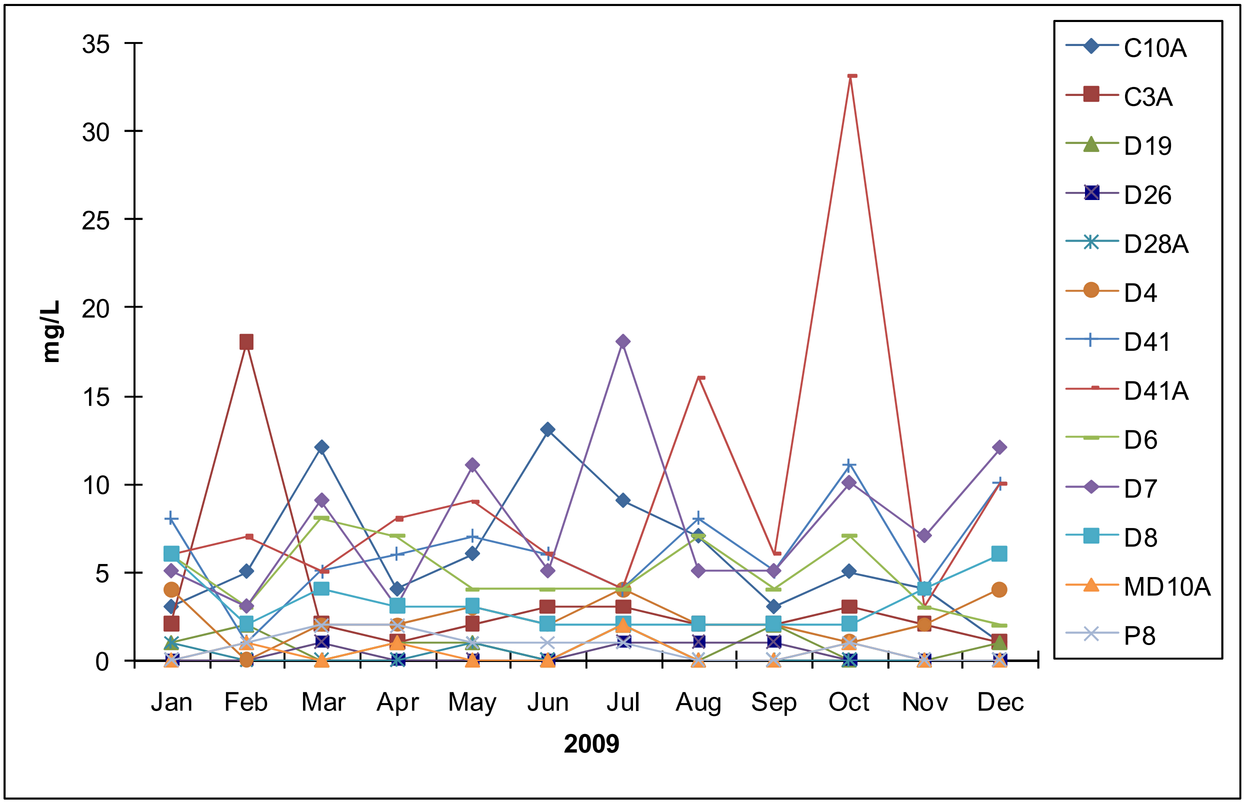


Figure 3-27 VSS by station, 2009

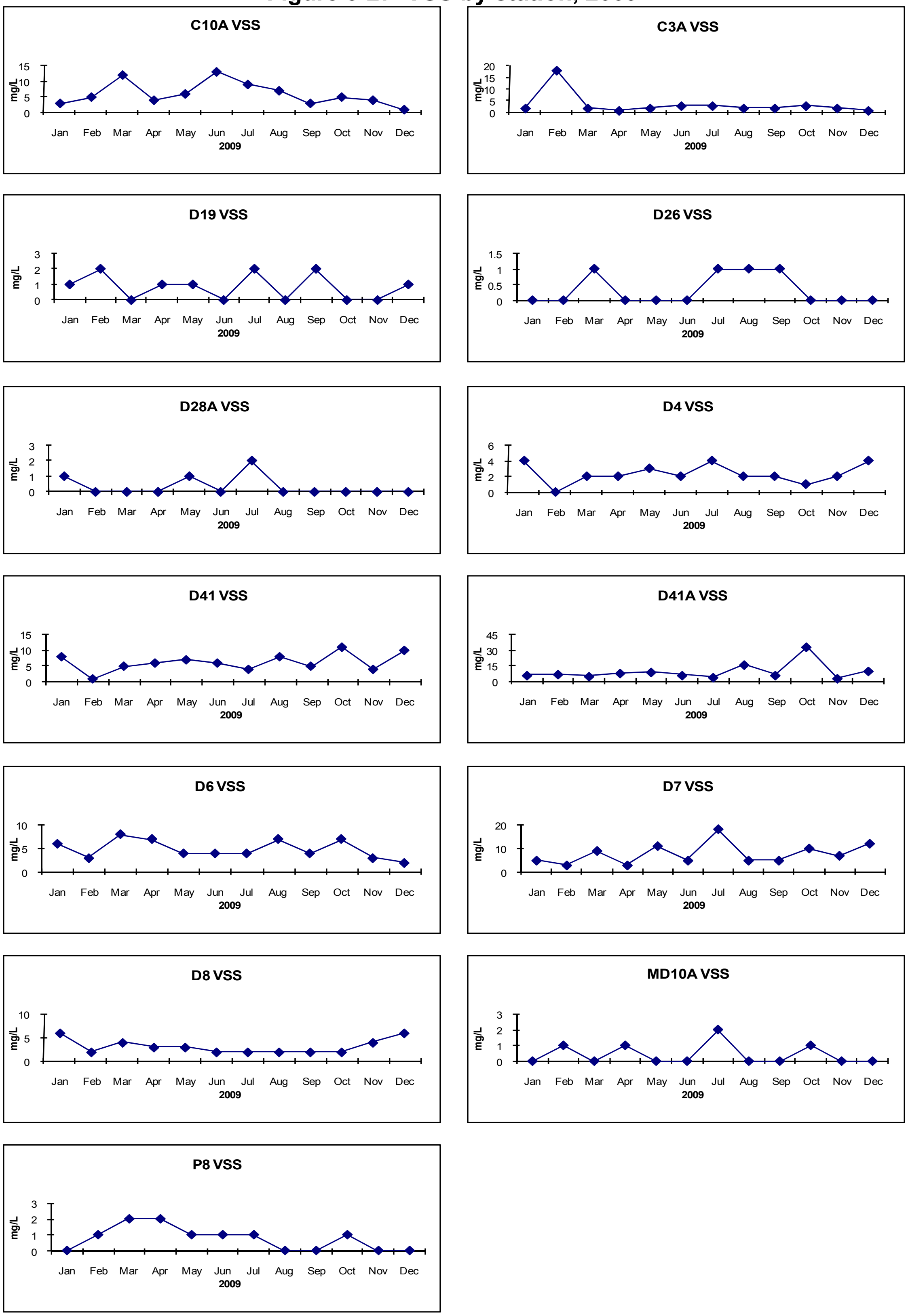


Figure 3-28 Silica comparisons, 2009

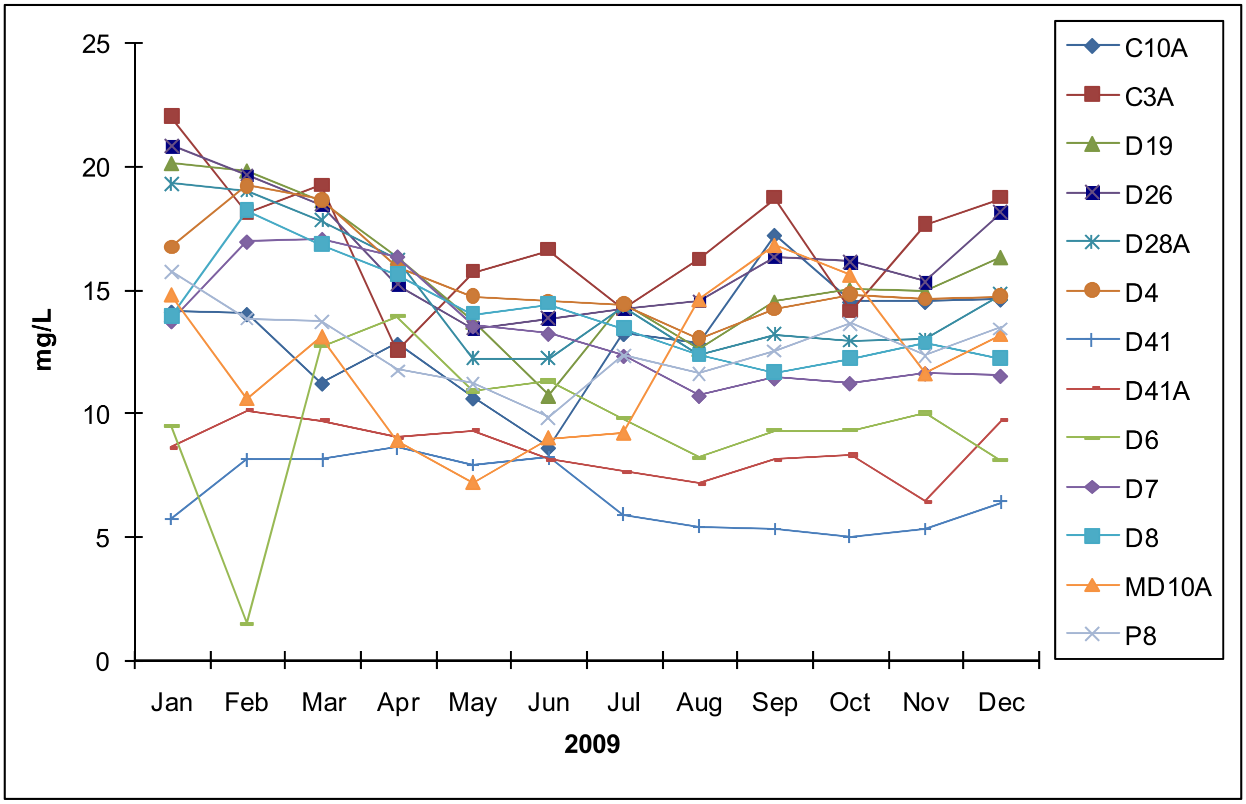


Figure 3-29 Silica by station, 2009

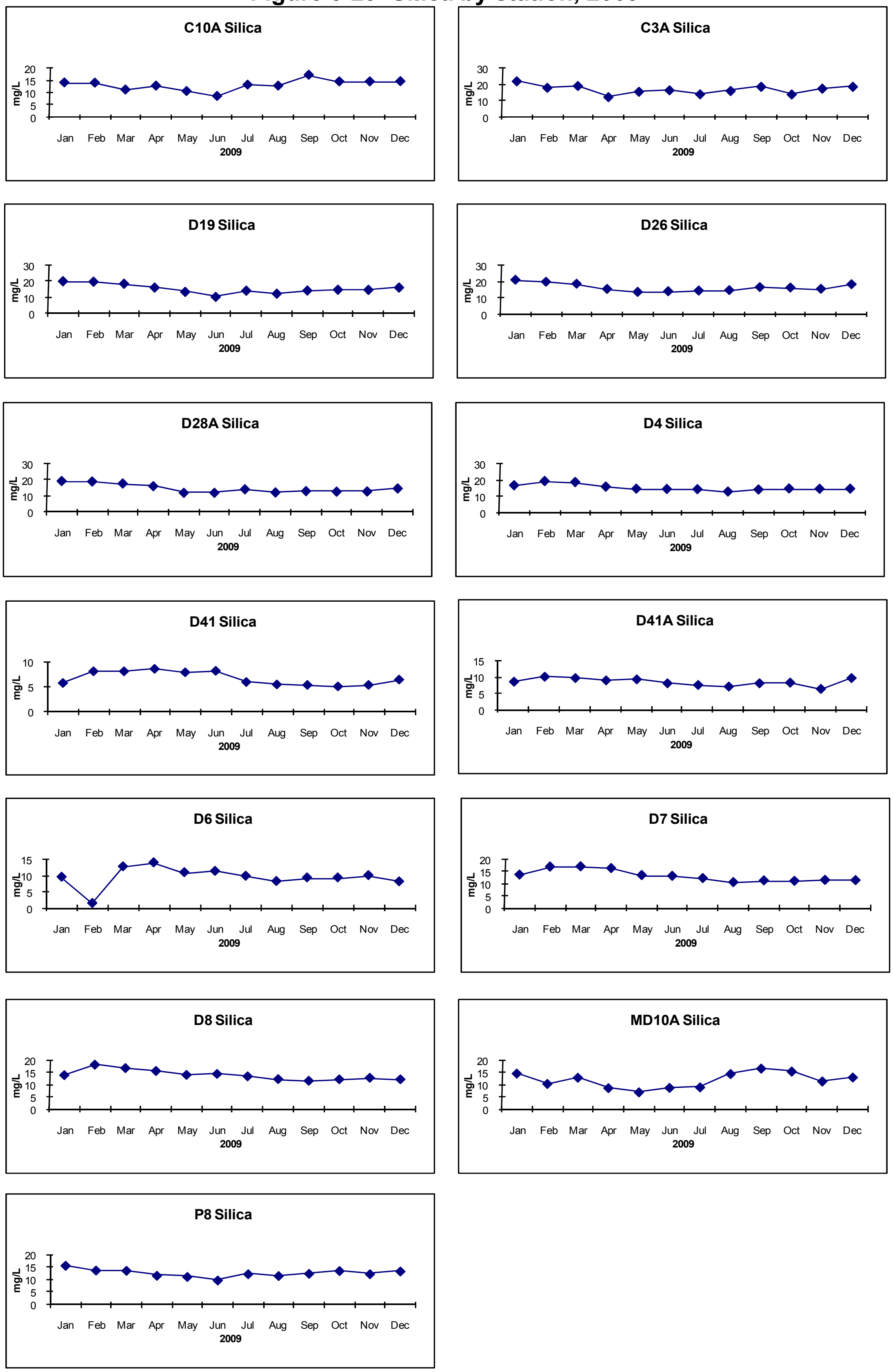


Figure 3-30 Chloride comparisons, 2009

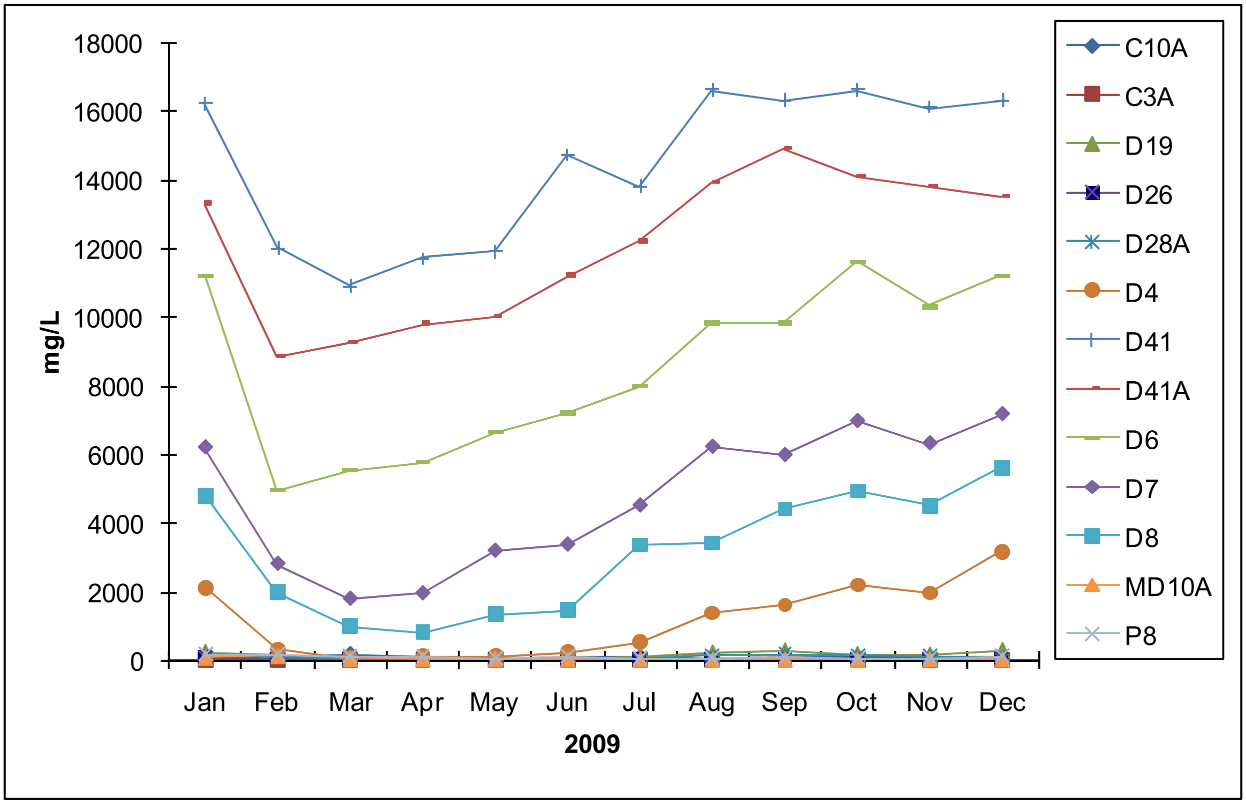


Figure 3-31 Chloride by station, 2009

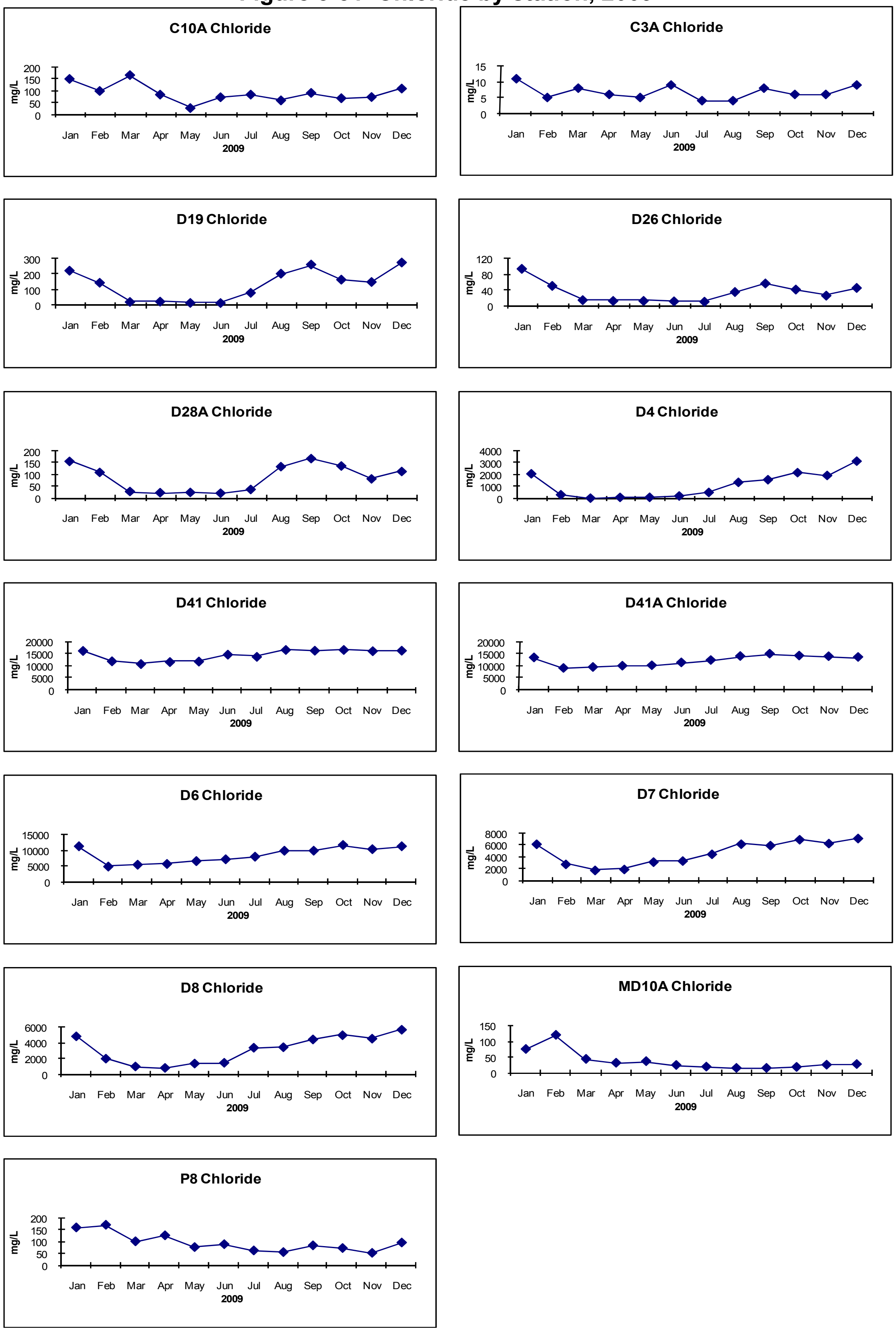


Table 3-1 Water quality parameters measured

Parameter	Units
Water temperature	°C
DO	mg/L
SC	µS/cm
Secchi disk depth	cm
Turbidity	NTU
Orthophosphate	mg/L
Total phosphorus	mg/L
Kjeldahl nitrogen	mg/L
DIN	mg/L
DON	mg/L
TDS	mg/L
TSS	mg/L
VSS	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 Sacramento 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 *a*

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Chapter 4 Phytoplankton and Chlorophyll *a*

Introduction

DWR and USBR are required by D-1641 to collect phytoplankton and chlorophyll *a* samples in order to monitor algal community composition and biomass at selected sites in the estuary. The 13 sampling sites range from the eastern region of San Pablo Bay to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays. This chapter describes the results of these monitoring efforts for calendar year 2009.

Primary production (carbon fixation through photosynthesis) by phytoplankton is 1 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 & Goldman, 1994). Phytoplankton can affect pH, color, and taste and odor in the water as well as the concentration of DO. Under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illnesses (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).

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 & 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 the extensive filtration of the water column by the introduced Asian clam, *Corbula amurensis* (Alpine & 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 & Cloern, 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 13 monitoring sites throughout the estuary (Figure 4-1). Samples were collected using a submersible pump from 1 m below the water's surface. The samples were stored in 50-mL 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 EcoAnalyst[1], a private contractor, using both the Utermöhl microscopic method (Utermöhl, 1958), and the modified phytoplankton analysis procedures as described in *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 org/mL using the following formula:

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

where:

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

This simplifies to:

Organisms = C / cV

where:

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

The 10 most common genera were determined by summing the number of org/mL across all stations and months for each genus.

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 13 monitoring sites throughout the estuary (Figure 4-1) using a submersible pump from 1 m 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 spectrophotometric procedure from *Standard Methods* (APHA, 1998). Samples were processed by mechanically grinding the glass-fiber filters and

[1] EcoAnalyst, Inc, 1420 S. Blaine St., Suite 14, Moscow, ID 83843

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 the procedure's formula (APHA, 1998).

Results

Phytoplankton Identification

Of the 15 groups identified, centric diatoms, cyanobacteria, pennate diatoms, and green algae constituted 94.12% of the organisms collected (Figure 4-2; "Other Taxa" is the sum of the last 7 groups, as they are too rare to appear individually on the graph).

All organisms collected in 2009 fell into these 15 categories:

- Centric diatoms (class Coscinodiscophyceae)
- Cyanobacteria (class Cyanophyceae)
- Pennate diatoms (classes Bacillariophyceae and Fragilariophyceae)
- Green algae (classes Chlorophyceae, Ulvophyceae and Zygnematophyceae)
- Cryptomonad flagellates (class Cryptophyceae)
- Euglenoid flagellates (class Euglenophyceae)
- Unknown Taxa
- Dinoflagellates (class Dinophyceae)
- Silico-flagellates (class Dictyochophyceae)
- Ciliates (classes Kinetofragminophora and Spirotrichea)
- Red Algae (class Bangiophyceae)
- Chrysophyte flagellates (class Chrysophyceae)
- Nanoflagellates
- Haptophyte flagellates (class Haptophyceae)
- Xanthophyte flagellates (class Xanthophyceae)

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

The 10 most common genera collected in 2009 were:

- *Cyclotella* (centric diatom; class Coscinodiscophyceae)
- *Oscillatoria* (cyanobacterium; class Cyanophyceae)
- *Fragilaria* (pennate diatom; class Fragilariophyceae)
- *Phormidium* (cyanobacterium; class Cyanophyceae)
- *Nitzschia* (pennate diatom; class Bacillariophyceae)
- *Actinastrum* (green alga; class Chlorophyceae)
- *Chlorococcum* (green alga; class Chlorophyceae)
- *Scenedesmus* (green alga; class Chlorophyceae)
- *Trachelomonas* (euglenoid flagellate; class Euglenophyceae)
- *Melosira* (centric diatom; class Coscinodiscophyceae)

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.water.ca.gov/bdma/docs/Phyto_Metadata_Phyto_Dictionary.doc

Pigment Concentrations

Chlorophyll *a* concentrations showed seasonal patterns at some stations, but not others. Most maxima occurred in spring and summer, while minima usually occurred in fall or winter. For some stations, peaks occurred in multiple seasons. All stations had 1 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 2009, 93.5% (146 samples) had chlorophyll *a* levels below 10 µg/L. Chlorophyll levels below 10 µg/L are considered limiting for zooplankton growth (Müller-Solger et. al., 2002). Of the 10 samples with chlorophyll *a* concentrations above 10 µg/L, 10 were from the south Delta (C10A).

The mean chlorophyll *a* concentration for all samples in 2009 was 5.38 µg/L, and the median value was 1.72 µg/L. The maximum chlorophyll *a* concentration in 2009 was 260.59 µg/L, recorded in June in the south Delta (C10A). Chlorophyll *a* maxima were recorded in spring and summer for all stations, except C3A (north Delta), which had its maximum value in February, and MD10A (east Delta), where the maximum occurred in September. The minimum chlorophyll *a* concentration was 0.47 µg/L, recorded in January in the north Delta (C3A). This was the lowest recorded value; chlorophyll *a* at D19 in March was below the detection limit. Chlorophyll *a* minima were recorded in fall and winter at all stations except D41, where the minimum was recorded in June.

Pheophytin *a* concentrations varied among stations, with some stations remaining relatively constant, while others had peaks during 1 or more months (Table 4-2 and Figures 4-3 through 4-15). The mean pheophytin *a* concentration for all samples in 2009 was 1.59 µg/L, and the median value was 0.94 µg/L. The maximum pheophytin *a* concentration was 24.99 µg/L, recorded at C10A (south Delta) in June. Pheophytin *a* maxima were recorded in spring and summer at most stations; the exceptions were C3A, D28A (maxima recorded in winter), MD10A, and D41A (maxima recorded in fall). The minimum pheophytin *a* concentration was 0.07 µg/L, recorded at D41A (San Pablo Bay) in January. Pheophytin *a* minima were recorded in fall and winter at all stations except C10A (south Delta) and D4 (lower Sacramento River). At both these stations, minima were recorded in spring.

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.

Site C3A: North Delta

The highest chlorophyll *a* concentration was recorded in February (7.65 µg/L), and the lowest was recorded in January (0.47 µg/L) (Figure 4-3a, Table 4-2). The mean was 2.10 µg/L, and the median was 1.39 µg/L. There was little seasonality, with highest values recorded mainly before May.

Pheophytin *a* data showed a pattern similar to chlorophyll *a* (Figure 4-3a). The maximum (6.44 µg/L) was recorded in February, and the minimum (0.23 µg/L) was recorded in January (Table 4-2). The mean was 1.84 µg/L and the median was 1.39 µg/L.

There were 2 large blooms of pennate diatoms in February and July; other phytoplankton were much lower in comparison (Figure 4-3b).

Site C10A: South Delta

The maximum chlorophyll *a* concentration was recorded in June (260.59 µg/L), and the minimum was in October (8.97 µg/L) (Figure 4-4a, Table 4-2). The large peak in chlorophyll *a* in June skewed the mean (49.57 µg/L) much higher than the median (14.10 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 June (24.99 µg/L) (Figure 4-4a; Table 4-2). The minimum occurred in March (2.24 µg/L). As with chlorophyll, the maximum concentration in June skewed the mean (8.11 µg/L) higher than the median (6.95 µg/L) (Table 4-2). There was a slight seasonal pattern, with highest values in summer and fall (Figure 4-4a).

A large bloom of centric diatoms in June was accompanied by smaller blooms of cyanobacteria, pennate diatoms, and green algae (Figure 4-4b).

Site P8: South Delta

Chlorophyll *a* showed a strong seasonal pattern, with highest values recorded in spring and summer (Figure 4-5a), except for a peak in February. The maximum was recorded in June (7.37 µg/L), and the minimum in November (1.01 µg/L) (Table 4-2). The mean (2.87 µg/L) was slightly higher than the median (2.37 µg/L).

Pheophytin *a* was relatively stable throughout the year (Figure 4-5a). As a result, the mean and median were fairly close (1.36 µg/L and 1.17 µg/L, respectively) (Table 4-2). The maximum was 2.50 µg/L in March, and the minimum was 0.67 µg/L in September.

A large bloom of green algae in July was bracketed by much smaller blooms of cryptomonads in June and August (Figure 4-5b).

Site MD10A: East Delta

Chlorophyll *a* did not really show a seasonal pattern; there were peaks in summer and fall with lower values the rest of the year (Figure 4-6a). The maximum (9.40 µg/L) occurred in September, and skewed the mean (2.76 µg/L) slightly higher than the median (2.01 µg/L) (Table 4-2). The minimum was recorded in December (1.20 µg/L).

Pheophytin *a* values were very low (below 2 µg/L) all year (Figure 4-6a). The mean and median were nearly identical (0.97 µg/L and 0.92 µg/L, respectively) (Table 4-2). The maximum was recorded in September (1.52 µg/L). The minimum was recorded in January (0.57 µg/L).

A bloom of centric and pennate diatoms and green algae in July were followed by a bloom of cyanobacteria in September (Figure 4-6b). Green algae and centric diatoms also contributed to the September bloom.

Site D26: Lower San Joaquin River

Chlorophyll *a* values were low (below 3 µg/L) at this station all year (Figure 4-7a). The maximum was 2.21 µg/L in April, and the minimum was 0.73 µg/L in December (Table 4-2). The peak in April skewed the mean (1.34 µg/L) slightly higher than the median (1.27 µg/L).

Pheophytin *a* values were extremely low (most values below 1 µg/L) all year (Figure 4-7a). The maximum was 1.02 µg/L in August, and the minimum was 0.50 µg/L in February (Table 4-2). The mean and median were nearly identical (0.69 µg/L and 0.63 µg/L, respectively).

There were large blooms of pennate diatoms, cyanobacteria, green algae, and cryptomonads throughout the summer (Figure 4-7b), followed by a bloom of cryptomonads and pennate diatoms in November.

Site D19: Central Delta

Chlorophyll *a* concentrations were very low all year (below 3 µg/L) (Figure 4-8a). The maximum of 2.81 µg/L occurred in April; the minimum was 1.07 µg/L in November (Table 4-2). The chlorophyll *a* concentration for March was below the detection limit. The mean and median were the same (1.69 µg/L).

Pheophytin *a* concentrations were also low, with most values below 2 µg/L (Figure 4-8a). The maximum was recorded in March (2.22 µg/L), and the minimum was recorded in September (0.47 µg/L) (Table 4-2). The mean was slightly higher than the median (1.06 µg/L and 0.96 µg/L, respectively).

A large bloom of cyanobacteria in March was followed by a smaller bloom of green algae, pennate and centric diatoms in August, and a bloom of cryptomonads and pennate diatoms in December (Figure 4-8b).

Site D28A: Central Delta

Chlorophyll *a* showed a slight seasonal pattern; however, values remained below 2 µg/L all year (Figure 4-9). The maximum of 1.99 µg/L occurred in June (Table 4-2). The minimum of 0.97 µg/L was recorded in February. The mean and median were similar (1.38 µg/L and 1.39 µg/L, respectively).

Pheophytin *a* values were low all year, with most values below 1 µg/L (Figure 4-9a). The mean and median were close in value (0.77 µg/L and 0.79 µg/L, respectively) (Table 4-2). The maximum of 1.43 µg/L was recorded in November; the minimum of 0.24 µg/L was recorded in January.

A large bloom of cryptomonads in October was accompanied by cyanobacteria and pennate diatoms (Figure 4-9b). Phytoplankton were low for the rest of the year.

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 4.90 µg/L in June; the minimum was 0.85 µg/L in November (Table 4-2). The peak in June skewed the mean (1.91 µg/L) higher than the median (1.45 µg/L).

Pheophytin *a* also showed a seasonal pattern, with peaks in spring and summer (Figure 4-10a). The maximum (1.96 µg/L) was recorded in July; the minimum (0.38 µg/L) was recorded in April (Table 4-2). The mean was 0.92 µg/L; the median was 0.87 µg/L.

There was a large bloom of cyanobacteria in March, followed by a much smaller bloom of pennate diatoms and cryptomonads in August (Figure 4-10b).

Site D6: Suisun Bay

Chlorophyll *a* did not show a seasonal pattern; a large peak in March was bracketed by much lower values the rest of the year (Figure 4-11a). The peak in March was the maximum for the year (8.76 µg/l); the minimum was 0.96 µg/L in October (Table 4-2). The mean was 2.20 µg/L, and the median was 1.55 µg/L.

Pheophytin *a* concentrations were extremely low; most values were below 1 µg/L (Figure 4-11a). The maximum was recorded in March (2.38 µg/L), and the minimum was recorded in January (0.43 µg/L) (Table 4-2). The mean was 0.78 µg/L and the median was lower at 0.65 µg/L.

There were blooms of various groups of phytoplankton throughout the year (Figure 4-11b); a bloom of dinoflagellates, pennate and centric diatoms in March was followed by a bloom of cyanobacteria in April and May. Centric diatoms bloomed throughout the summer and fall, accompanied by blooms of cryptomonads, pennate diatoms, and occasionally haptophytes and green algae.

Site D7: Suisun Bay

Chlorophyll *a* did not show a seasonal pattern; there were peaks throughout the year, though values were low (below 3 µg/L) (Figure 4-12a). The maximum was 2.04 µg/L in May, and the minimum was 0.97 µg/L in February (Table 4-2). The mean was 1.44 µg/L, and the median was 1.41 µg/L.

Pheophytin *a* showed a pattern similar to chlorophyll *a*; there were peaks throughout the year (Figure 4-12a). The maximum (2.52 µg/L) was recorded in July; the minimum (0.33 µg/L) was recorded in February (Table 4-2). The mean was 1.24 µg/L; the median was 0.90 µg/L.

Blooms of pennate diatoms in March and May were followed by a multi-group bloom (dinoflagellates, centric and pennate diatoms, euglenoids, cryptomonads, ciliates, and unknown taxa) in summer (Figure 4-12b).

Site D8: Suisun Bay

Chlorophyll *a* showed a seasonal pattern, with peaks in spring and summer (Figure 4-13a), though all values for the year were below 3 µg/L. The maximum was 2.84 µg/L in May, and the minimum was 0.76 µg/L in November (Table 4-2). The mean was 1.62 µg/L, and the median was 1.41 µg/L.

Pheophytin *a* showed no clear pattern; values were stable for most of the year, though slightly higher in spring (Figure 4-13a). The maximum (1.14 µg/L) was recorded in May; the minimum (0.39 µg/L) was recorded in January (Table 4-2). The mean was higher than the median (1.62 µg/L and 1.41 µg/L, respectively).

Phytoplankton densities were low all year, except for a multi-group bloom (cryptomonads, dinoflagellates, pennate and centric diatoms, cyanobacteria, green algae, and unknown taxa) in summer (Figure 4-13b).

Site D41: San Pablo Bay

Chlorophyll *a* did not show a seasonal pattern; there was a large peak in July, with lower values the rest of the year (Figure 4-14a). The maximum occurred in July (7.90 µg/L) (Table 4-2). The minimum of 1.69 µg/L was recorded in June. The mean (3.10 µg/L) was higher than the median (2.67 µg/L) (Table 4-2).

Pheophytin *a* also did not show a pattern; values were low (below 2 µg/L) all year. The maximum of 1.91 µg/L was recorded in December; the minimum of 0.47 µg/L was recorded in

January (Table 4-2). The mean and median were very close (1.00 µg/L and 0.99 µg/L, respectively).

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

Site D41A: San Pablo Bay

Chlorophyll *a* showed a slight seasonal pattern; the highest values were in spring and summer (Figure 4-15a). The maximum (7.05 µg/L) occurred in March (Figure 4-15a, Table 4-2). The minimum of 1.37 µg/L was recorded in December. The mean and median were similar (3.44 µg/L and 3.23 µg/L, respectively) (Table 4-2).

Pheophytin *a* fluctuated throughout the year, with no clear pattern (Figure 4-15a). The maximum of 2.87 µg/L was recorded in October, and the minimum of 0.07 µg/L was recorded in January (Figure 4-15a, Table 4-2). The mean was 1.16 µg/L; the median was 0.94 µg/L.

A bloom of pennate diatoms, ciliates, centric diatoms, and green algae in January was followed by low phytoplankton densities until summer and fall (Figure 4-15b). The summer and fall blooms consisted of cryptomonads, pennate and centric diatoms, and a large bloom of green algae in September.

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2009. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following 15 categories: centric diatoms, cyanobacteria, pennate diatoms, green algae, cryptomonad flagellates, euglenoid flagellates, unknown taxa, dinoflagellates, silico-flagellates, ciliates, red algae, chrysophyte flagellates, nanoflagellates, haptophyte flagellates, and xanthophyte flagellates. The 10 most common genera were *Cyclotella, Oscillatoria, Fragilaria, Phormidium, Nitzschia, Actinastrum, Chlorococcum, Scenedesmus, Trachelomonas,* and *Melosira.* Seasonality in chlorophyll *a* varied among the stations; some showed seasonality while others did not. Values ranged from 0.47 µg/L to 260.59 µg/L. Pheophytin *a* concentrations mainly did not show a seasonal pattern; values ranged from 0.07 µg/L to 24.99 µg/L. Despite sporadic peaks at some stations, chlorophyll *a* concentrations overall were relatively low when compared with historical data.

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Chapter 4 Appendix

Figure 4-1 Map of chlorophyll *a* and phytoplankton monitoring sites

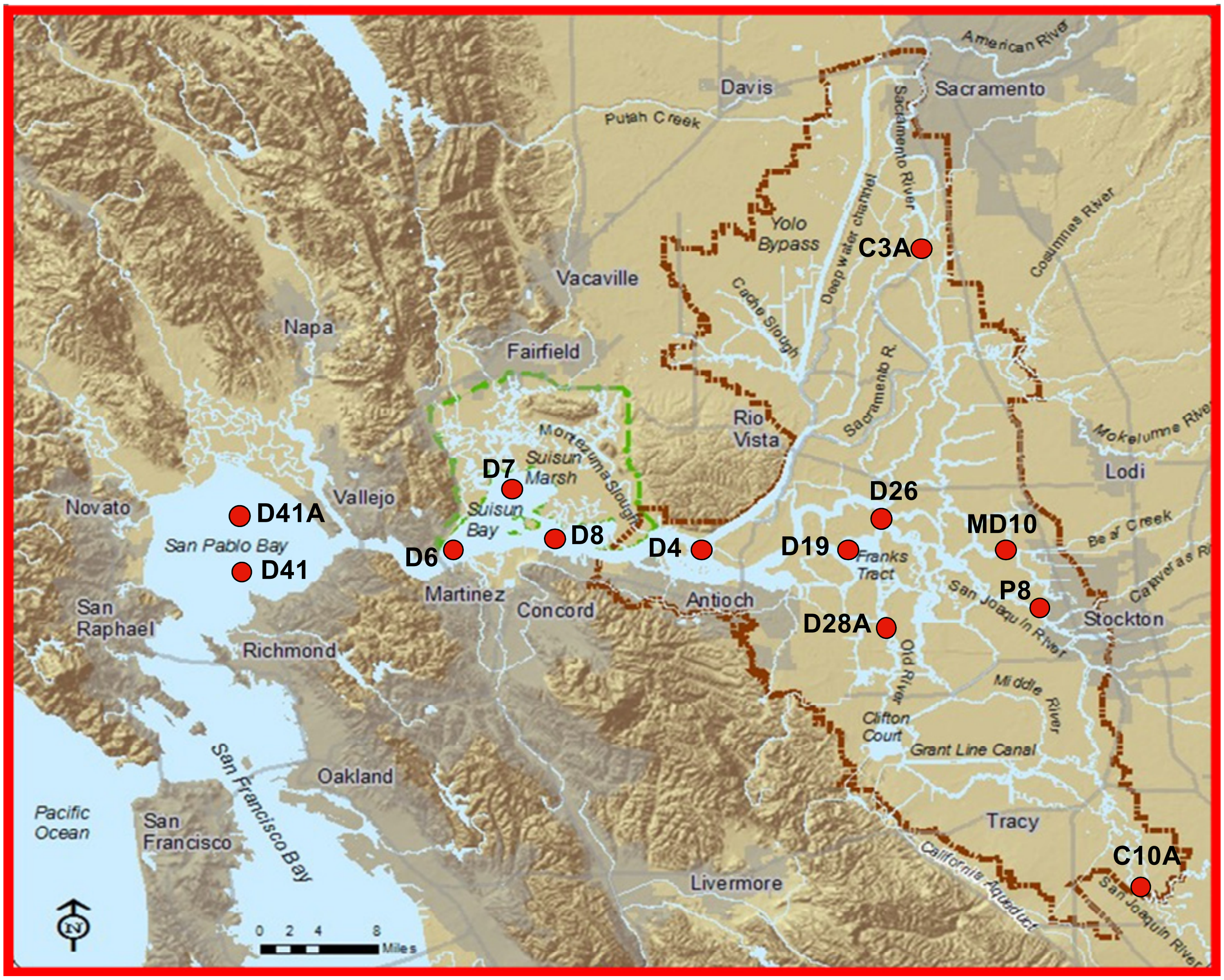

Figure 4-2 Percent of phytoplankton composition by group, 2009

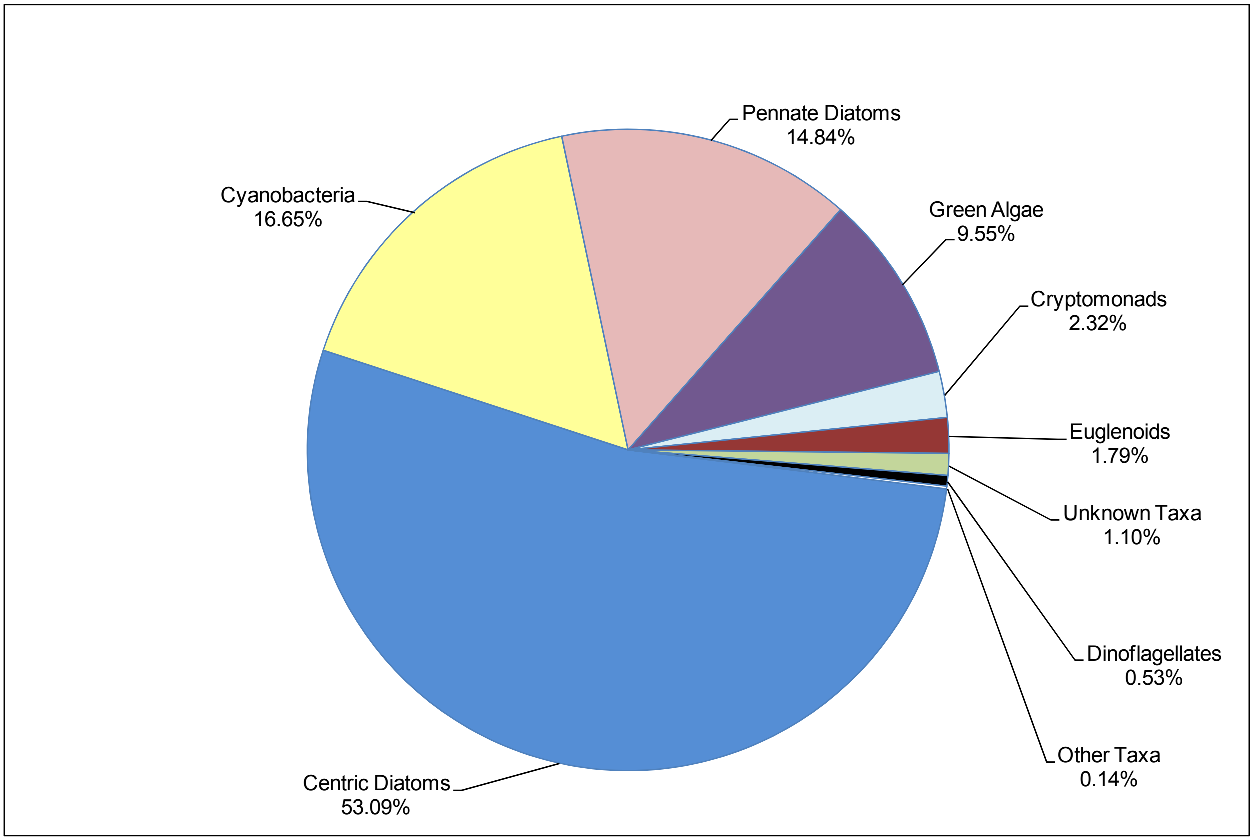

Figure 4-3a Pigment concentrations at C3A, 2009

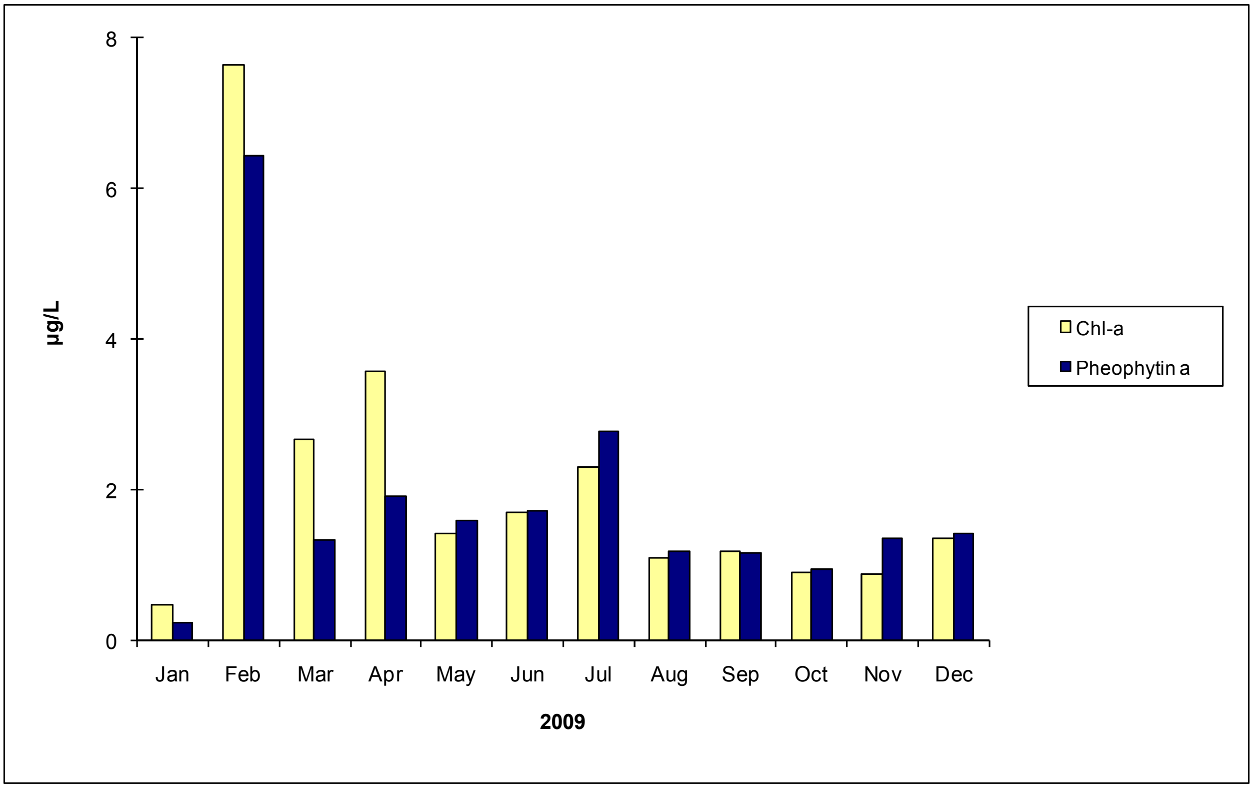

Figure 4-3b Phytoplankton composition at C3A, 2009

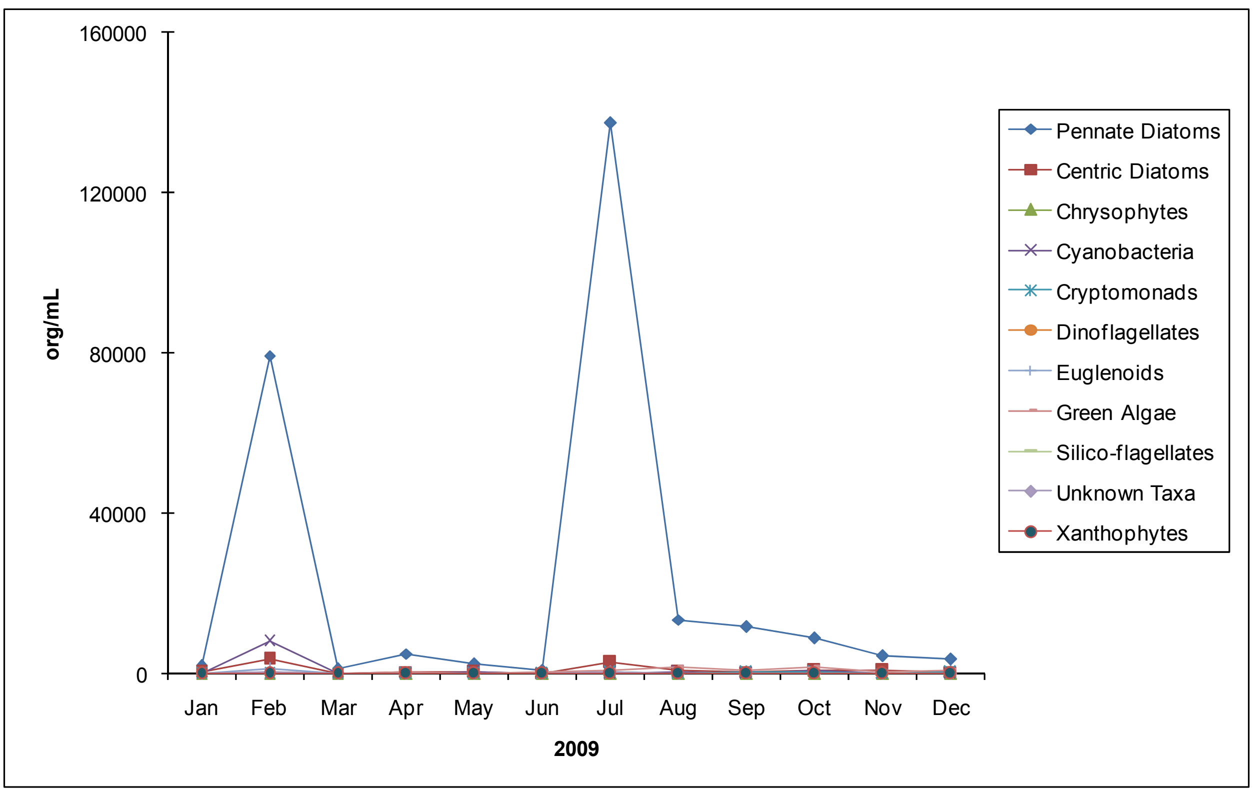

Figure 4-4a Pigment concentrations at C10A, 2009

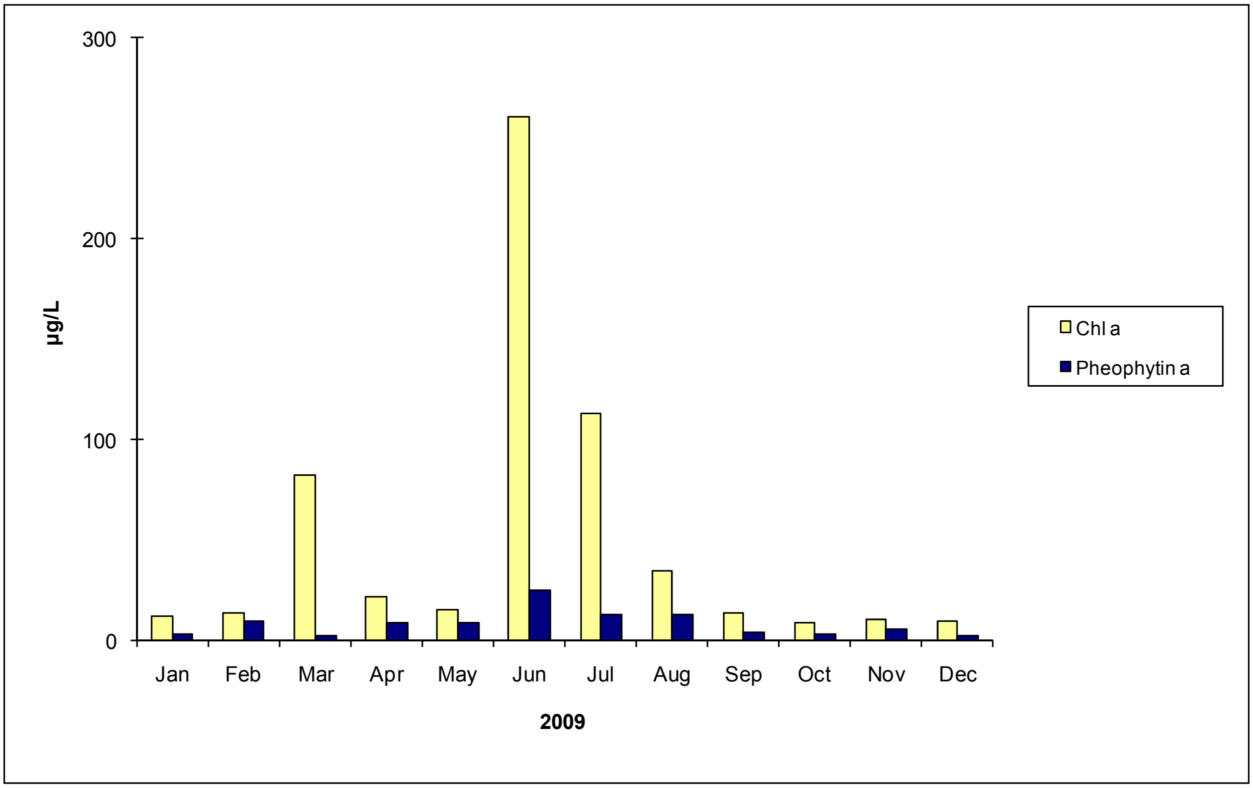

Figure 4-4b Phytoplankton composition at C10A, 2009

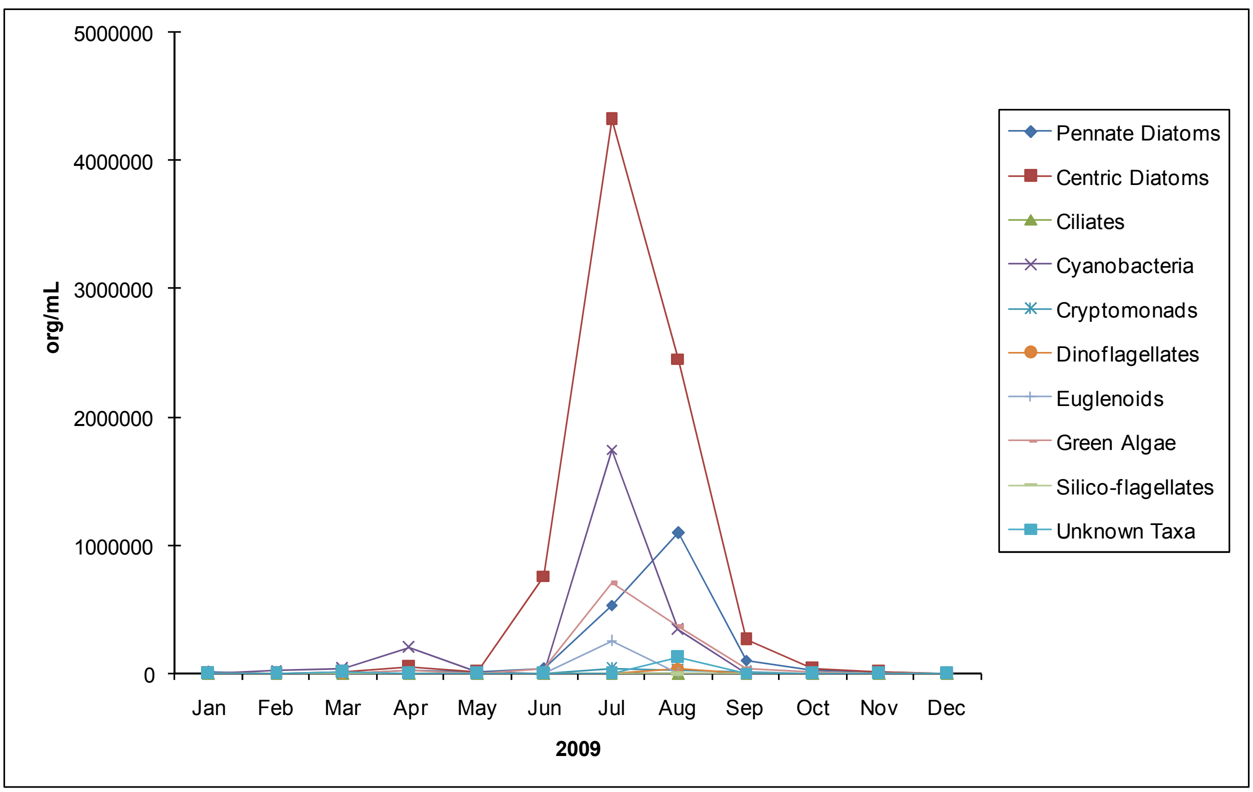

Figure 4-5a Pigment concentrations at P8, 2009

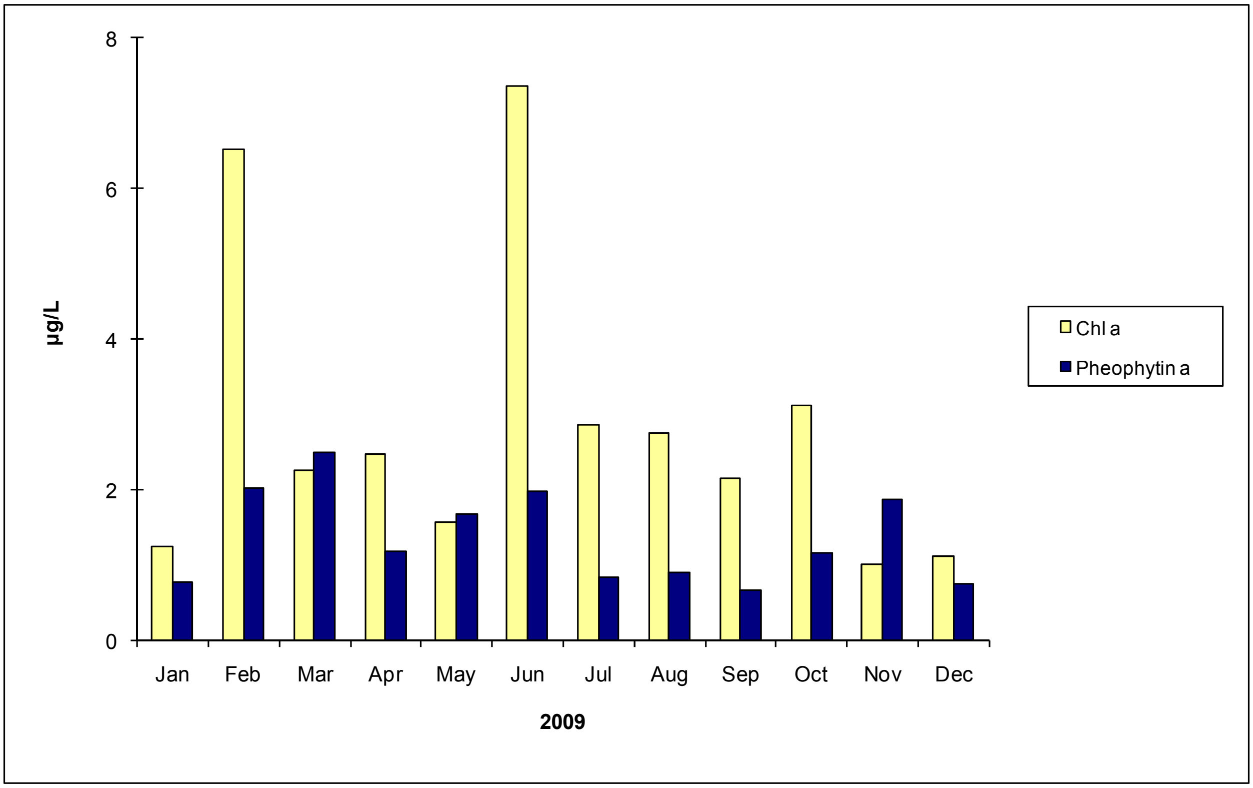

Figure 4-5b Phytoplankton composition at P8, 2009

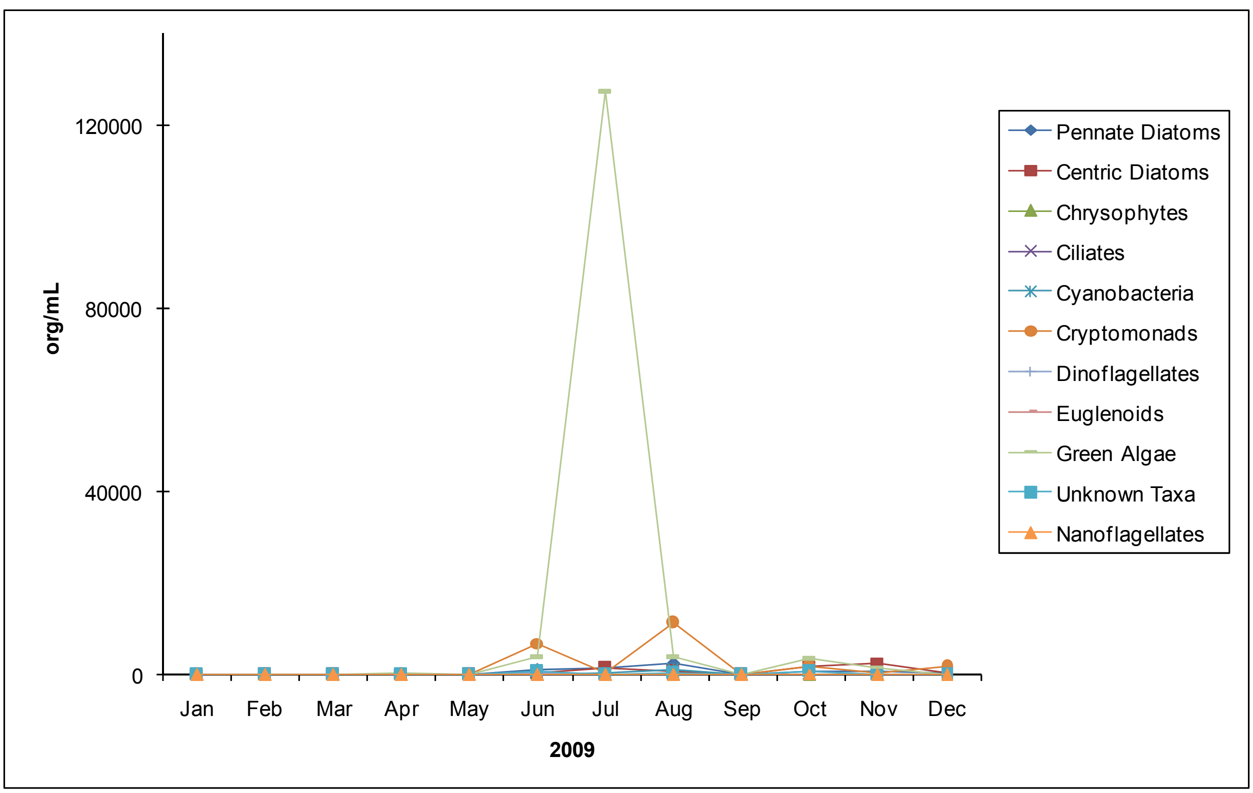

Figure 4-6a Pigment concentrations at MD10A, 2009

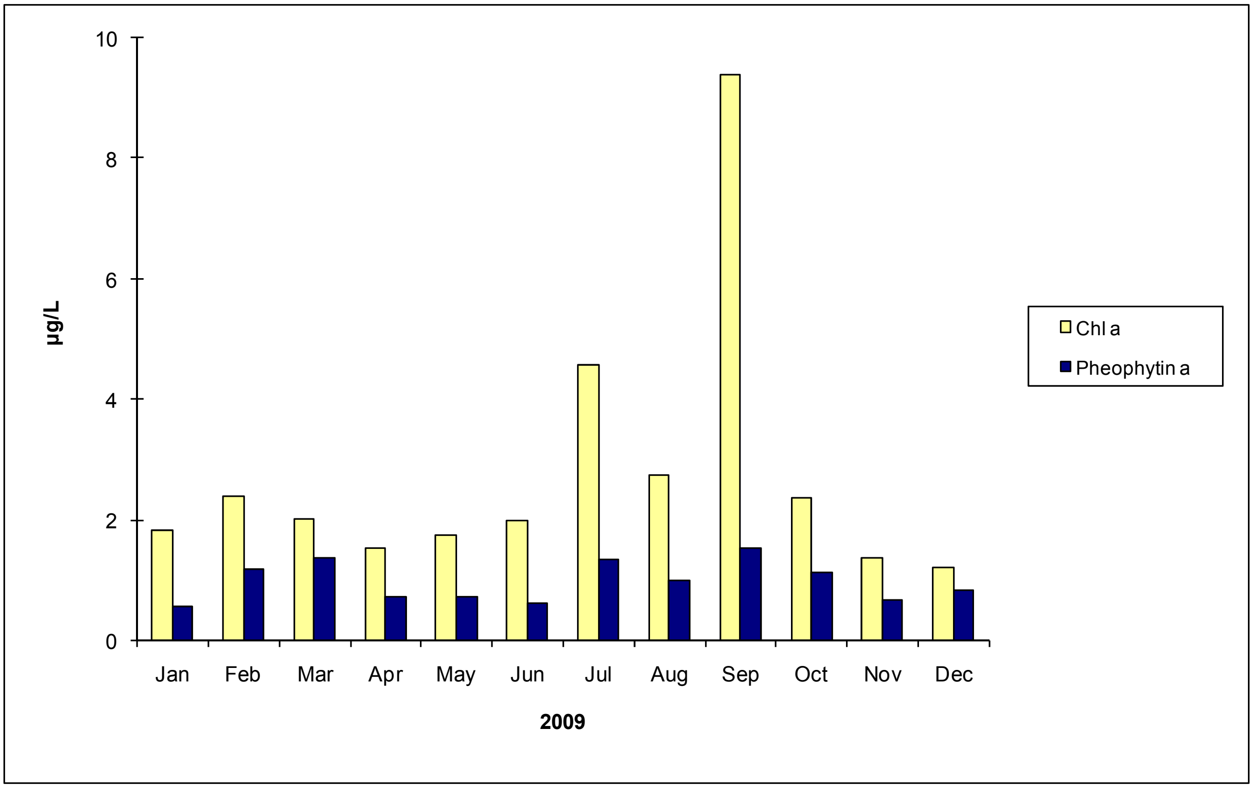

Figure 4-6b Phytoplankton composition at MD10A, 2009

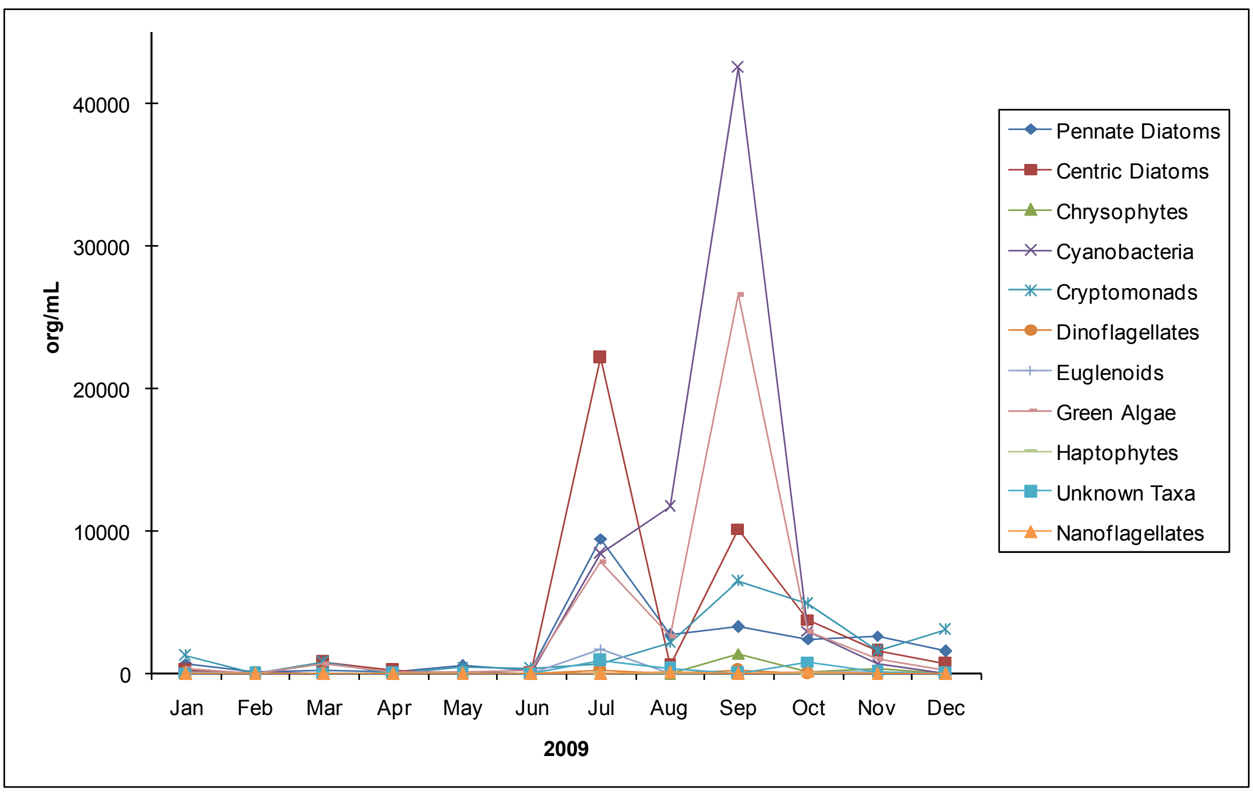

Figure 4-7a Pigment concentrations at D26, 2009

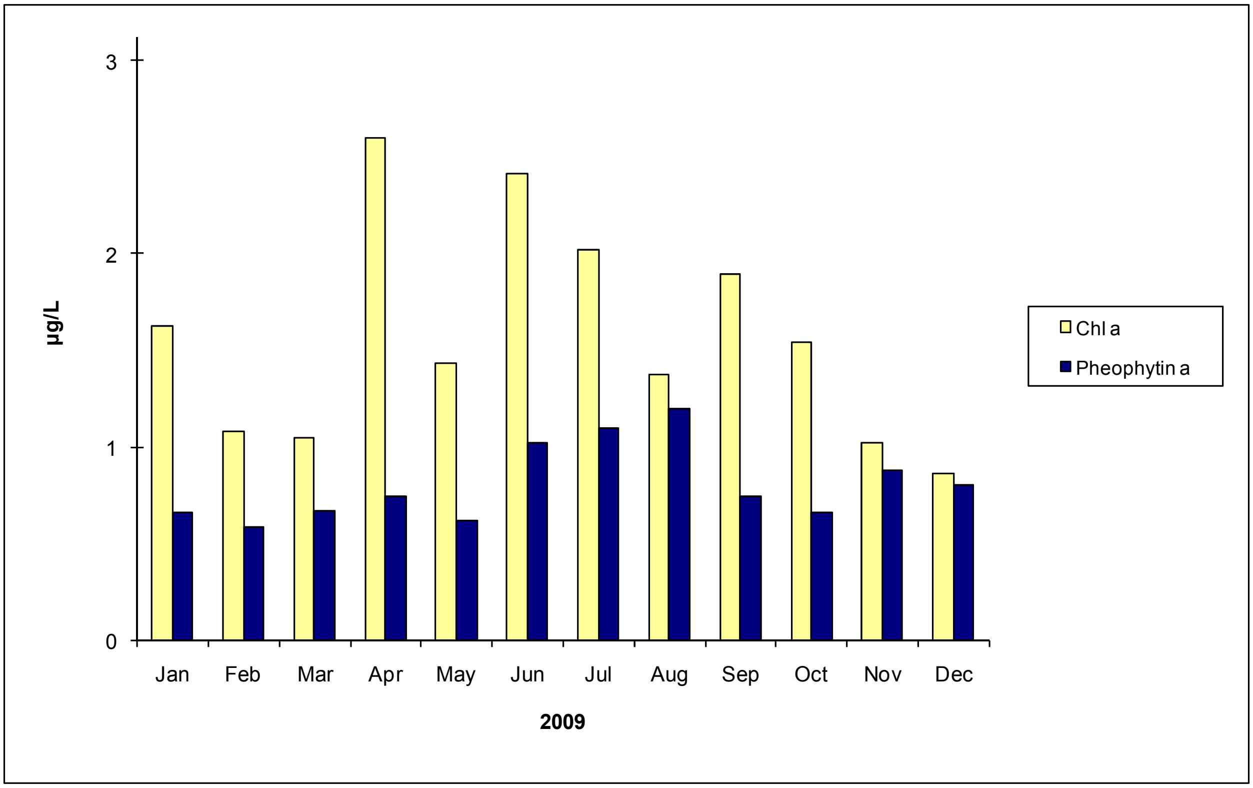

Figure 4-7b Phytoplankton composition at D26, 2009

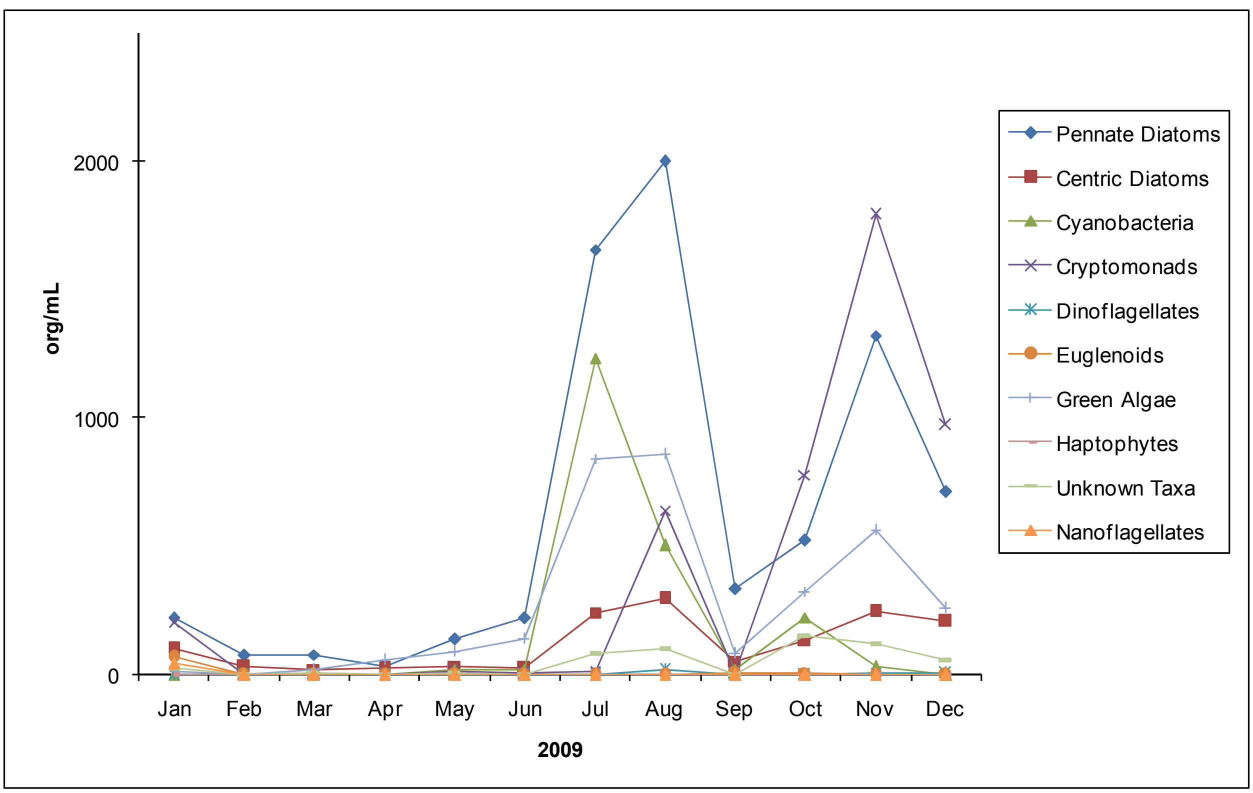

Figure 4-8a Pigment concentrations at D19, 2009

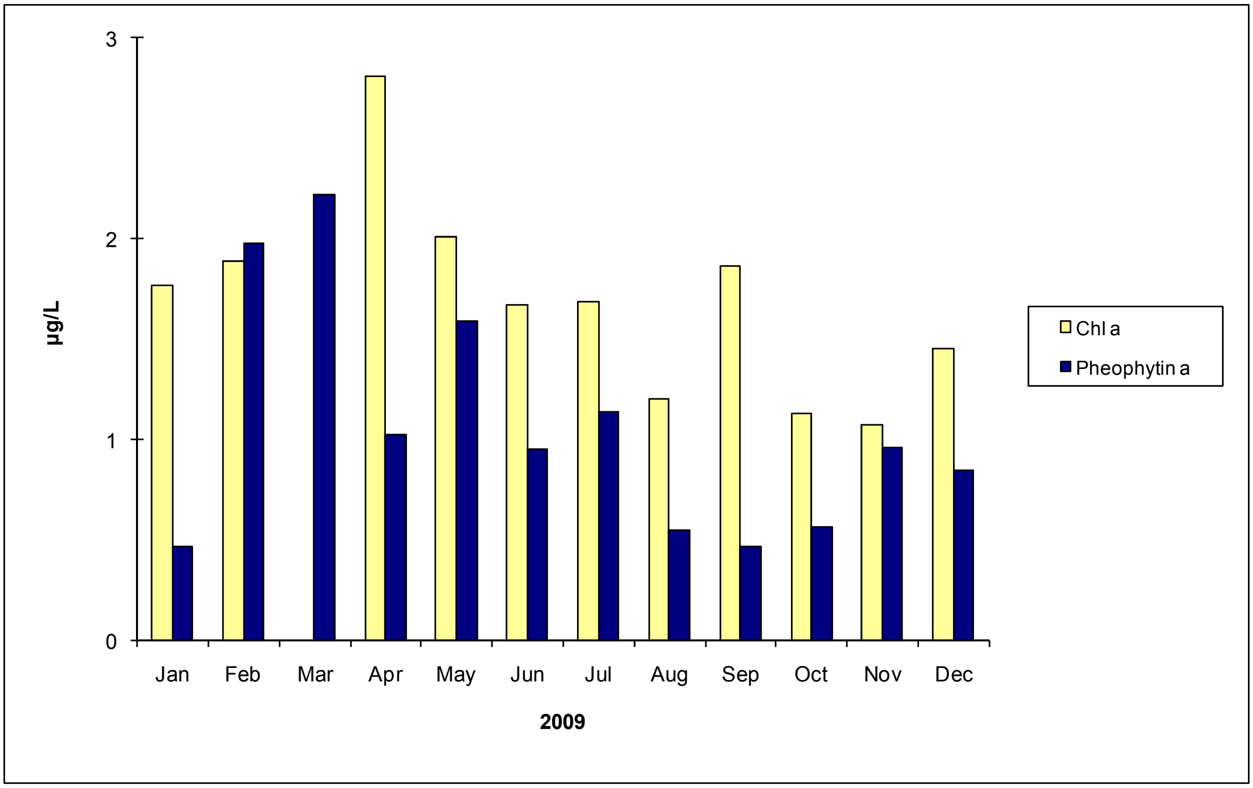

Figure 4-8b Phytoplankton composition, D19 in 2009

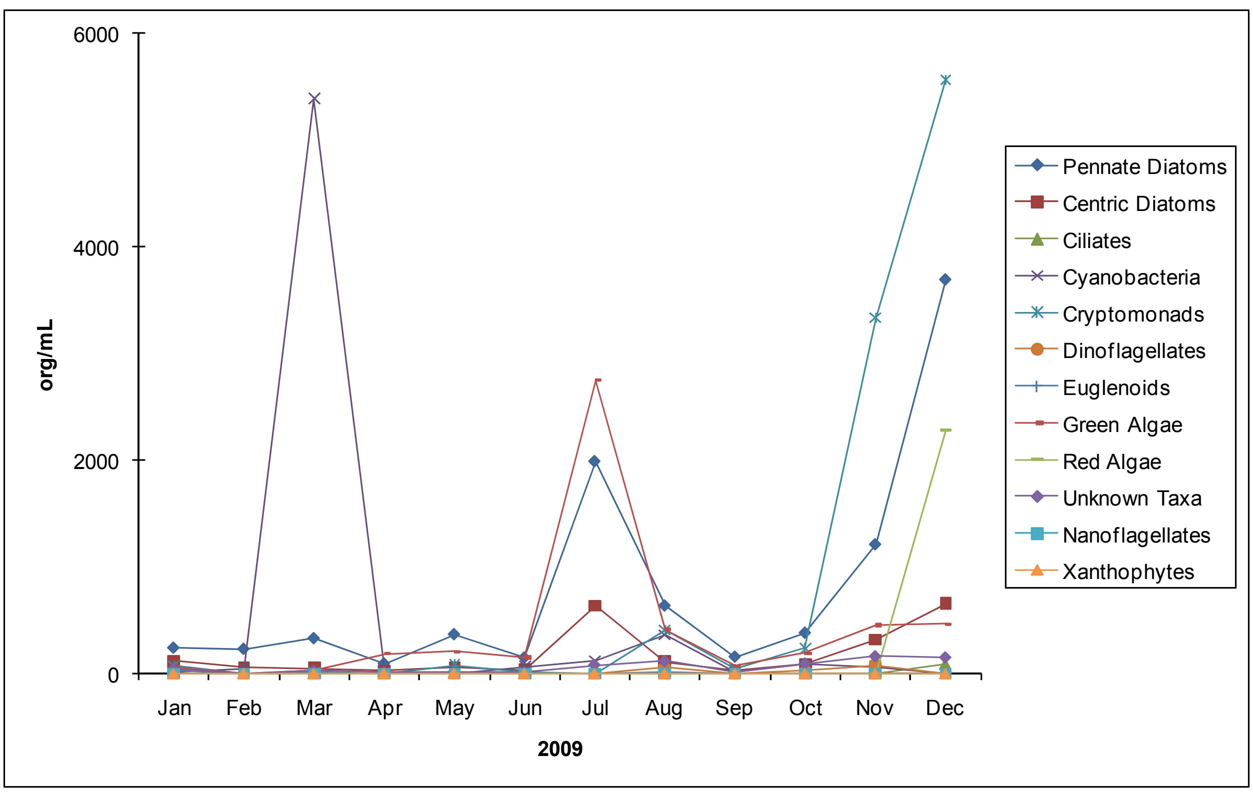

Figure 4-9a Pigment concentrations at D28A, 2009

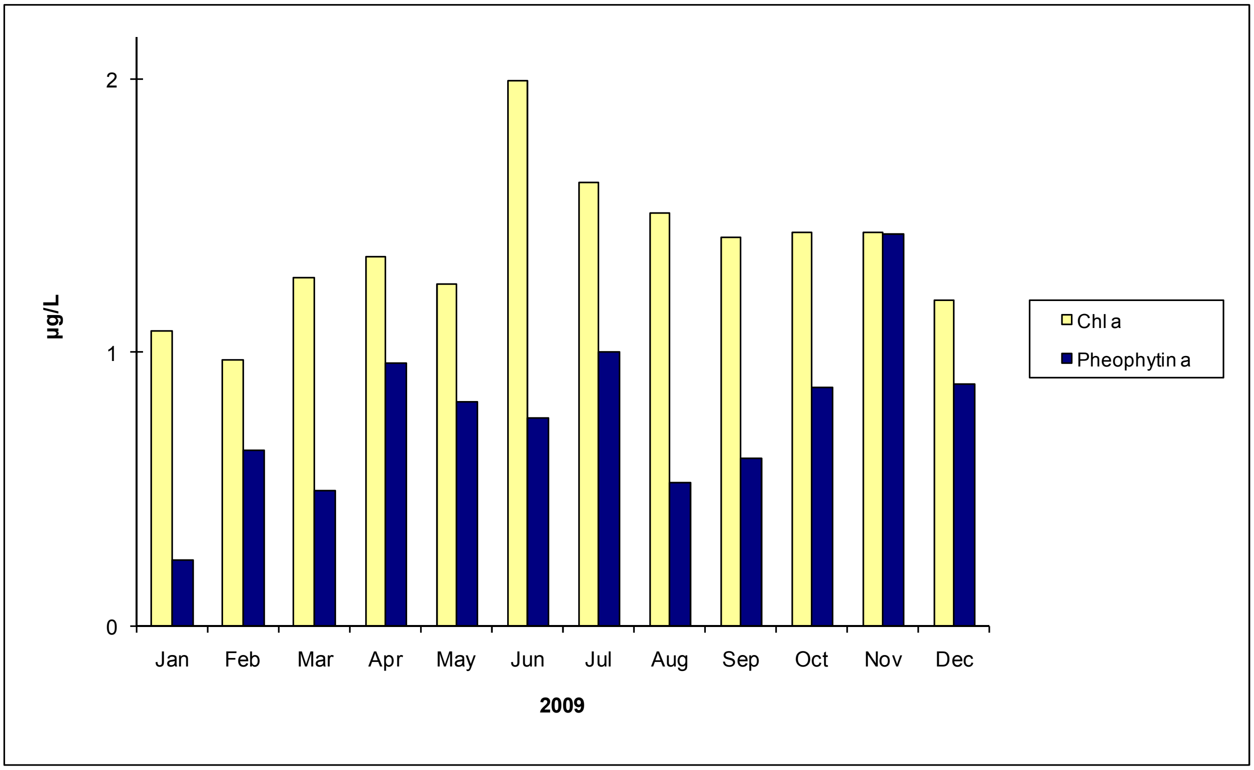

Figure 4-9b Phytoplankton composition at D28A, 2009

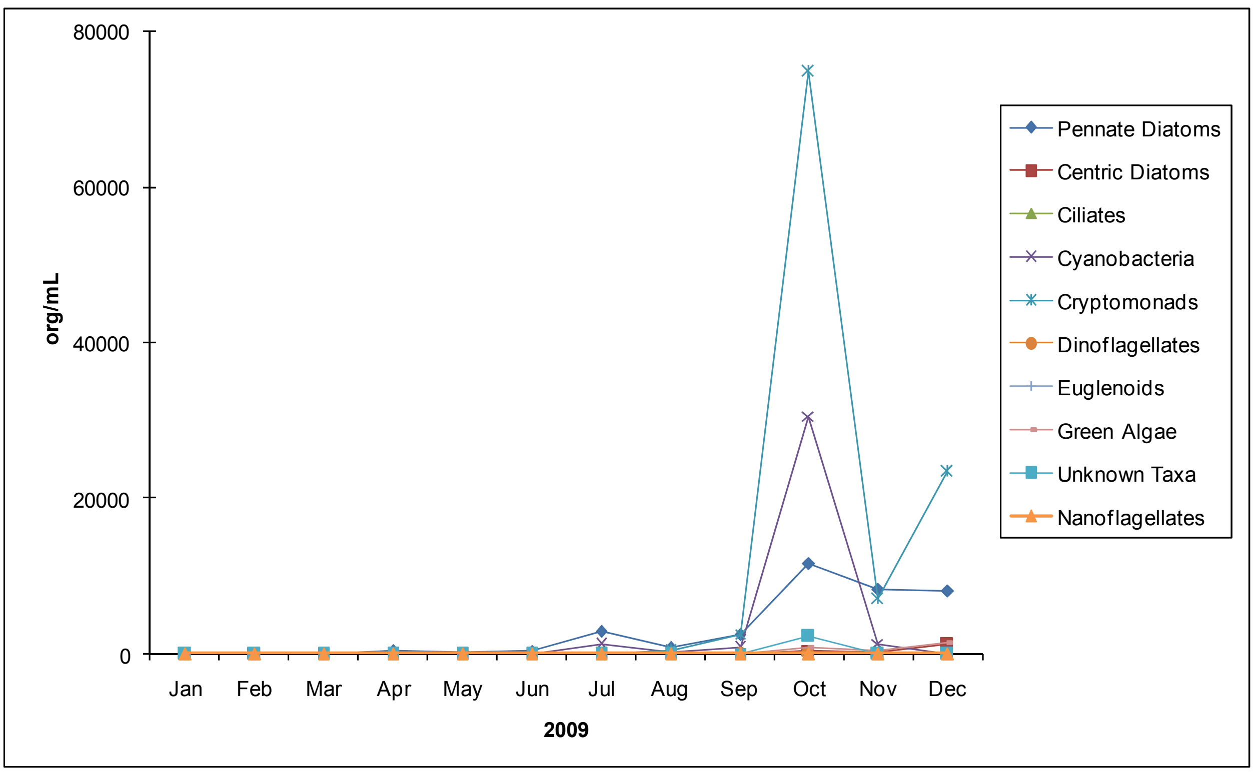

Figure 4-10a Pigment concentrations at D4, 2009

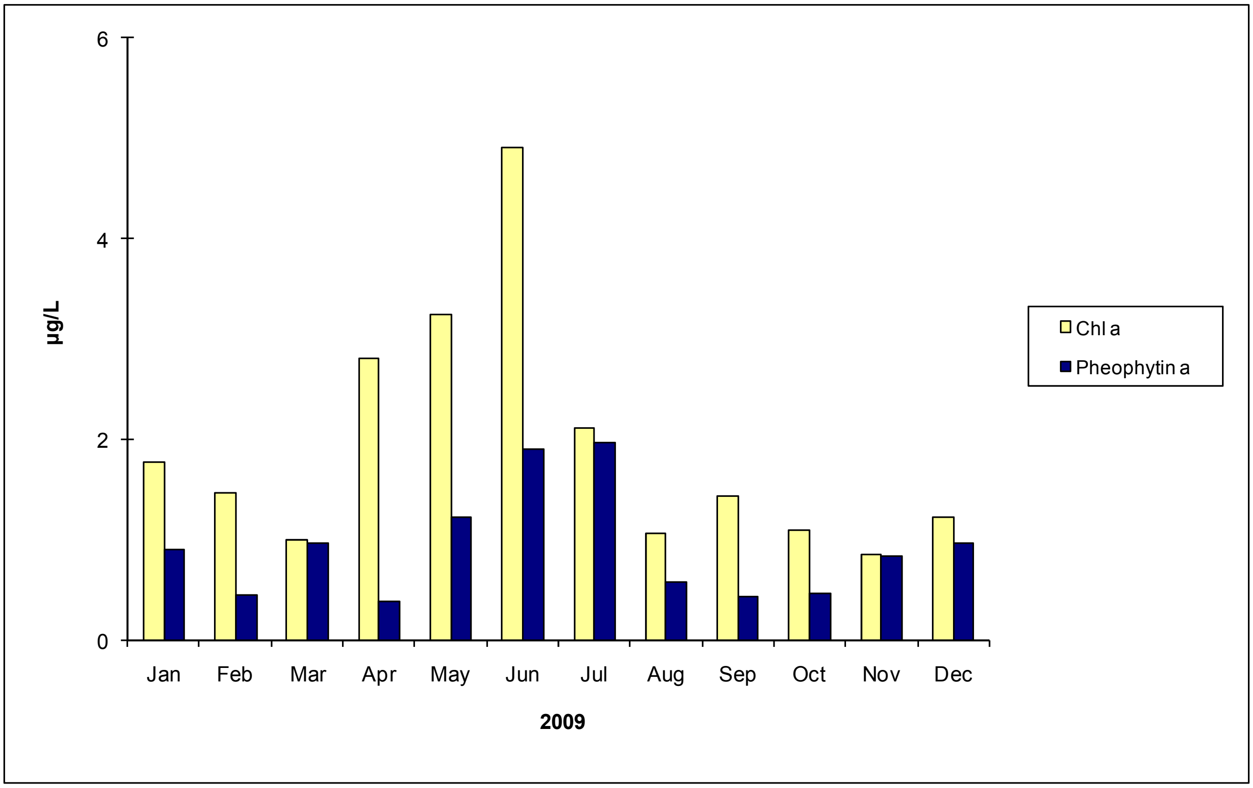

Figure 4-10b Phytoplankton composition at D4, 2009

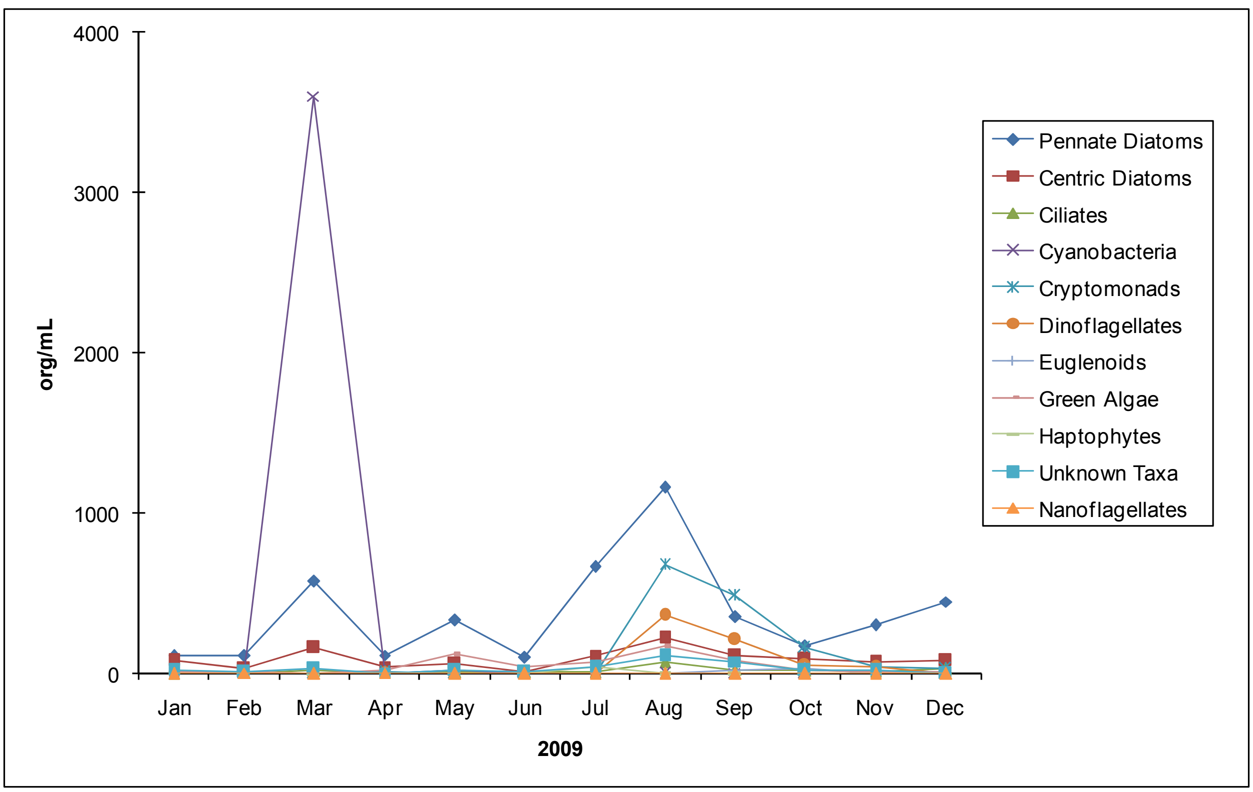

Figure 4-11a Pigment concentrations at D6, 2009

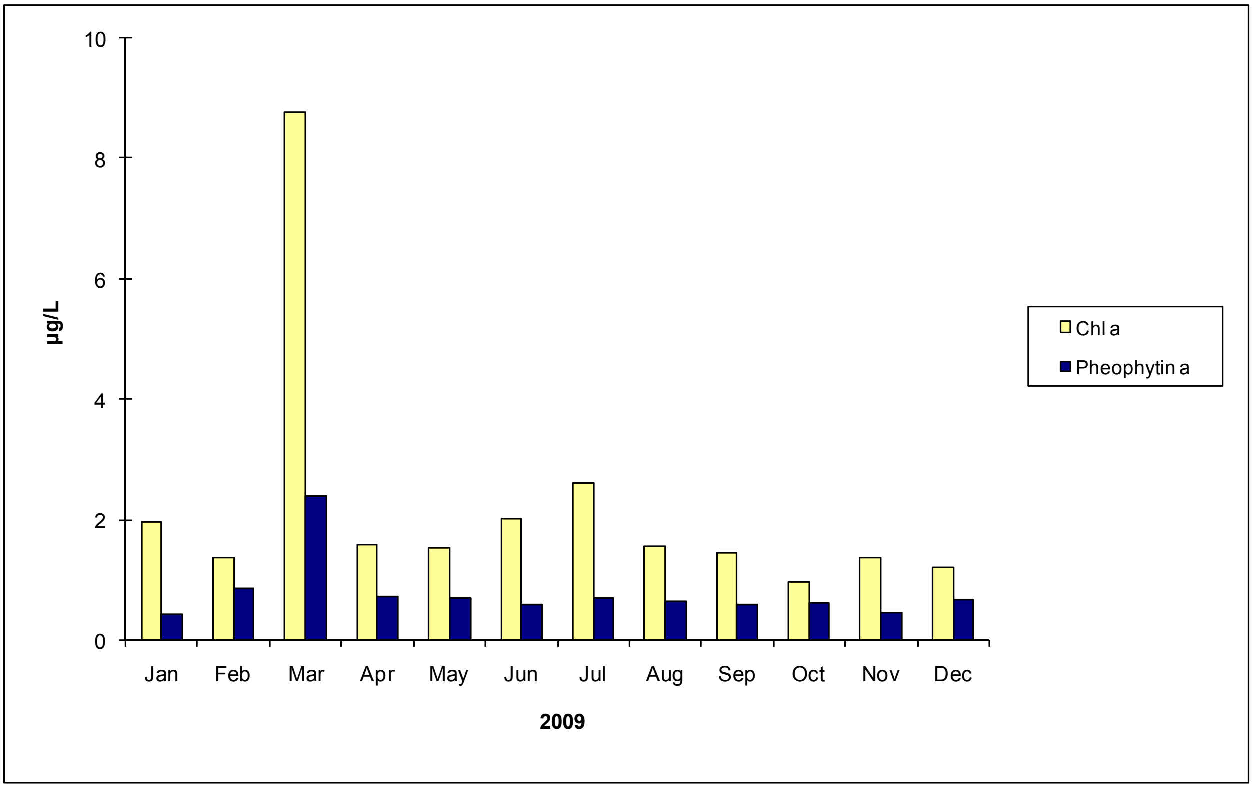

Figure 4-11b Phytoplankton composition at D6, 2009

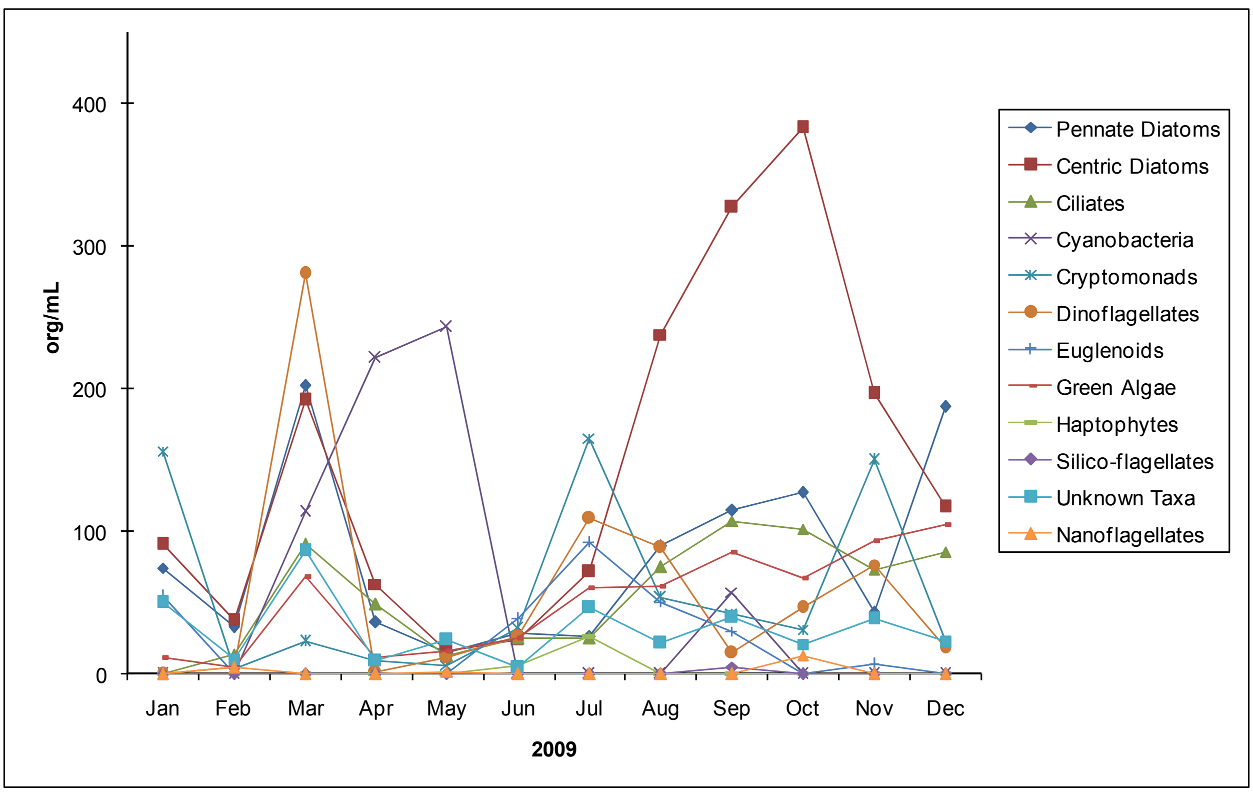

Figure 4-12a Pigment concentrations at D7, 2009

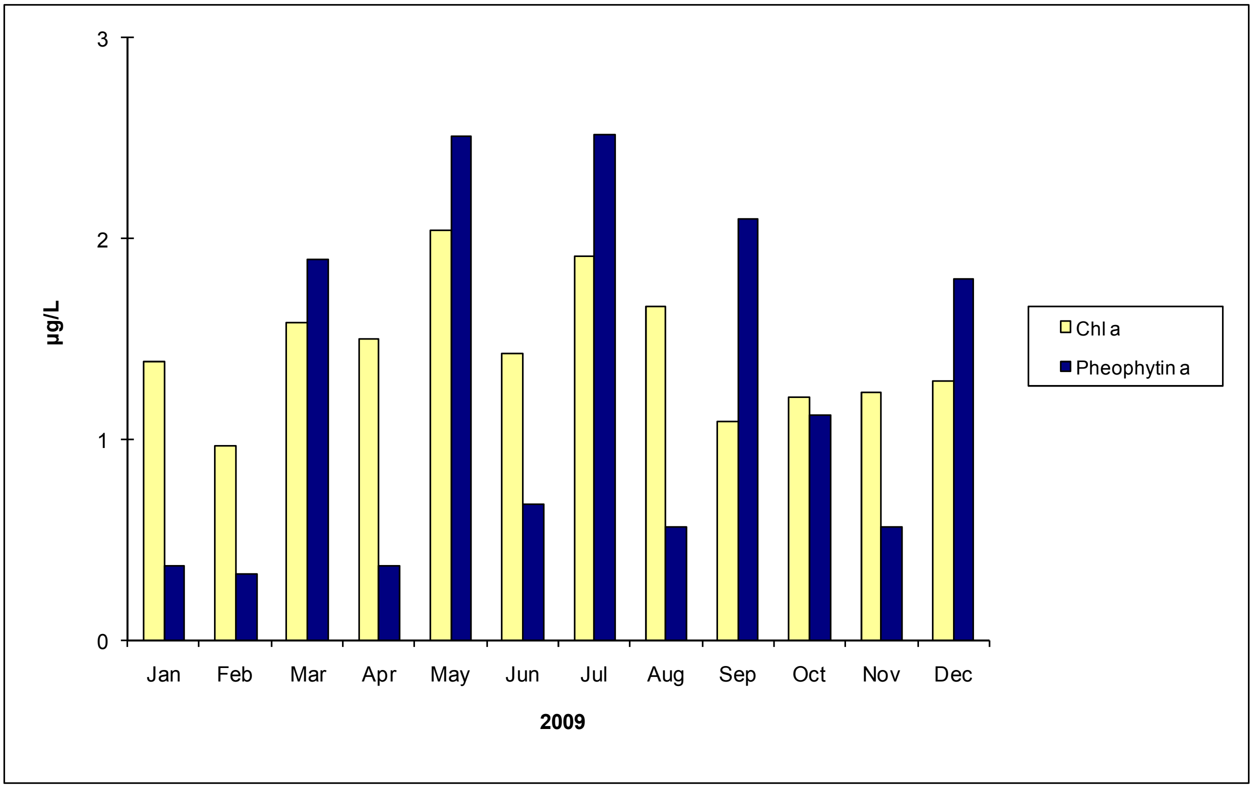

Figure 4-12b Phytoplankton composition at D7, 2009

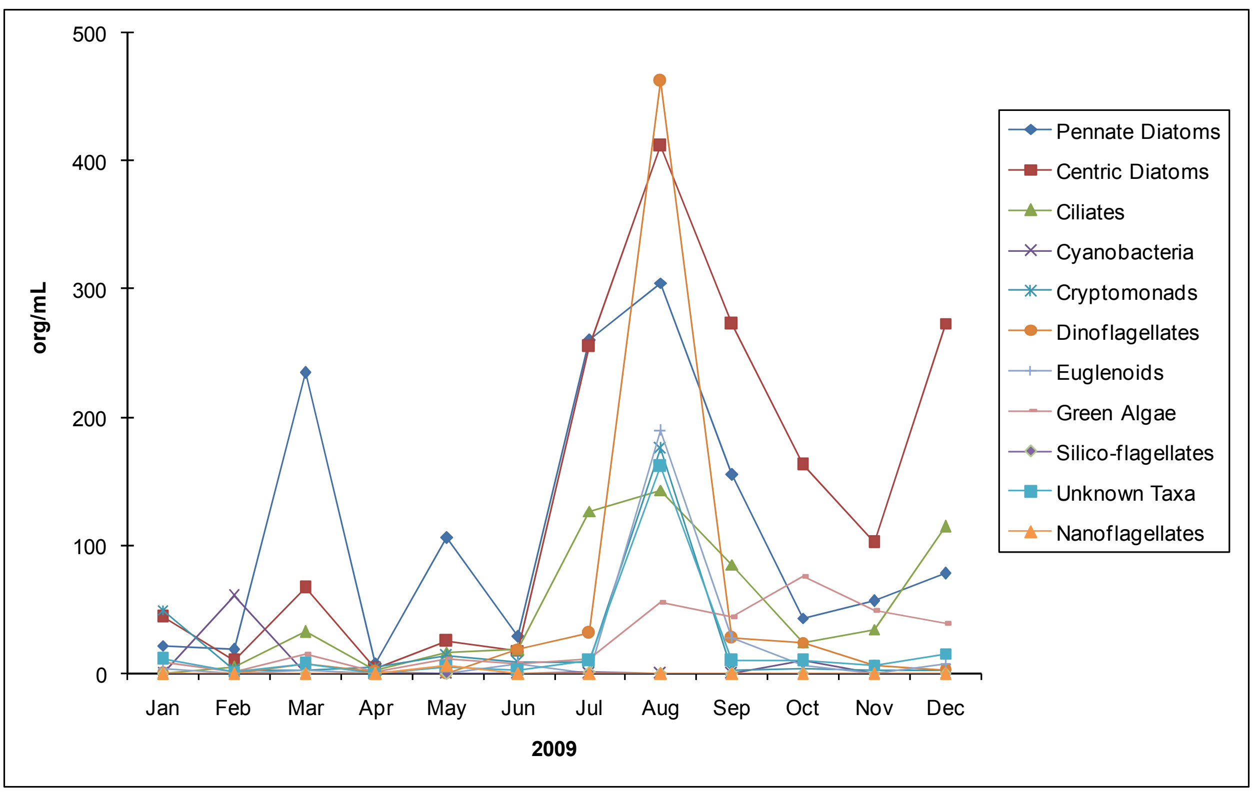

Figure 4-13a Pigment concentrations at D8, 2009

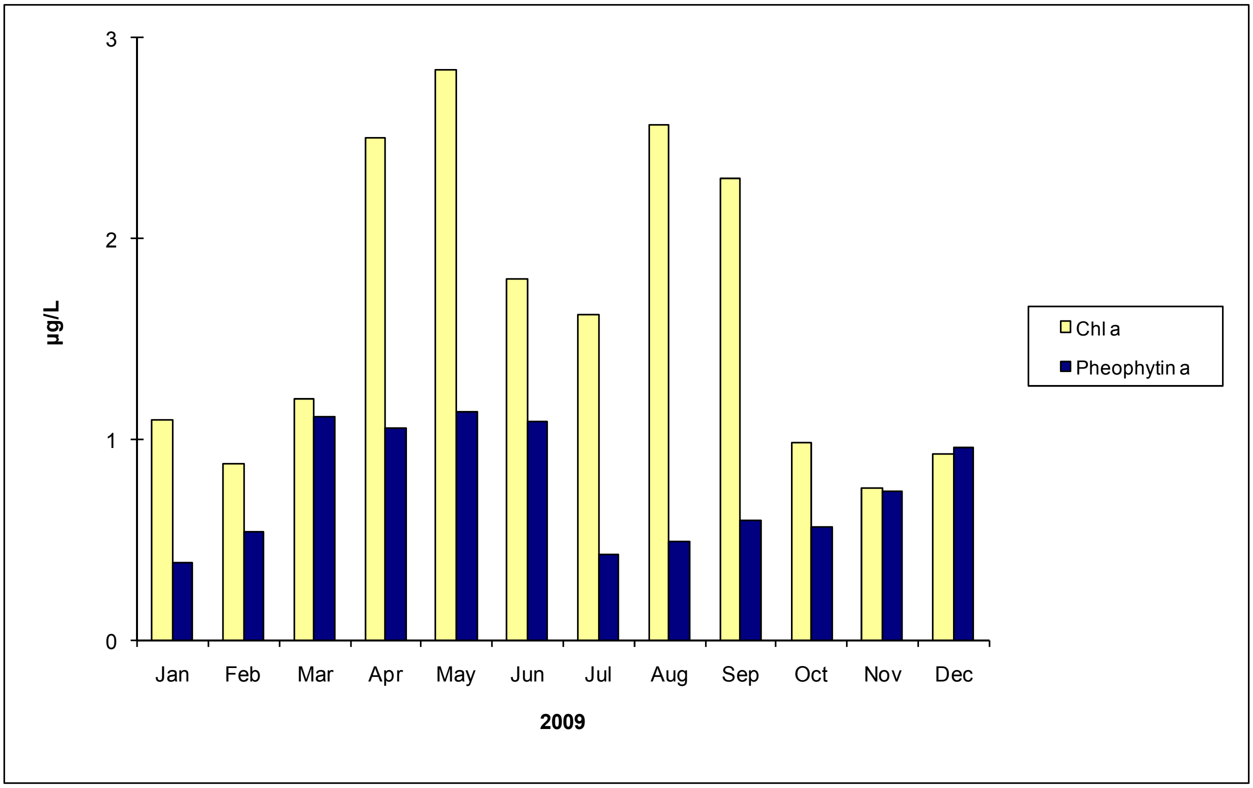

Figure 4-13b Phytoplankton composition at D8, 2009

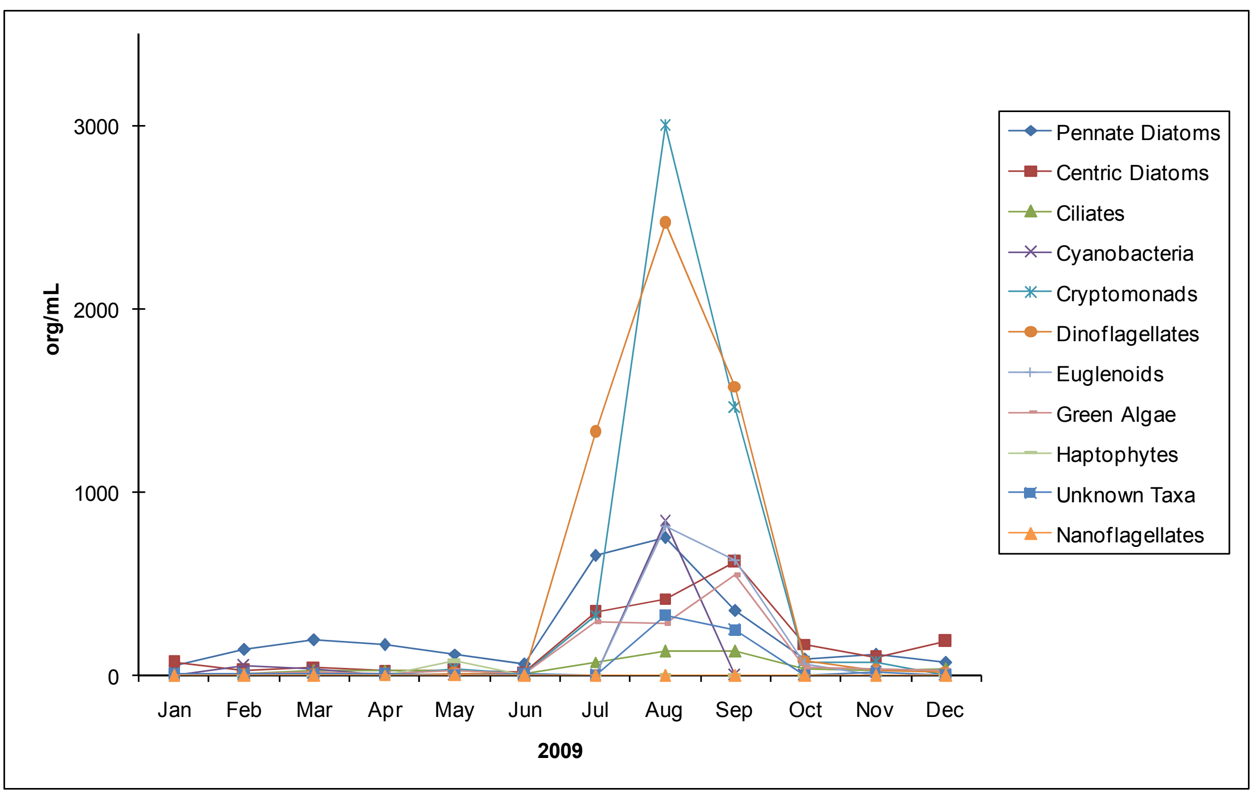

Figure 4-14a Pigment concentrations at D41, 2009

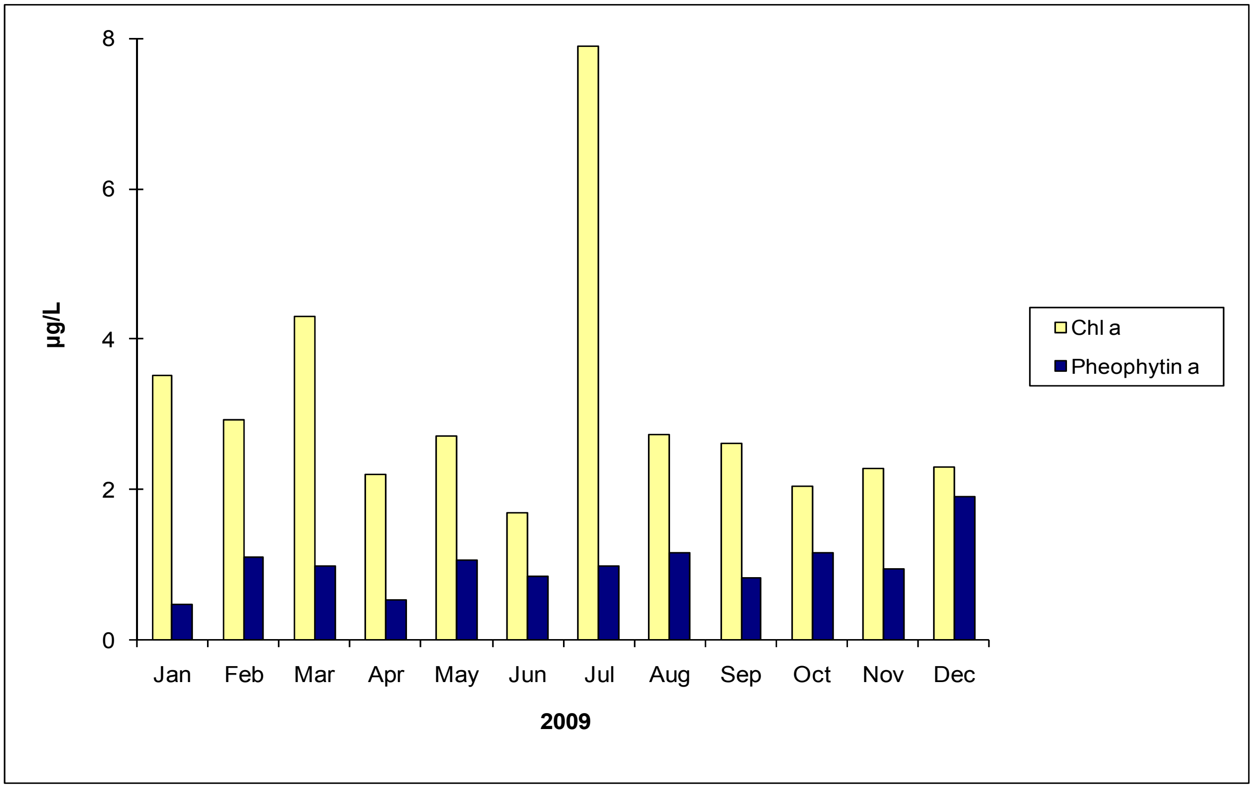

Figure 4-14b Phytoplankton composition at D41, 2009

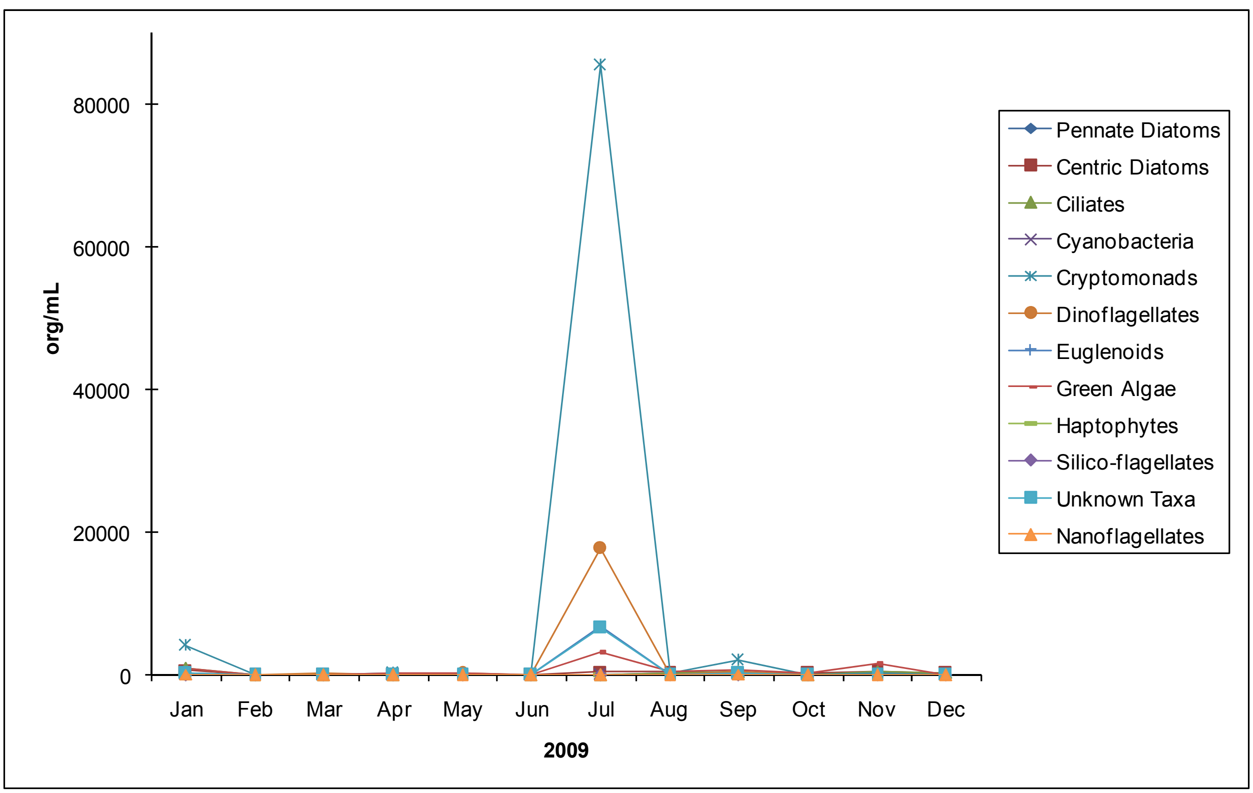

Figure 4-15a Pigment concentrations at D41A, 2009

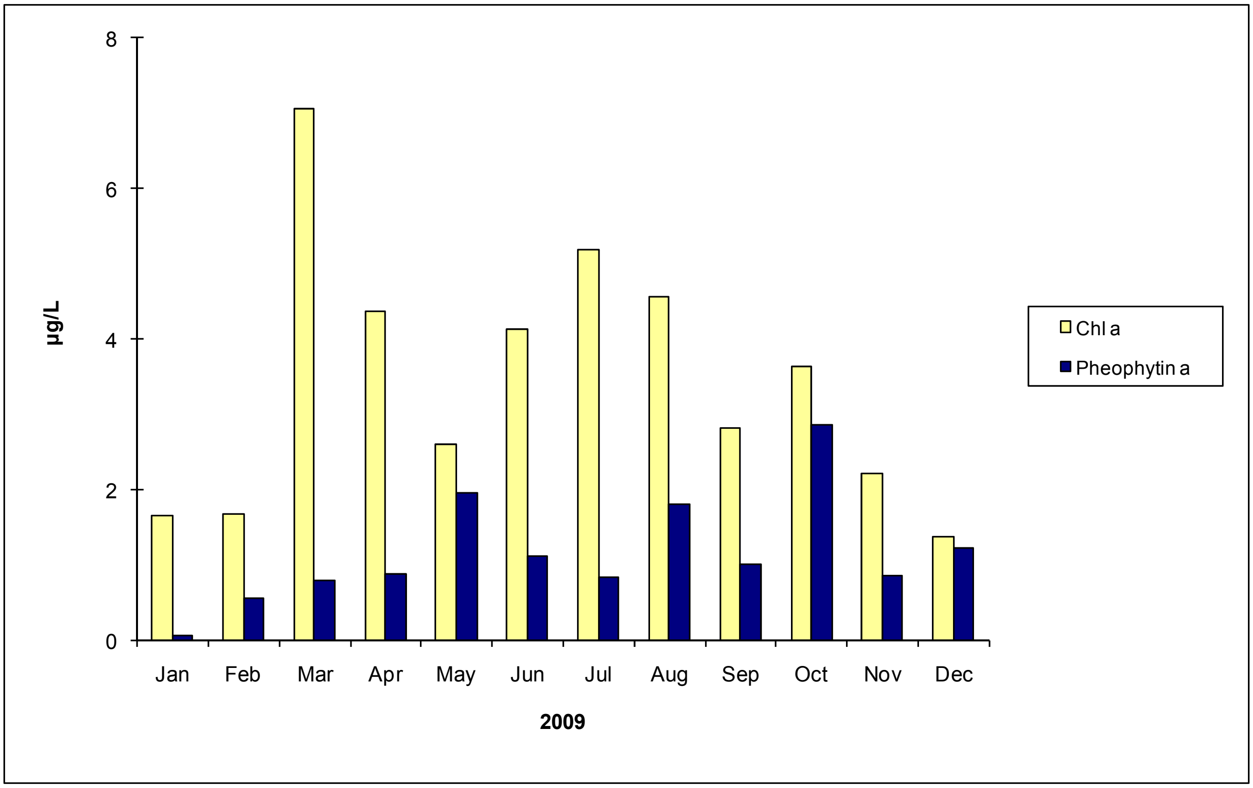

Figure 4-15b Phytoplankton composition at D41A, 2009

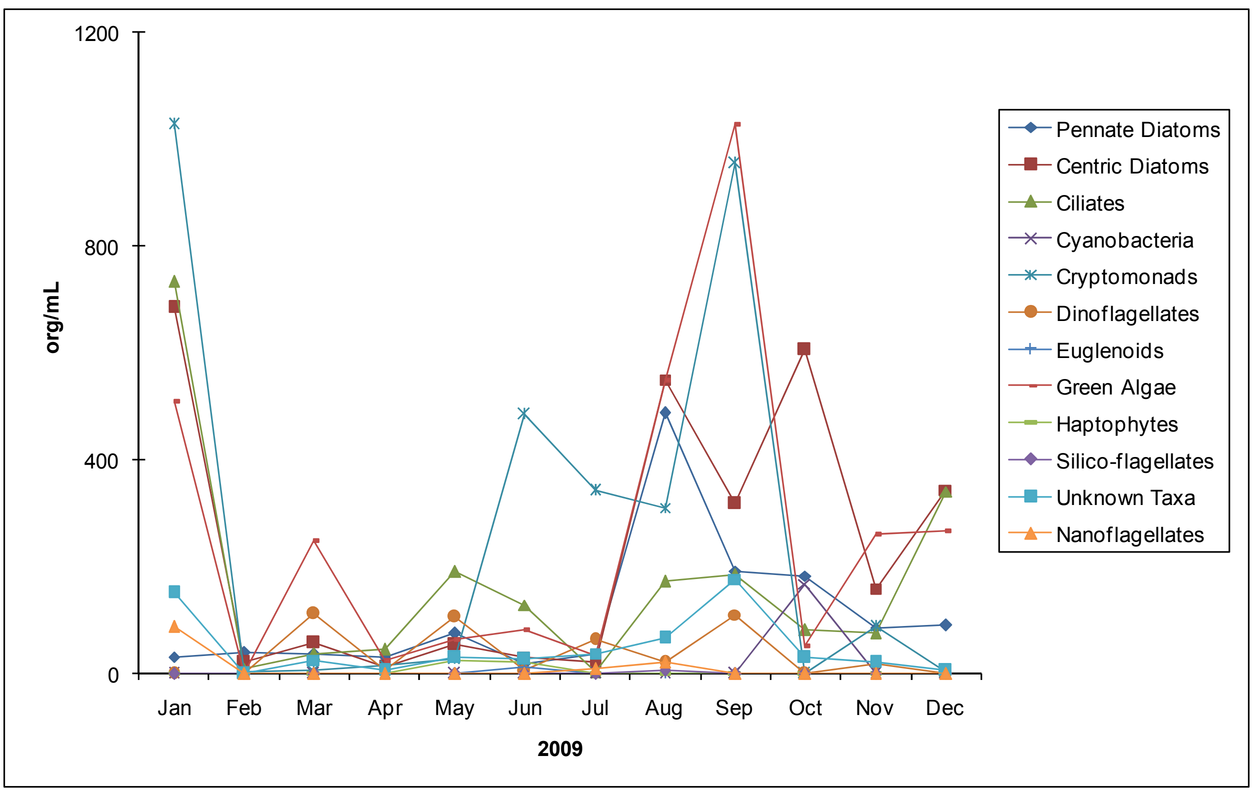

Table 4-1 Phytoplankton genera by group, 2009

Pennate Diatoms	Green Algae	Centric Diatoms	Dinoflagellates	Silico-flagellates
Achnanthes	Actinastrum	Aulacoseira	Alexandrium	Dictyocha
Amphipleura	Carteria	Biddulphia	Ceratium	Pedinella
Amphora	Chlamydomonas	Coscinodiscus	Crypthecodinium	**Haptophytes**
Asterionella	Chlorococcum	Cyclotella	Dinophysis	Chrysochromulina
Bacillaria	Chlorolobion	Eucampia	Gonyaulax	**Red Algae**
Caloneis	Closteriopsis	Hydrosera	Gymnodinium	Bangia
Campylodiscus	Closterium	Leptocylindrus	Ornithocercus	**Xanthophytes**
Cocconeis	Coelastrum	Melosira	Oxyphysis	Characiopsis
Cymatopleura	Cosmarium	Odontella	Peridiniopsis	**Unknown**
Cymbella	Crucigenia	Terpsinoe	Peridinium	Unknown Taxa
Diatoma	Crucigeniella	Thalassiosira	Prorocentrum	Nanoflagellates
Diploneis	Desmatractum	Unknown centric diatom	Protoperidinium	
Entomoneis	Elakatothrix	**Cyanobacteria**	Unknown dinoflagellates	
Epithemia	Gloeocystis	Anabaena	Woloszynskia	
Eunotia	Haematococcus	Chroococcus	**Cryptomonads**	
Fragilaria	Kirchneriella	Coelosphaerium	Chroomonas	
Gomphonema	Microspora	Gloeocapsa	Cryptomonas	
Gyrosigma	Monoraphidium	Hapalosiphon	Komma	
Navicula	Oedogonium	Leptolyngbya	Pyrenomonas	
Neidium	Oocystis	Merismopedia	Rhodomonas	
Nitzschia	Pediastrum	Microcystis	**Euglenoids**	
Pinnularia	Pyramimonas	Nostoc	Euglena	
Pleurosigma	Radiococcus	Oscillatoria	Phacus	
Rhoicosphenia	Scenedesmus	Phormidium	Trachelomonas	
Rhopalodia	Schroederia	Planktolyngbya	**Chrysophytes**	
Stauroneis	Sphaerocystis	Pseudanabaena	Chromulina	
Stenopterobia	Staurastrum	Spirulina	Dinobryon	
Surirella	Tetracystis	Synechococcus	**Ciliates**	
Synedra	Tetraedron		Mesodinium	
Tabellaria	Tetrastrum		Salpingella	
Unknown pennate diatom				

Table 4-2 Chlorophyll *a* and pheophytin *a* concentrations, 2009

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	7.65	0.47	1.39	2.10	1.95
C10A	260.59	8.97	14.10	49.57	74.24
P8	7.37	1.01	2.37	2.87	2.03
MD10A	9.40	1.20	2.01	2.76	2.27
D26	2.21	0.73	1.27	1.34	0.48
D19	2.81	1.07	1.69	1.69	0.49
D28A	1.99	0.97	1.39	1.38	0.27
D4	4.90	0.85	1.45	1.91	1.20
D6	8.76	0.96	1.55	2.20	2.11
D7	2.04	0.97	1.41	1.44	0.32
D8	2.84	0.76	1.41	1.62	0.76
D41	7.90	1.69	2.67	3.10	1.66
D41A	7.05	1.37	3.23	3.44	1.70

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	6.44	0.23	1.39	1.84	1.57
C10A	24.99	2.24	6.95	8.11	6.56
P8	2.50	0.67	1.17	1.36	0.62
MD10A	1.52	0.57	0.92	0.97	0.33
D26	1.02	0.50	0.63	0.69	0.17
D19	2.22	0.47	0.96	1.06	0.58
D28A	1.43	0.24	0.79	0.77	0.30
D4	1.96	0.38	0.87	0.92	0.54
D6	2.38	0.43	0.65	0.78	0.52
D7	2.52	0.33	0.90	1.24	0.87
D8	1.14	0.39	0.67	0.76	0.29
D41	1.91	0.47	0.99	1.00	0.36
D41A	2.87	0.07	0.94	1.16	0.74

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Chapter 5 Zooplankton

Introduction

Zooplankton are important food organisms for larval and juvenile salmon, striped bass, and splittail as well as for planktivorous fishes, such as delta smelt, longfin smelt, and threadfin shad, throughout their lives. DFG's zooplankton study monitors the annual and seasonal abundance and distribution of the major zooplankton taxa to assess fish food resources in the 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. Other mysid species were consistently identified and enumerated since 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 2 were "floating" entrapment zone stations, located where bottom SC 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 SC was less than 20 mS/cm. Monthly sampling was scheduled such that each station was sampled at approximately high slack tide.

At each station, 3 types of gear were deployed: (1) a mysid net for macrozooplankton; (2) a modified 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. The mesh net was attached to a ski-mounted towing frame made of steel tubing, with a General Oceanics 2030 flowmeter mounted at the center of the mouth. The CB net was 75 cm long, with an interior mouth diameter of 12.4 cm and a mesh size of 154 µm. The CB frame was a 19.1 cm long, clear acrylic pipe, with an inside diameter of 12.0 cm. A General Oceanics 2030 flowmeter was suspended at the center of the pipe. The CB net and frame were mounted on top of the mysid frame, and the nets were deployed together. The Teel Marine pump sampler for microzooplankton had a capacity of 15 L/min and was 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 were 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. Afterwards, the pump was 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 and suspended in a large plastic garbage can that was 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

DFG's Bay-Delta Branch Laboratory[1] for identification (usually to genus or species level) and enumeration.

Before and after each mysid-CB tow, water temperature (± 0.1 °C) and SC (in mS/cm) were measured at the top (1 m below the surface) and bottom (1 m 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 net and pump for the cyclopoid copepods, *Limnoithona tetraspina* and *Oithona davisae*. Abundance for both gears is presented for the latter 2 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 3 SC zones: (1) upstream of the entrapment zone (where bottom SC < 1.8 mS/cm); (2) the entrapment zone (where bottom SC ranged from 1.8 mS/cm to 6.6 mS/cm); and (3) downstream of the entrapment zone (where bottom SC > 6.6 mS/cm). All floating entrapment zone stations were included in the entrapment zone SC zone, as well as all stations within the SC range noted above.

Monthly and annual abundance indices for each taxon were calculated as the mean number per cubic meter (CPUE)[2] for each gear type and SC 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 2009 CPUE for all stations sampled. Monthly abundance trends are presented for the top 3 to 5 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 estuary in 1993, and has been the most abundant mysid in the estuary since 1995. In 2009, *H. longirostris* was again the most abundant mysid in all zones (Table 5-1). Abundance was highest in the entrapment zone, and downstream of the entrapment zone abundance was 41% of the entrapment zone abundance. Upstream abundance was much lower at only 8% of entrapment zone abundance. Seasonality was similar among zones, with abundance peaks in June through August upstream and downstream of the entrapment zone (Figure 5-2). Entrapment zone abundance rose steadily starting in April and peaked in August. 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.

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[1] DFG's Bay-Delta Branch Laboratory, 4001 North Wilson Way, Stockton, CA 95205
[2] CPUE standardizes catch data based on the amount of the effort (total time or area sampled) exerted.

Alienacanthomysis macropsis is a native brackish-water mysid that was the second most abundant mysid in 2009, although numbers were very low (Table 5-1). From 2008 to 2009, *A. macropsis* abundance increased slightly, causing *A. macropsis* to switch places with *Neomysis kadiakensis,* which was second most abundant in 2008. *A. macropsis* was not collected upstream of the entrapment zone in 2009, and was only collected twice in the entrapment zone (once in January and again in February) (Figure 5-3). Downstream of the entrapment zone, *A. macropsis* was collected in low numbers during every month of 2009, except in July when none were caught. *A. macropsis* abundance peaked downstream of the entrapment zone from January through March, and again in November and December.

The native brackish-water mysid *N. 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 2 species, they will be grouped together as *N. kadiakensis/japonica*. *N. kadiakensis/japonica* was the third most abundant mysid overall in 2009, decreasing from second most abundant in 2008 (Table 5-1). Upstream of the entrapment zone, *N. kadiakensis/japonica* was only caught 3 times, once in May and twice in June and in very low numbers. This indicated that if *N. japonica* was present in the estuary in 2009, then abundance was very low (Figure 5-4). Abundance was highest downstream of the entrapment zone, with peaks in March and May. Entrapment zone abundance was slightly lower than abundance downstream, with similar seasonal peaks in March through May.

Acanthomysis aspera is an introduced mysid that was first collected from the estuary in 1992, although it has never been very abundant. In 2009, *A. aspera* was the fourth most abundant mysid, switching rankings with *N. mercedis,* which was the fourth most abundant in 2008 (Table 5-1). *A. aspera* was only found downstream of the entrapment zone in 2009. Although *A. aspera* was only found in low numbers, a small peak occurred in October in San Pablo Bay (Figure 5-5).

N. mercedis fell from the fourth most abundant mysid in 2008 to the fifth most abundant in 2009, 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, *N. mercedis* abundance has been very low. *N. mercedis* abundance was highest in the entrapment zone in 2009. Upstream of the entrapment zone abundance was much lower at only 29% of entrapment zone abundance. In 2009, abundance peaked in May in the entrapment zone, but was very low in all zones in every month (Figure 5-6). Upstream of the entrapment zone, *N. mercedis* was caught from February through June with a small peak occurring in June. After July, only 1 individual of *N. mercedis* was caught at 1 station sampled.

Calanoid Copepods

The genus *Acartia* consists of 3 native brackish water species and was the most abundant calanoid copepod in 2009, switching ranks with *Pseudodiaptomus forbesi*, which was the most abundant 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 June from a single station and in very low numbers (Figure 5-7). Within the entrapment zone, it was collected in March, May, and November, in very low numbers. Downstream abundance was highest from January through April and lowest during the summer. After a small peak in August, abundance decreased in September and October, before increasing again in November and December.

The introduced *P. forbesi* was the second most abundant calanoid copepod in 2009 (Table 5-2). *P. forbesi* was most abundant upstream of the entrapment zone, with the highest abundance during summer and fall (Figure 5-8). Entrapment zone abundance was much lower at only 28% of upstream abundance. Downstream abundance was even lower at only 2% of upstream abundance. Seasonality was similar among the zones with lower abundances from January through April, after which abundance gradually increased and was higher for the remainder of the year.

Like 2007 and 2008, the introduced *Acartiella sinensis* was again the third most abundant calanoid copepod (Table 5-2). *A. sinensis* abundance was highest within the entrapment zone in late summer and early fall (Figure 5-9). Upstream of the entrapment zone, abundance was much lower at only 20% of entrapment zone abundance. January through May abundance upstream of the entrapment zone was low, but was much higher from June through October before declining again in November and December. Downstream abundance was 53% of entrapment zone abundance, and showed a similar seasonal pattern. In the entrapment zone and downstream, abundance was lower in spring and increased in summer and fall before declining again.

Sinocalanus doerrii was the fourth most abundant calanoid copepod for the second year in a row (Table 5-2). It was most common upstream of the entrapment zone, where abundance peaked in late spring and early summer (Figure 5-10). A similar seasonal trend was seen in the entrapment zone and downstream of the entrapment zone, although abundance was much lower.

Eurytemora affinis was the fifth most abundant calanoid copepod in 2009 (Table 5-2), as it was in 2008. *E. affinis* was most common in the entrapment zone, where abundance peaked February through May and declined sharply thereafter (Figure 5-11). Upstream of the entrapment zone, abundance peaked in April and May, and then again in December. Downstream of the entrapment zone, abundance peaked in early spring and declined thereafter. This seasonal decline in summer and fall has been typical since 1987, when *C. amurensis* and *P. forbesi* were introduced. Prior to 1987, *E. affinis* was common throughout the year.

Cyclopoid Copepods

Since it was first detected in 1993, *L. tetraspina* has become the most abundant copepod in the study area. It was abundant in all 3 SC zones in 2009, 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 in January and February in the upstream of the entrapment zone, where there was no catch in the pump samples and very low numbers in the CB samples (Figure 5-12). In all zones, pump abundance was highest May through October, while CB abundance was relatively stable with slight fluctuations.

Another introduced species, *O. davisae*, was the most abundant cyclopoid copepod in the CB samples again in 2009, 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 and early fall (Figure 5-13). Within and upstream of the entrapment zone, pump abundance was 0 all year, whereas CB abundance was low with small peaks in the entrapment zone in July and September.

The native *A. vernalis* was the third most common cyclopoid copepod in 2009 for the fourth 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 spring and then declined in summer and fall (Figure 5-14).

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, followed by *Diaphanosoma* and *Daphnia* for the second year in a row.

Bosmina spp. was the most abundant cladoceran in 2009 (Table 5-4). Upstream abundance was relatively high all year with a lot of fluctuation (Figure 5-15). Upstream abundance peaked in April, September, and October, with lows in March, June, and July. Within and downstream of the entrapment zone, abundance was much lower and these zones showed similar seasonal trends with a peak in April. In the entrapment zone, none were caught in August. There were none caught downstream of the entrapment zone in November.

The second most abundant cladoceran in 2009 was *Diaphanosoma* spp. (Table 5-4). It was most common upstream of the entrapment zone, where abundance peaked June through September, before declining again in fall (Figure 5-16). Within the entrapment zone, abundance was very low all year with a small peak from June through September. Downstream of the entrapment zone, *Diaphanosoma* was present in July, August, and October in very low numbers.

Daphnia spp. was the third most abundant cladoceran in 2009 (Table 5-4). As with *Bosmina* and *Diaphanosoma*, *Daphnia* was also the most common upstream of the entrapment zone. Upstream abundance was relatively high most of the year, with a peak from April through June followed by a sharp decline in July that lead to a crash in August (Figure 5-17). Within and downstream of the entrapment zone, abundance was much lower. In the entrapment zone, abundance peaked in February and April, whereas downstream abundance peaked in February and declined thereafter.

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. The same taxa were most common in both 2008 and 2009, and their relative rankings remained unchanged.

Synchaeta spp., which includes the brackish-water species *S. bicornis*, was the most common rotifer in 2009, as it was in 2008 (Table 5-5). It was most abundant downstream of the entrapment zone, where abundance was relatively stable most of the year with a peak in March and another in June (Figure 5-18). Upstream and within the entrapment zone abundance was more variable with lows in June and July.

Polyarthra spp. was again the second most abundant rotifer in 2009, as it was in 2008 and 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 March and July (Figure 5-19). Within the entrapment zone, abundance was highest in January and February, after which abundance was highly variable and for several months abundance was 0. During April, July, August, and October, none were collected in the entrapment zone. Downstream of the entrapment zone abundance was relatively stable, except in January and July when none were collected.

Keratella spp. was the third most abundant rotifer in 2009 (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 5-20). Upstream of the entrapment zone, abundance was fairly stable throughout the year with a slight dip in summer and another in December. In the entrapment zone, abundance was highest in March and April, declined in May and fell to 0 in June, before increasing again in late summer and early fall. Downstream of the entrapment zone, abundance was highly variable, and in July none were caught downstream of the entrapment zone. Fall abundance rebounded and remained fairly stable through December.

Summary

In 2009, the most common zooplankton taxa were the same as 2008, although some of their relative rankings changed. Monthly abundance patterns in 2008 and 2009 were also similar. Mysid, cladoceran, and rotifer abundances were lower in 2009 than 2008. While most copepod abundances were also lower in 2009 than 2008, some were higher like *Acartia* spp., *A. sinensis,* and *O. davisae.* As in 2008, the introduced *H. longirsotris* was also the most abundant mysid in 2009. The native *A. macropsis* and the *N. kadiakensis/japonica* complex switched rankings in 2009 from 2008 and were the second and third most abundant mysids in 2009. The native *N. mercedis* fell to the fifth most abundant mysid, while the introduced *A. aspera* moved up to the fourth most abundant in 2009. The native *Acartia* spp. replaced the introduced *P. forbesi* as the most abundant calanoid copepod in 2009. *P. forbesi*, ranked first in 2008, was second in 2009 followed by *A. sinensis*, *S. doerrii*, and *E. affinis*. The 3 most common cyclopoid copepods remained the introduced *O. davisae*, *L. tetraspina*, and *A. vernalis*. In 2009, as in 2008, *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 2009 as it was in 2008. *Diaphanosoma* spp. and *Daphnia* spp. were also the second and third most abundant cladocerans in 2009 as they were in 2008. The rotifers also ranked the same from 2008 to 2009, with *Synchaeta* spp. being most abundant, *Polyarthra* spp. was again the second most abundant, and *Keratella* spp. was third most abundant.

Chapter 5 Appendix

Figure 5-1 Zooplankton monitoring stations

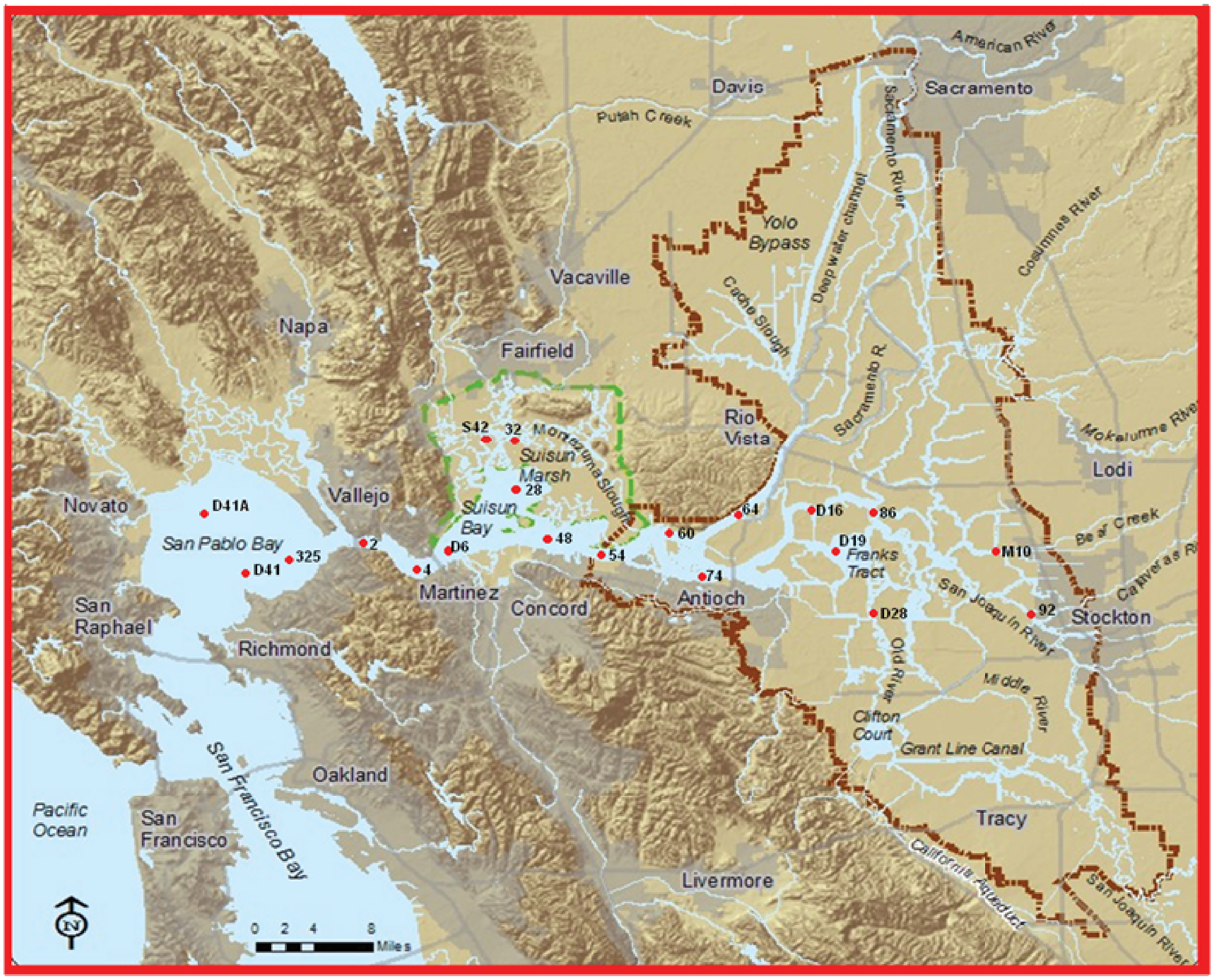

Figure 5-2 Monthly *H. longirostris* (*A. bowmani*) abundance upstream, within, and downstream of the entrapment zone, 2009

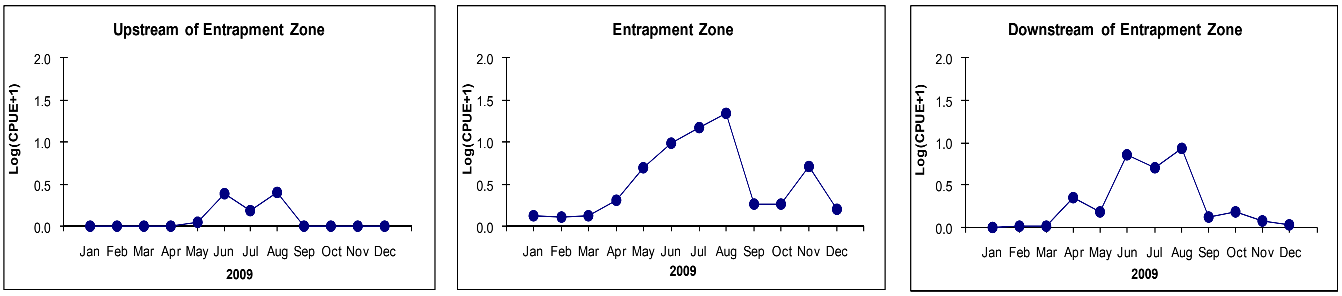

Figure 5-3 Monthly *A. macropsis* abundance upstream, within, and downstream of the entrapment zone, 2009

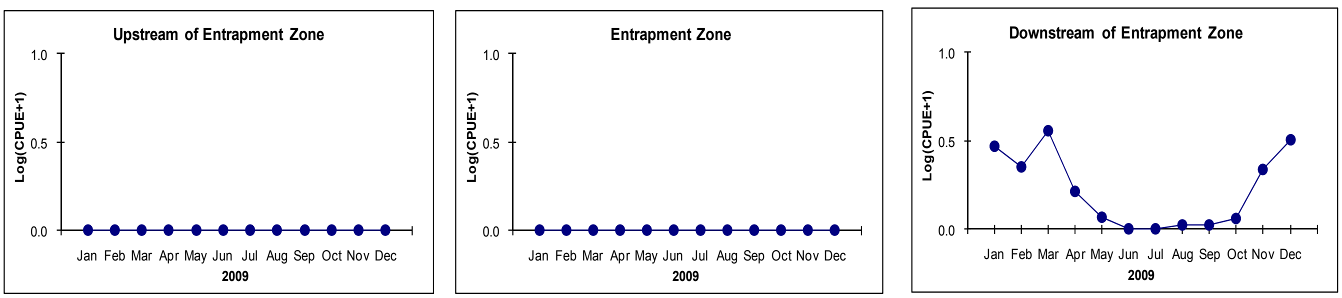

Figure 5-4 Monthly *N. kadiakensis/japonica* abundance upstream, within, and downstream of the entrapment zone, 2009

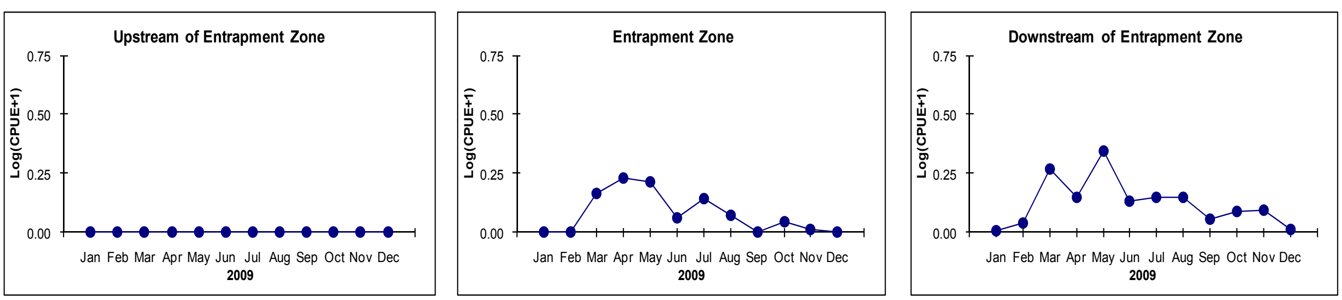

Figure 5-5 Monthly *A. aspera* abundance upstream, within, and downstream of the entrapment zone, 2009

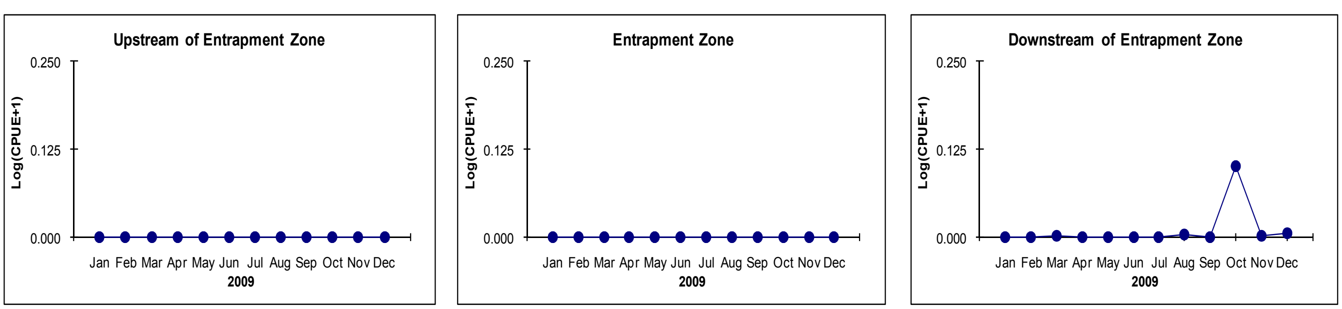

Figure 5-6 Monthly *N. mercedis* abundance upstream, within, and downstream of the entrapment zone, 2009

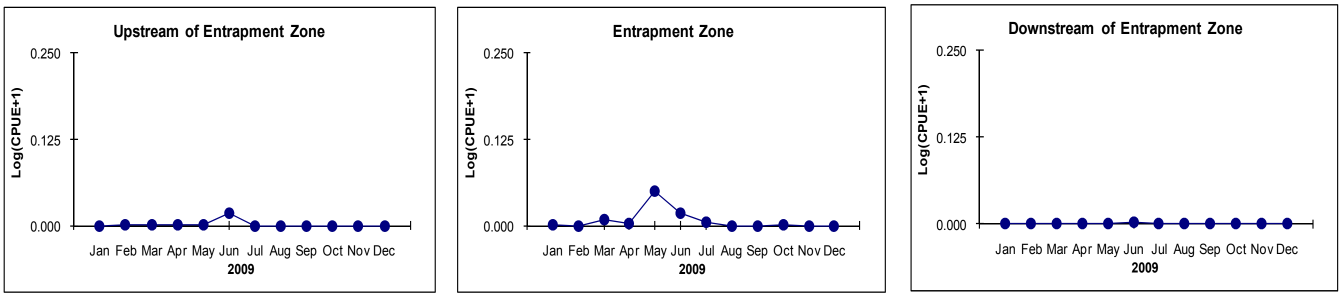

Figure 5-7 Monthly *Acartia* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

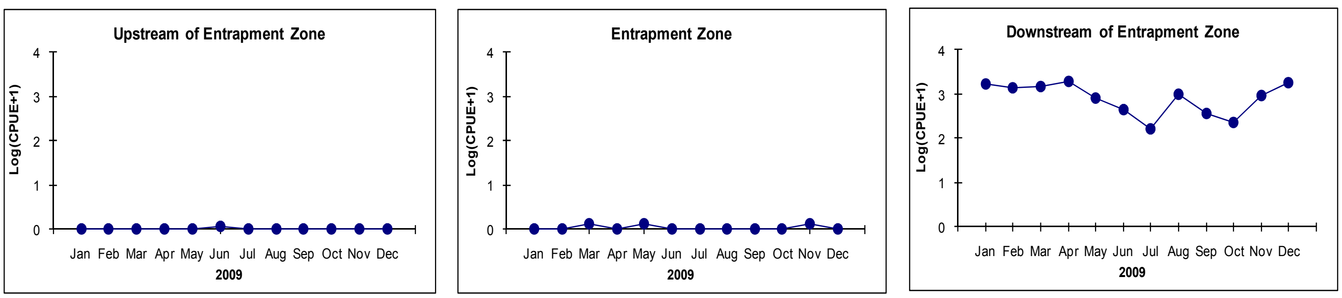

Figure 5-8 Monthly *P. forbesi* abundance upstream, within, and downstream of the entrapment zone, 2009

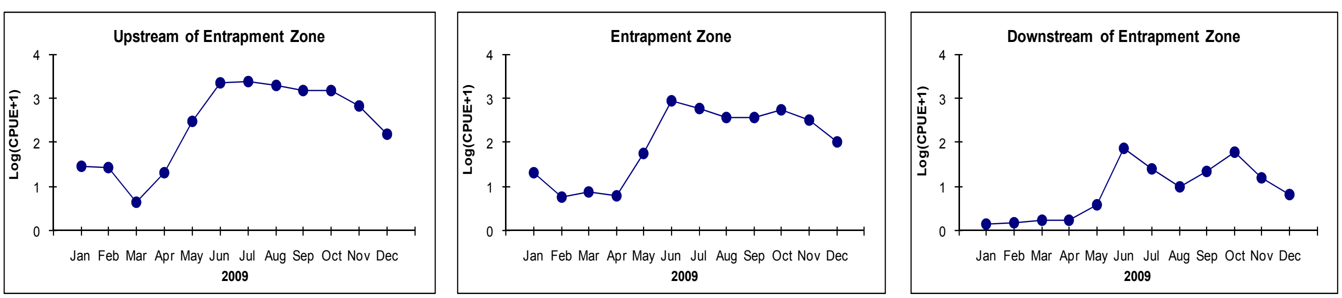

Figure 5-9 Monthly *A. sinensis* abundance upstream, within, and downstream of the entrapment zone, 2009

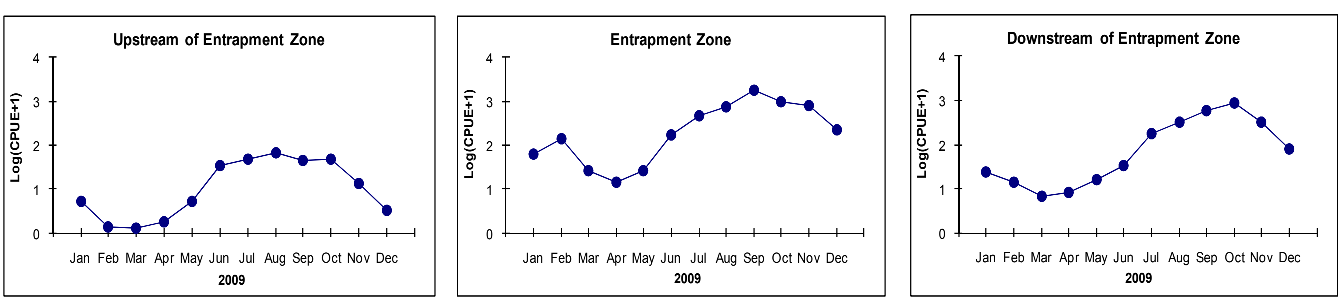

Figure 5-10 Monthly *S. doerrii* abundance upstream, within, and downstream of the entrapment zone, 2009

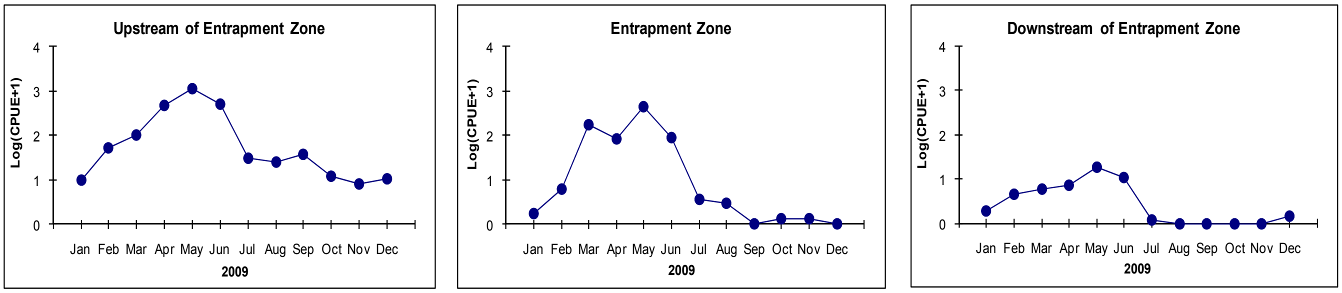

Figure 5-11 Monthly *E. affinis* abundance upstream, within, and downstream of the entrapment zone, 2009

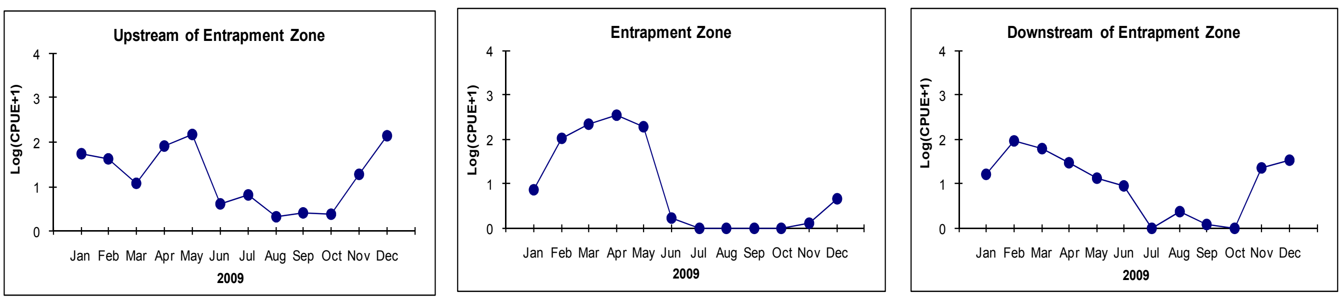

Figure 5-12 Monthly *L. tetraspina* abundance upstream, within, and downstream of the entrapment zone, 2009

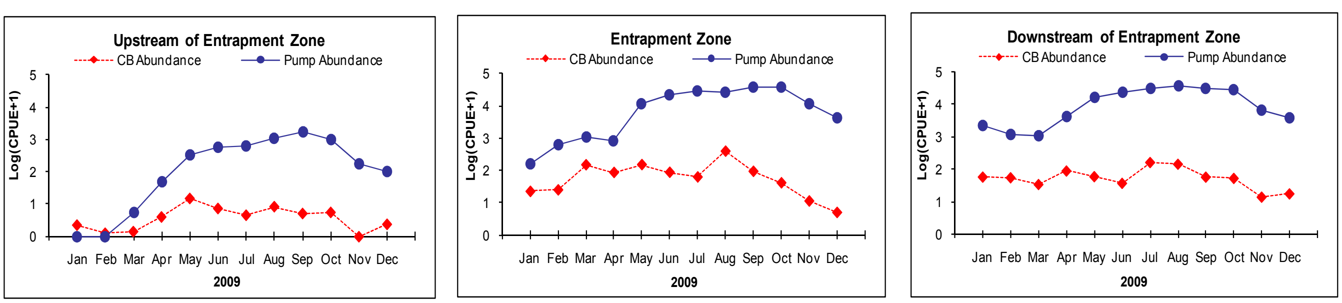

Figure 5-13 Monthly *O. davisae* abundance upstream, within, and downstream of the entrapment zone, 2009

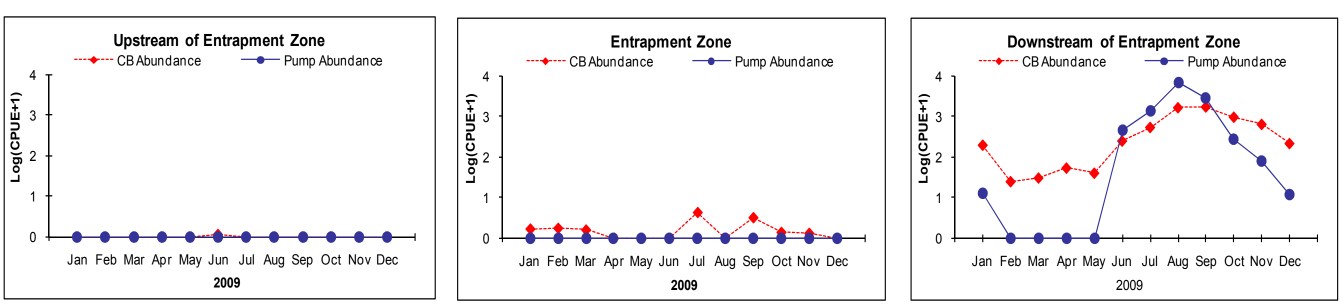

Figure 5-14 Monthly *A. vernalis* abundance upstream, within, and downstream of the entrapment zone, 2009

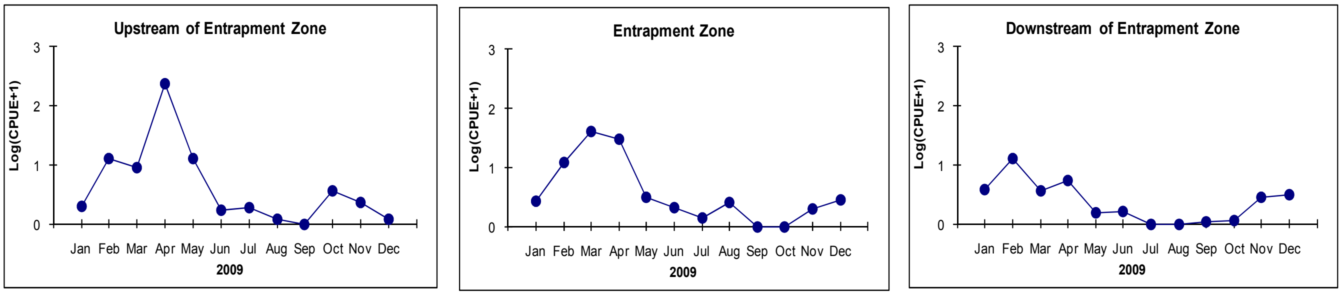

Figure 5-15 Monthly *Bosmina* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

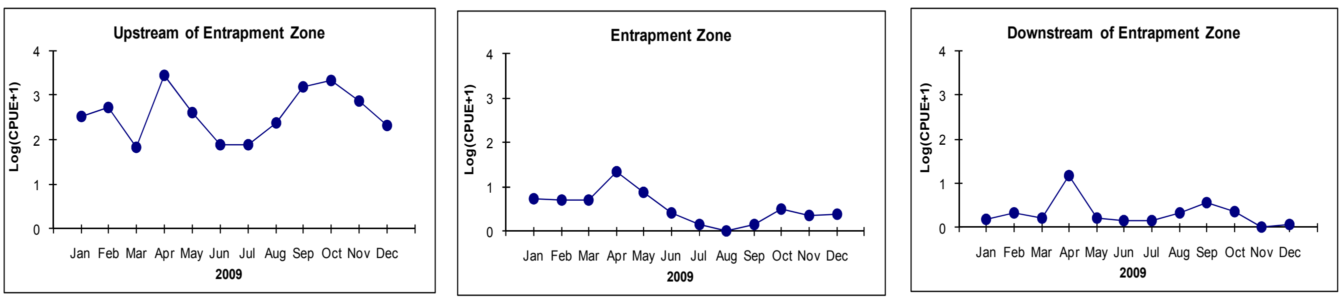

Figure 5-16 Monthly *Diaphanosoma* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

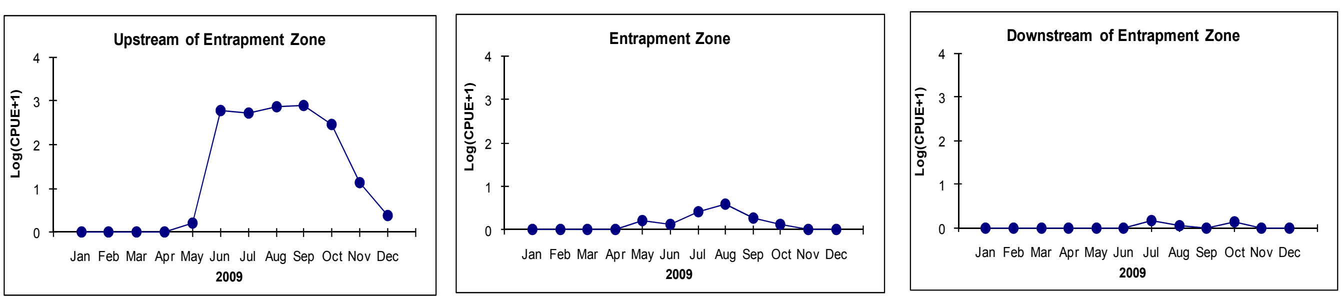

Figure 5-17 Monthly *Daphnia* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

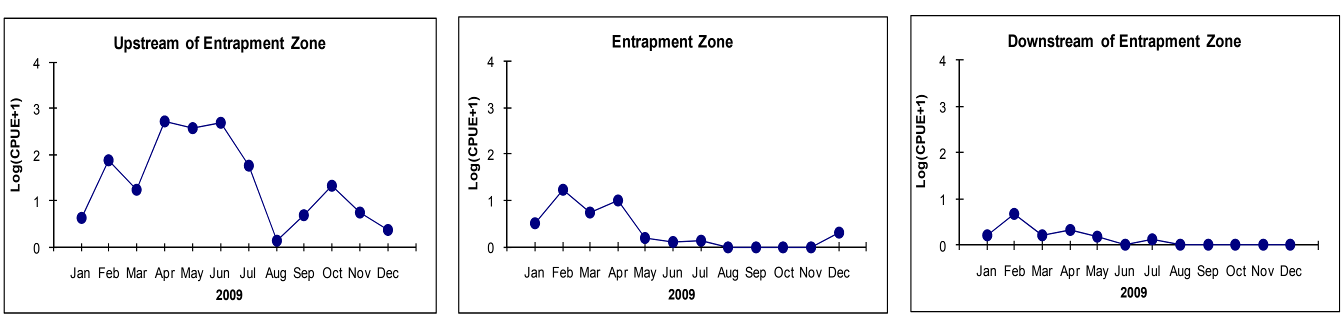

Figure 5-18 Monthly *Synchaeta* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

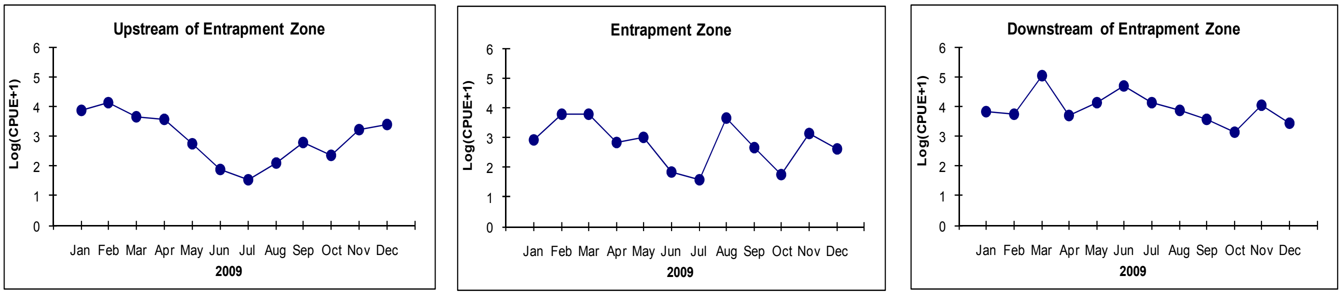

Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

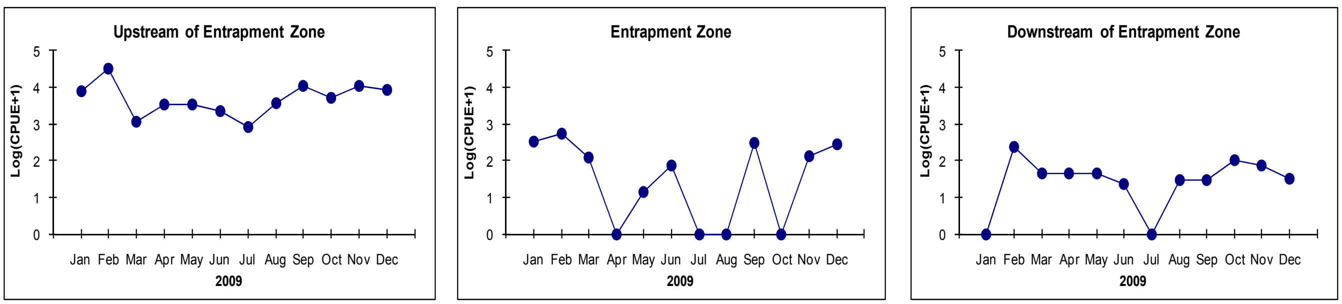

Figure 5-20 Monthly *Keratella* spp. abundance upstream, within, and downstream of the entrapment zone, 2009

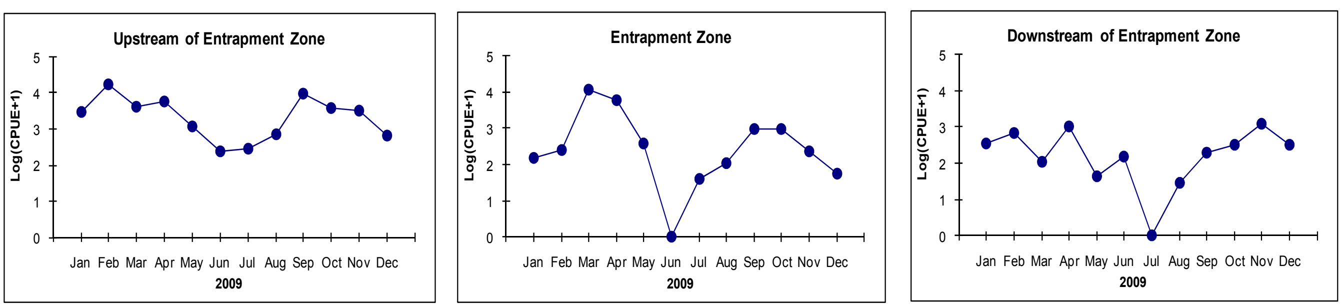

Table 5-1 Mysid abundance (CPUE) upstream, within, and downstream of the entrapment zone, 2009

Mysids	Upstream	Entrapment Zone	Downstream	All Zones
H. longirostris	0.342	4.143	1.697	1.634
A. macropsis	0.000	0.001	0.869	0.361
N. kadiakensis	0.001	0.245	0.304	0.174
A. aspera	0.000	0.000	0.028	0.012
N. mercedis	0.005	0.019	0.001	0.006

Table 5-2 Calanoid copepod abundance (CPUE) upstream, within, and downstream of the entrapment zone, 2009

Calanoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
Acartia spp.	<0.1	0.1	1003.5	414.0
P. forbesi	890.9	245.1	18.1	406.3
A. sinensis	21.2	425.5	225.4	183.4
S. doerrii	239.8	76.4	2.8	110.5
E. affinis	42.9	87.9	22.5	43.2

Table 5-3 Cyclopoid copepod abundance (CPUE) upstream, within, and downstream of the entrapment zone, 2009

Cyclopoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
CB net:				
O. davisae	<0.1	0.7	583.9	241.0
L. tetraspina	4.1	91.7	63.3	45.4
A. vernalis	27.9	9.0	2.3	13.7
Pump:				
L. tetraspina	447	14344	15608	9366
O. davisae	0	0	1094	448

Table 5-4 Cladoceran abundance (CPUE) upstream, within, and downstream of the entrapment zone, 2009

Cladocerans	Upstream	Entrapment Zone	Downstream	All Zones
Bosmina spp.	750.7	4.4	1.5	297.7
Diaphanosoma spp.	241.3	0.5	0.1	95.3
Daphnia spp.	157.0	3.3	0.6	62.8

Table 5-5 Rotifer abundance (CPUE) upstream, within, and downstream of the entrapment zone, 2009

Rotifers	Upstream	Entrapment Zone	Downstream	All Zones
Synchaeta spp.	2846	2006	15359	7801
Polyarthra spp.	6936	144	56	2794
Keratella spp.	4027	2157	390	2174

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 the eastern region of San Pablo Bay through the Delta to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. The benthic community of the 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) and sediment composition (Lehman et al., 2001). General trends in sediment composition are documented at the same sites where benthic samples are collected.

The benthic monitoring program began in 1975. From 1975 through 1979, the program collected samples biannually from 11 to 16 sites. In 1980, 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 on a monthly basis at 10 sampling sites. However, 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.

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 IEP Technical Report 12 (Markmann, 1986) and IEP Technical Report 38 (Hymanson et al., 1994).

Methods

Benthic Organisms

In 2009, 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 m^2. Five grabs were done using the Ponar at each benthic monitoring site each month. Four of these grabs were used for organism enumeration and identification and one was used for sediment analysis. 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* (APHA, 1998).

In the laboratory, the field preservative was decanted and the sample was washed with deionized water over a Standard No. 30 stainless steel mesh screen. Organisms were then placed in 70% ethyl alcohol for identification and enumeration. Hydrozoology[1], a private laboratory under

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

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 org/grab to org/m^2 (where 19 = 1.0 m^2 / 0.053 m^2 and 0.053 m^2 = sample area of the Ponar). Furthermore, prior to summarizing the organism data, the individual counts from the 4 grabs done at each site were averaged to get an average number of individuals of each species at each site every month.

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 L plastic jar for storage and transported to the DWR's Soils and Concrete Laboratory[2] 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 (ASTM, 2000a). 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 (ASTM, 2000b). For this method, the ash-free dry weight of the sample was used to determine the organic content of the sediment.

Results

Benthic Composition and Abundance

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 177 species collected in 2009, 10 represented 80.8% of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods

Ampelisca abdita

Americorophium spinicorne

Americorophium stimpsoni

Corophium alienense

Gammarus daiberi

[2] Department of Water Resources' Soils and Concrete Laboratory, 1450 Riverbank Road, West Sacramento, CA 95605

Sabellidae Polychaete

Manayunkia speciosa

Tubificidae Worms

Limnodrilus hoffmeisteri

Varichaetadrilus angustipenis

Asian Clams

Corbula amurensis

Corbicula fluminea

Of the 10 dominant species, *C. amurensis and A. abdita* represent macrofauna that inhabit a typically higher saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *C. alienense, A. stimpsoni, and A. spinicorne* 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 5 species; *G. daiberi, M. speciosa, L. hoffmeisteri, V. angustipenis,* and *C. fluminea,* are predominantly freshwater species and were collected at sites east of Suisun Bay.

Summarization

All organisms collected during 2009 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 98.9% 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.

Organism abundance (org/m^2) and dominant phyla varied between sites. Temporal changes in organism abundance (e.g., intra- and interannual) also varied greatly between sites. These variations and trends (e.g., 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).

Benthic Abundance

Maximum abundances in 2009 ranged from 42,489 org/m^2 in July at D41A to 2,199 org/m^2 in October at D16. Minimum abundances ranged from 7,906 org/m^2 in October at D41A to 117 org/m^2 in March at D16.

Site C9: South Delta
Maximum abundance in 2009 occurred in June with a total of 39,579 org/m^2 (Figure 6-3). *A. stimpsoni* (18,430 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in February with a total of 3,580 org/m^2. *V. angustipenis* and *L. hoffmeisteri* (each with 1,107 org/m^2) were the dominant species.

Site P8: South Delta
The maximum abundance in 2009 occurred in March with a total of 12,206 org/m^2 (Figure 6-4). *M. speciosa* (8,783 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in September with a total of 2,400 org/m^2. *V. angustipenis* (841 org/m^2) was the dominant species.

Site D28A: Central Delta
Maximum abundance in 2009 occurred in December with a total of 13,522 org/m^2 (Figure 6-5). *Cyprideis sp. A* (6,341 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in June with a total of 738 org/m^2. *V. angustipenis* (137.75 org/m^2) and *Spirosperma nikolskyi* (114 org/m^2) were the dominant species.

Site D16: Lower San Joaquin River
Maximum abundance in 2009 occurred in October with a total of 2,199 org/m^2 (Figure 6-6). *C. fluminea* (1,534 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in March with a total of 117 org/m^2. *G. daiberi* (48 org/m^2) was the dominant species.

Site D24: Lower Sacramento River
Maximum abundance in 2009 occurred in March with a total of 3,678 org/m^2 (Figure 6-7). *V. angustipenis* (1,872 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in December with a total of 1,349 org/m^2. *C. fluminea* (865 org/m^2) was the dominant species.

Site D4: Lower Sacramento River
Maximum abundance in 2009 occurred in July with a total of 29,271 org/m^2 (Figure 6-8). *A. spinicorne* (13,243 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in October with a total of 7,906 org/m^2 . *V. angustipenis* (2,836 org/m^2) was the dominant species.

Site D6: Suisun Bay
Maximum abundance in 2009 occurred in September with a total of 30,186 org/m^2 (Figure 6-9). *C. amurensis* (29,859 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in May with a total of 4,815 org/m^2. *C. amurensis* (4,118 org/m^2) was the dominant species.

Site D7: Suisun Bay
Maximum abundance in 2009 occurred in June with a total of 29,372 org/m^2 (Figure 6-10). *C. amurensis* (23,750 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in May with a total of 5,035 org/m$^{2.}$ *C. alienense* (3,083 org/m^2) was the dominant species.

Site D41: San Pablo Bay
Maximum abundance in 2009 occurred in August with a total of 25,531 org/m^2 (Figure 6-11). *A. abdita* (17,893 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in February with a total of 1,104 org/m^2. *Sabaco elongatus* (218.5 org/m^2) was the dominant species.

Site D41A: San Pablo Bay

Maximum abundance in 2009 occurred in July with a total of 42,489 org/m^2 (Figure 6-12). *A. abdita* (28,229 org/m^2) was the dominant species. The minimum abundance in 2009 occurred in September with a total of 7,462 org/m^2 . *A. abdita* (5,733 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 2009, organic content ranged from 0.2% at site D16 to 19.9% at site D4.

Site C9: South Delta

Sand with silt dominated the sediment content at C9 in most of 2009, except for July and October through December, which was mainly silty sand (Figure 6-13). The percentage of organic content ranged from 0.7% to 3.1%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

Site P8: South Delta

All through 2009 the sediment at P8 was consistently about two-thirds sand with silt, with a large dip in November and December when silt dominated (Figure 6-14). The organic matter ranged from 1.0% to 4.3%, with the higher organic values typically coinciding with finer sediments.

Site D28A: Central Delta

Sandy sediment was dominant most months at site D28A for 2009 with the exception of March, September, and December when there was more fine sediment at the site (Figure 6-15). The organic matter ranged from 1.2% to 12.3%. Larger quantities of organic matter coincided with an abundance of fine sediment.

Site D16: Lower San Joaquin River

Sand dominated the sediment type at site D16 for 2009 with the exception of June, October, and December when silt dominated (Figure 6-16). The amount of organic matter at this site ranged from 0.2% to 2.9% with higher values coinciding with higher percentages of fine sediment.

Site D24: Lower Sacramento River

Sand dominated the sediment at site D24 during 2009 (Figure 6-17). The amount of organic matter ranged from 0.5% to 1.5%. May had a higher organic content, but seemed to have no affect on sediment content.

Site D4: Lower Sacramento River

Peat with sand dominated the sediment at site D4 during the months of July through September. The rest of the year was described as silty clay or sandy silt (Figure 6-18). The percent of organic matter at this site was high for most of the year and ranged from 2.4% to 19.9%.

Site D6: Suisun Bay

Silty clay dominated site D6 throughout 2009 (Figure 6-19). Organic matter at this site remained quite constant ranging from 1.4% to 5.0%.

Site D7: Suisun Bay

Silty clay dominated site D7 for all of 2009 (Figure 6-20). The organic matter at this site was stable throughout the year ranging from 2.6% to 4.4%.

Site D41: San Pablo Bay

The majority of the months at site D41 in 2009 contained higher percentages of sandy sediment with the exception of January, March, and November, which contained a slightly higher percent of silty fines (Figure 6-21). The organic matter at this site ranged from 0.9% to 3.6% with higher values coinciding with higher percentages of fine sediment.

Site D41A: San Pablo Bay

Fine clay and silt sediments dominated site D41A for all of 2009 (Figure 6-22). The percent organic matter at this site evenly ranged from 1.3% to 4.2%.

Summary

The benthic monitoring program is designed to document the distribution, diversity, and abundance of benthic organisms in the estuary. The monitoring program collects a large number of organisms, but a relatively small number of species. All organisms collected during 2009 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida, and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda, and Mollusca constituted 98.9% 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— *A. abdita, A. stimpsoni, C. alienense, A. spinicorne, and G. daiberi*; (2) the S. polychaete— *M. speciosa*; (3) the Tubificidae worms— *V. angustipenis and L. hoffmeisteri*; and (4) the Asian clams—*C. amurensis* and *C. fluminea*.

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Chapter 6 Appendix

Figure 6-1 Location of macrobenthic monitoring stations

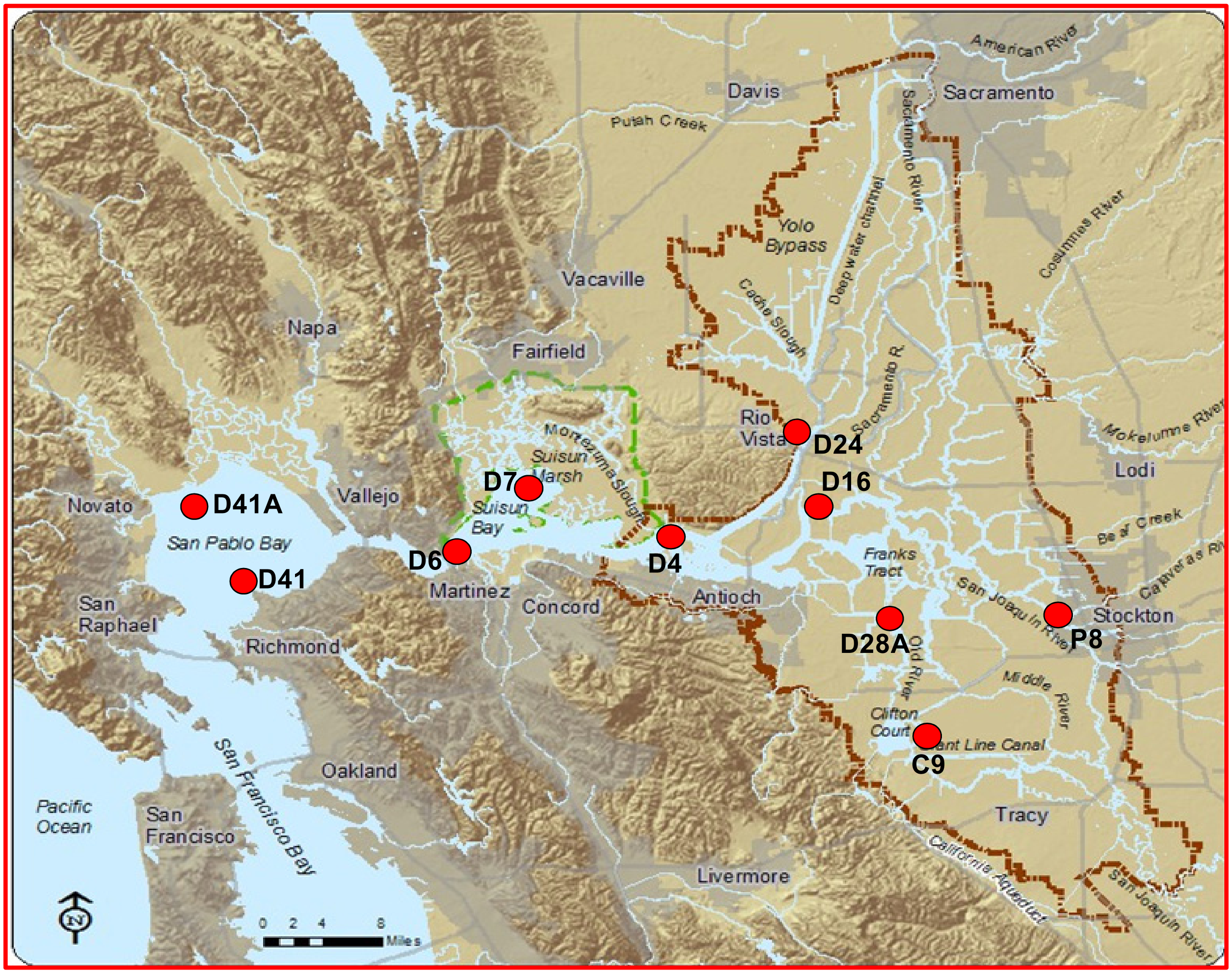


Figure 6-2 Total contribution by phyla for all stations, 2009

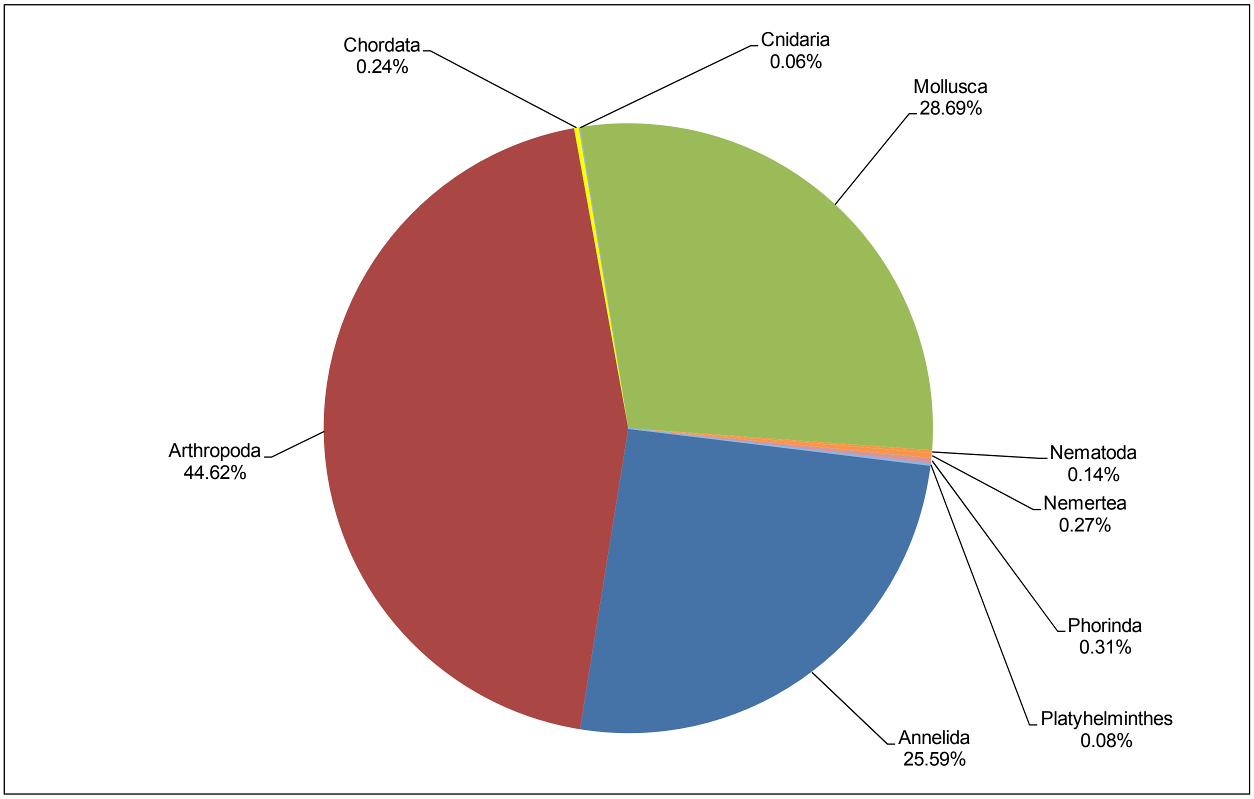


Figure 6-3 Total abundance at C9, 2009

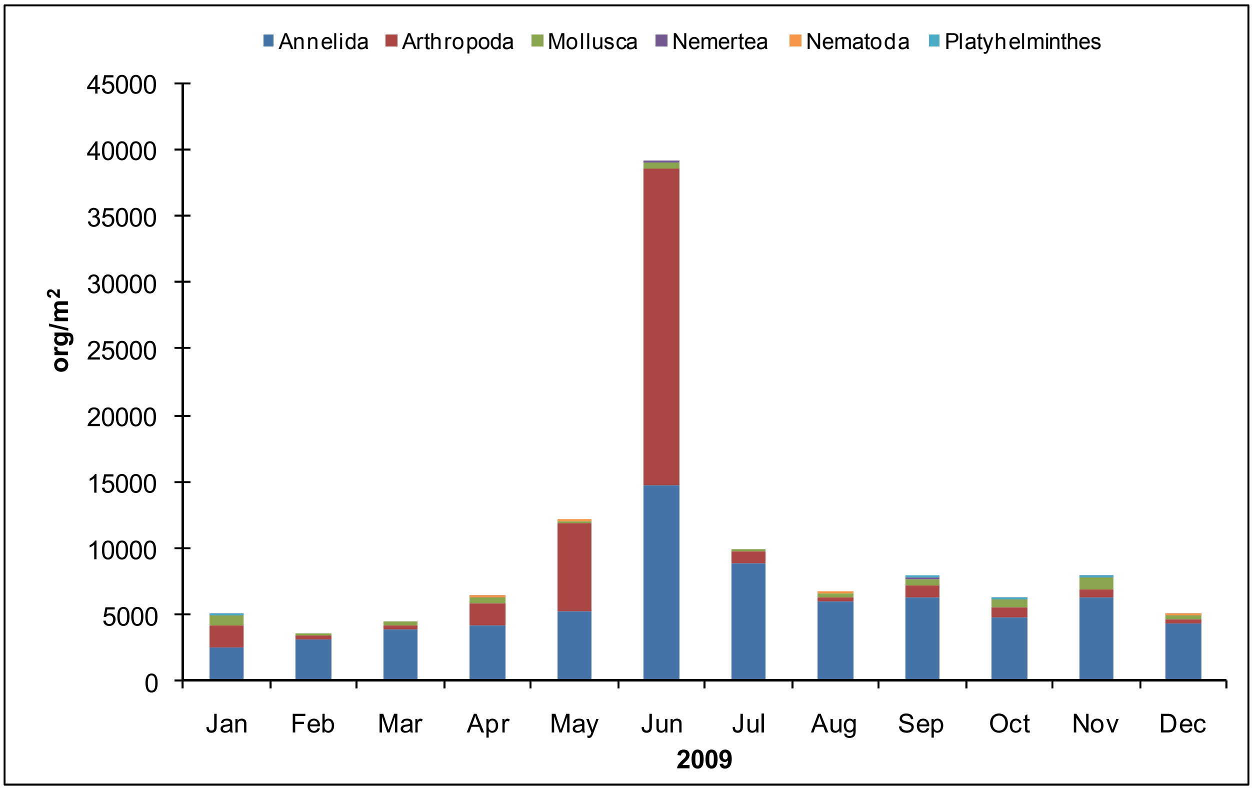


Figure 6-4 Total abundance at P8, 2009

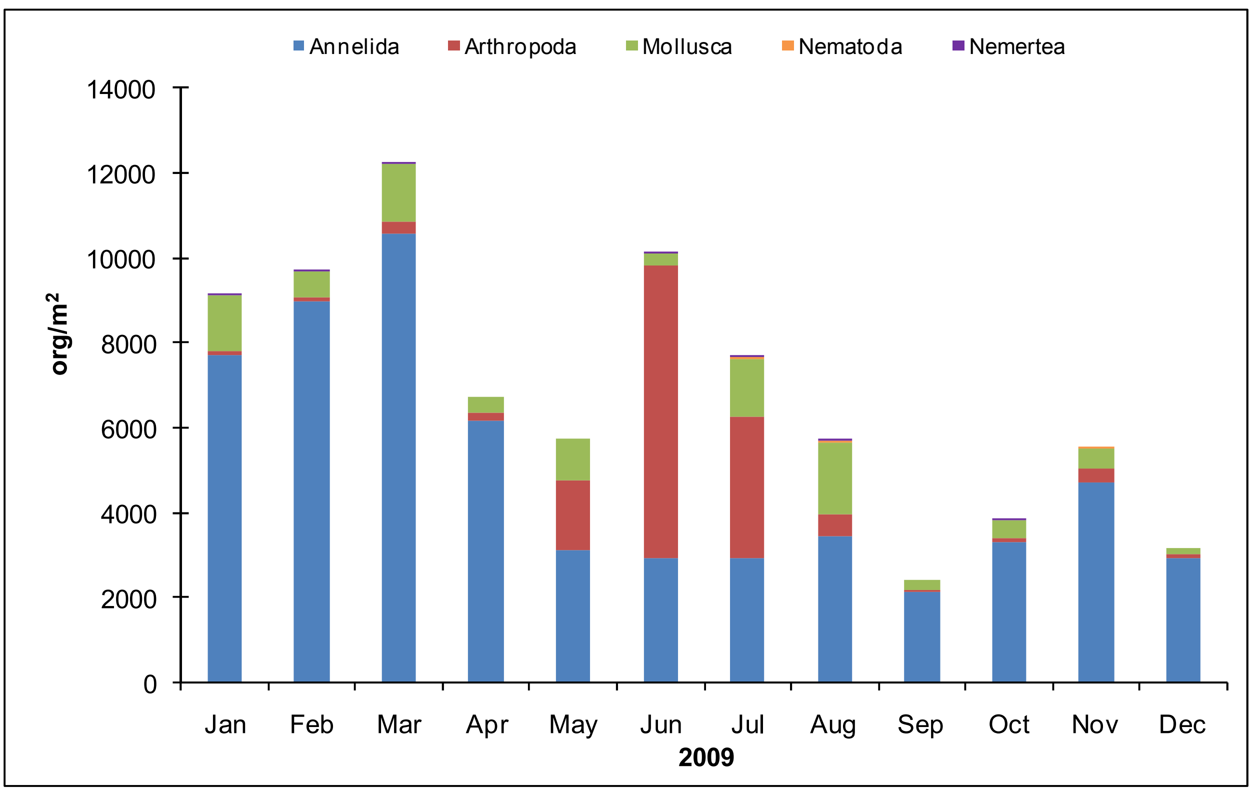


Figure 6-5 Total abundance at D28A, 2009

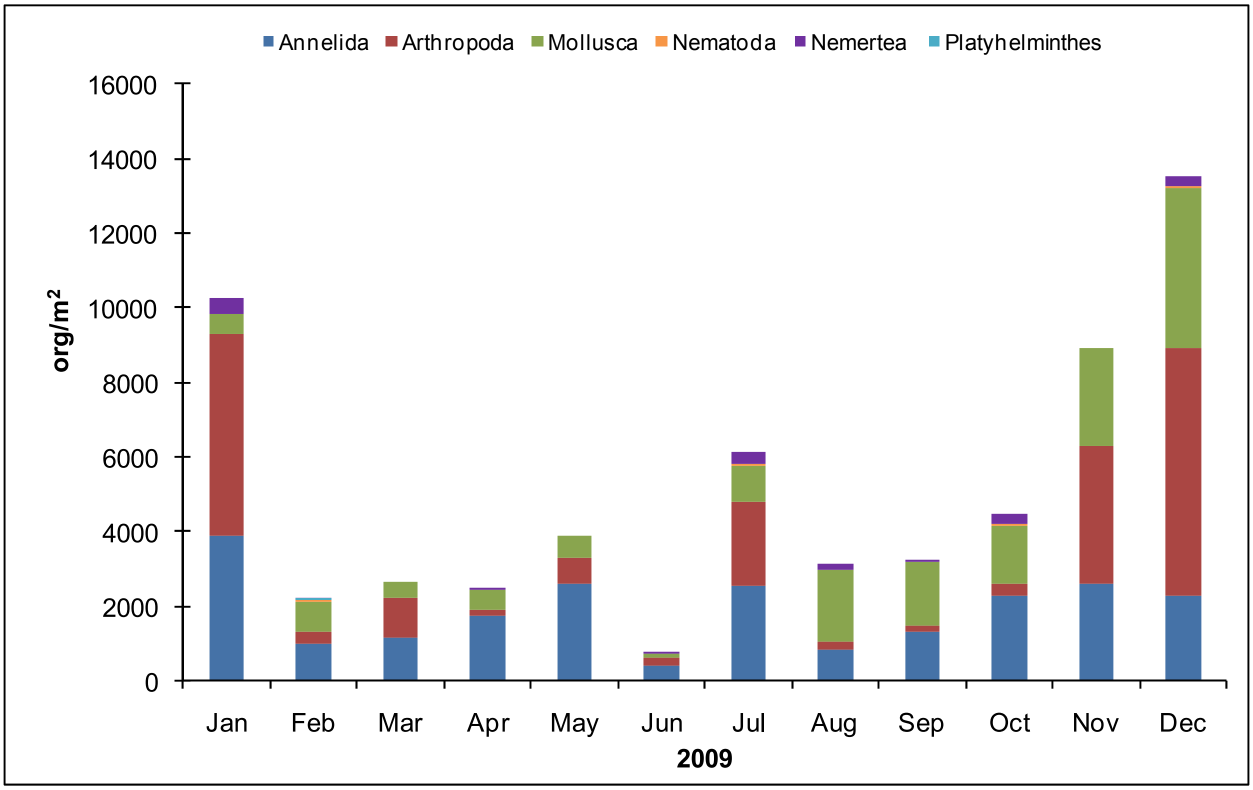


Figure 6-6 Total abundance at D16, 2009

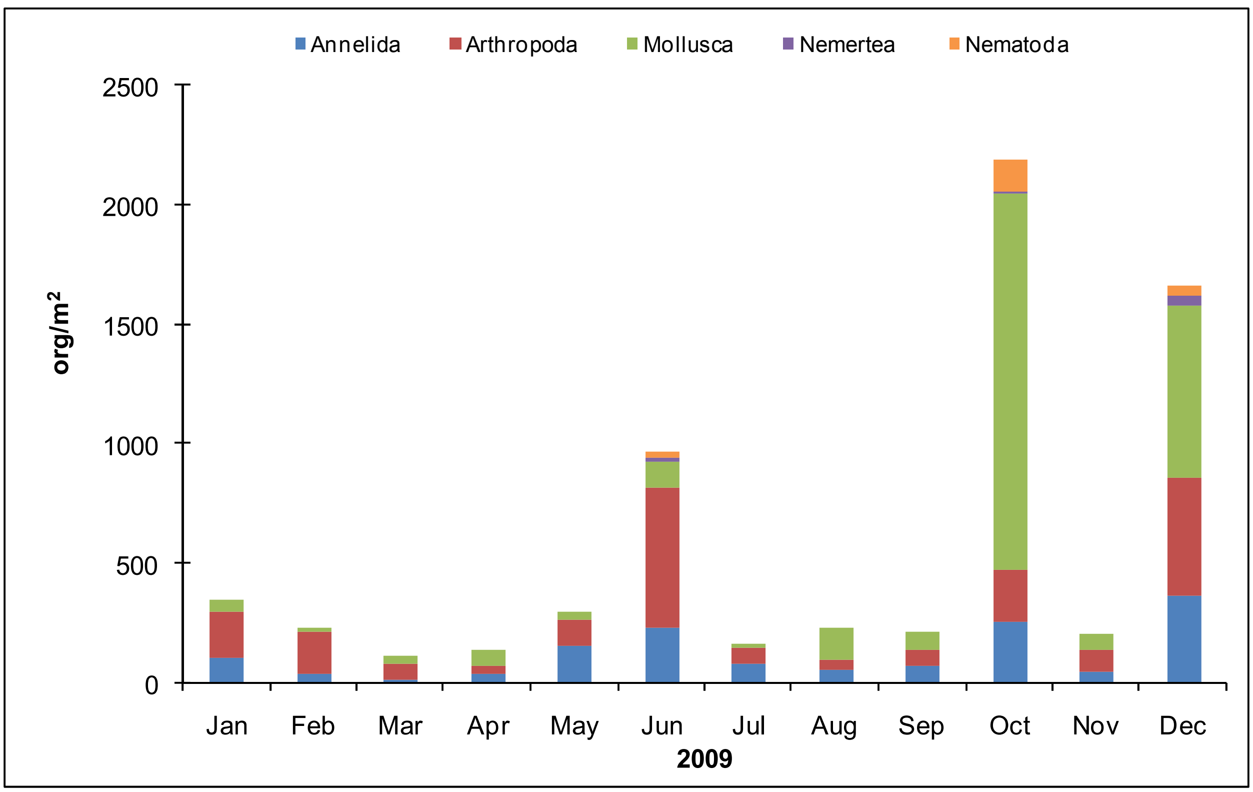


Figure 6-7 Total abundance at D24, 2009

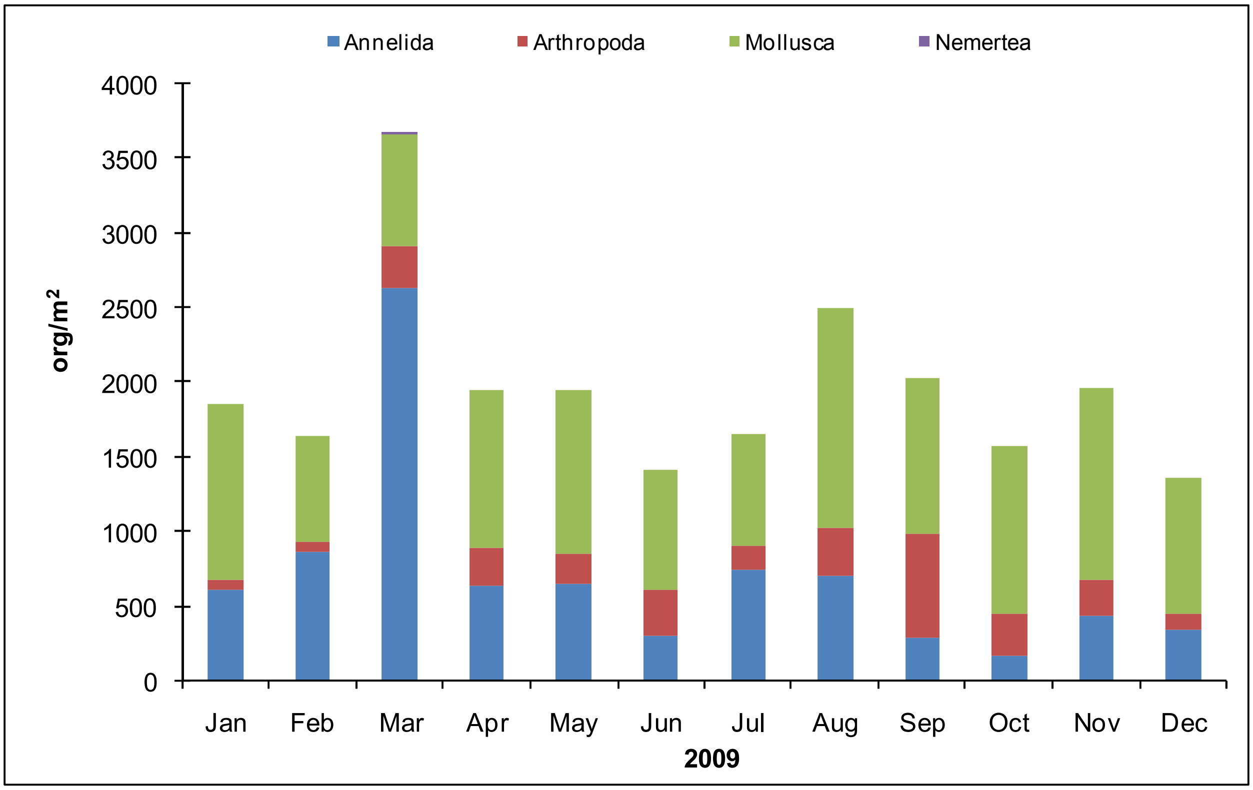


Figure 6-8 Total abundance at D4, 2009

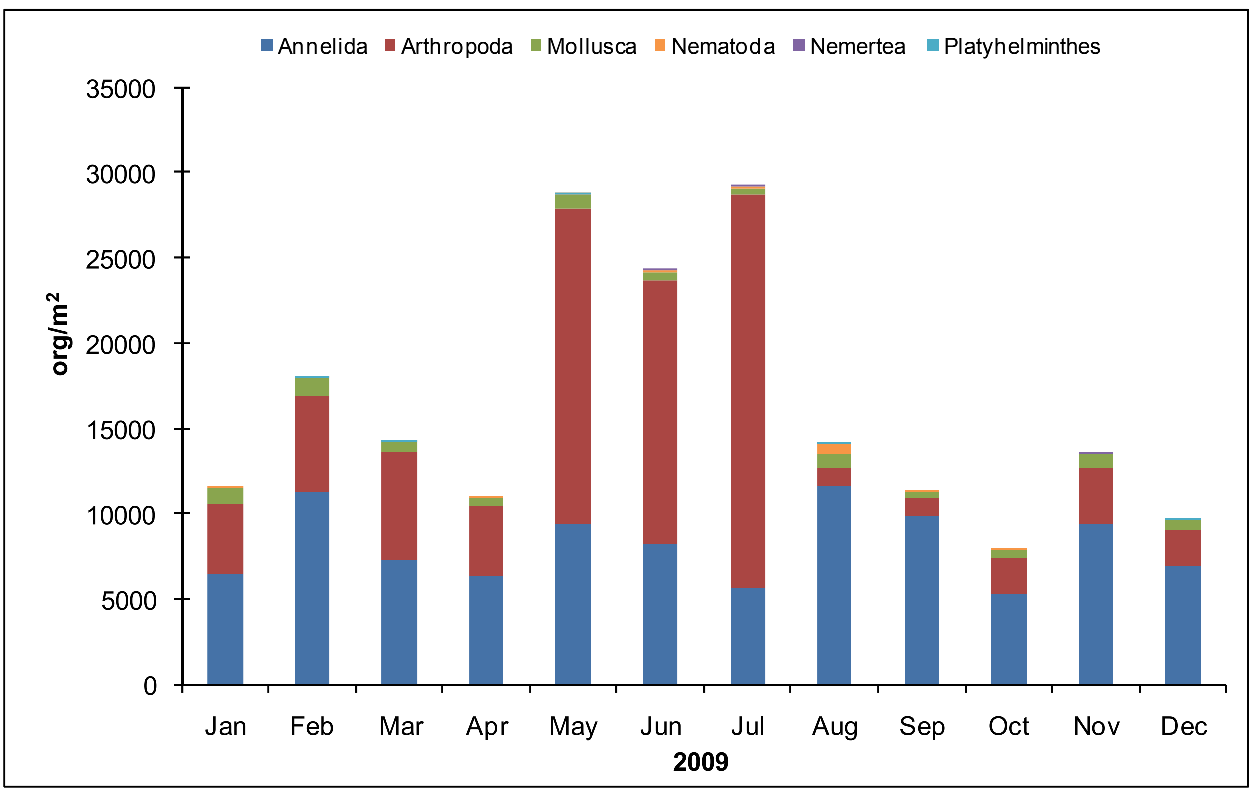


Figure 6-9 Total abundance at D6, 2009

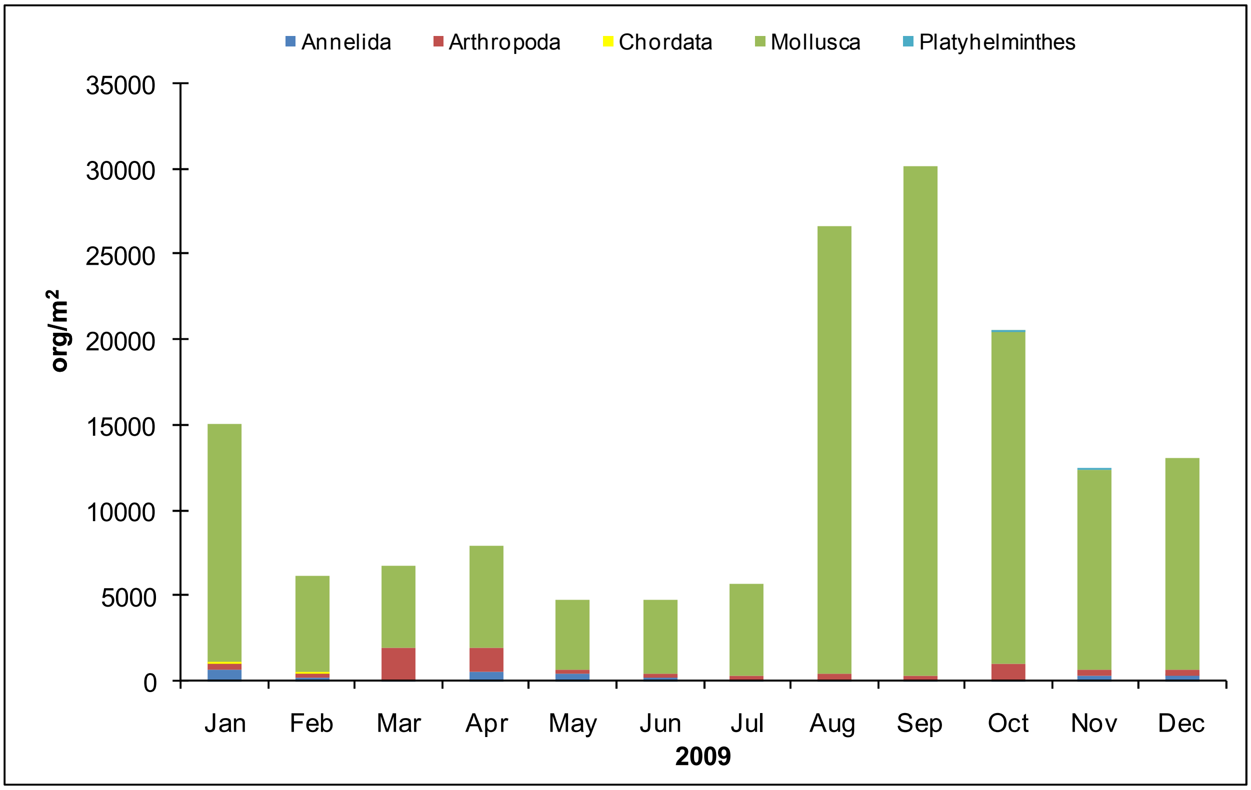


Figure 6-10 Total abundance at D7, 2009

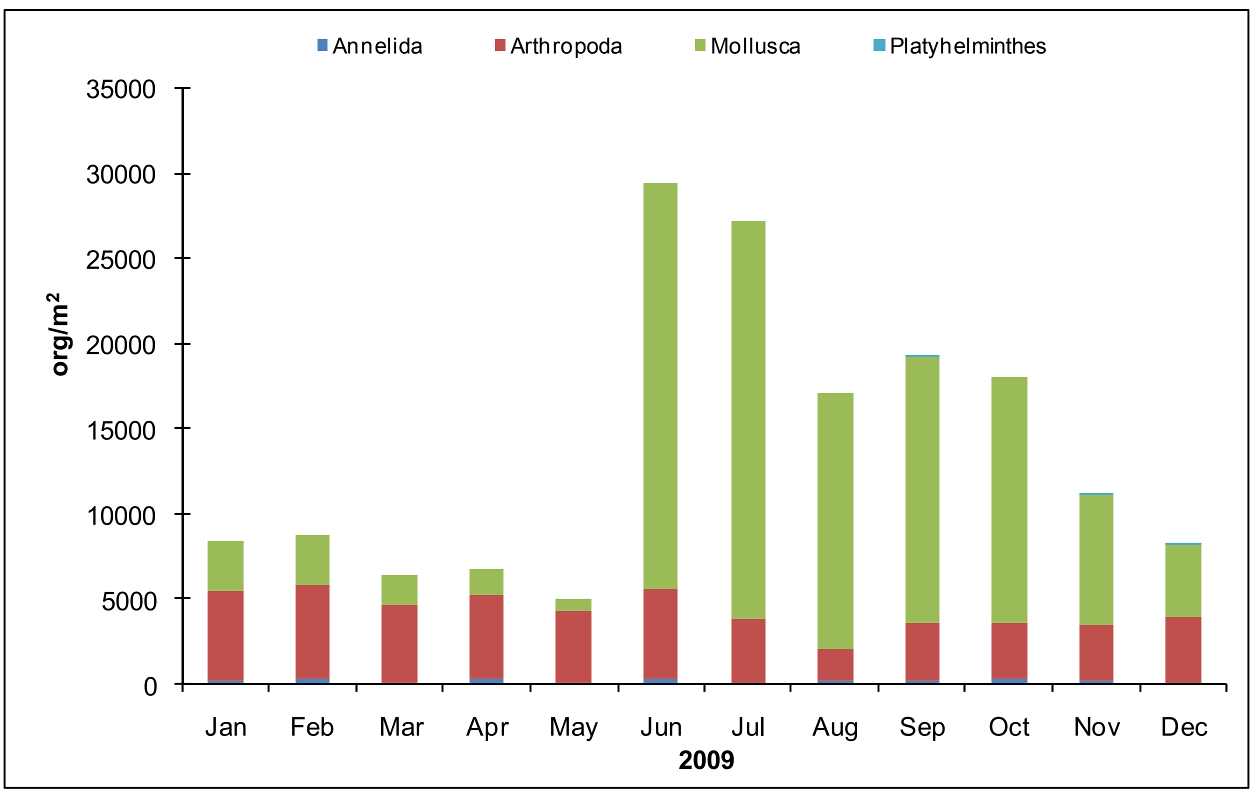


Figure 6-11 Total abundance at D41, 2009

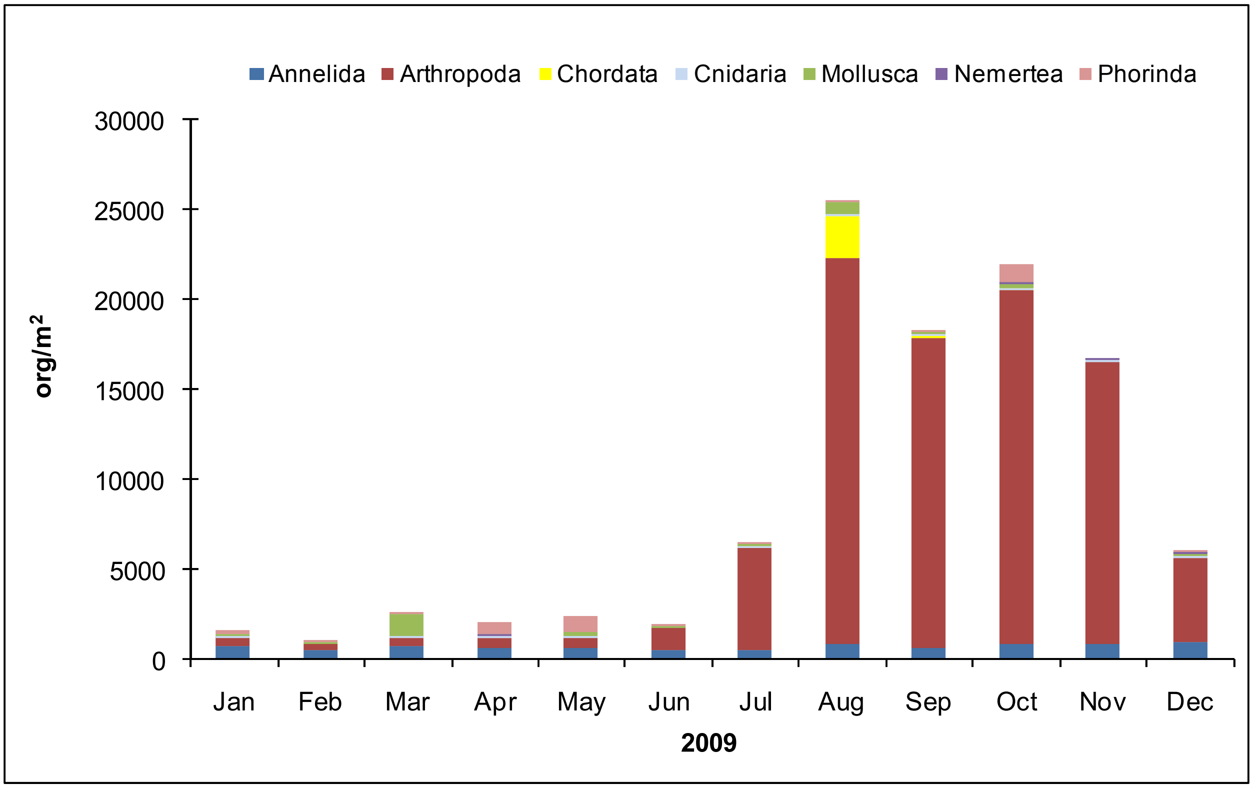


Figure 6-12 Total abundance at D41A, 2009

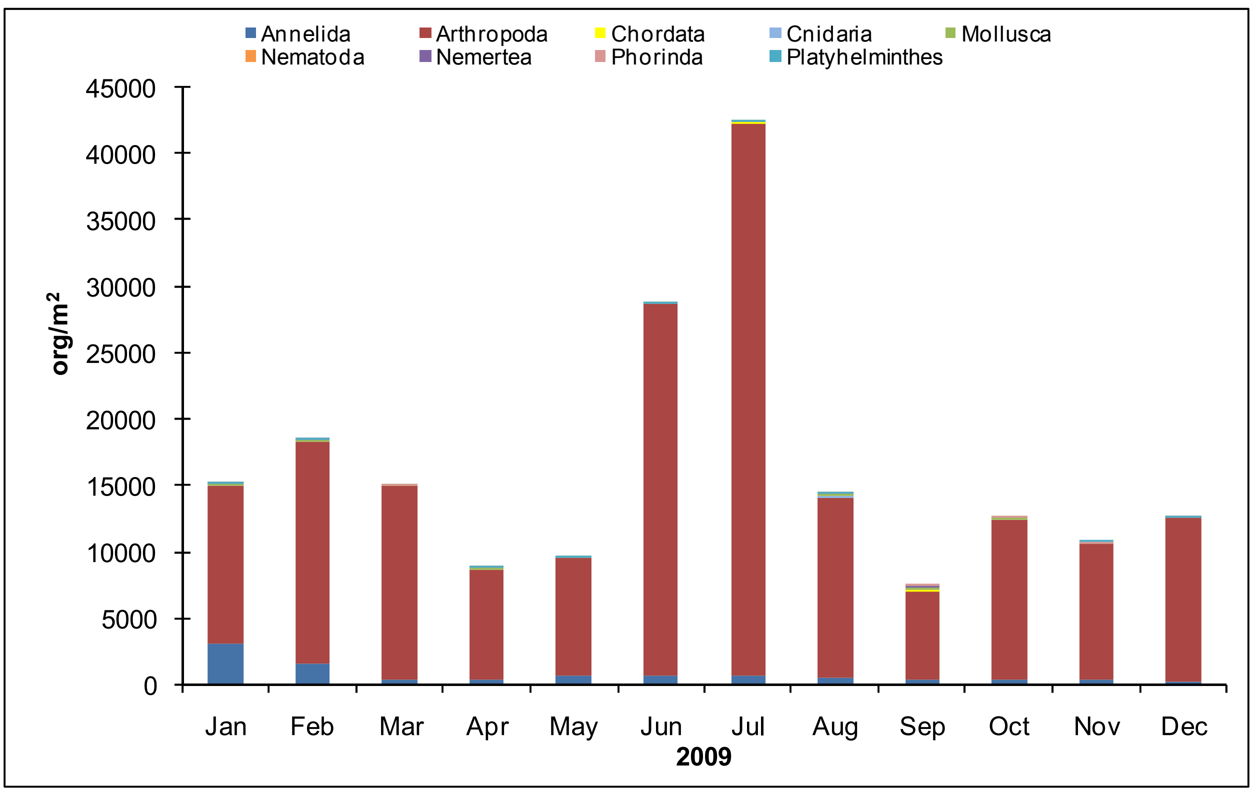
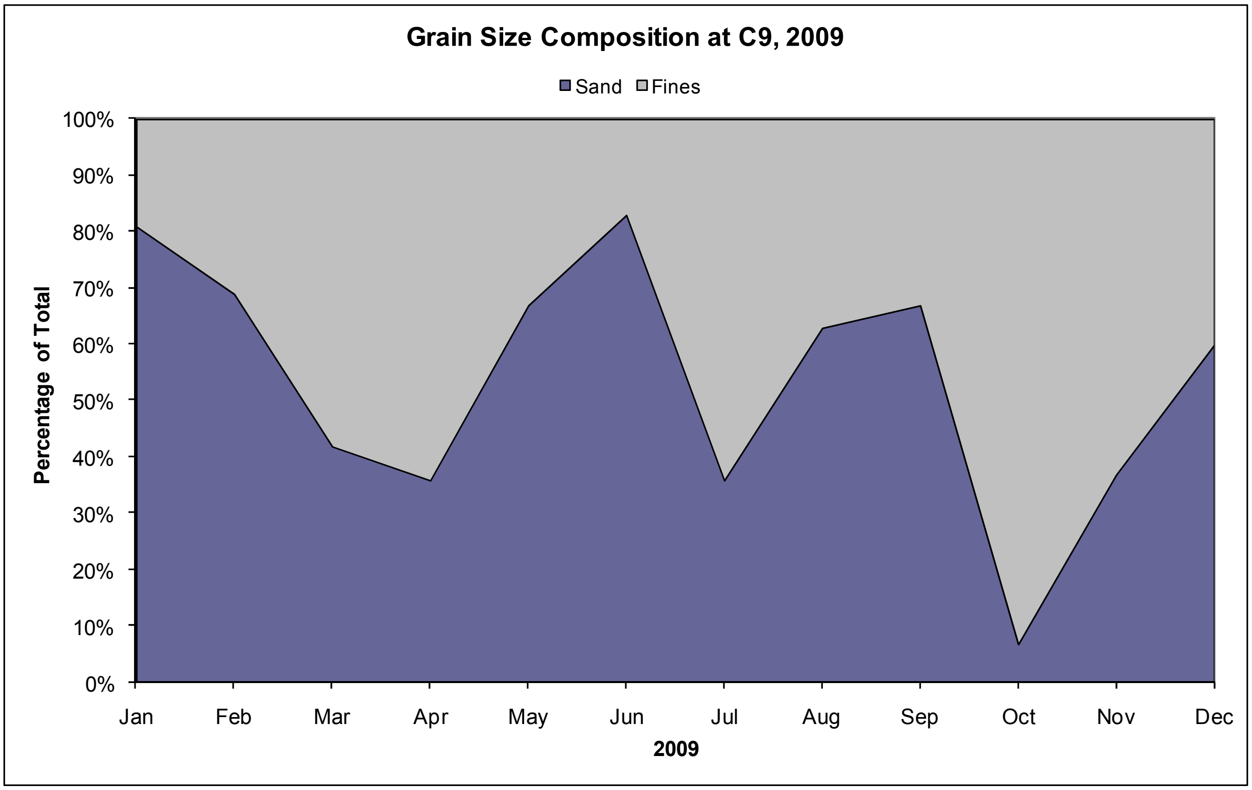


Figure 6-13 Sediment grain size and organic content at C9, 2009



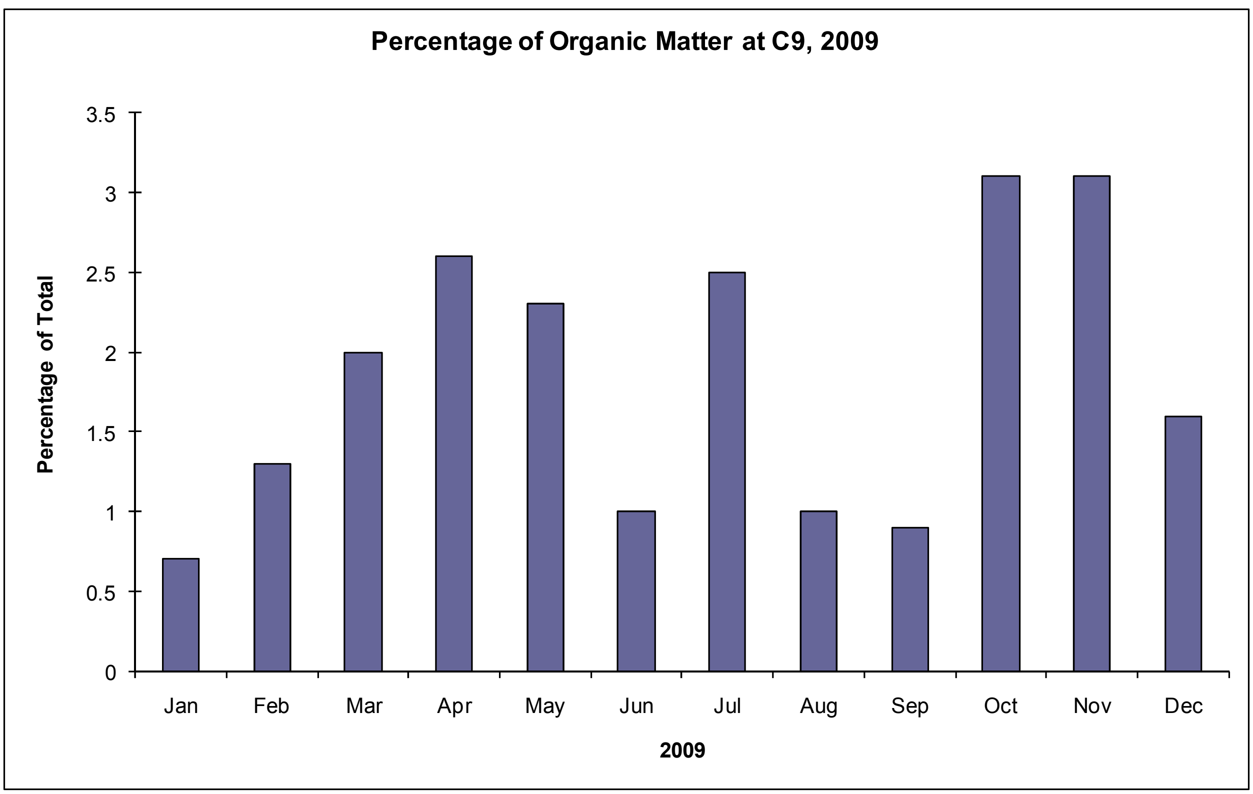
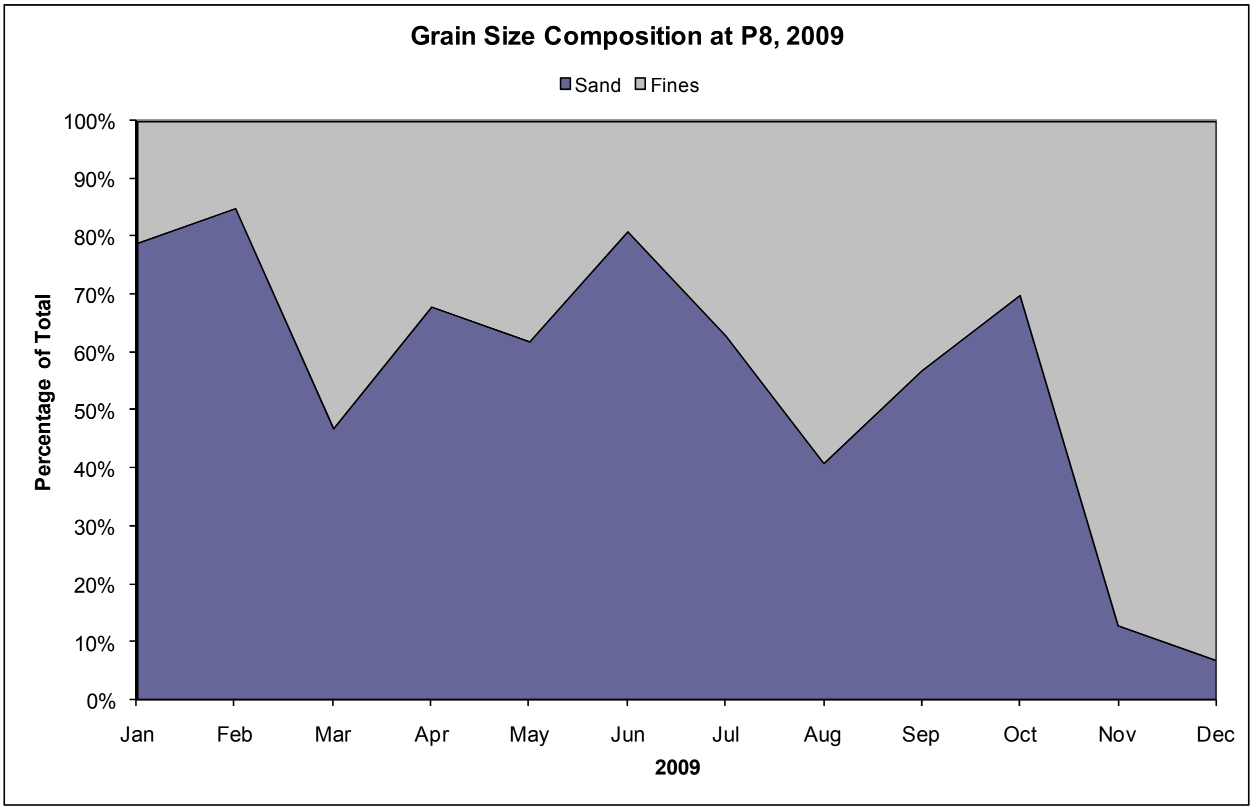


Figure 6-14 Sediment grain size and organic content at P8, 2009



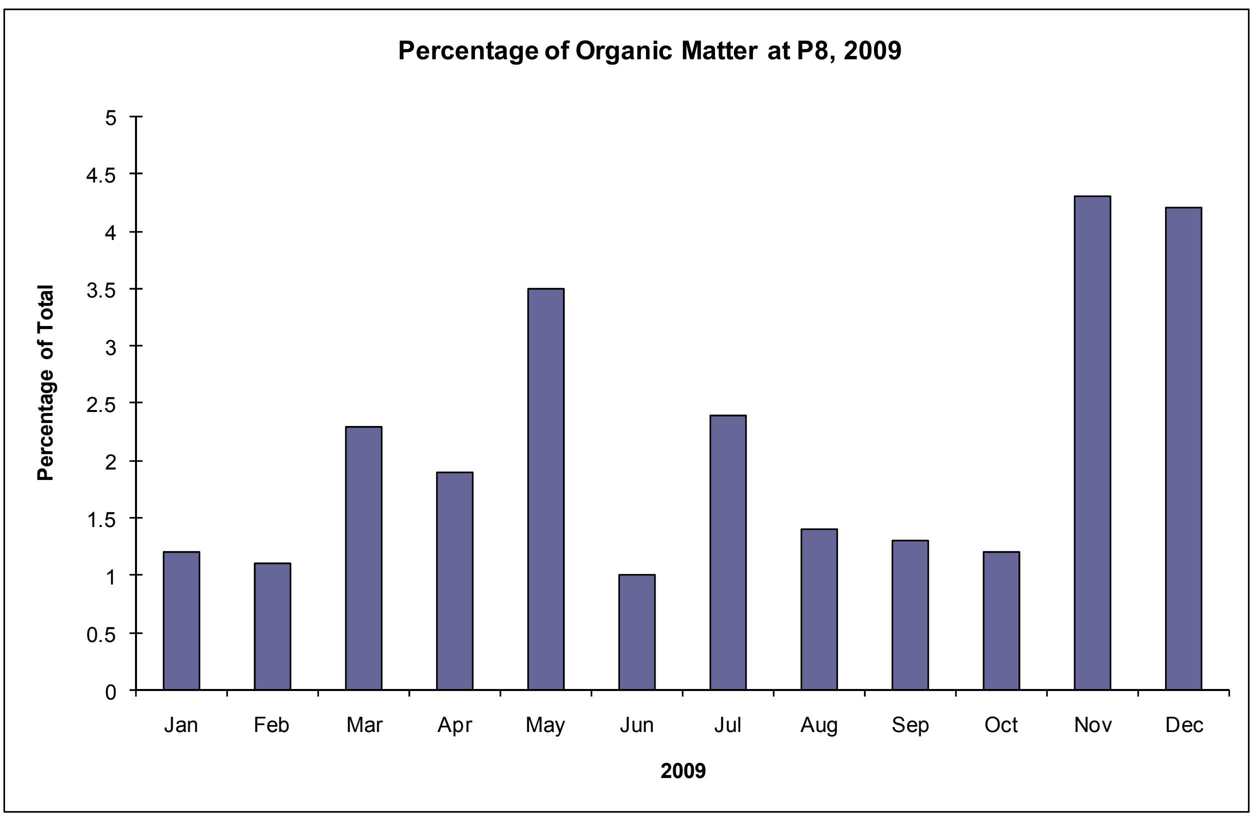
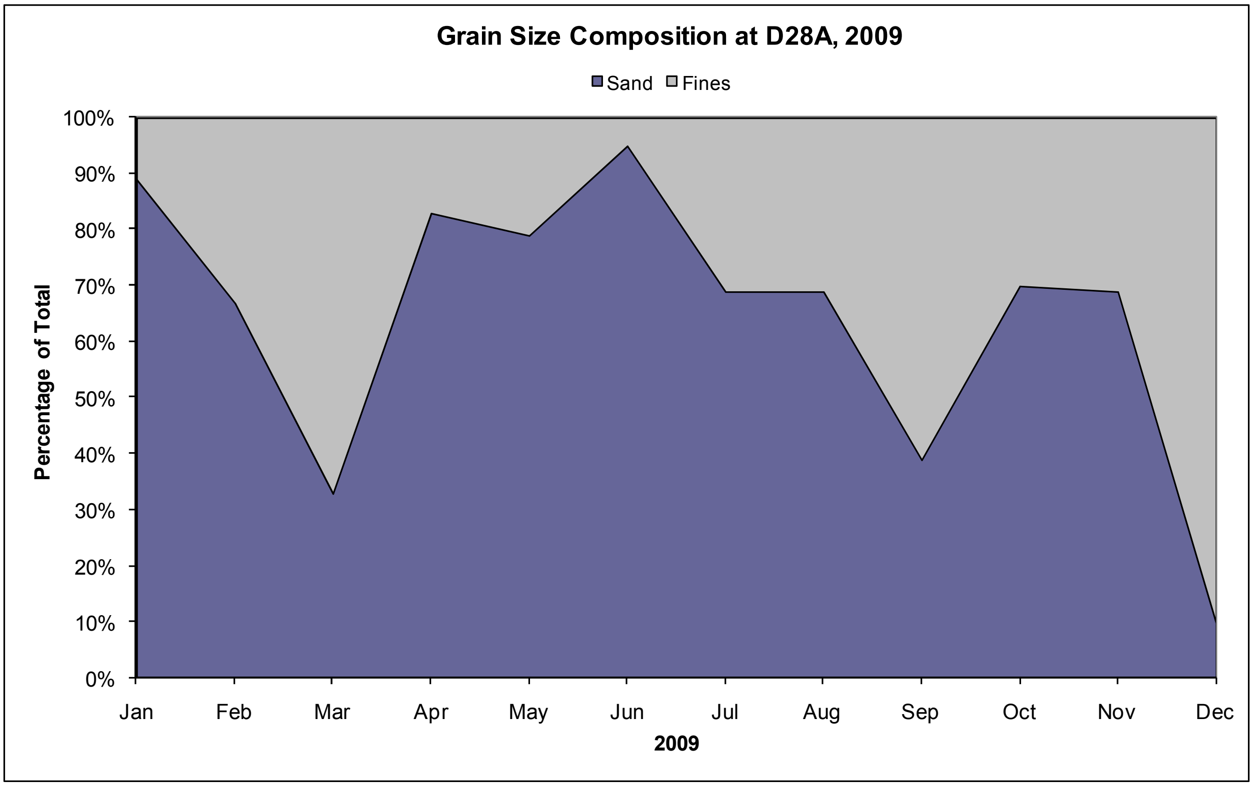


Figure 6-15 Sediment grain size and organic content at D28A, 2009



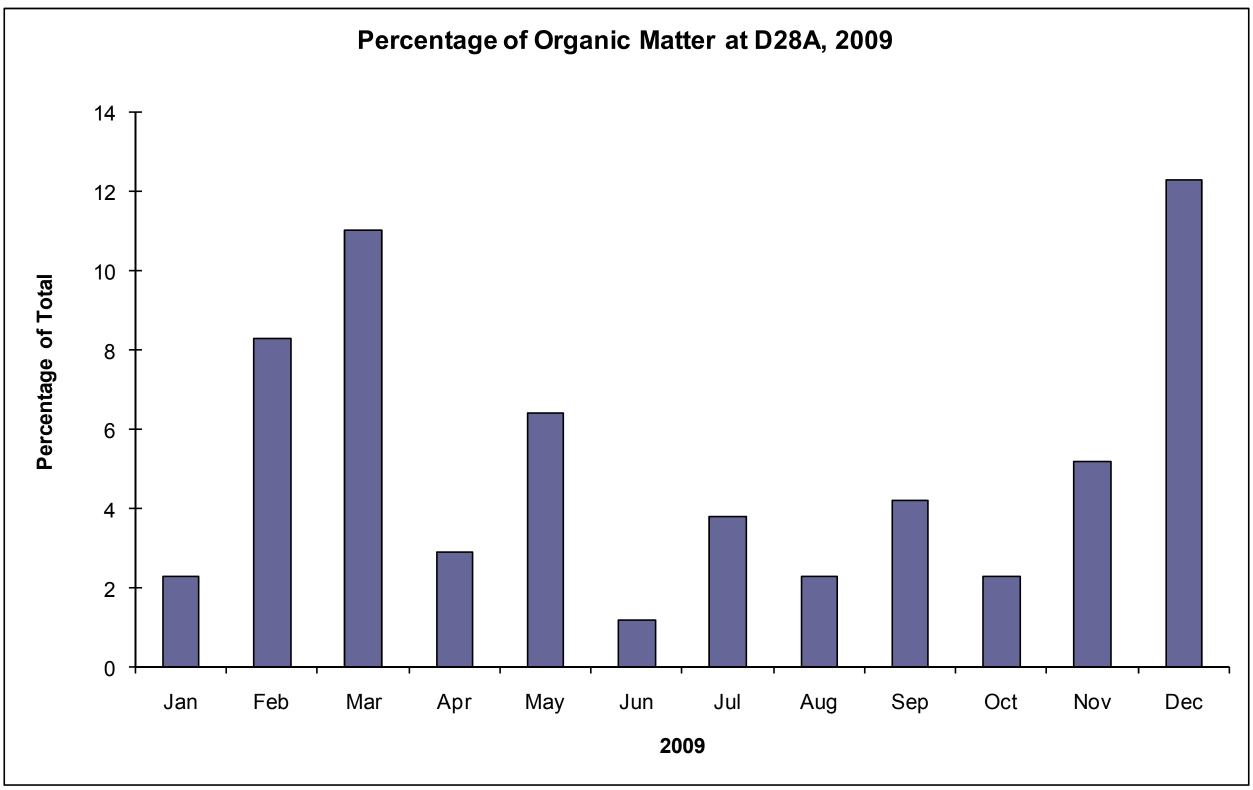
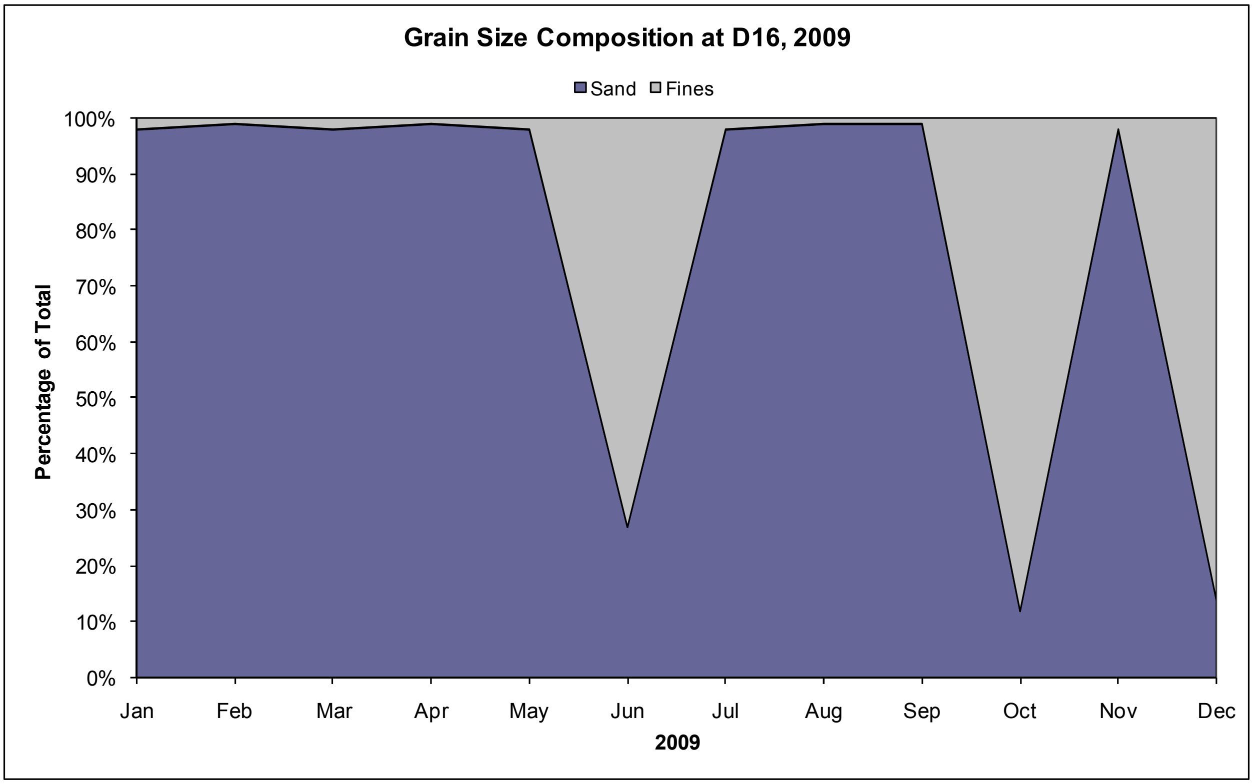


Figure 6-16 Sediment grain size and organic content at Station D16, 2009



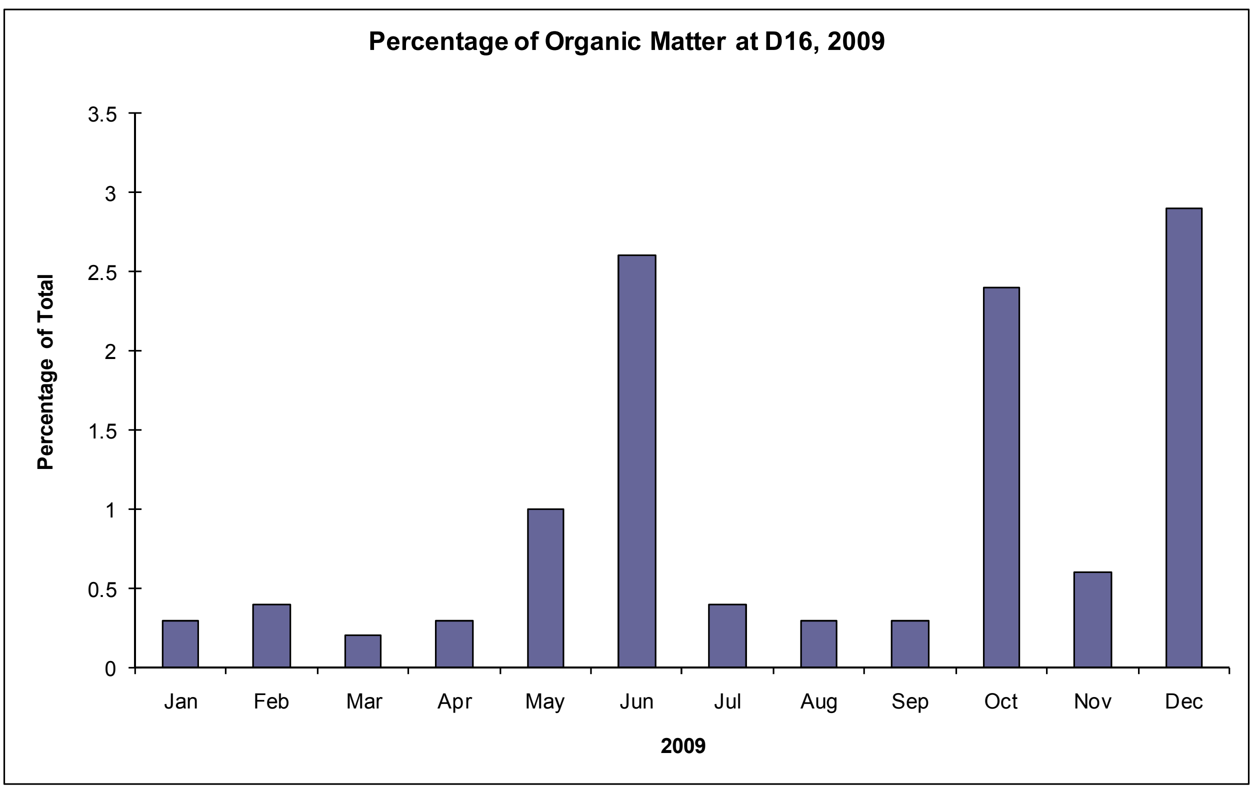
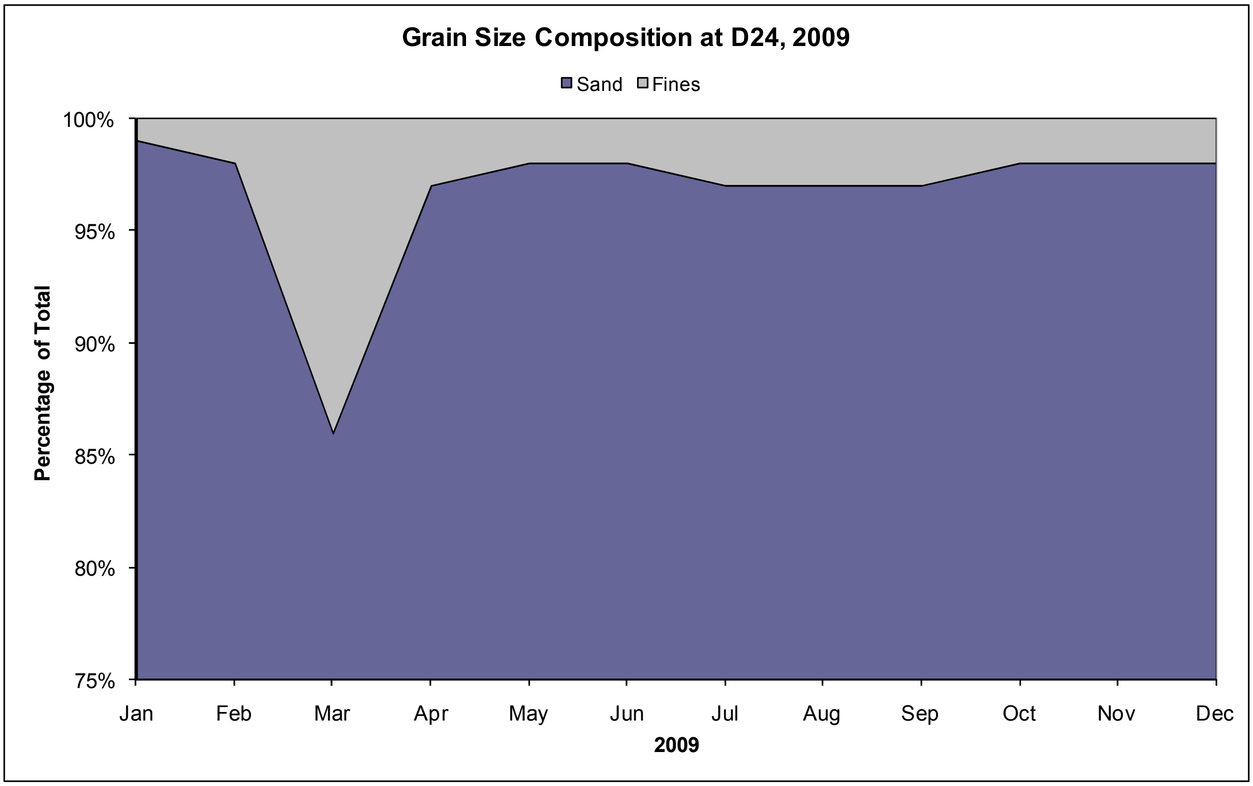


Figure 6-17 Sediment grain size and organic content at D24, 2009



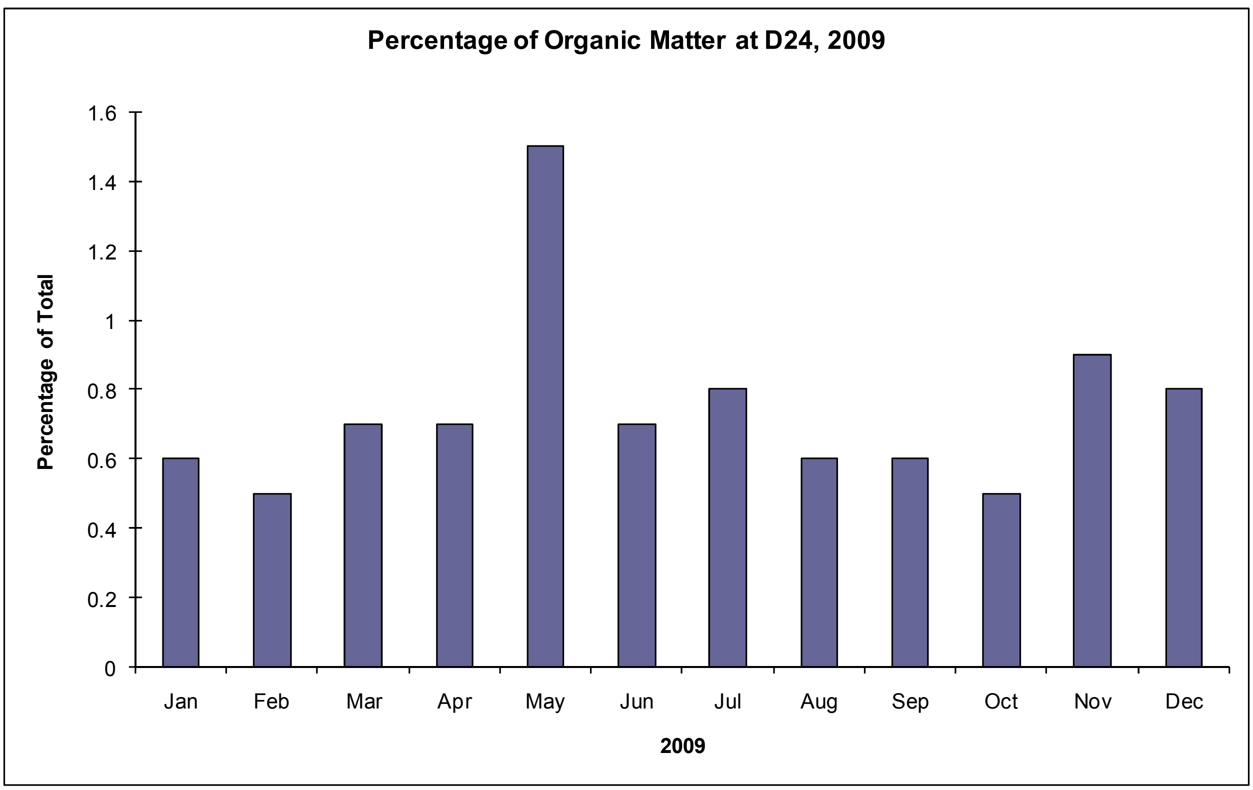
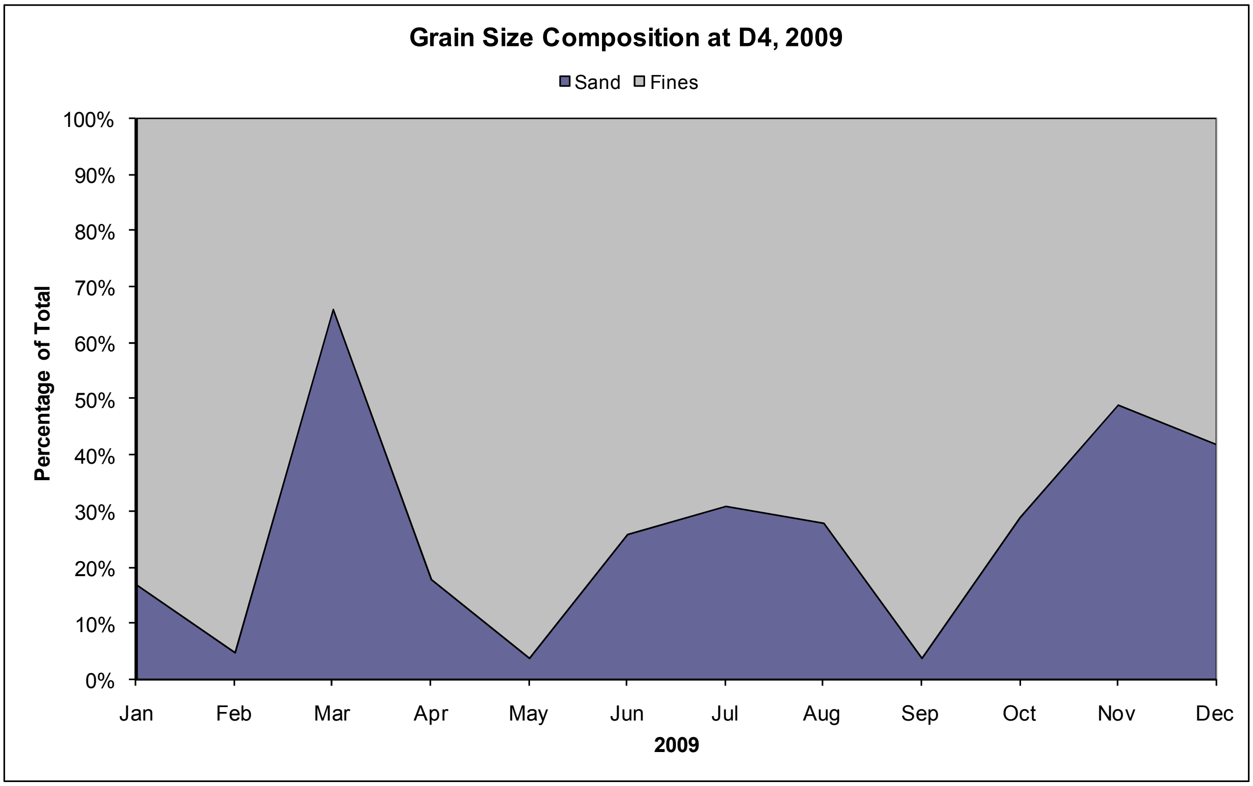


Figure 6-18 Sediment grain size and organic content at Station D4, 2009



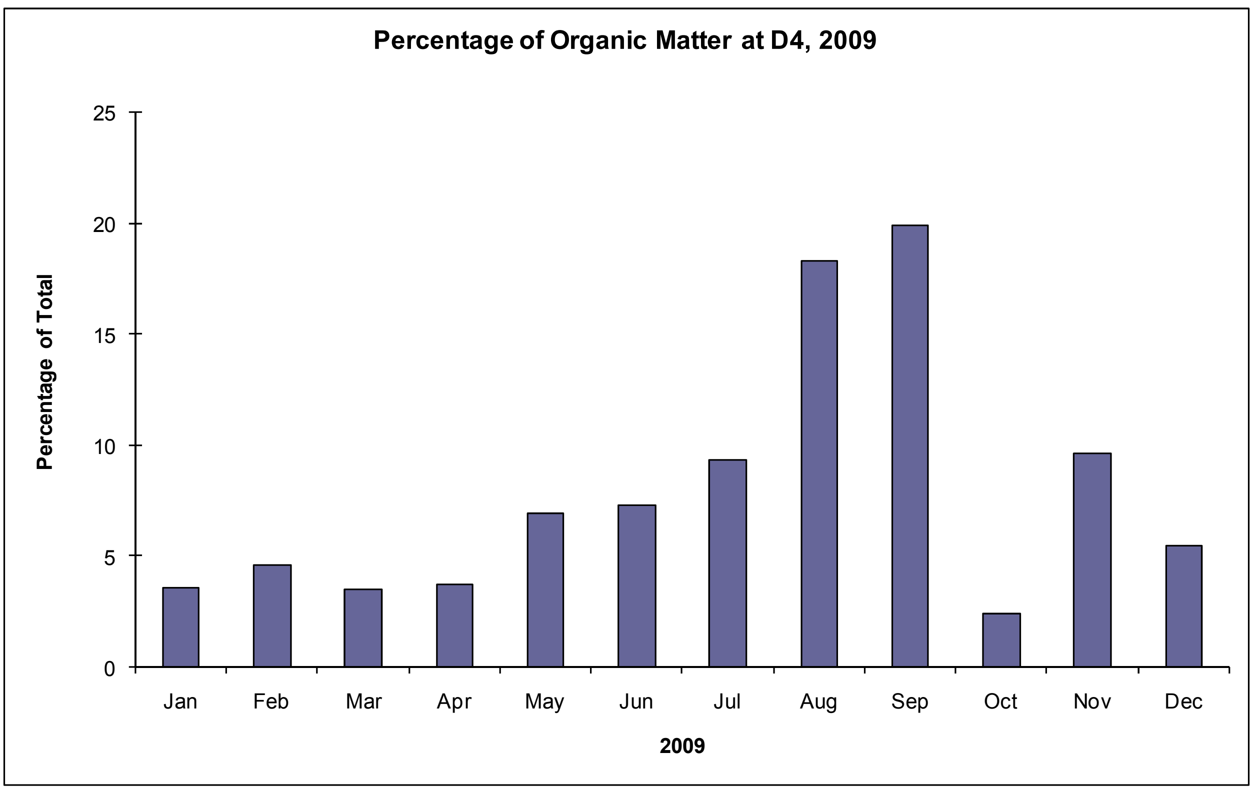
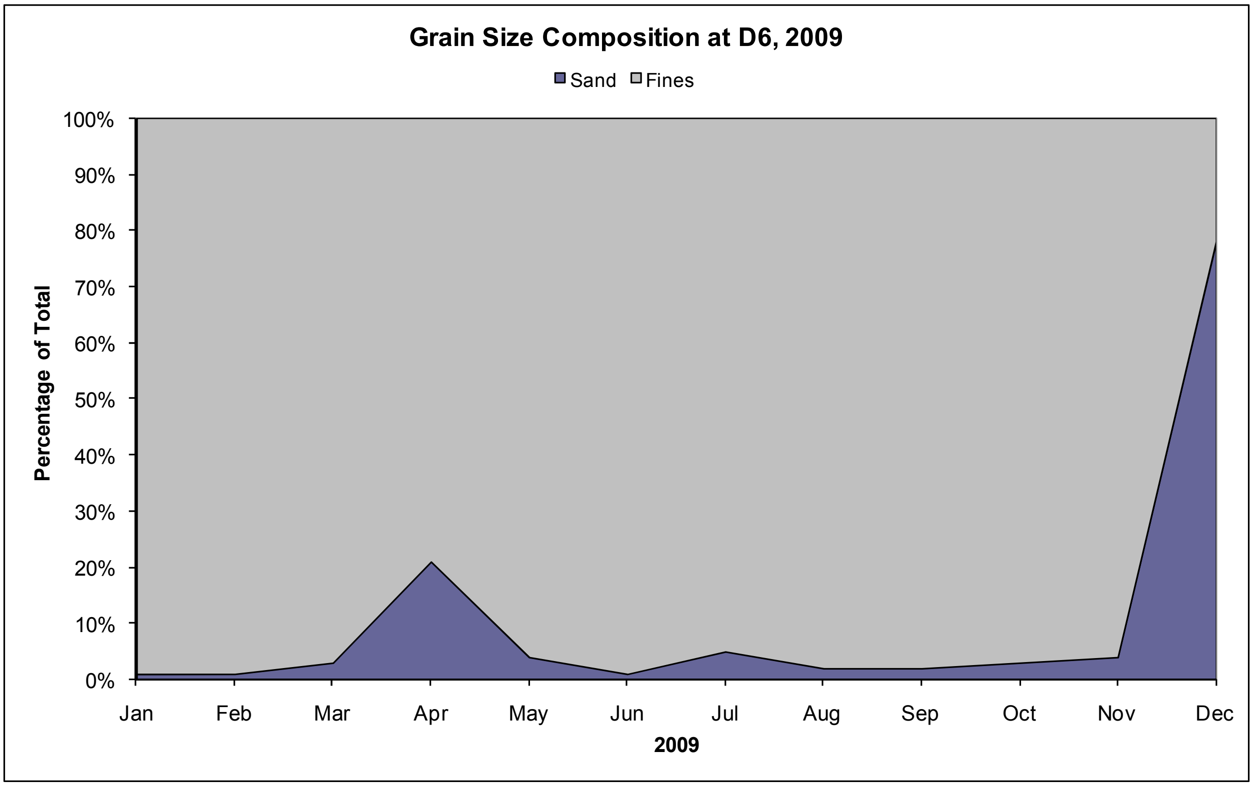


Figure 6-19 Sediment grain size and organic content at D6, 2009



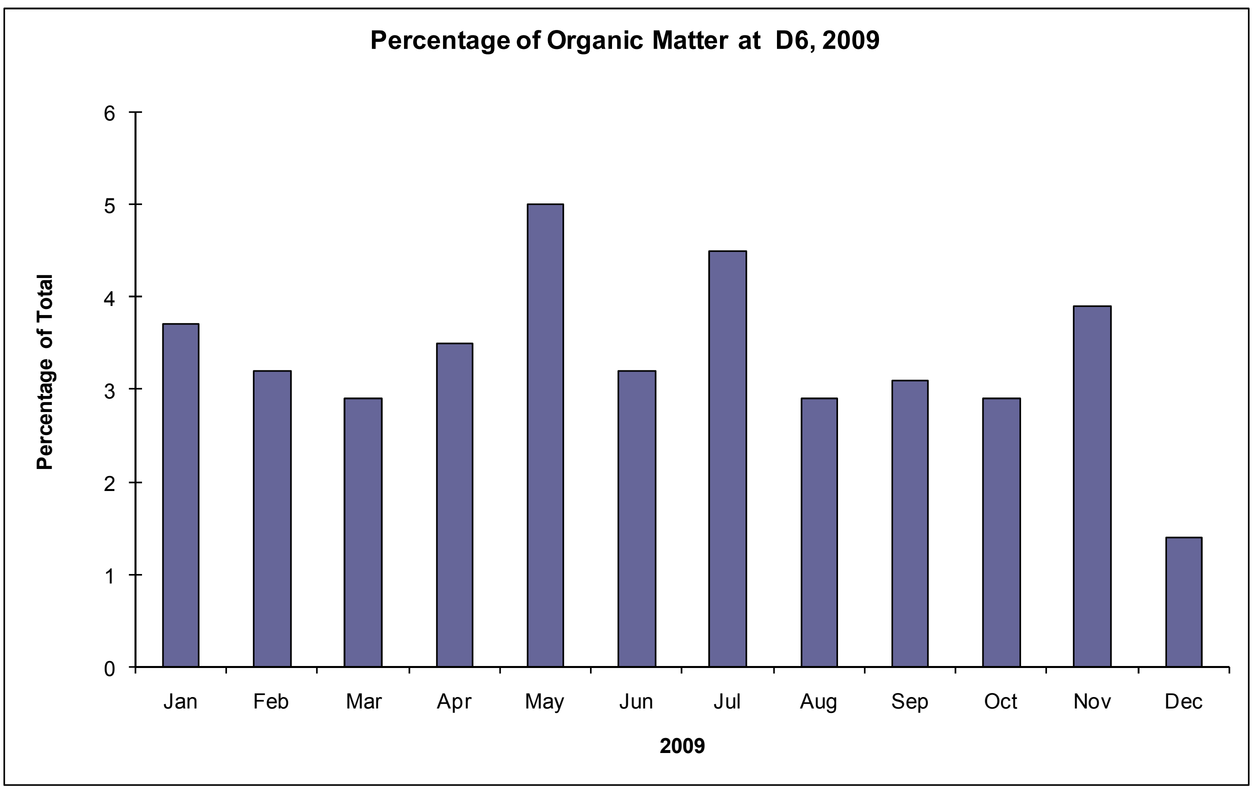
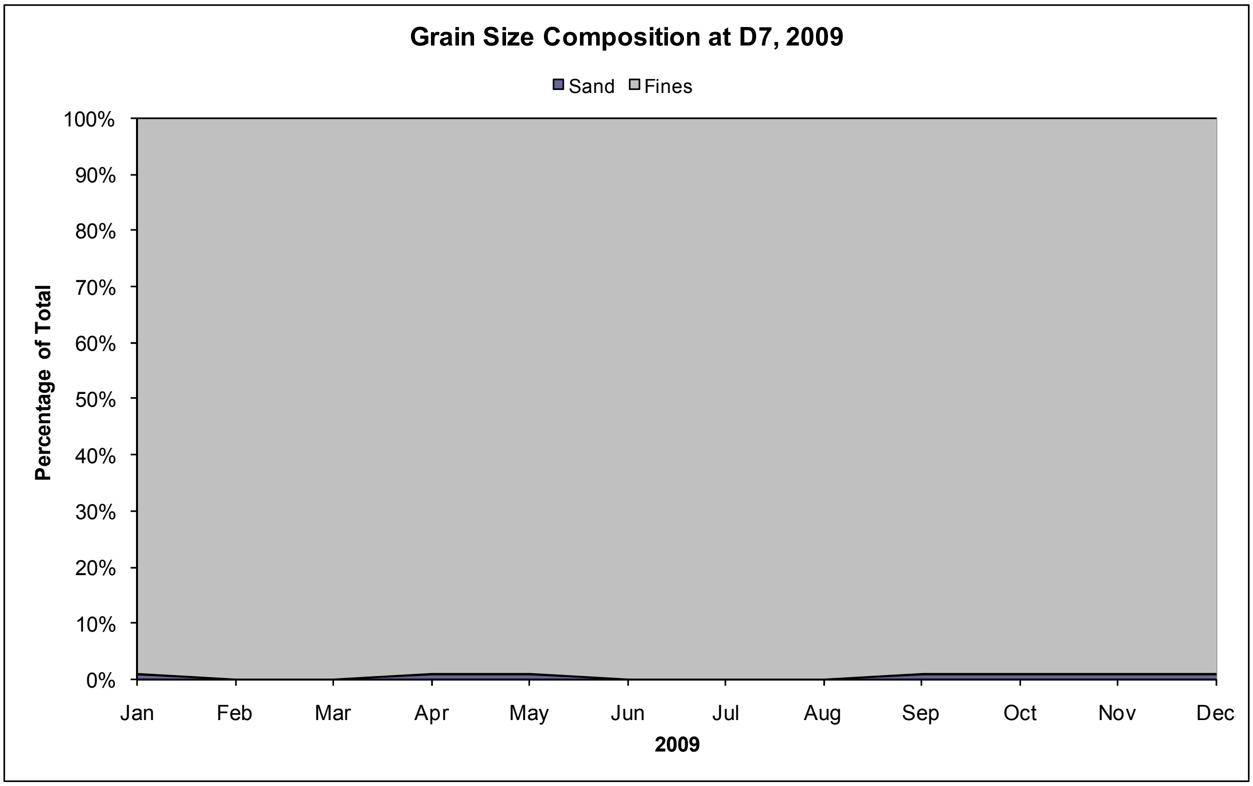


Figure 6-20 Sediment grain size and organic content at D7, 2009



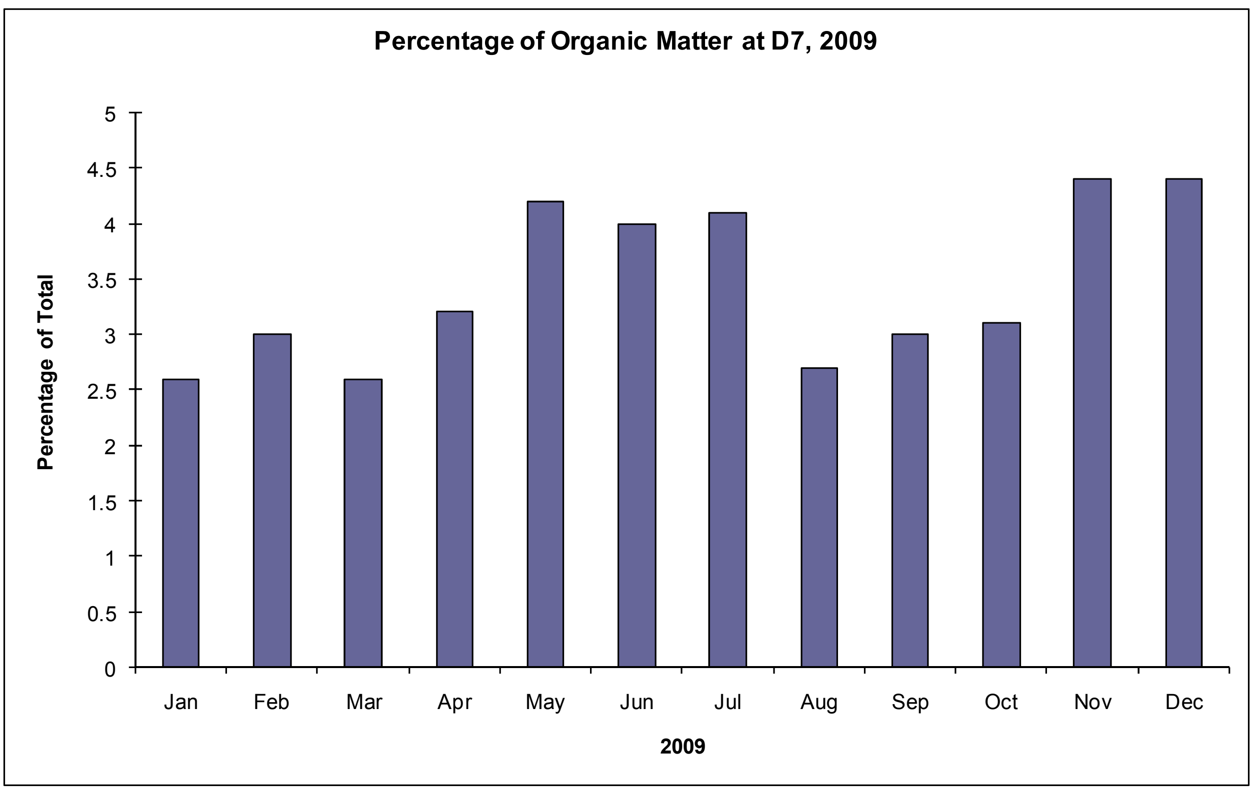
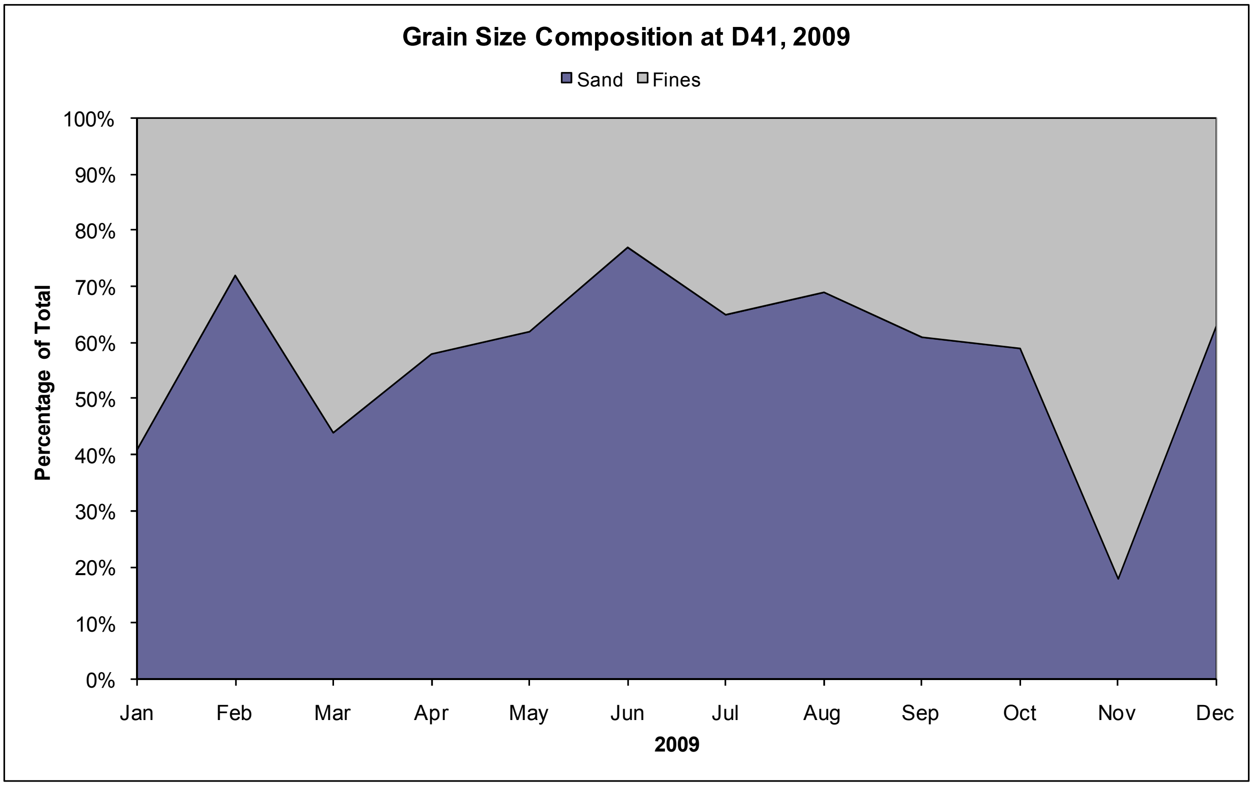


Figure 6-21 Sediment grain size and organic content at D41, 2009



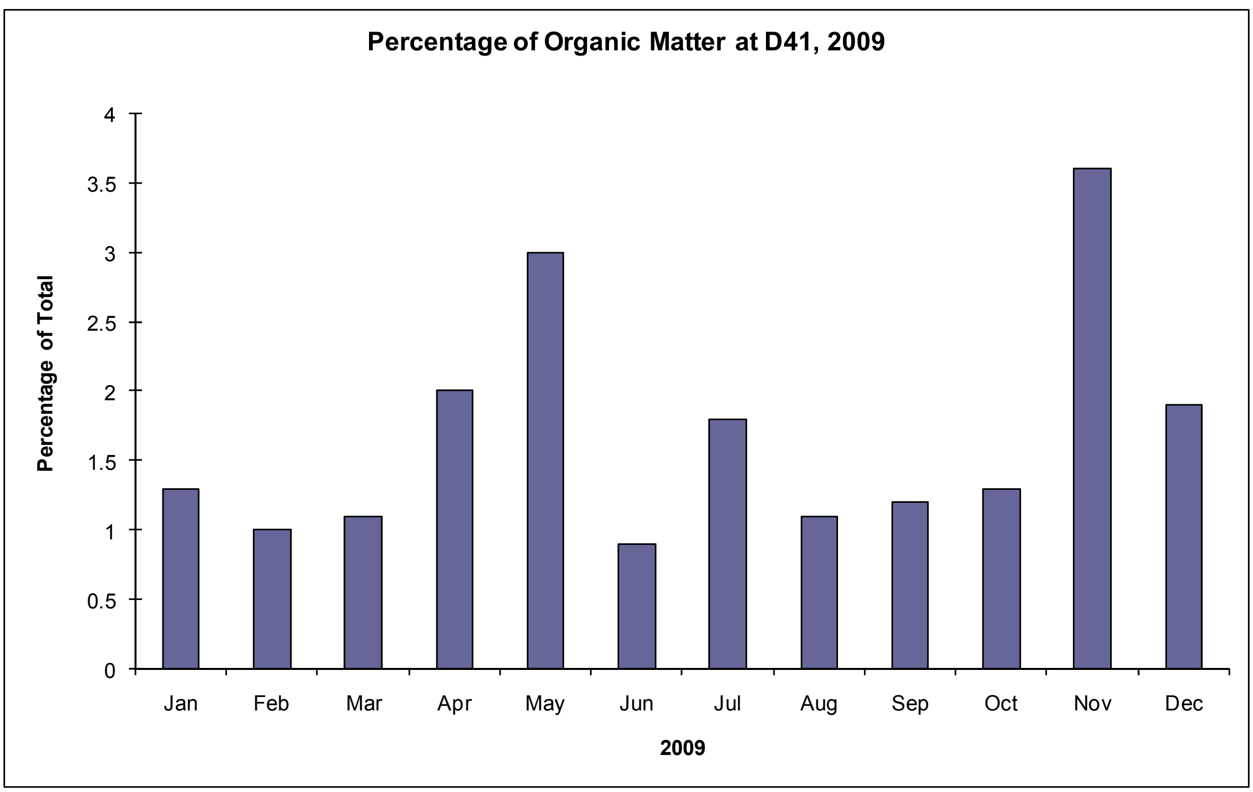
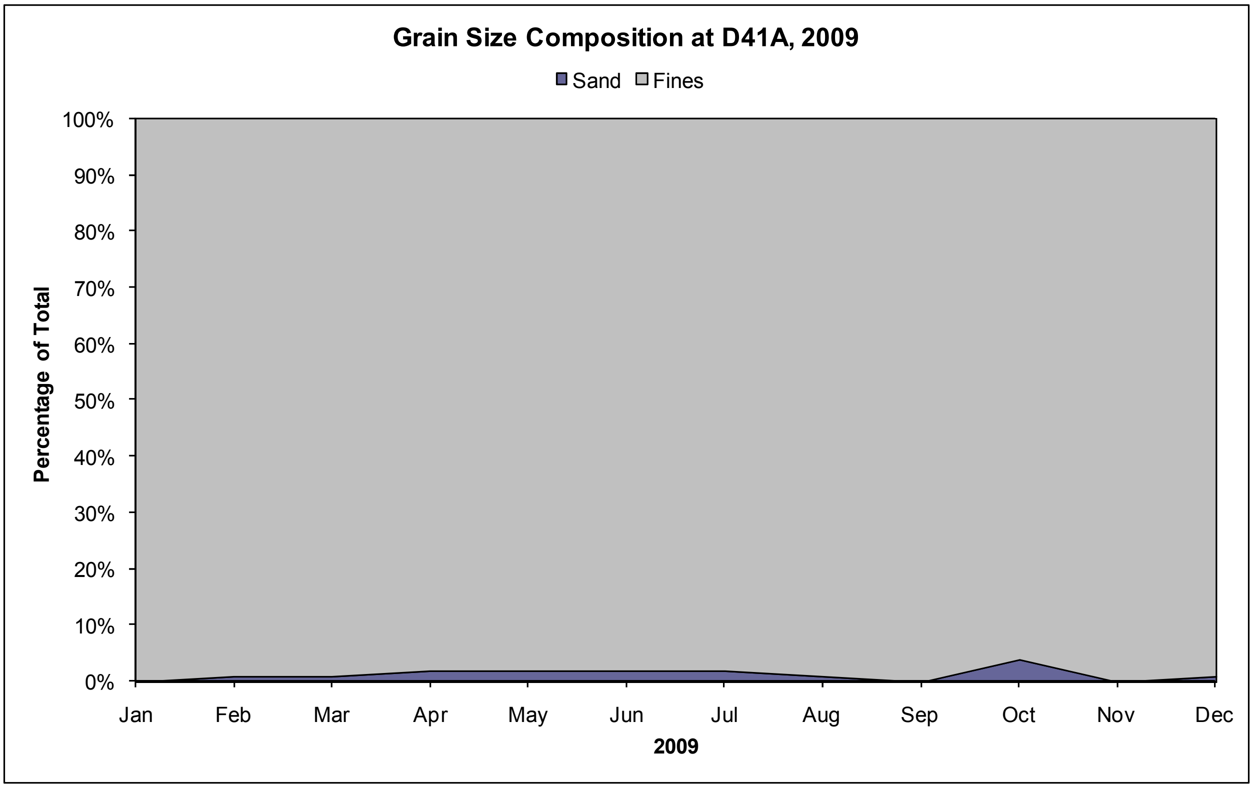


Figure 6-22 Sediment grain size and organic content at D41A, 2009



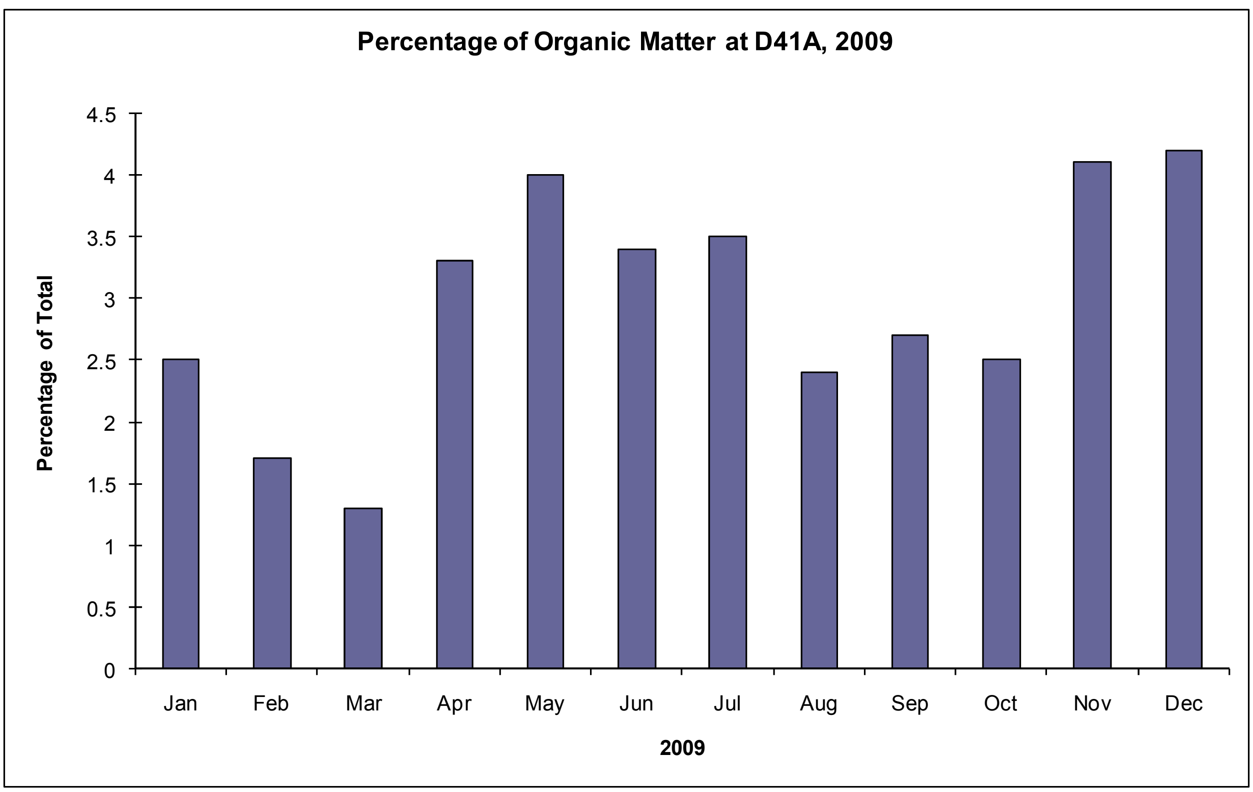


Table 6-1 Macrobenthic monitoring station characteristics, 2009

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 Special Studies: DO Monitoring in the Stockton Ship Channel

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Chapter 7 Special Studies: DO Monitoring in the Stockton Ship Channel

Introduction

DWR's Bay-Delta Monitoring and Analysis Section has been monitoring 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 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 SWRCB established specific water quality objectives to protect these uses. Within the channel, 2 separate DO objectives have been established. The most recent *Basin Plan* (1998) of the CVRWQCB establishes a baseline DO objective of 5.0 mg/L for the entire Delta region (including the 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, USFWS, USBR, and DFG, 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 cfs or less. In 2009, the spring barrier was not installed; instead, a non-physical "bubble barrier" was installed as a pilot test to prevent salmon from entering Old River. The fall barrier was also not installed in 2009 because existing flows and DO levels were sufficient for salmon.

This report describes DO monitoring results during the period of June through November 2009, which includes an instance when San Joaquin River net flow at Stockton reached a minimum of -385 cfs.

Methods

Monitoring was conducted approximately every 2 weeks by vessel on 12 monitoring cruises from June 16 to November 25, 2009. 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 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.

Discrete samples were taken from the top (1 m from the surface) and bottom (1 m 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 5739 polarographic electrode 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 YSI 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 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, located 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 0 and can sometimes reverse direction. During July 2009, net flow at Stockton reached a minimum of -385 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 period range was 5.3 to 9 mg/L at the surface and 3.6 to 9.6 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 6.7 to 8.9 mg/L at the surface and 6.8 to 9.2 mg/L at the bottom. In the central portion of the channel, DO concentrations were variable, ranging from 5.5 to 8.9 mg/L at the surface and 5.3 to 9.1 mg/L at the bottom. In the eastern channel, DO levels were slightly lower and tended to be more stratified than the other stations, ranging from 5.3 to 9.6 mg/L at the surface and 3.6 to 9.6 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 2,809 cfs in October to a low of 498 cfs in August. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 1,450 cfs in October to a low of -385 cfs in July (Figure 7-2).

The findings for the summer and fall of 2009 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 5 and 22. Surface DO levels ranged from 5.5 mg/L at station 13 to 8.0 mg/L at station 1. Bottom DO levels ranged from 5.7 mg/L at station 12 to 7.7 mg/L at station 1 (Figure 7-3).

[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.

Water temperatures ranged from 20.1 ^{o}C (station 3) to 23.4 ^{o}C (station 12) at the surface and 20.1^{o}C (station 1) to 23.2 ^{o}C (stations 12 and 13) at the bottom (Figure 7-3).

Flows on the San Joaquin River near Vernalis during the month of June ranged from 954 to 1,608 cfs. Net flow in the San Joaquin River near Stockton during June ranged from -134 to 367 cfs (Figure 7-2).

July

Monitoring cruises were conducted on July 6 and 20. Surface DO levels ranged from 5.3 mg/L at station 13 to 8.0 mg/L at station 1. Bottom DO levels ranged from 3.6 mg/L at station 12 to 7.9 mg/L at station 1 (Figure 7-4).

Water temperatures ranged from 21.9 ^{o}C (station 1) to 26.9 ^{o}C (stations 12 and 13) at the surface and 21.8 ^{o}C (station 1) to 26.5 ^{o}C (station 13) at the bottom (Figure 7-4).

Flows on the San Joaquin River near Vernalis during the month of July ranged from 525 to 1,140 cfs. Net flow in the San Joaquin River near Stockton during July ranged from -385 to -65 cfs (Figure 7-2).

August

Monitoring cruises were conducted on August 3 and 20. Surface DO levels ranged from 5.6 mg/L at station 13 to 7.9 mg/L at station 1. Bottom DO levels ranged from 5.1 mg/L at station 12 to 7.8 mg/L at station 1 (Figure 7-5).

Water temperatures ranged from 21.9 ^{o}C (station 1) to 26.8 ^{o}C (station 12) at the surface and 21.7 ^{o}C (station 1) to 26.1 ^{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 498 to 716 cfs. Net flow in the San Joaquin River near Stockton during August ranged from -310 to 128 cfs (Figure 7-2).

September

Monitoring cruises were conducted on September 2 and 18. Surface DO levels ranged from 5.5 mg/L at station 9 to 9.1 mg/L at stations 12 and 13. Bottom DO levels ranged from 4.7 mg/L at station 12 to 9.2 mg/L at station 13 (Figure 7-6). The DO objective increased to 6 mg/L and 6 stations fell below the objective on September 2, and 4 stations fell below the objective on September 18.

Water temperatures ranged from 22.3 ^{o}C (station 1) to 26.1 ^{o}C (station 12) at the surface and 22.2 ^{o}C (station 1) to 25.6 ^{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 542 to 1,070 cfs. Net flow in the San Joaquin River near Stockton during September ranged from -71 to 852 cfs (Figure 7-2).

October

Monitoring cruises were conducted on October 2 and 16. Surface DO levels ranged from 6.2 mg/L at stations 8 and 9 to 8.4 mg/L at station 1. Bottom DO levels ranged from 6.2 mg/L at station 9 to 8.5 mg/L at station 1 (Figure 7-7).

Water temperatures ranged from 17.5 ^{o}C (stations 1 and 2) to 22.2 ^{o}C (stations 8 and 9) at the surface and 17.4 ^{o}C (station 1) to 22.0 ^{o}C (stations 7 - 9) at the bottom (Figure 7-7).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 1,014 to 2,809 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 523 to 1,450 cfs (Figure 7-2).

November

Monitoring cruises were conducted on November 3 and 18. Surface DO levels ranged from 8.2 mg/L at stations 9 - 11 to 9.6 mg/L at stations 12 and 13. Bottom DO levels ranged from 8.2 mg/L at stations 10 and 11 to 9.6 mg/L at station 13 (Figure 7-8).

Water temperatures ranged from 13.8 ^{o}C (stations 1 - 5) to 16.0 ^{o}C (stations 1 and 3 - 5) at the surface and 13.7 ^{o}C (station 3) to 15.9 ^{o}C (station 7) at the bottom (Figure 7-8).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 1, 268 to 1, 745 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 275 to 754 cfs (Figure 7-2).

Stockton Turning Basin (Station 14)

DO levels at the surface in the Stockton turning basin did not fall below SWRCB objectives during the study period, and bottom DO levels dropped below the SWRCB standards during 6 monitoring cruises from June through September. DO levels in June ranged from 8.2 mg/L at the surface to 5.4 mg/L at the bottom (Figure 7-9). DO levels in July ranged from 12.3 mg/L at the surface to 1.0 mg/L at the bottom. DO levels in August ranged from 8.6 mg/L at the surface to 4.6 mg/L at the bottom. September DO levels at the surface and bottom ranged from 11.7 to 1.7 mg/L, respectively. DO levels in October ranged from 8.0 mg/L at the surface to 6.5 mg/L at the bottom. November DO readings ranged from 11.7 mg/L at the surface to 8.8 mg/L at the bottom (Figure 7-9).

Summary

DO concentrations in the channel fell below the SWRCB's 5.0 mg/L and 6.0 mg/L objectives at 6 stations (excluding the Stockton turning basin) during 5 of 12 monitoring cruises during the study period. The Stockton turning basin was below DO objectives during 6 of 12 monitoring cruises.

Flows on the San Joaquin River near Vernalis ranged from a low of 498 cfs in August to a high of 2,809 cfs in October. Net daily flow on the San Joaquin River past Stockton ranged from a low of -385 cfs in July to a high of 1,450 cfs in October. The head of Old River barrier was not installed during this sampling season.

Further monitoring operations for the summer and fall 2009 special study were suspended after November 18, 2009.

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

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Chapter 7 Appendix

Figure 7-1 Monitoring sites in the channel

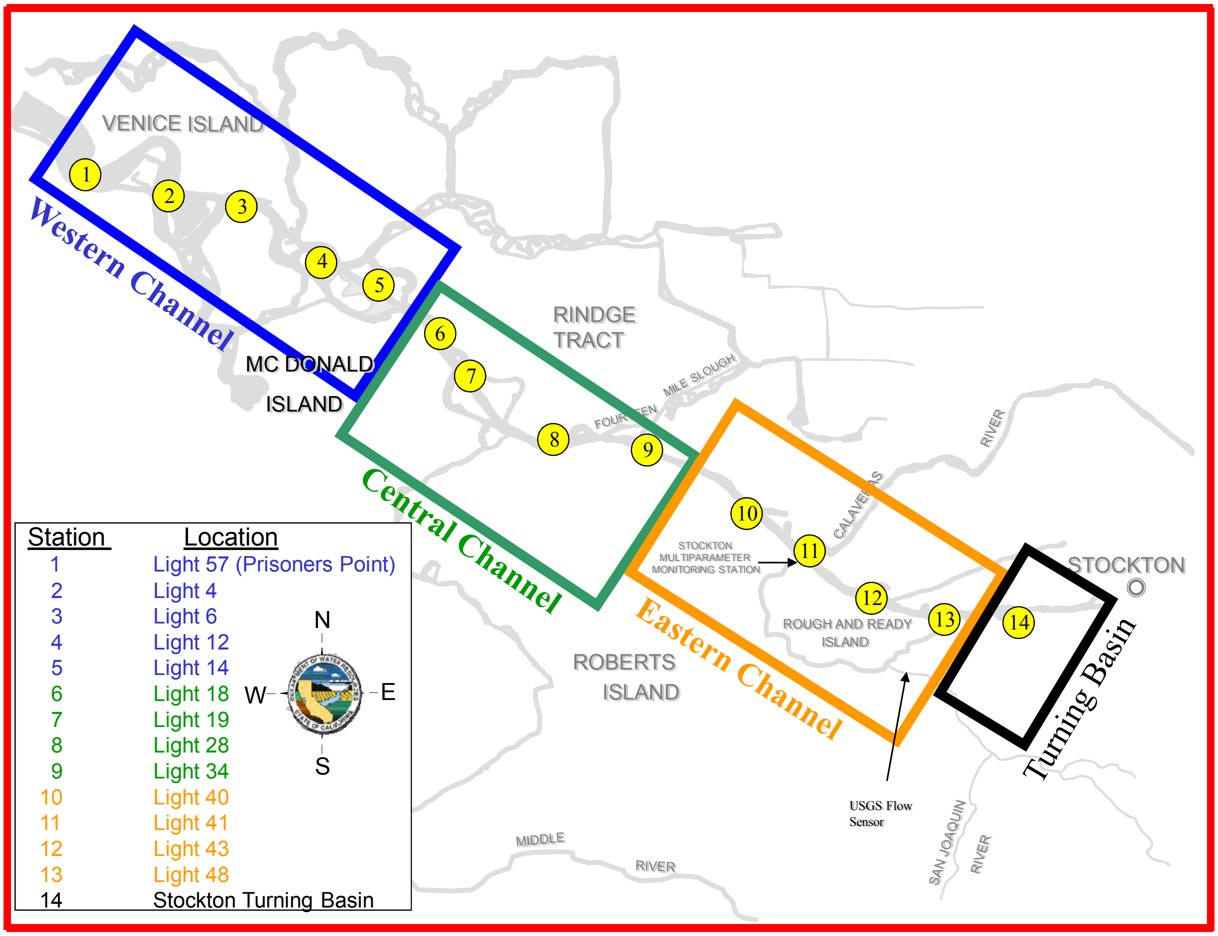


Figure 7-2 San Joaquin River's mean daily flow during summer/fall 2009

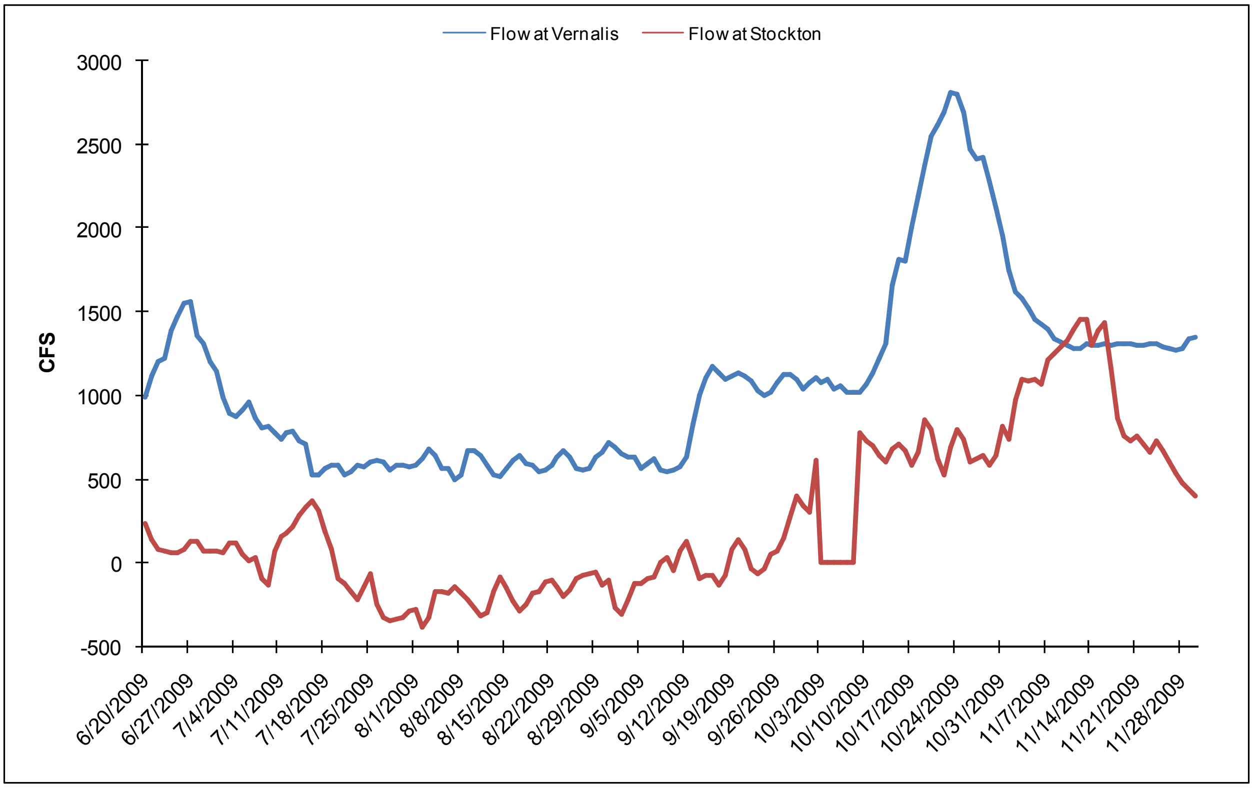
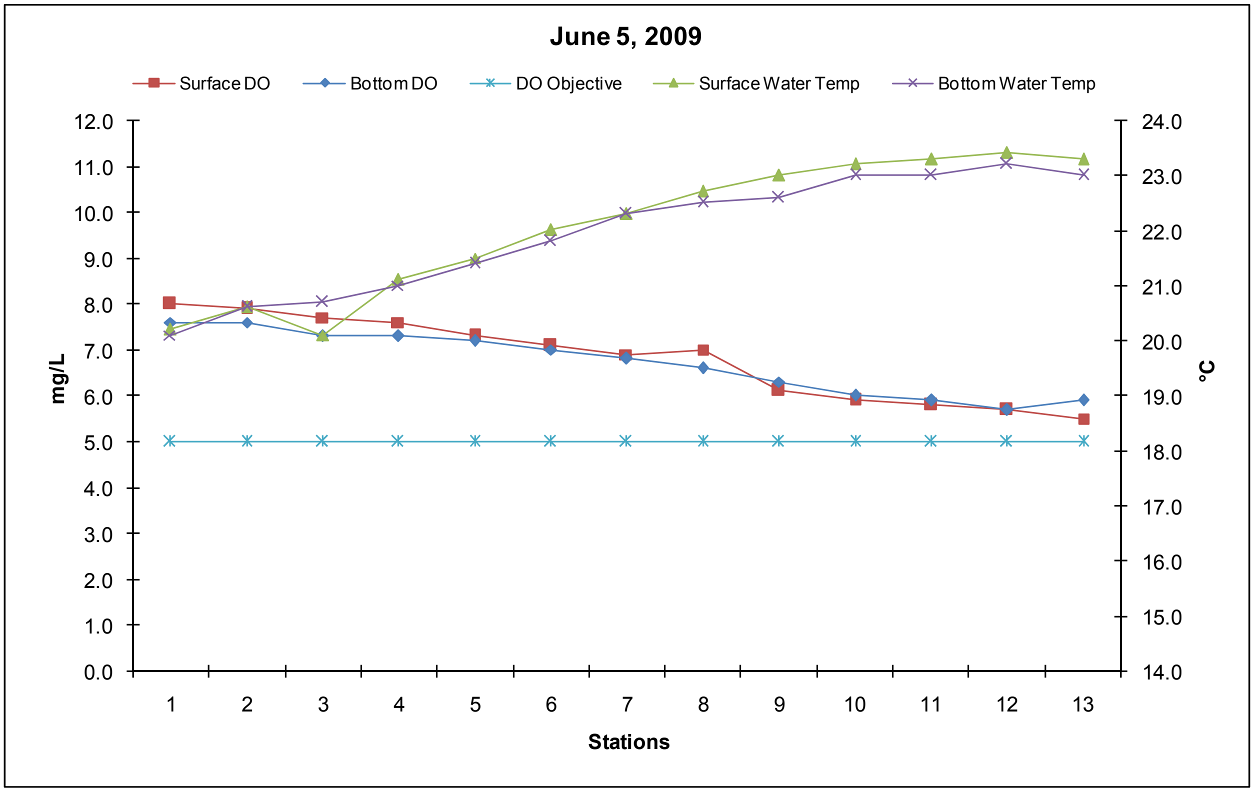


Figure 7-3 Surface and bottom DO and water temperature values in the channel, June 2009



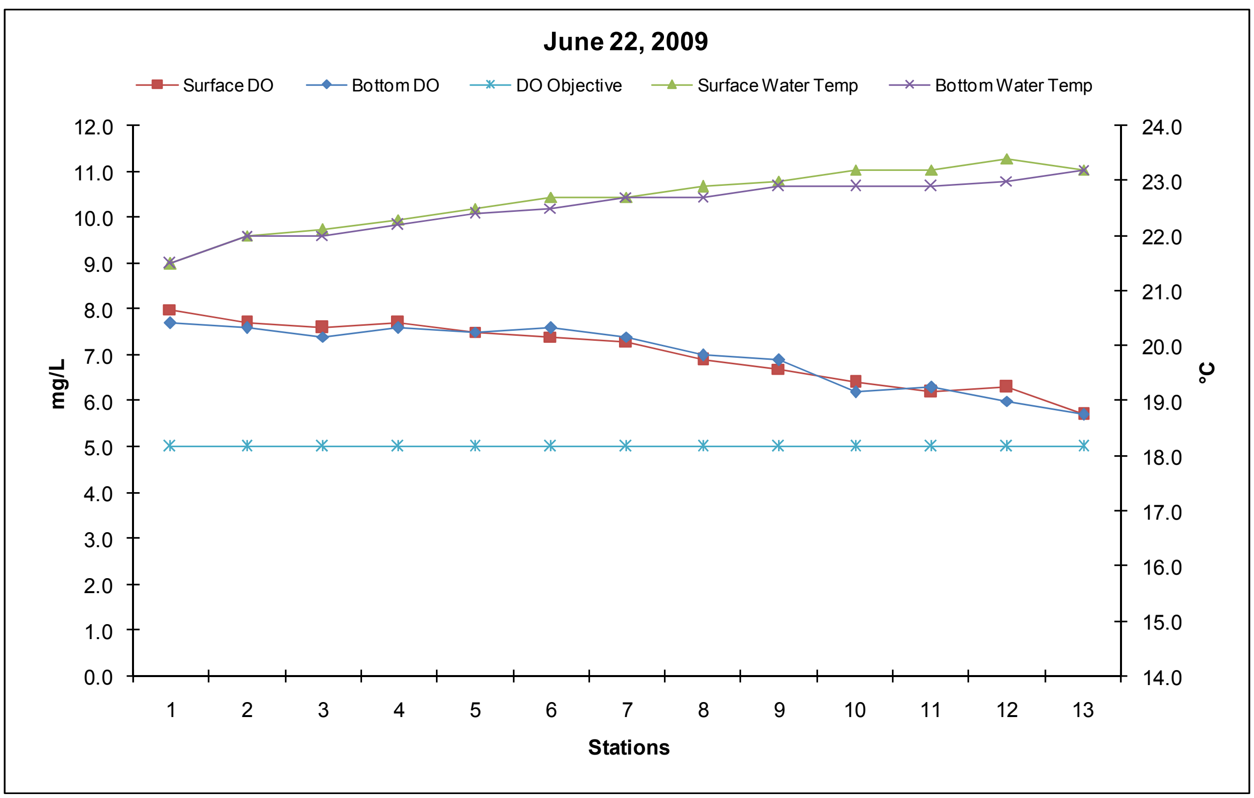
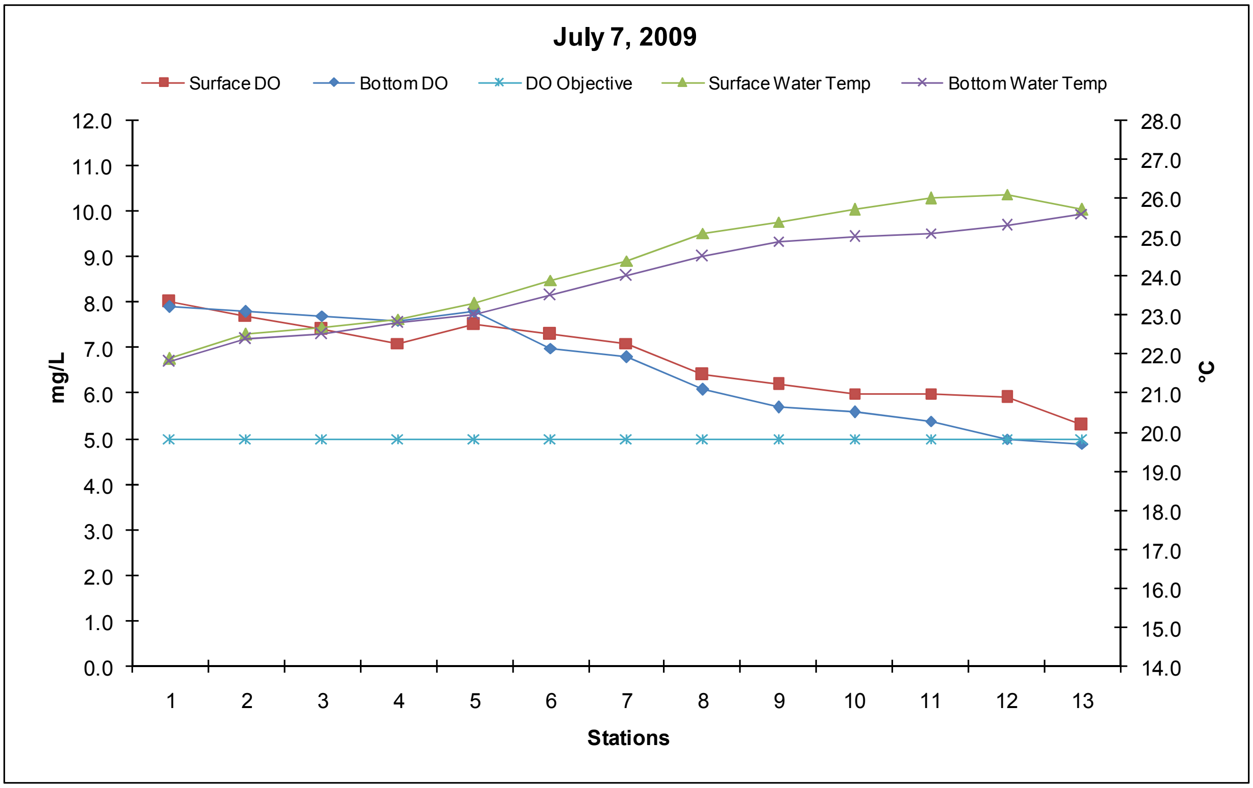


Figure 7-4 Surface and bottom DO and water temperature values in the channel, July 2009



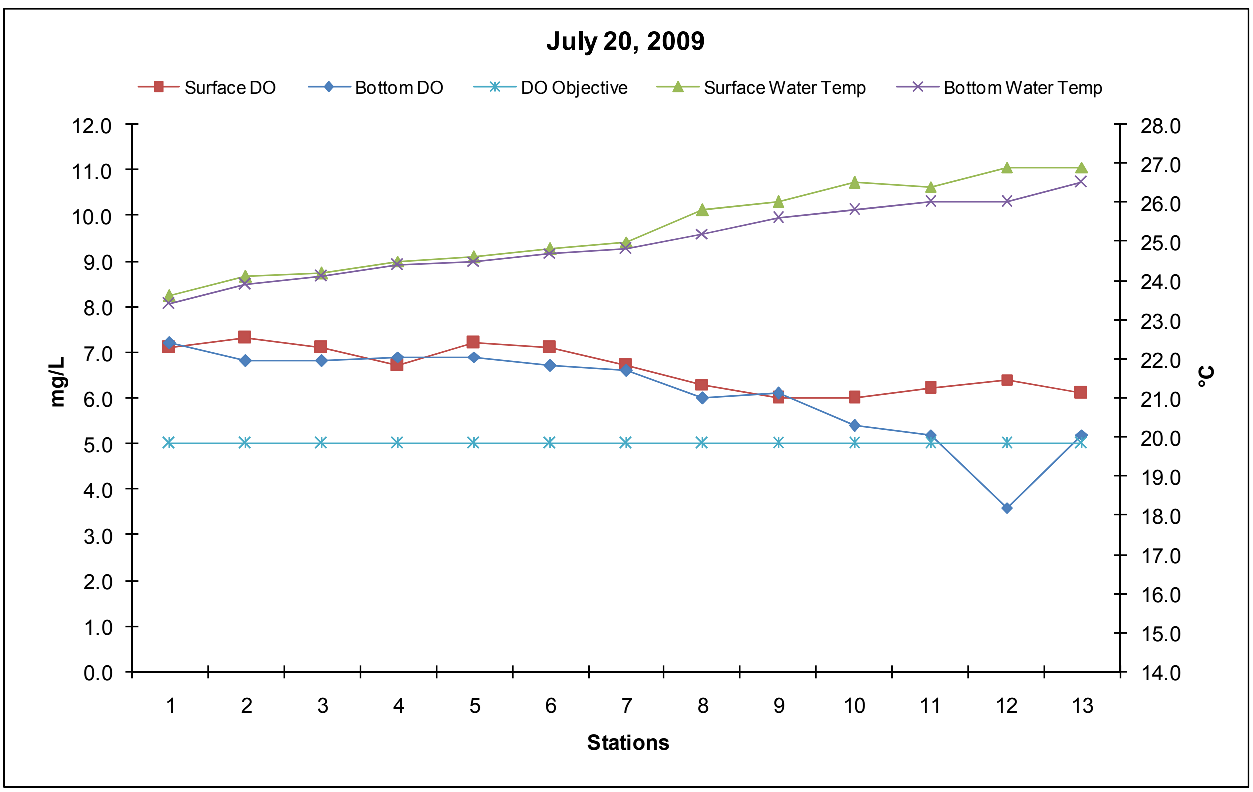
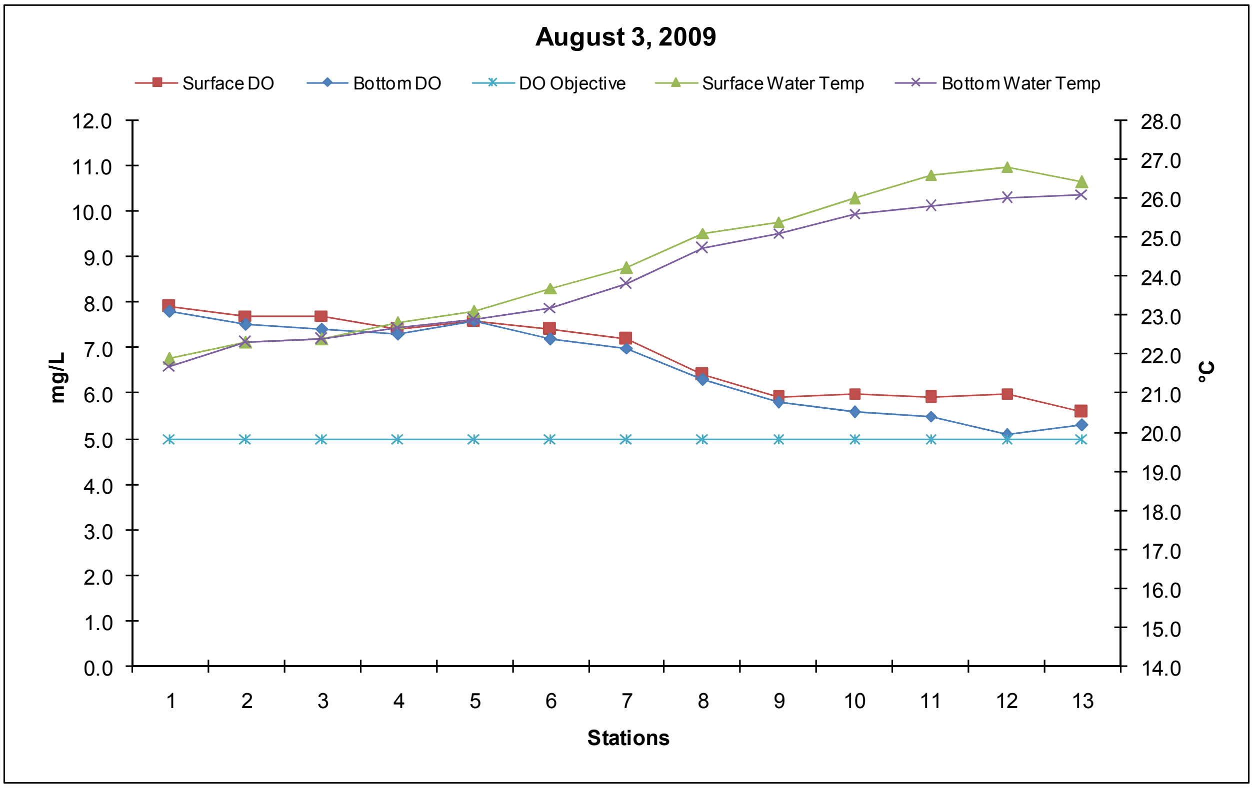


Figure 7-5 Surface and bottom DO and water temperature values in the channel, August 2009



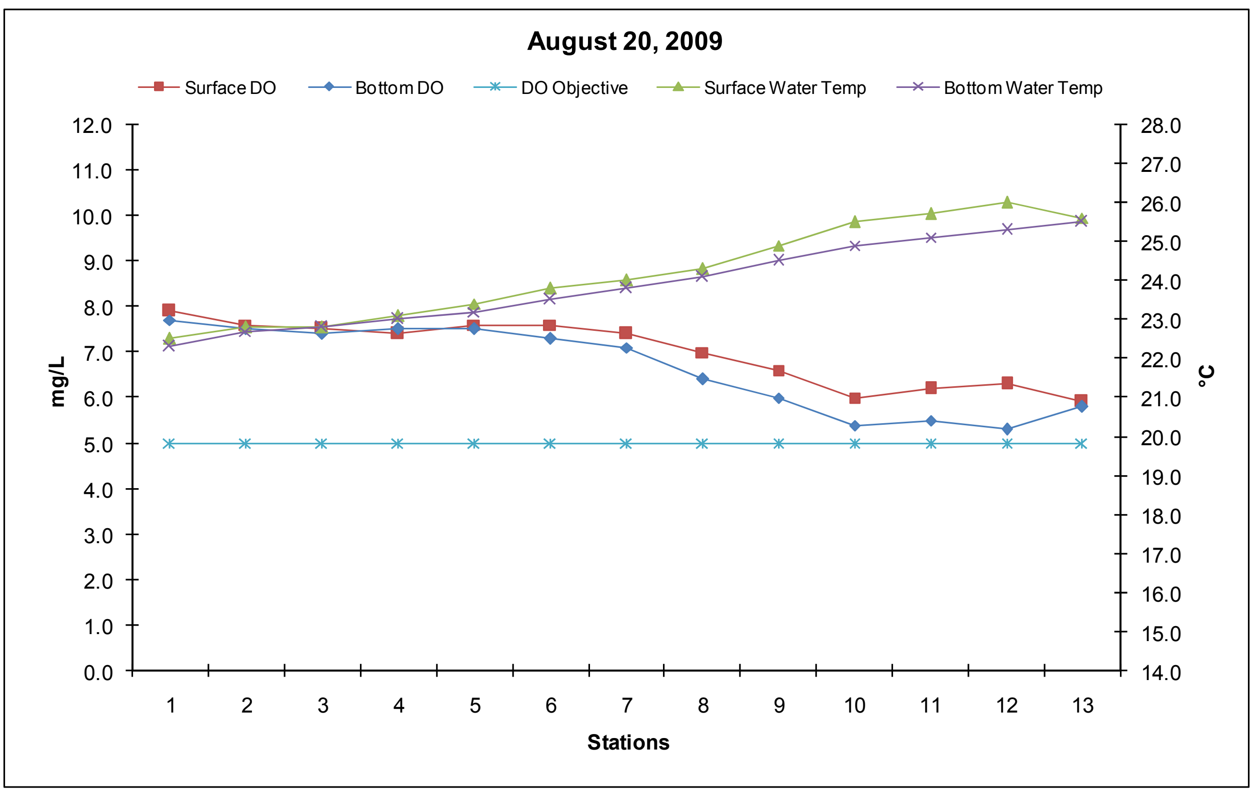
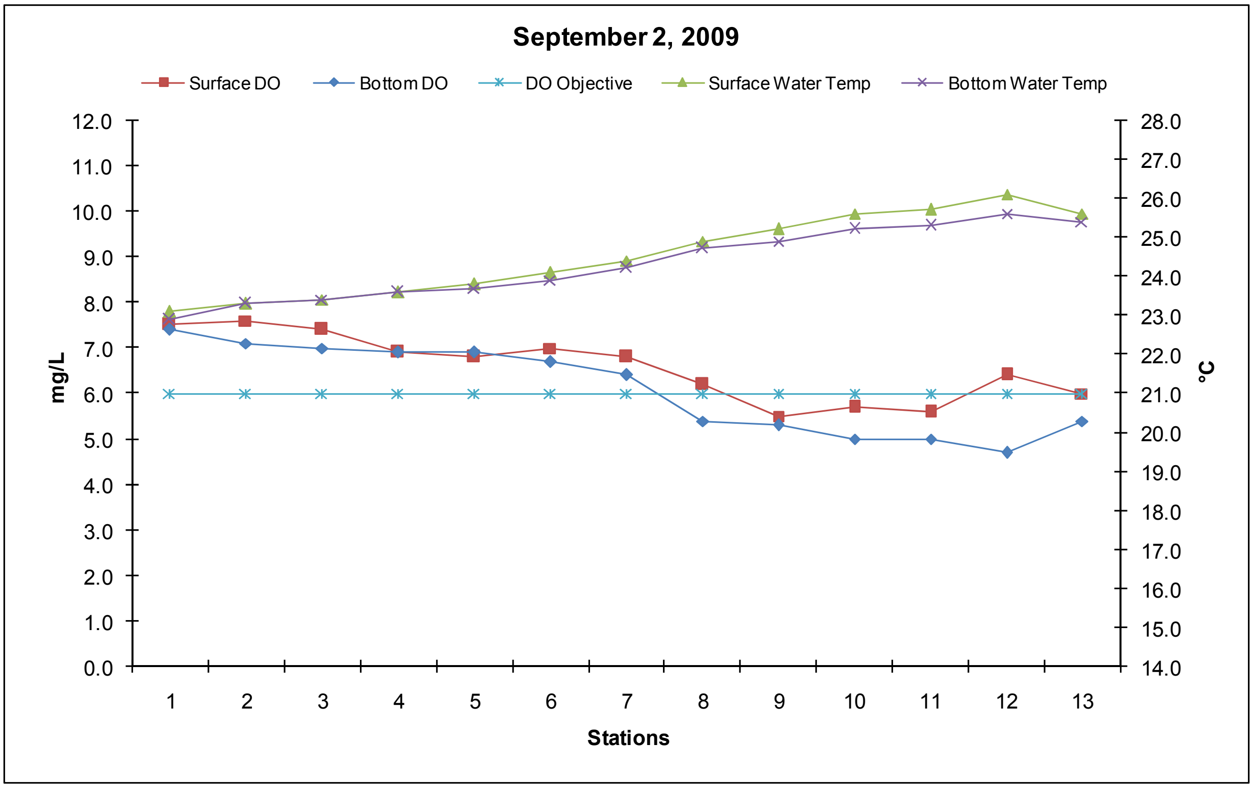


Figure 7-6 Surface and bottom DO and water temperature values in the channel, September 2009



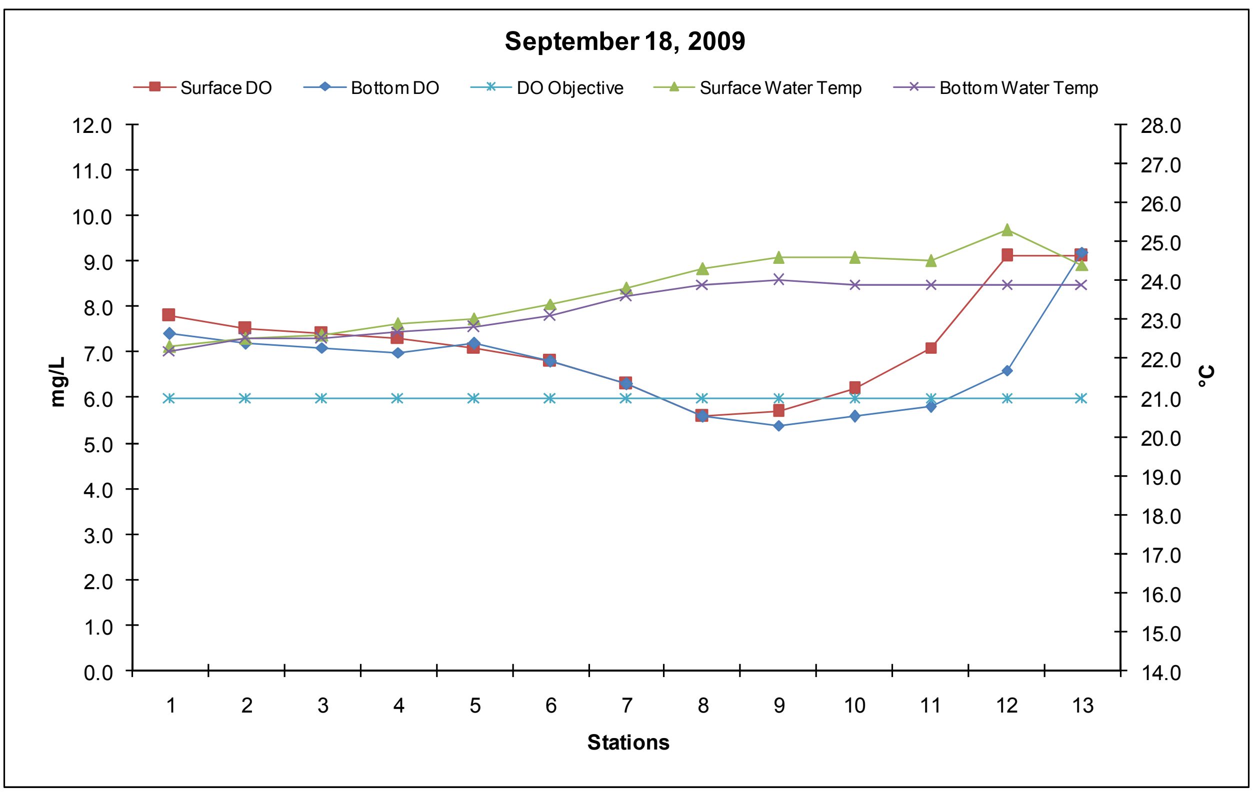
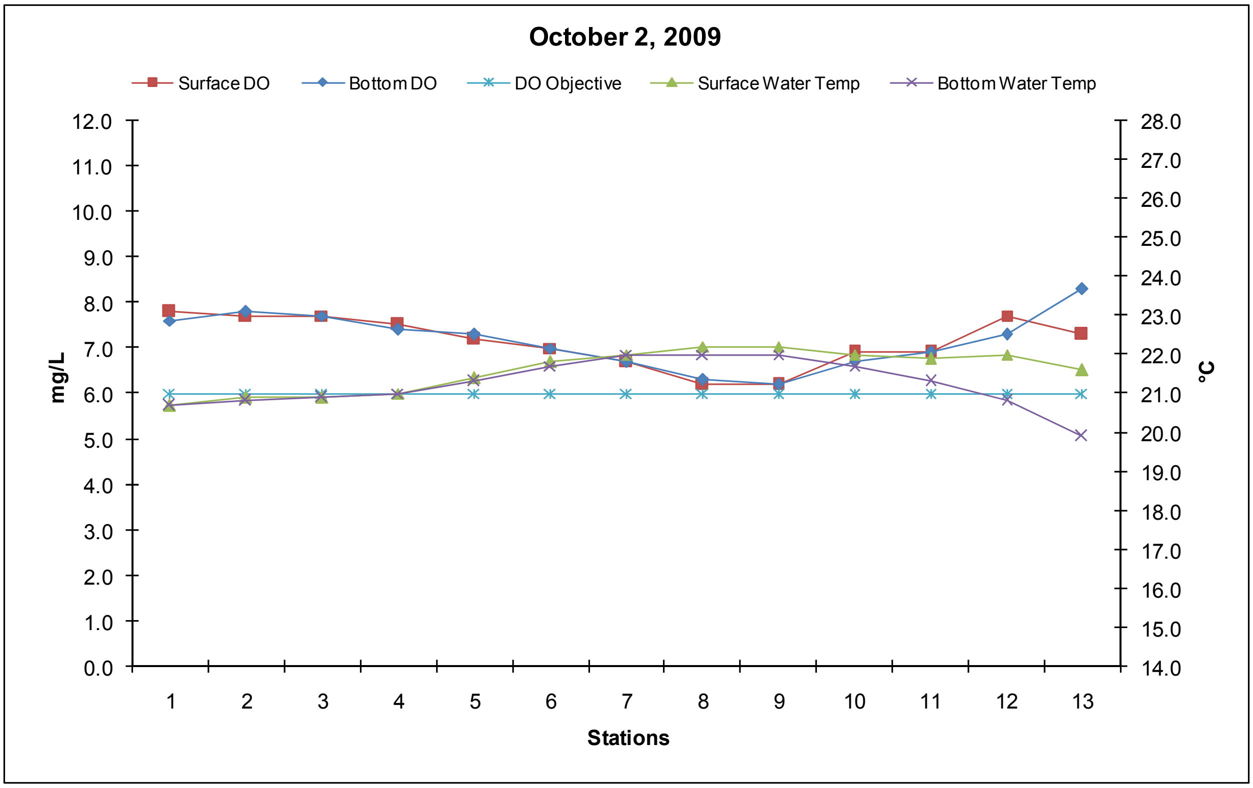


Figure 7-7 Surface and bottom DO and water temperature values in the channel, October 2009



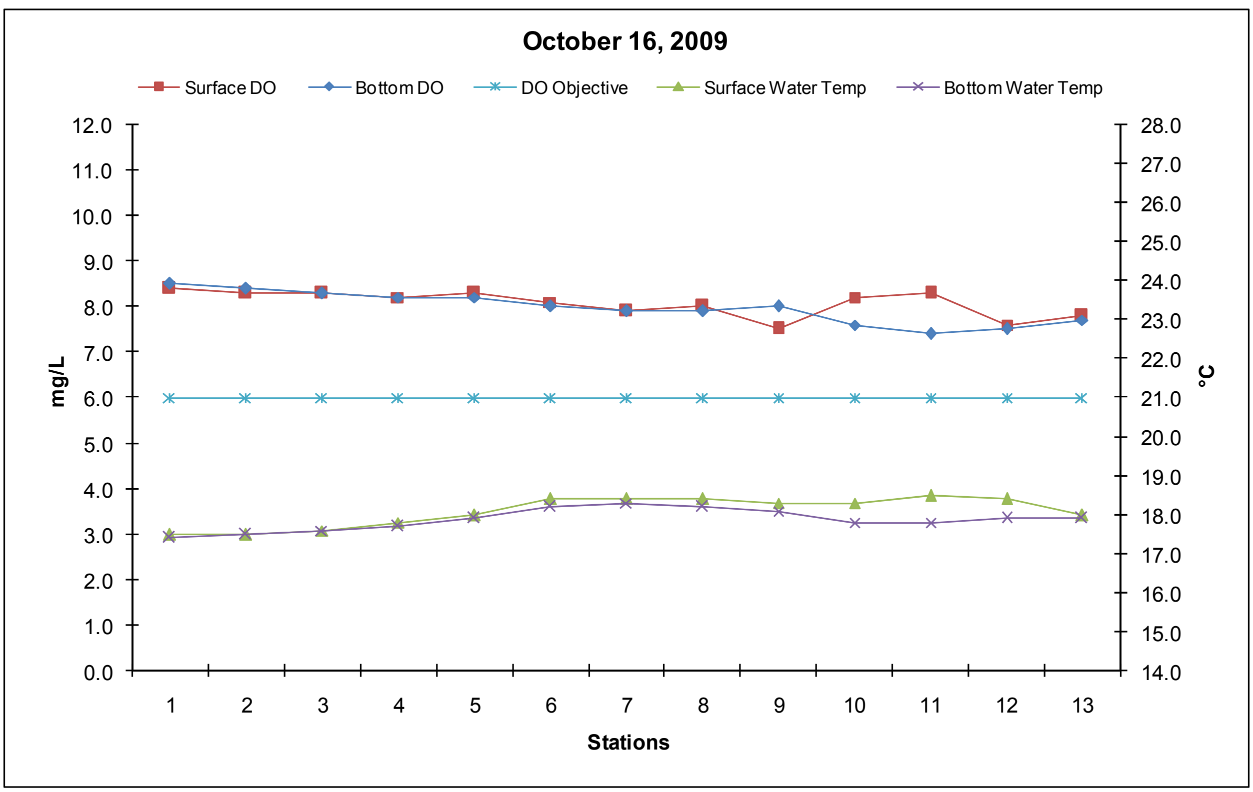
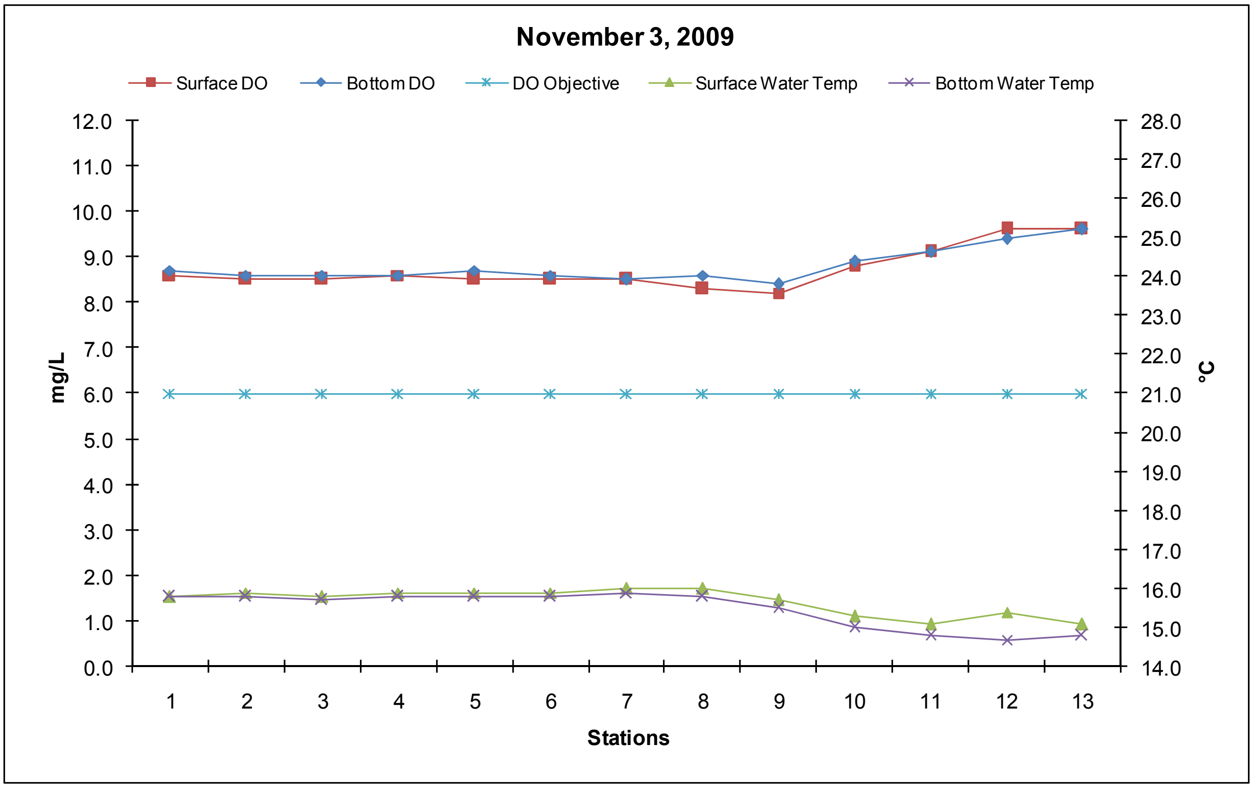


Figure 7-8 Surface and bottom DO and water temperature values in the channel, November 2009



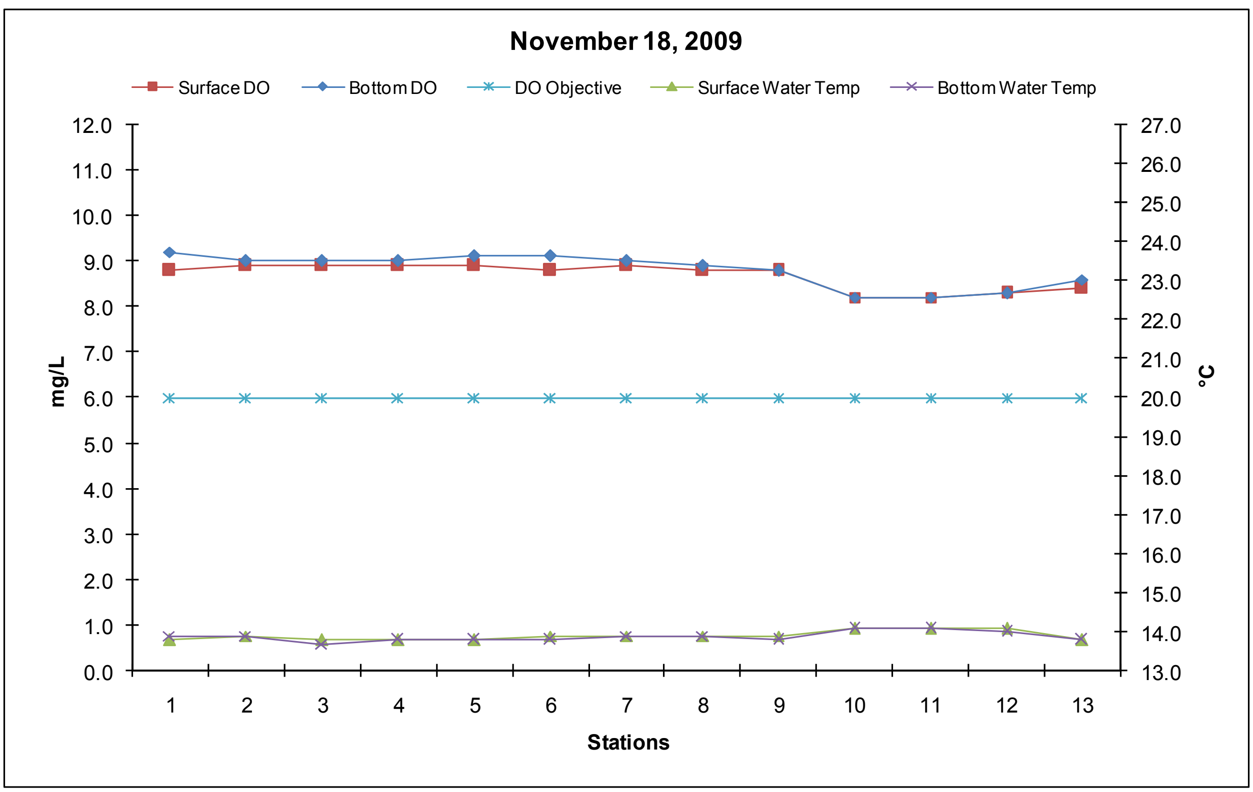
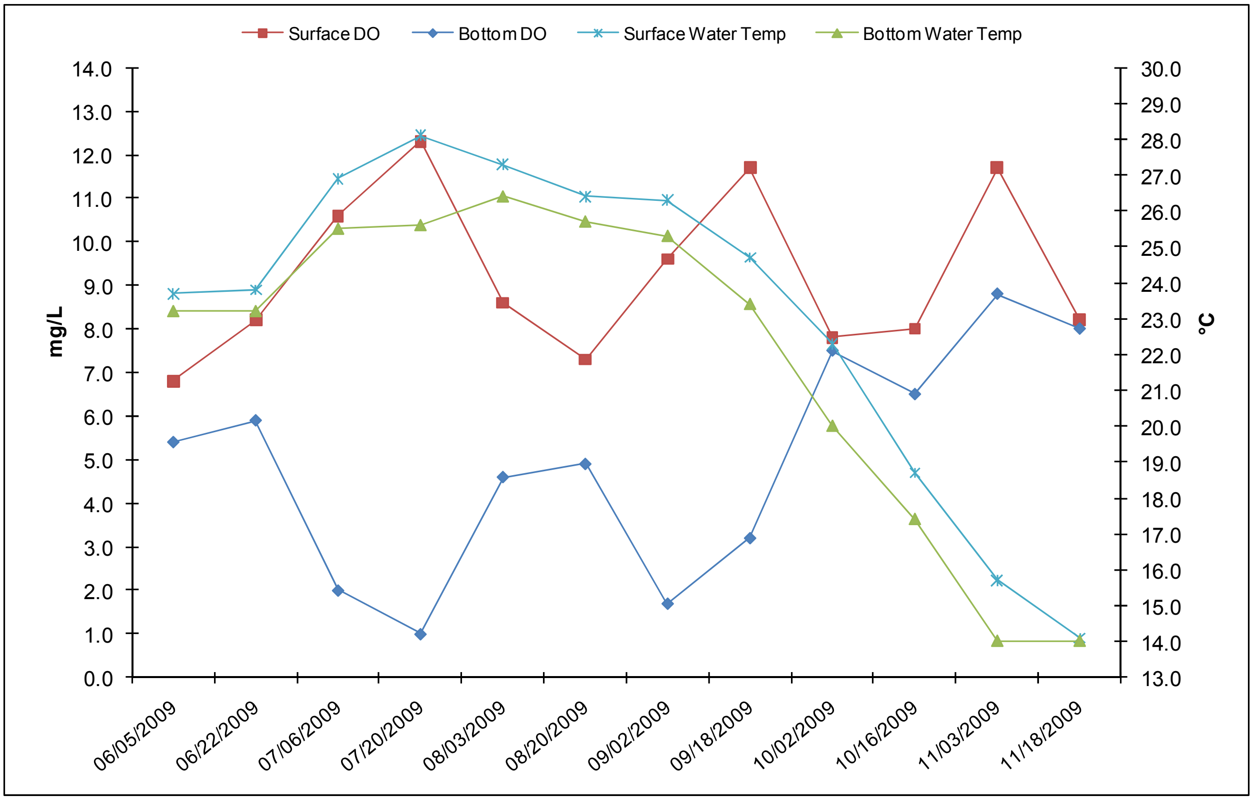


Figure 7-9 Surface and bottom DO and water temperature values in the Stockton turning basin from June through November 2009



Chapter 8 Continuous Monitoring

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Chapter 8 Continuous Monitoring

Introduction

The continuous monitoring program supplements the monthly discrete compliance monitoring program by providing real-time hourly and quarter-hourly water quality and environmental data from 9 shore-based automated sampling stations in the estuary (Figure 8-1). These stations provide continuous measurements of 7 water quality parameters and 4 environmental parameters. These measurements are used by operators of the SWP and the CVP 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 9 sites for calendar year 2009. The stations were divided into 3 regions to allow for detail in the plots:

Sacramento River stations:	C3A (Hood) and D24A (Rio Vista)
San Joaquin River stations:	C7A (Mossdale), D29 (Prisoner's Point), C10A (Vernalis), and P8A (Stockton)
Tidally influenced stations:	D11 (Antioch), D10A (Mallard Island), and D6A (Martinez)

Methods

Continuous data are collected for the water quality and environmental parameters shown in Table 8-1. Each of the 9 monitoring stations collects continuous data for water temperature, pH, DO, surface SC, chlorophyll *a* fluorescence, and turbidity. Additional sensors are installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom SC, 1.5 m 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 the Mossdale (only air temperature), Prisoners Point, Vernalis, and Hood stations (none) as part of D-1641's Table 3 objectives (SWRCB, 1999).

Except for bottom SC, all water samples are collected at 1 m 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.

Results

The monthly averages of the continuous 15-minute data collected for air and water temperature, pH, DO, surface and bottom SC, chlorophyll *a* fluorescence, and turbidity for calendar year 2009 are shown in Figures 8-2 to 8-10.

Water Temperature

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

Average monthly water temperatures in the estuary ranged from 8.6 °C in January 2009 at the Prisoners Point station on the San Joaquin River to 26.1 °C in July 2009 at the Stockton station on the San Joaquin River (Figure 8-2). Maximum water temperature values are similar to the same time period in 2008.

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.

DO

DO was measured using a YSI 6600 multi-parameter water quality sonde utilizing the optical DO sensor. Average monthly DO values for the 9 monitoring stations ranged from 5.7 mg/L to 13.1 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 5.7 mg/L was calculated for the Stockton station in June and July 2009, and a value of 12.8 mg/L was calculated for the Mossdale station for June 2009. 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 July 2009. The Hood station showed a significant decrease in the measured values from May to June 2009 and not recovering until October 2009. All compliance monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the CVRWQCB in the *Basin Plan* (CVRWQCB, 1998). Compared to a 10 unit swing in 2008, monthly average DO values at the Stockton station were more consistent from month to month showing a 5 unit swing from high to low values of 5.7 mg/L to 10.5 mg/L. The Stockton station, located in ship channel, showed a DO sag to 5.7 mg/L in June 2009, which was similar to 2008. The operation of the aeration facility located near the Stockton station had not been operated from September 2008 until testing in September of 2009. The monthly average DO values remained above the baseline objective established by the CVRWQCB for all periods. The San Joaquin River stations at Mossdale and Vernalis showed a significant rise in DO from June to August 2009. The pattern of the winter sag, first identified in 2000, was not evident in 2009.

During summer and fall 2009, monthly average DO values at the Mossdale and Vernalis stations showed a familiar pattern of increase for June and August. Monthly average DO values in previous years showed a similar pattern from June to September. The DO increase to 13.1 mg/L at the Mossdale station in 2009 was later than the 2008 increase which occurred in June. The high average summer DO levels seen at the Mossdale and Vernalis stations coincided with high chlorophyll *a* fluorescence during the same period (Figure 8-9a).

SC

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

Monthly average surface SC for the estuary ranged from 115 μS/cm to 27,209 μS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 8-4a). The 2009 data is very similar to the 2008 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 SC 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 8-4b).

The Vernalis, Mossdale, and Stockton stations showed a significant decrease in SC values in May 2009 after the April VAMP pulse.

Bottom SC measured at the Antioch, Mallard Island, and Martinez stations exhibited seasonal patterns and ranges similar to the surface SC (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 7.1 to 9.3 (Figure 8-6). In 2009, the Mossdale and Vernalis stations showed a significant increase in pH values from April through June. This differs from 2008, where the stations on the San Joaquin River showed a decrease during the April through June time frame. The Stockton station showed a slight decrease in pH starting in May 2009 and continued through August 2009.

Air Temperature

Air temperature was measured using a MET-1 Instruments Mod. 062 sensor. No data was collected for the months of February, March, and April of 2009 due to data logger program issues.

Monthly average air temperatures in the estuary ranged from 7.1 °C in December 2009 at the Rio Vista station on the Sacramento River to 25.2 °C in August 2009 at the Mossdale station on the San Joaquin River (Figure 8-7). The maxima monthly average air temperatures for 2009 were the same as the 2008 values and the minima value was 1°C higher than in 2008.

Chlorophyll *a* Fluorescence

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

Monthly average chlorophyll *a* fluorescence recorded at the stations in the estuary ranged from a minima of 1.16 FU in November 2009 at the Rio Vista station on the Sacramento River to a maxima of 52.2 FU in July 2009 at the Mossdale station on the San Joaquin River (Figure 8-9, a-d).

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 a minima of 2 NTU at the Hood station on the Sacramento River in October 2009 to a maxima of 47 NTU at the Antioch station on the San Joaquin River in February 2009 (Figure 8-10, a-d).

DO at Stockton Station P8a

As part of DWR's mandate to monitor water quality in the Delta, a special monitoring study is focused on 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.

Monthly average DO values in 2009 ranged from 5.7 to 10.5 mg/L. The lowest DO value occurred in May 2009 at the Stockton station on the San Joaquin River, while the highest value occurred in January 2009.

Monthly average DO values did not drop below the state-mandated standards of 5.0 mg/L for 2009 at the Stockton station on the San Joaquin River in the channel. The quarter hourly values for the Stockton station ranged from 4.7 mg/L to 12.4 mg/L. The minimum value of 4.7 mg/L was recorded in May 2009, with the maximum value recorded in January 2009. As seen in previous years, the DO levels drop during the summer months of May and June and recovered by September. DWR's oxygen aeration station did not operate during 2009, with only minimal testing occurring in September 2009. The pattern of falling DO levels in the winter, first observed in 2000, was not observed in 2009 and remained above the 5.0 mg/L standard.

For 2009, average monthly DO values at the Stockton station did not drop below the standard 6.0 mg/L from September through November 2009 (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 estuary for calendar year 2009 were in the expected range of values for water temperature, DO, SC, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. The exceptions continue to be found on the San Joaquin River.

The upper San Joaquin River stations at Mossdale and Vernalis showed higher chlorophyll *a* fluorescence values in July than any other station in the estuary. The San Joaquin station at Mossdale showed higher DO values in July and August than any other station in the estuary with the Stockton station showing the lowest values for DO in June and July. As in 2008, 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 by the end of the year.

The San Joaquin River station at Stockton did not fall below the 5.0 mg/L standard, which was set by the CVRWQCB (1998). The DO levels did not drop below the 6.0 mg/L standard (SWRCB, 1995) for the passage of fall-run Chinook salmon through the ship channel for September through November 2009 control period.

References

[CVRWQCB] Central Valley Regional Water Quality Control Board. (1998). *Water Quality Control Plan for the California Regional Water Quality Control Board Central Valley Region, the Sacramento River Basin, and San Joaquin River Basin* [*Basin Plan*] (4th ed.).

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

[SWRCB] State Water Resources Control Board. (1999). *Water Rights Decision 1641 for the Sacramento-San Joaquin Delta and Suisun Marsh* (Adopted December 29, 1999, Revised in Accordance with order WR2000-02 March 15, 2000). Sacramento, CA.

Chapter 8 Appendix

Figure 8-1 Location of 9 shore-based automated sampling stations in the estuary

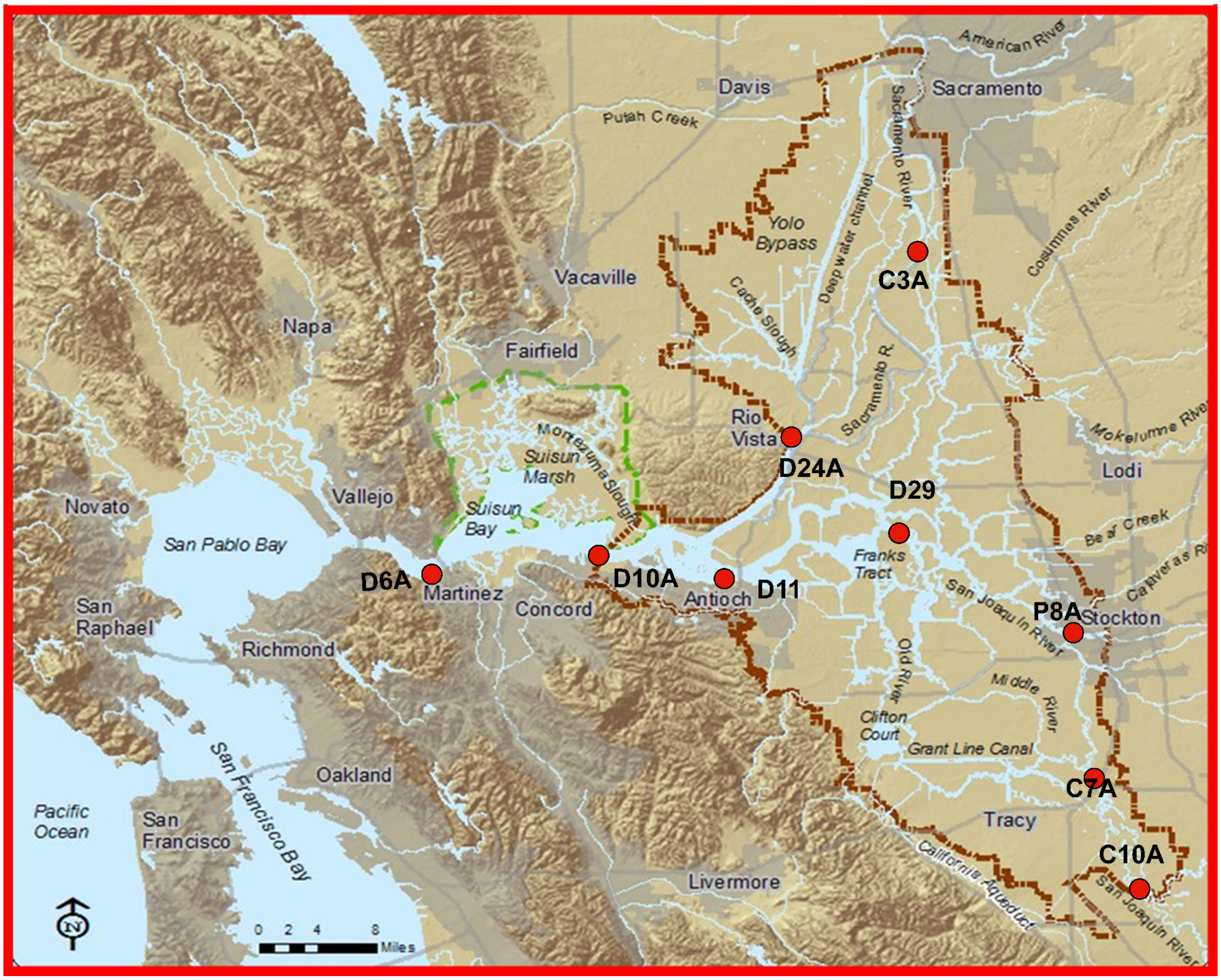


Figure 8-2 Average monthly water temperature at 9 stations, 2009

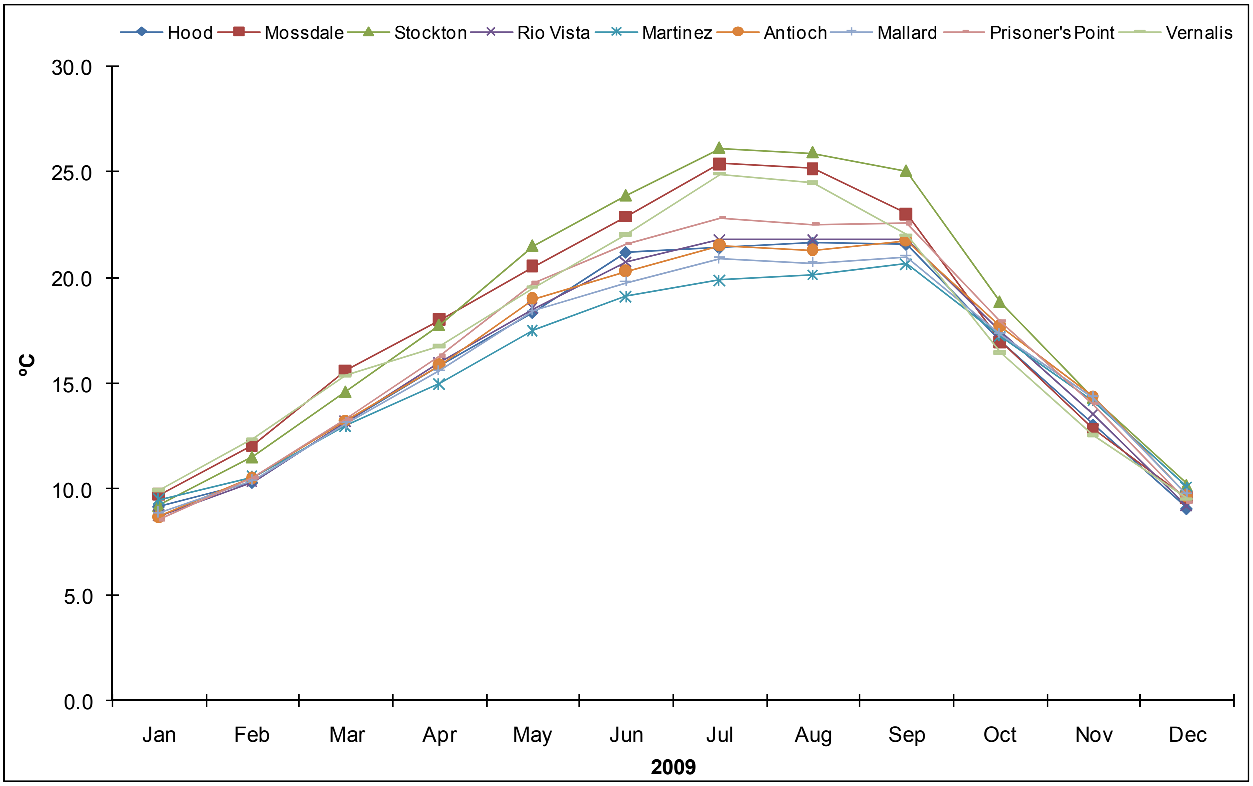


Figure 8-3 Average monthly DO at 9 stations, 2009

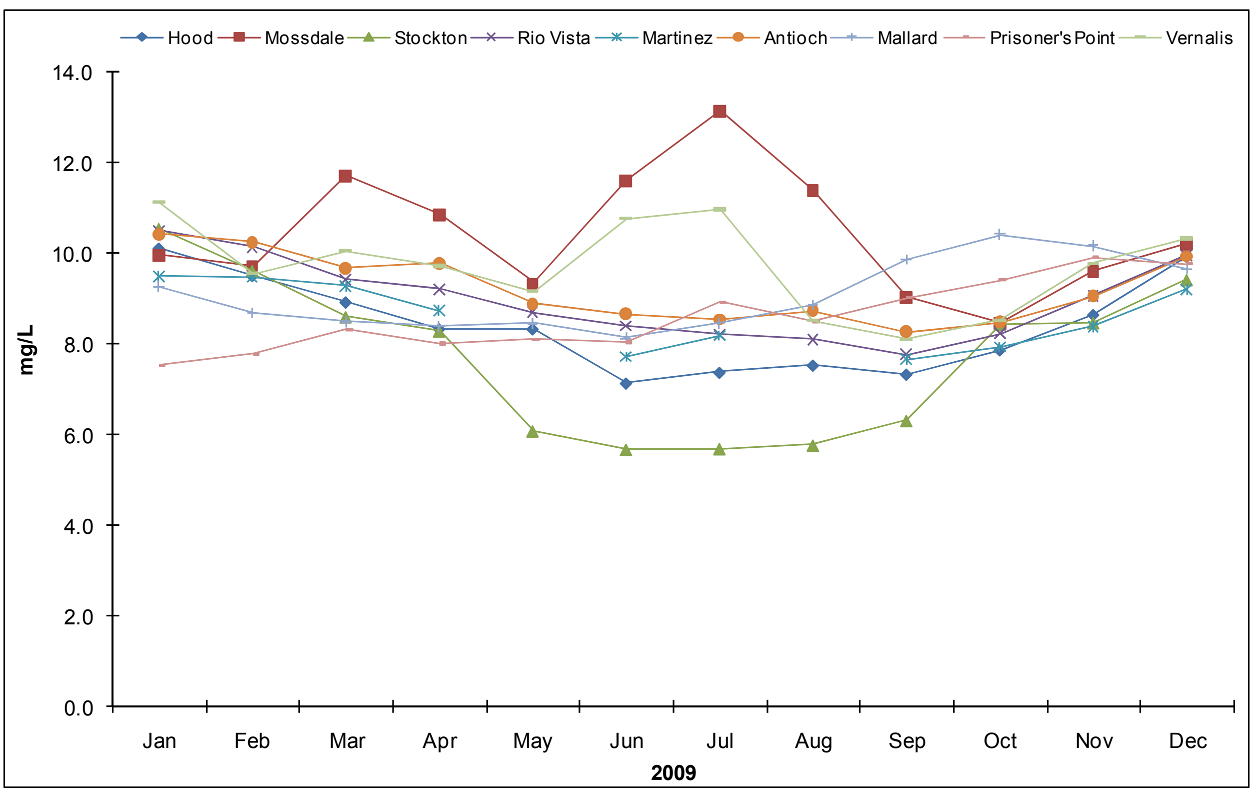


Figure 8-4a Average monthly SC at 9 Stations, 2009

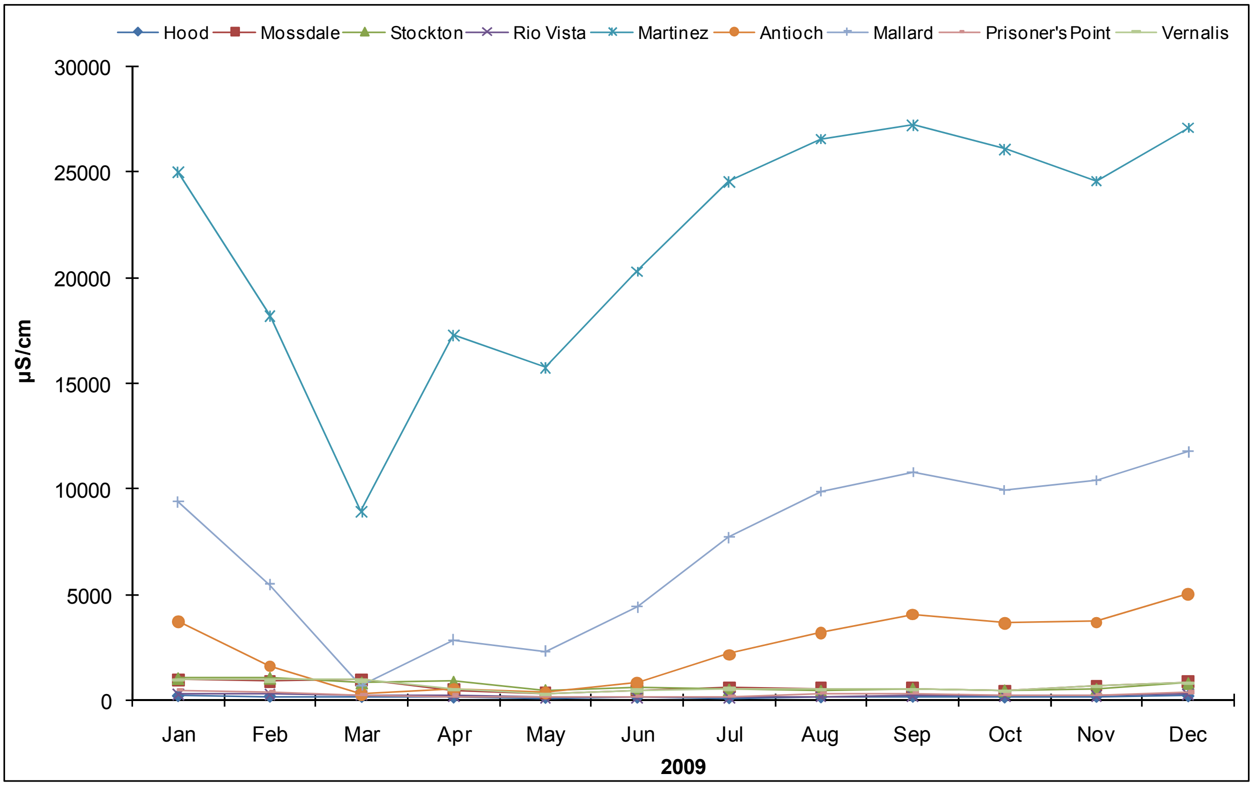


Figure 8-4b Average monthly SC at 6 stations, 2009

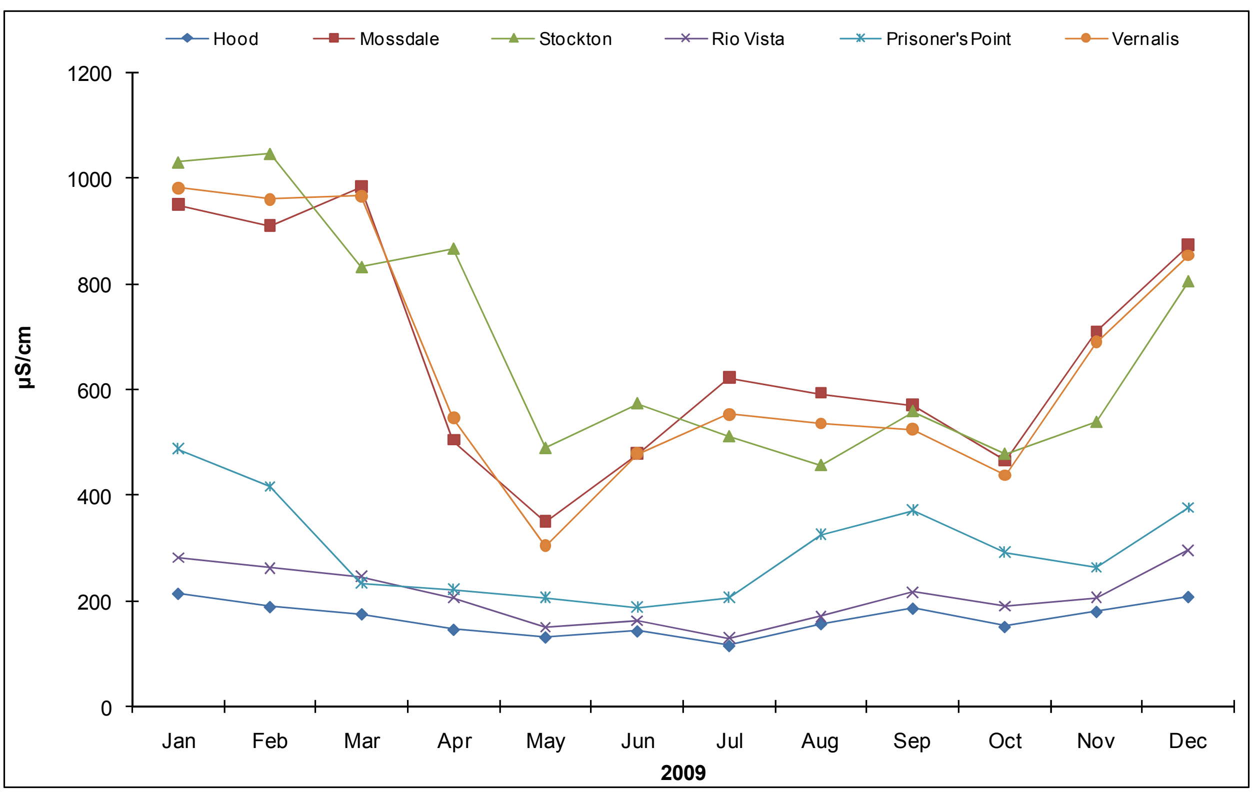


Figure 8-5 Average monthly surface and bottom SC at 3 tidally influenced stations, 2009

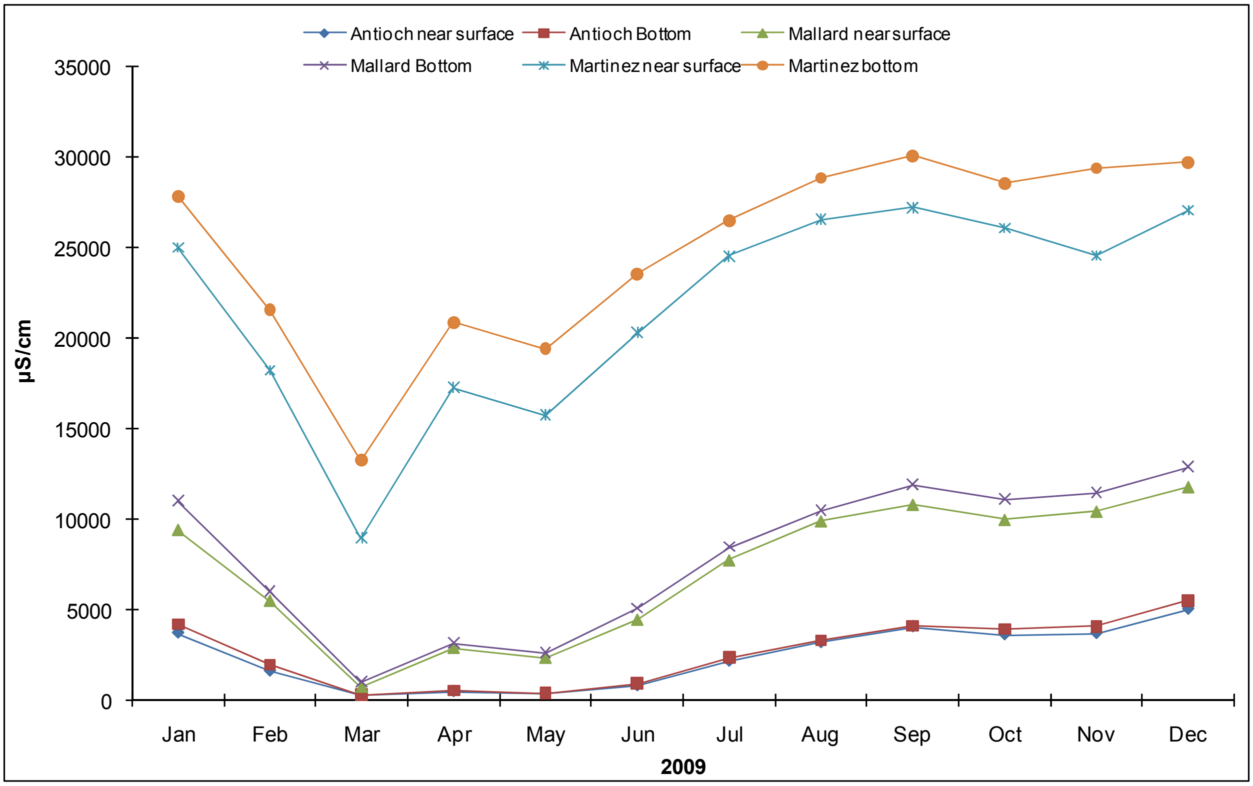


Figure 8-6 Average monthly pH at 9 stations, 2009

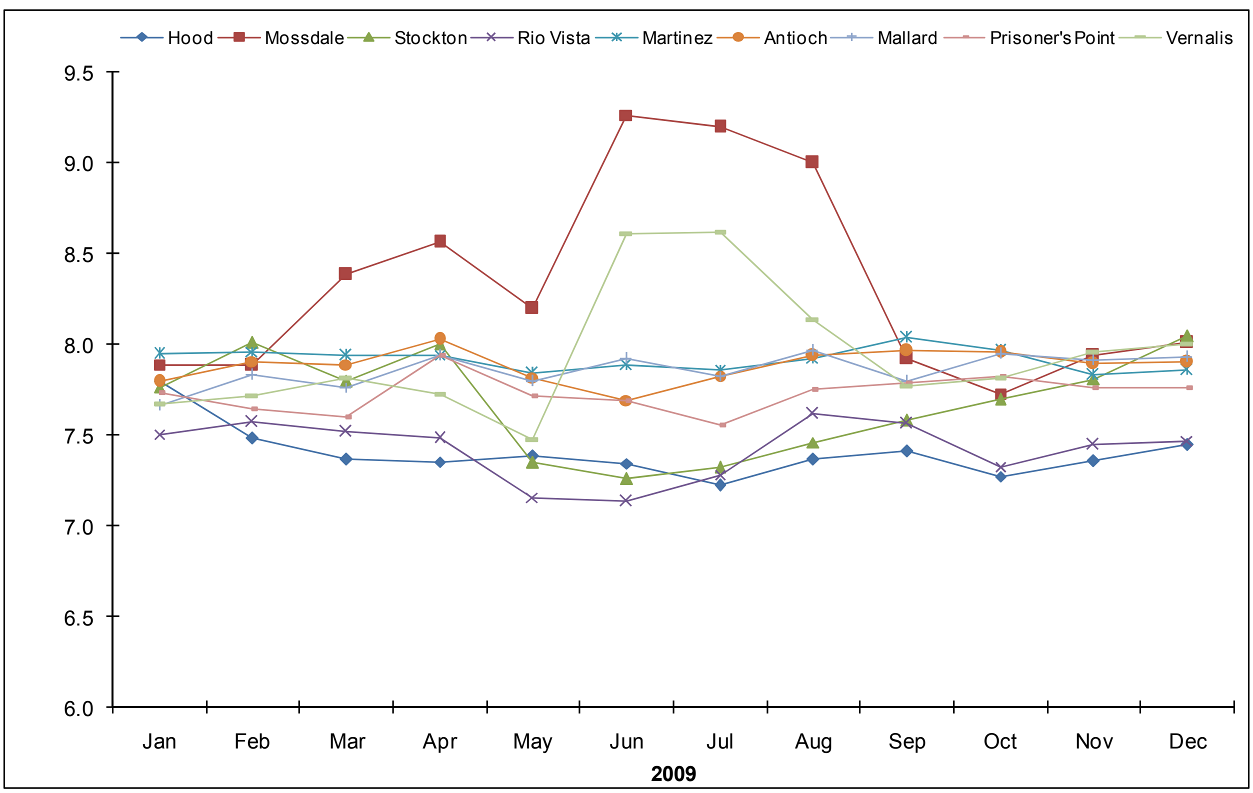


Figure 8-7 Monthly average air temperature at 6 stations, 2009

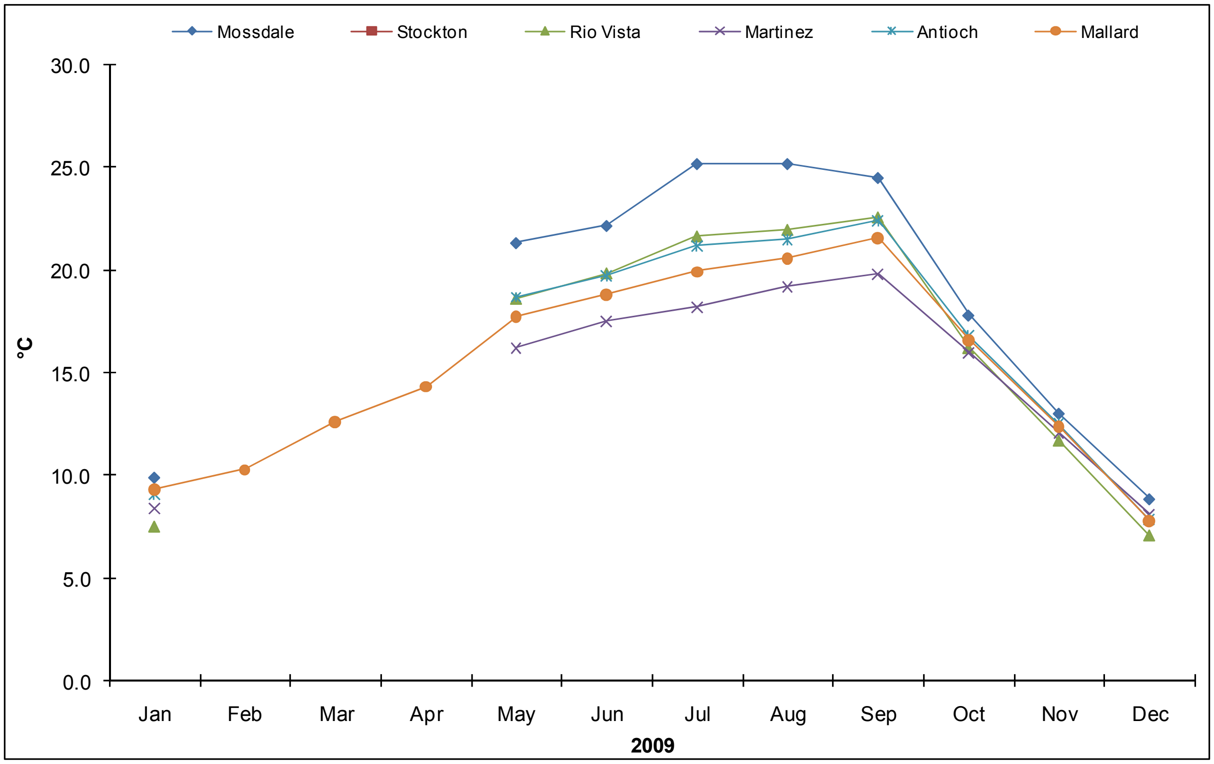
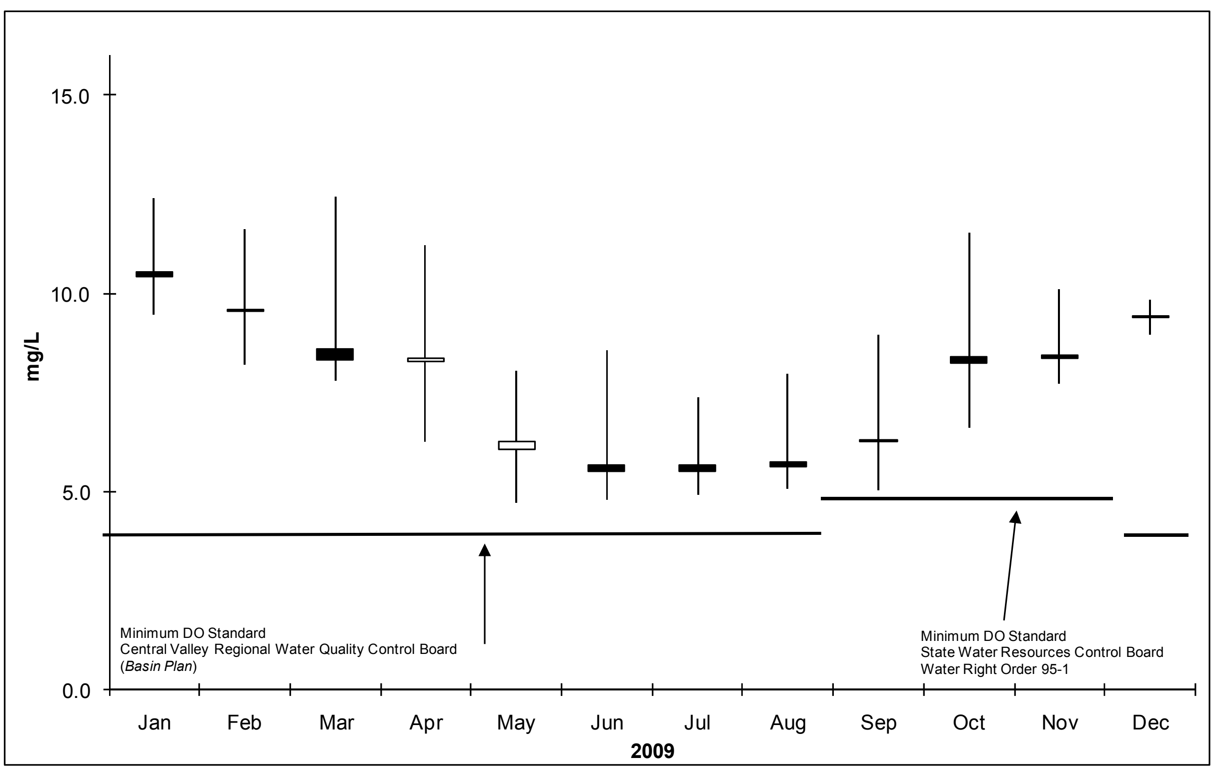


Figure 8-8 Range of monthly DO values at the San Joaquin River @ Rough and Ready Island, 2009



Note: Solid boxes when monthly average higher than monthly median.

Figure 8-9a Average monthly chlorophyll *a* fluorescence at 9 stations, 2009

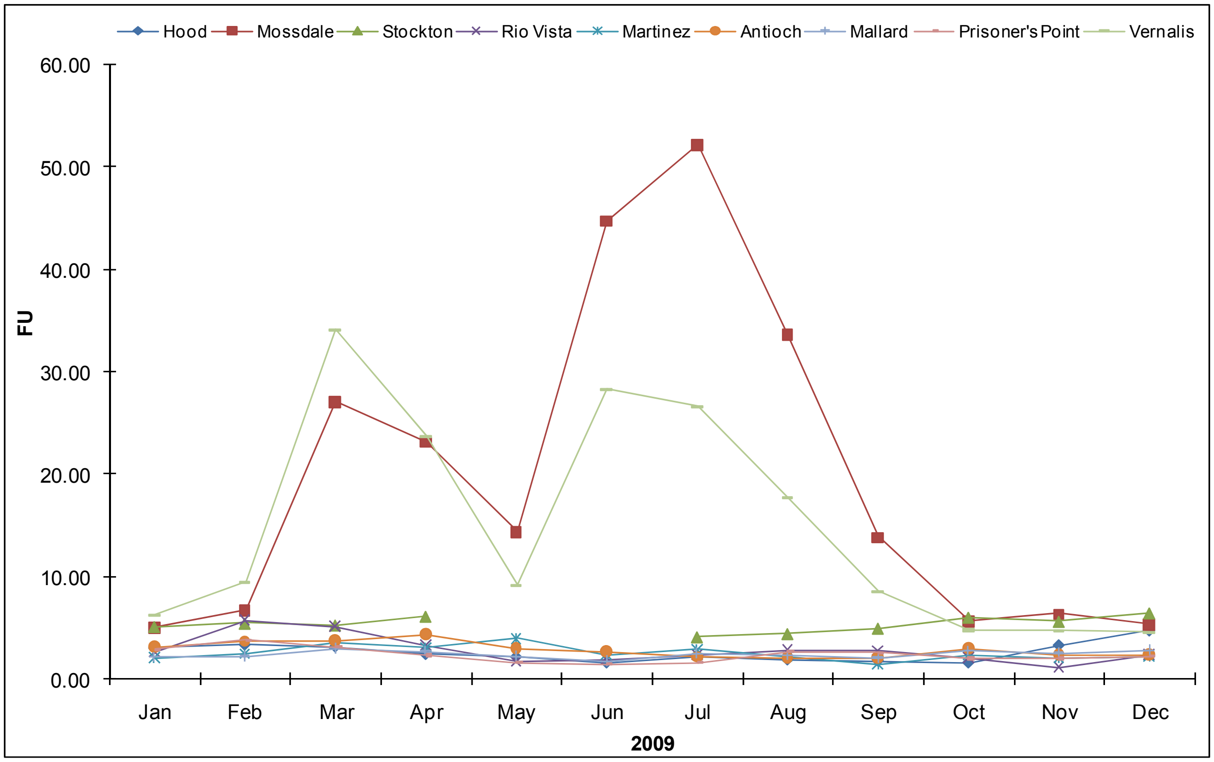


Figure 8-9b Average monthly chlorophyll *a* fluorescence at 2 Sacramento River stations, 2009

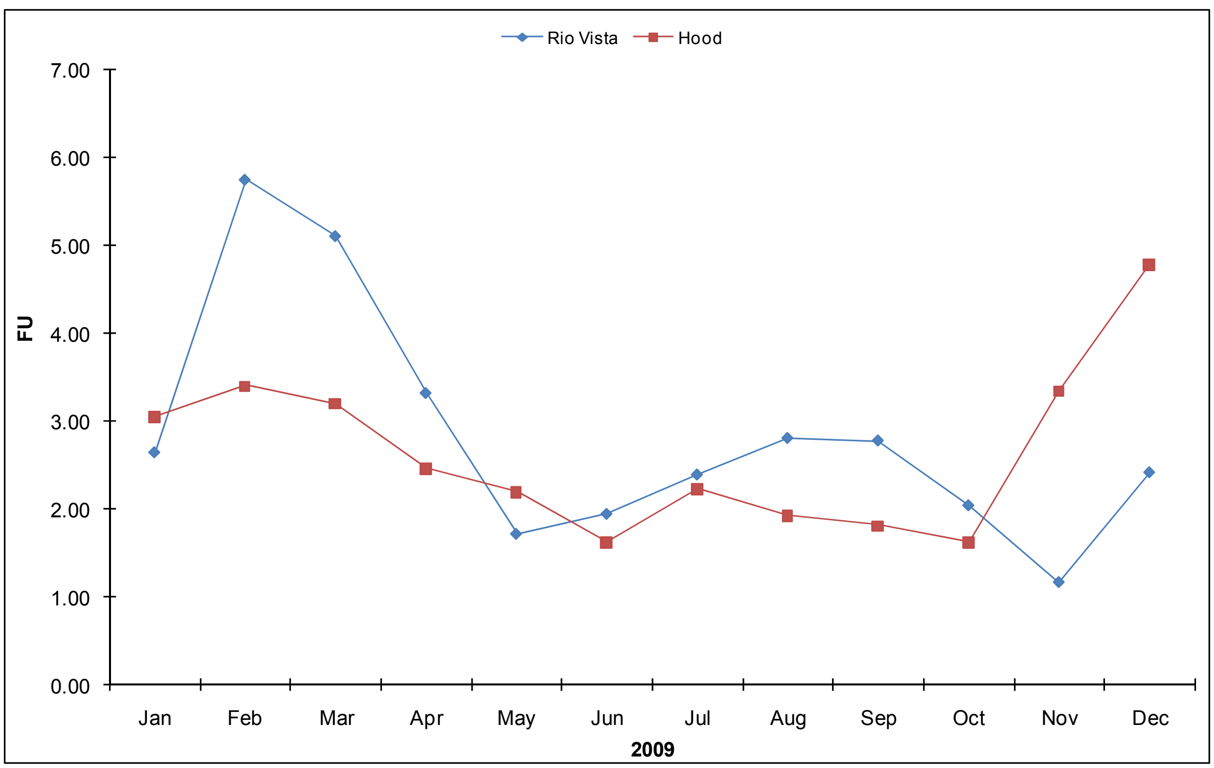


Figure 8-9c Average monthly chlorophyll *a* fluorescence at 4 San Joaquin River stations, 2009

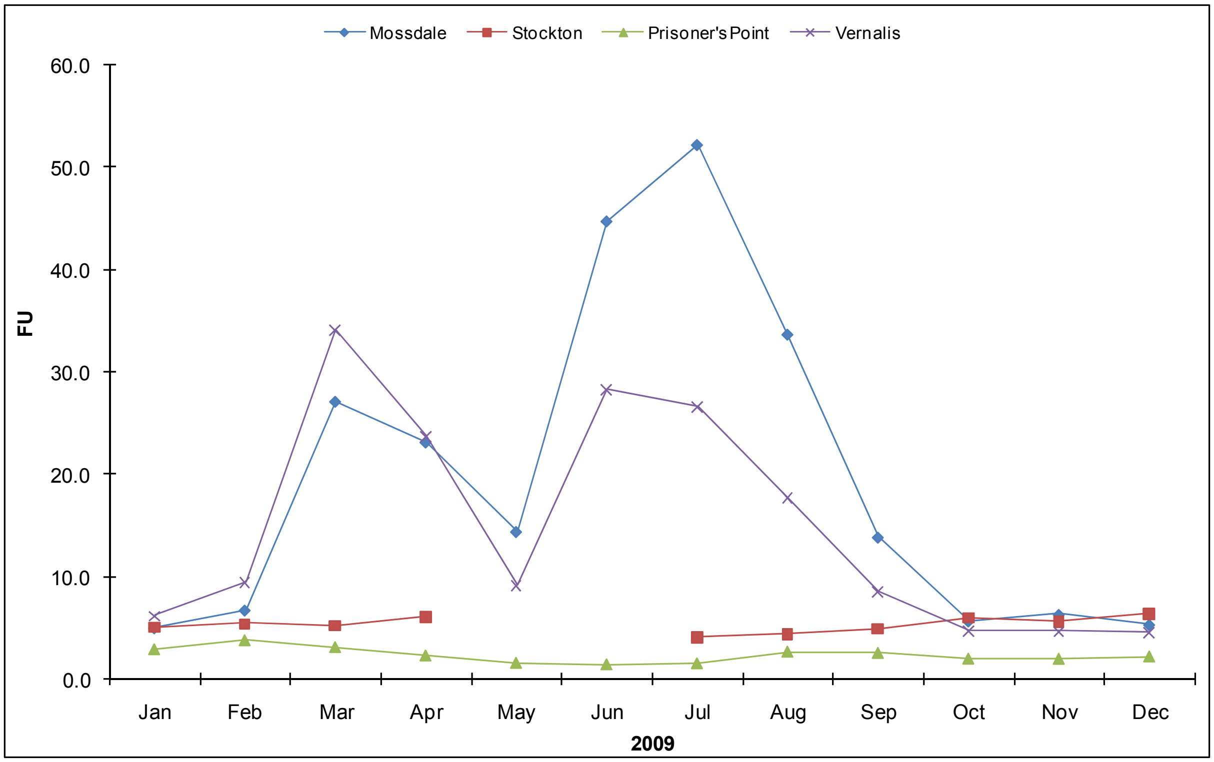


Figure 8-9d Average monthly chlorophyll *a* fluorescence at 3 tidally influenced stations, 2009

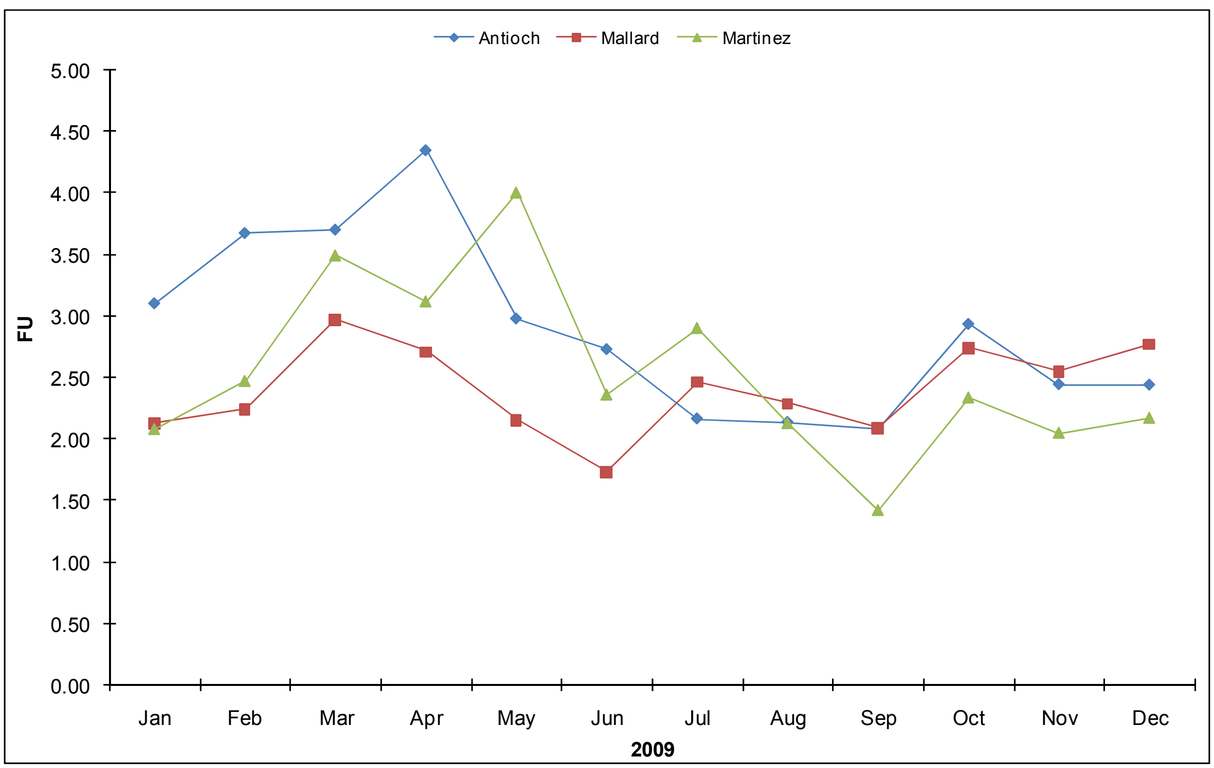


Figure 8-10a Average monthly turbidity at 9 stations, 2009

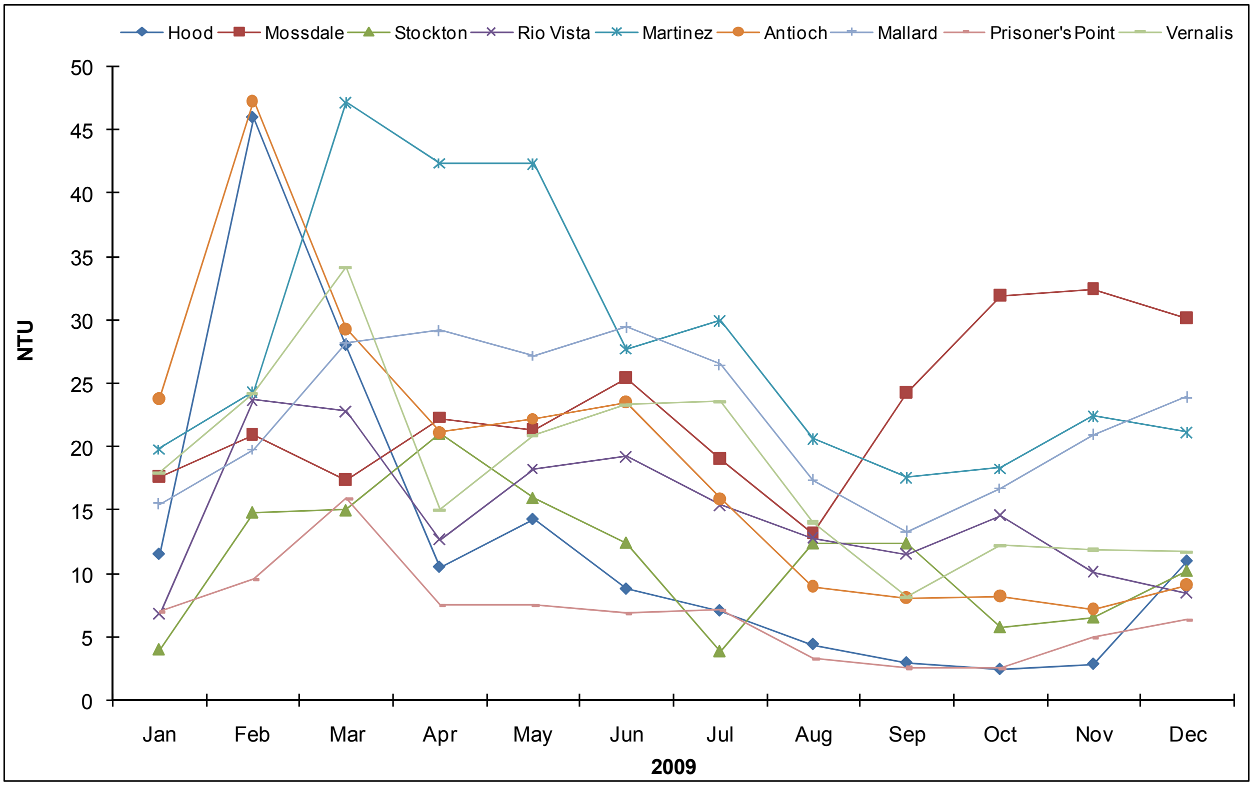


Figure 8-10b Average monthly turbidity at 2 Sacramento River stations, 2009

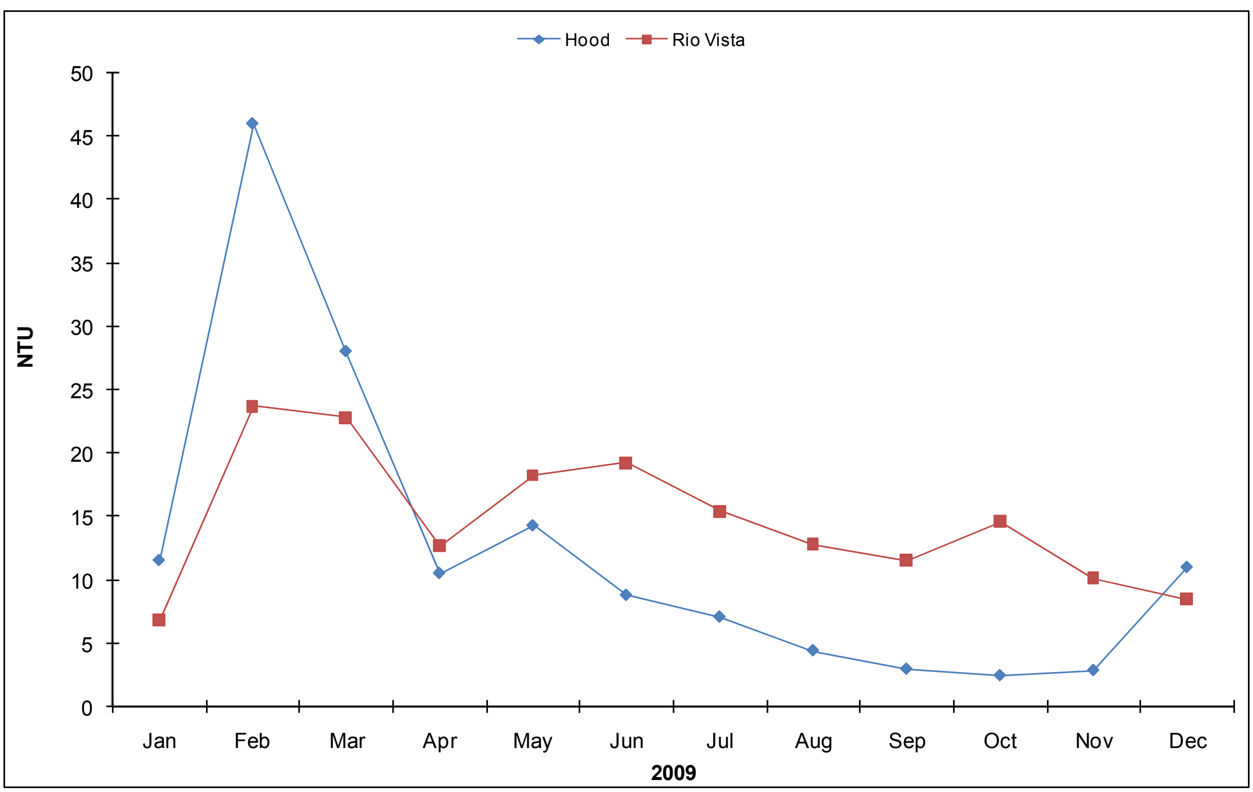


Figure 8-10c Average monthly turbidity at 4 San Joaquin River stations, 2009

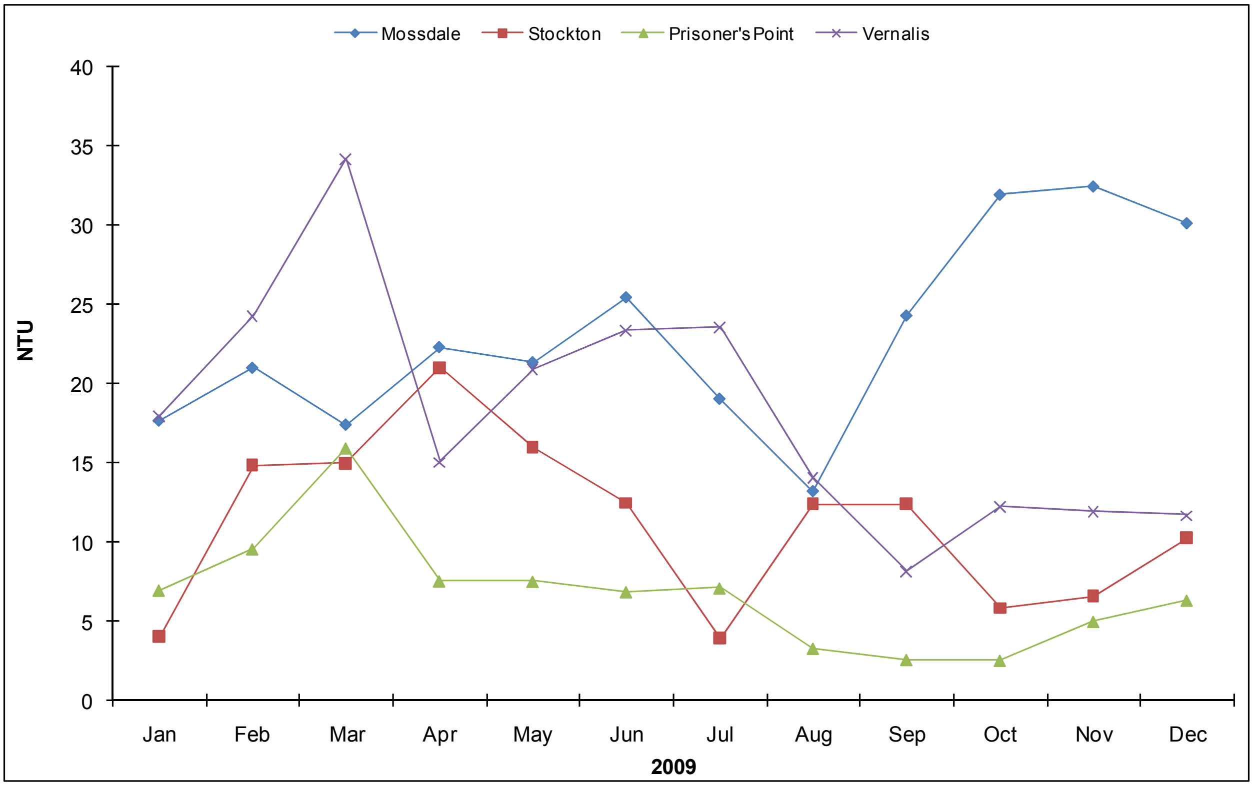


Figure 8-10d Average monthly turbidity at 3 tidally influenced stations, 2009

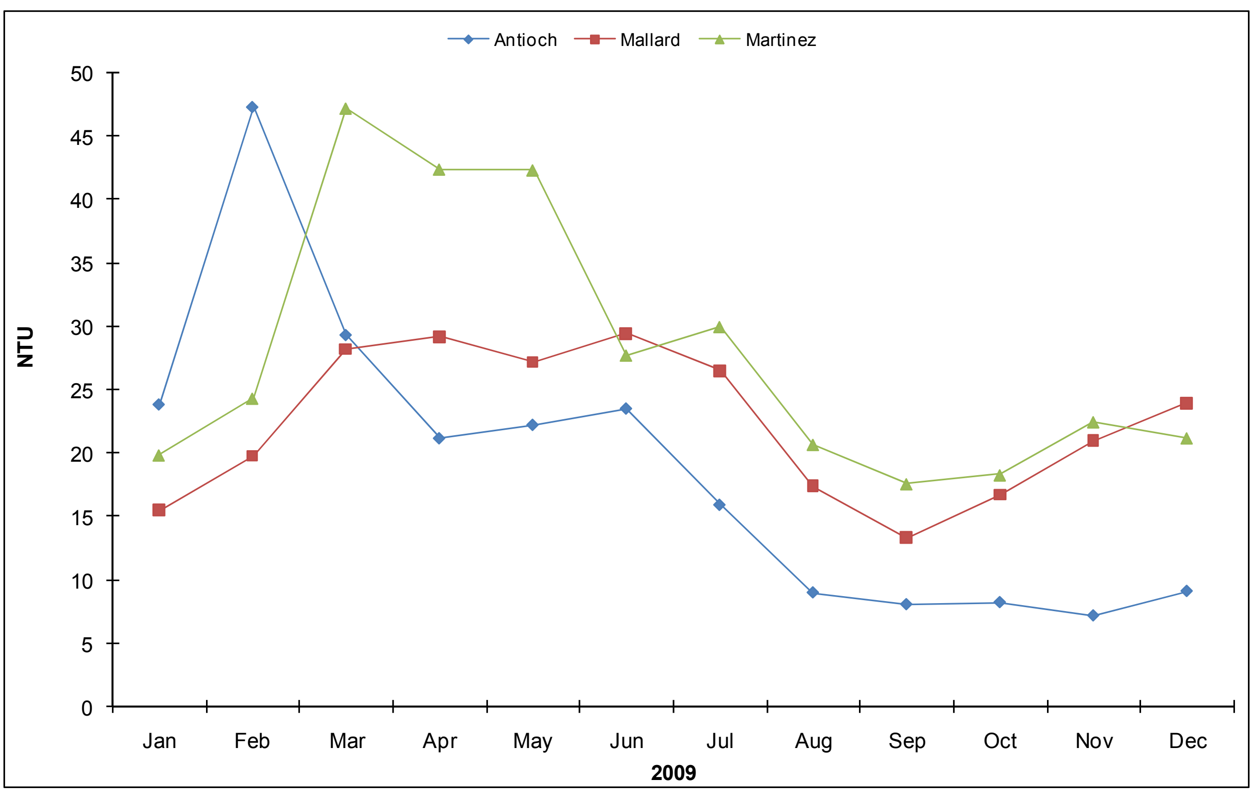


Table 8-1 Parameters

Parameter	*Units*	*Frequency*
Water Temperature	°C	15 minute instantaneous
Air Temperature	°C	15 minute instantaneous
DO	mg/L	15 minute instantaneous
pH	unit less	15 minute instantaneous
Chlorophyll *a* Fluorescence	FU	15 minute instantaneous
Turbidity	NTU	15 minute instantaneous
Surface SC	µS/cm	15 minute instantaneous
Bottom SC	µS/cm	15 minute instantaneous
River Stage	ft (from mean sea level NGVD88)	15 minute instantaneous
Wind Speed	km	15 minute instantaneous
Wind Direction	degrees	15 minute instantaneous
Solar Radiation	Cal/min/cm²	15 minute instantaneous

Chapter 9 Data Management

Content

Chapter 9 Data Management

Introduction

All data collected by the EMP are stored in a digital format. 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/.

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 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 a Microsoft Access database. EMP staff periodically review the data against datasheet records for accuracy, completeness, and consistency.

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 telemetry to an EMP server. Data are then loaded into a Microsoft Access 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 CDEC. **These real time data are unchecked and may include data that are the result of malfunctioning instruments.** They are available for view and download at http://cdec.water.ca.gov/.

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 and Sediment Data

Laboratory identification and enumeration of macrobenthic organisms in each sample is performed by Hydrozoology. 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 a Microsoft Access database. 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. 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 identified, enumerated, and measured the size of phytoplankton. These data are entered into a Microsoft Access database. 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.

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