State of California
The California Natural 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 2010

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

December 2011

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

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Executive Summary 2010

This report summarizes the results of water quality monitoring and special studies conducted by the Environmental Monitoring Program (EMP) within the Sacramento-San Joaquin Delta and Suisun and San Pablo bays (the estuary) during calendar year 2010. This monitoring is mandated by Water Right Decision 1641 (D-1641) and this report is being submitted to fulfill the reporting requirements of that decision.

The EMP monitors 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 estuary were monitored for 15 physical and chemical water quality parameters. The results gathered from the sampling of these 15 parameters are described herein. 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 composition of phytoplankton, zooplankton, and benthic communities.

Chlorophyll *a* samples were collected at 24 monitoring sites in the estuary. Chlorophyll *a* is the principal photosynthetic pigment, is common to all phytoplankton, and is thus used as a measure of phytoplankton biomass. Samples for chlorophyll *a* and phytoplankton were taken at 15 sampling sites in the estuary. Chlorophyll *a* concentrations for 2010 showed seasonal patterns and were generally below 10 µg/L and ranged between 0.38 µg/L and 59.20 µg/L throughout the estuary. Of the 156 samples taken in 2010, 94.2% (147 samples) had chlorophyll *a* levels below 10 µg/L. Phytoplankton samples were collected using a submersible pump from 1 m below the water's surface. All organisms collected in 2010 fell into 13 categories: centric diatoms, pennate diatoms, green algae, cryptomonad flagellates, cyanobacteria, haptophyte flagellates, dinoflagellates, euglenoid flagellates, ciliates, chrysophytes, little green algal balls, kathablepharid flagellates, and silico-flagellates. Of the thirteen groups identified, centric diatoms, pennate diatoms, green algae, cryptomonad flagellates, and cyanobacteria constituted 99.2% of the organisms collected.

Zooplankton were collected at 22 monitoring sites in the estuary. The introduced *Hyperacanthomysis longirostris* (formerly *Acanthomysis bowmani*) was the most abundant mysid, followed by the native *Alienacanthomysis macropsis* and *Neomysis kadiakensis/japonica*. *Pseudodiaptomus forbesi* was the most common calanoid copepod followed by the native *Acartia* spp. *Sinocalanus doerrii* 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 *Diaphanosoma* spp., *Bosmina* spp., and *Daphnia* spp. *Synchaeta* spp. was the most common rotifer, followed by *Polyarthra* spp. and *Keratella* spp.

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

2010 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida, and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda, and Mollusca constituted 93% of the organisms collected during the study period. Ten species in these phyla represent 78% 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 2010. 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 11 to November 19 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 4.6 to 9.1 mg/L at the surface and 4.2 to 9.2 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

Contents

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 2010*, summarizes the findings of the EMP for calendar year 2010. 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 because it 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 periodically 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 percent of the land area of California and consists of about 50 percent 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 million acre feet (MAF) per year from the 2 pumping stations in the southern Delta and about 83 percent 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 2010 covered by this report comprises the period October 1, 2009 to September 30, 2010.

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 May 1st forecast of future runoff (CDEC, 2010b). Indices are based on flow in MAF. 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 for the State Water Project, and the Central Valley Project (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.).

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 2010 was classified as above normal for the San Joaquin Valley[7] and below normal 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 14 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 14 years for reference. Table 2-2 summarizes these conditions and includes the previous 14 years for reference. Maximum Delta outflow indices were 134,318 ac-ft/day (67,735 cfs) in January and minimum outflow indices were 4,811 ac-ft/day (2,426 cfs) in August (Kate Le, personal communication, 2011). 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, 2011a).

A series of cold Pacific storms significantly increased precipitation, snowpack conditions, and reservoir levels during April through June. During this period regulated reservoir releases supplied close to 70 percent of the Delta inflows from the Sacramento and San Joaquin Rivers. The spring runoff forecast was above average and significantly boosted the late season water supply outlook. Precipitation from October through April was about 110 percent of average. The largest peak flows for both Sacramento and the Net Delta Outflow Index occurred in January, surpassing 58,000 cfs. Primary regulatory constraints were the main restrictions for the Central Valley Project and the State Water Project in the Delta during April through June. SWRCB Bay Delta habitat protection outflow requirements (also known as X2) and the Vernalis Adaptive Management Program (VAMP) were the primary regulatory constraints for the 2010 Water Year. (Shahcheraghi & Chu, 2010).

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Chapter 2 Appendix

Figure 2-1 Net Delta Outflow Indices, water year 2010

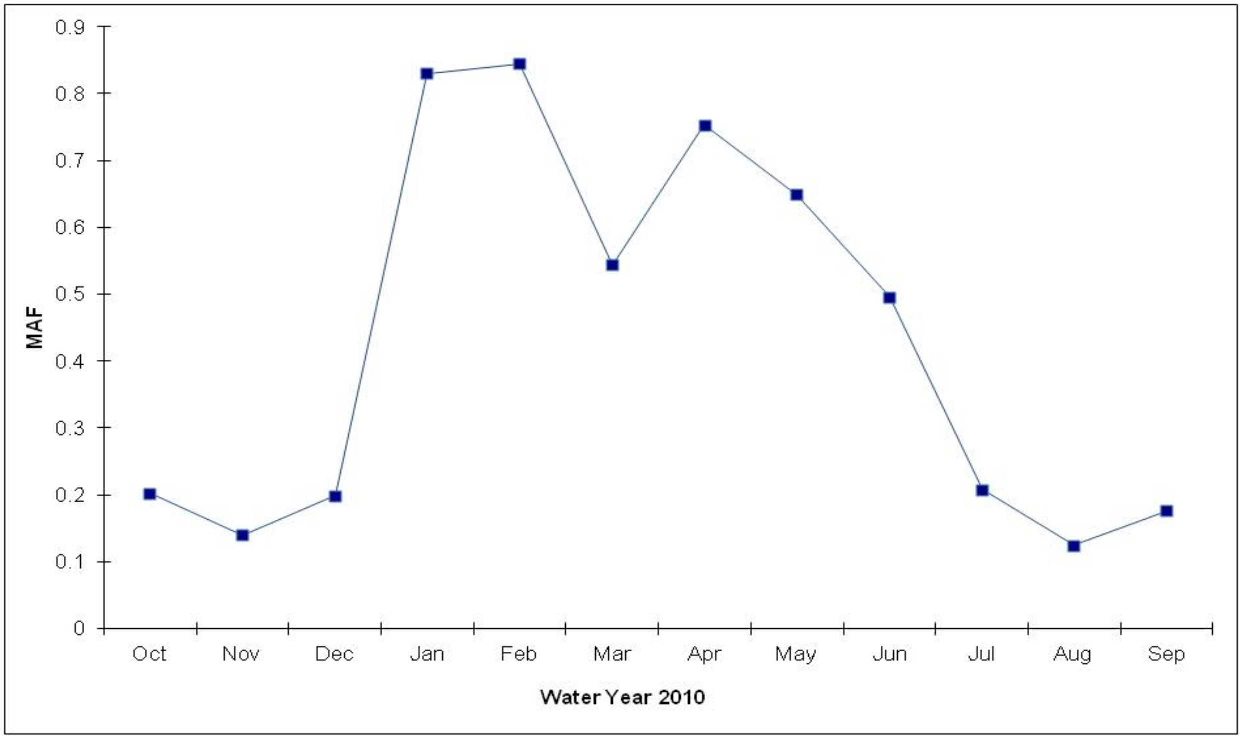

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, water years 1996–2010

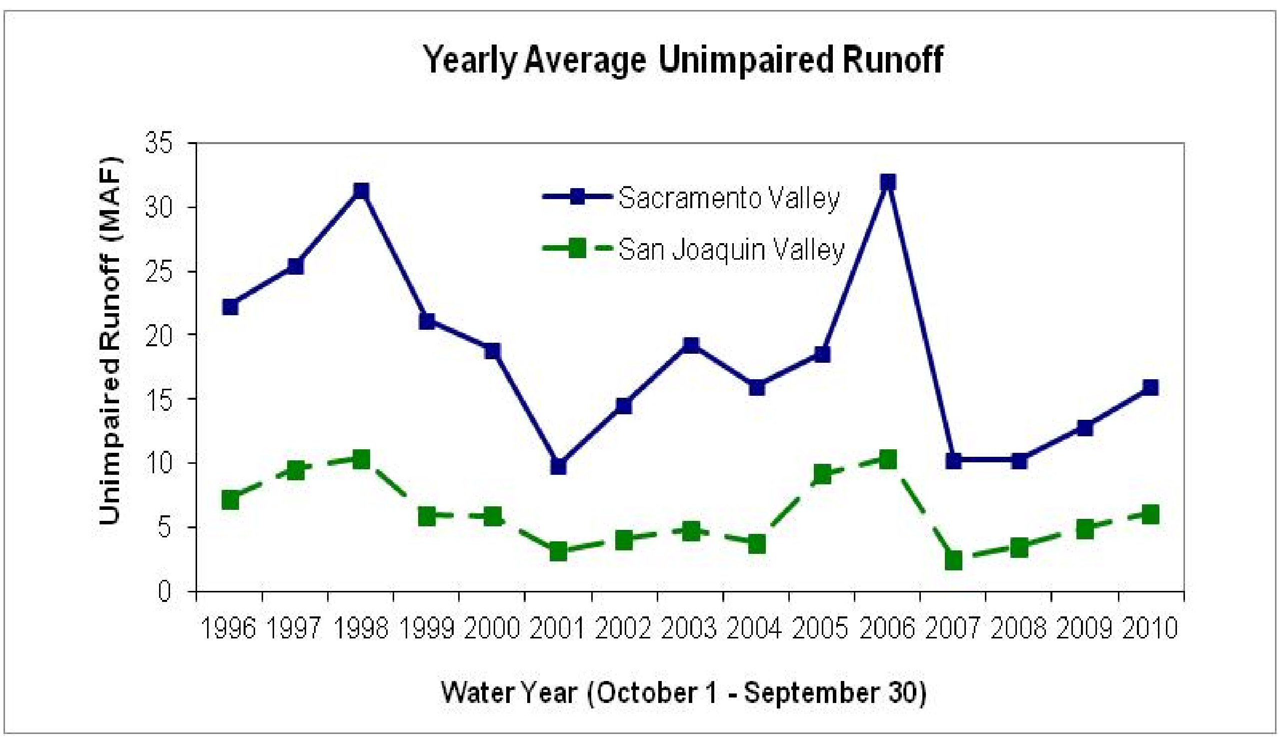

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, water years 1996–2010

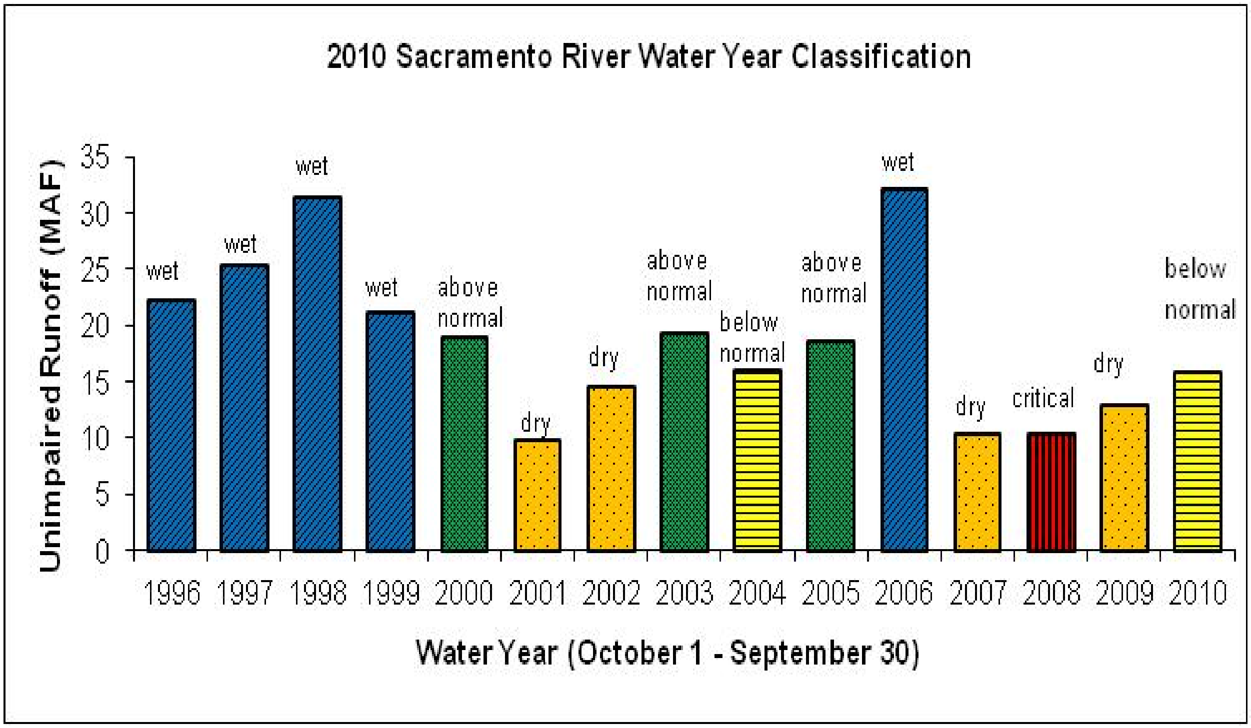

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, water years 1996–2010

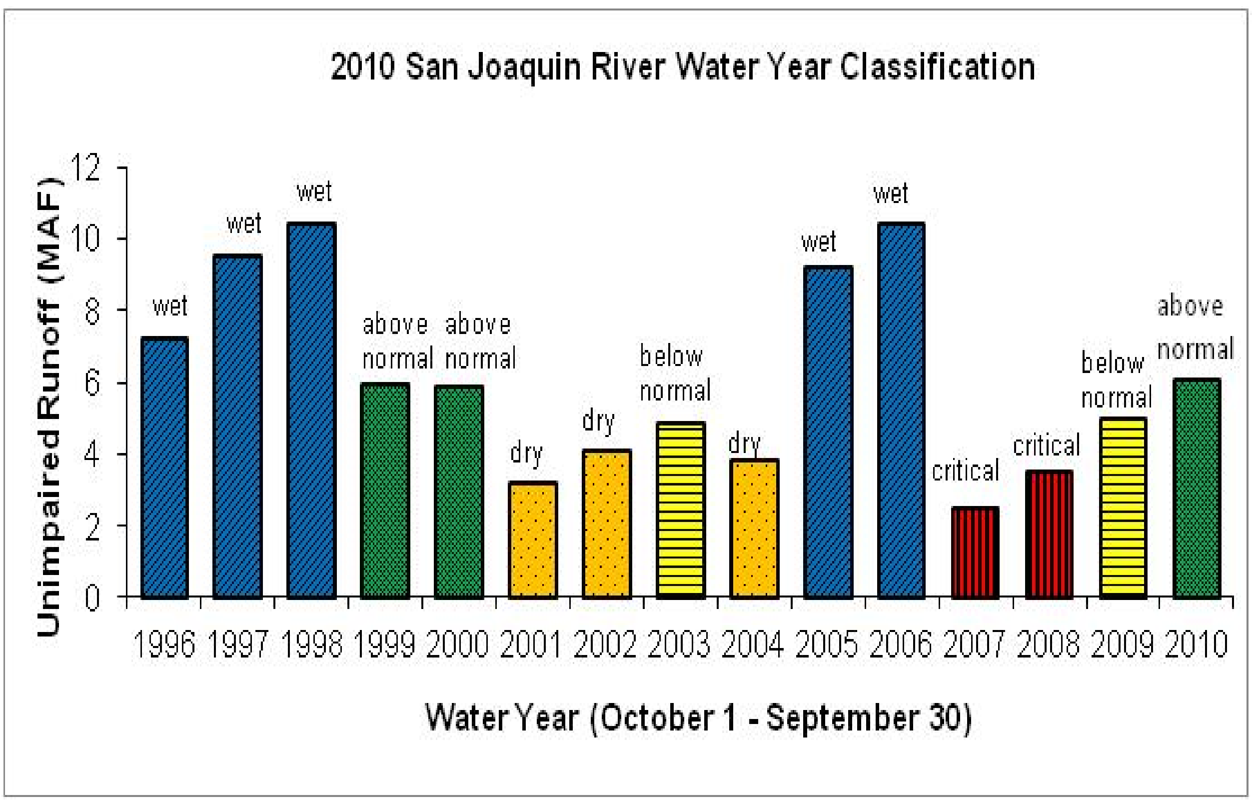

Table 2-1 Summary of statewide major hydrologic characteristics on May 1, water years 1996–2010

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
2010	110	115	95	140

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 1996–2010

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
2010	7.45	7.70	15.94	2010	1.43	4.53	6.09

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

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Chapter 3 Water Quality Monitoring

Introduction

Water quality monitoring in 2010 continued according to the amended protocol implemented by DWR in 1996, with the incorporation of several changes recommended by the 2001-2002 EMP review. (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.

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 9.1°C was recorded in January 2010 at station D28A in the central Delta (Figures 3-2 and 3-3). This minimum temperature represents an increase of 0.7 °C from the previously recorded minima in 2009 (Riordan et al., 2010).

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

A water temperature maximum of 26.7 °C was recorded in August at station P8 in the south Delta. This maximum is a 0.6 °C increase over the temperature maximum reported for 2009 (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 2010, DO concentrations ranged from 5.7 mg/L at site P8 in July to 11.1 mg/L at site MD10A in May (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 127 µS/cm at site C3A in July and August to 44,994 µS/cm at site D41 in January (Figures 3-6 and 3-7). This range of SC was similar to the range of 101.3 - 45,634 µS/cm reported for 2009 (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 early 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 20 cm was recorded at multiple sites; D7 in Suisun Bay in February, March, May and June; D8 (Suisun Bay) in February; and D41A (San Pablo Bay) in August. (Figures 3-8 and 3-9). A maximum Secchi depth of 312 cm was recorded at sampling site D28A (central Delta) in October and December. Secchi values during 2009 ranged from 10 to 228 cm (Riordan et al., 2010).

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

Turbidity

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

Turbidity was determined from samples collected from a through-hull pump at a 1 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 0.6 NTU at site MD10A (east Delta) in April to 60.3 NTU at site C3A (north Delta) in February. This range of turbidity was smaller than the 2.5 to 299 NTU range reported for 2009 (Riordan et al., 2010). 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 0.03 mg/L at stations MD10A in November, D4 in June, D26 in August and October, and C3A in August, September, October and December. The 2009 study period showed the lowest value (0.01 mg/L) of orthophosphate occurring at site MD10A in December (Riordan et al., 2010).

The highest value of orthophosphate was 0.19 mg/L at site MD10A in March and at site P8 in February. During 2009, the highest orthophosphate concentration was 0.12 mg/L at site P8 in May and June and site C10A in March (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 0.04 mg/L was recorded at several sites; C3A in August; D26 in August and October; and MD10A in September and November. This value is slightly higher than the minimum value of 0.02 mg/L recorded during 2009 at site C3A in August (Riordan et al., 2009). A maximum value of 0.31 mg/L was recorded at site C10A in March. This value is close to the maximum value of 0.29 mg/L recorded during 2009 at site C3A in February(Riordan et al., 2010).

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

Site C10A had the highest average total phosphorus concentrations during 2010. Site D26 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 a low of 0.2 mg/L at several sites; C3A in August; D19 in August, September and November; D26 in July, August and October; D28A in August and October; and D4 in August, to 1.3 mg/L at site P8 in February and March (Figures 3-16 and 3-17). During 2008, Kjeldahl nitrogen levels peaked at site C3A with a high of 1.3 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 August to a maximum of 3.43 mg/L at site P8 in January. (Figures 3-18 and 3-9). This range is similar to the values observed during 2009, which recorded a minimum value of 0.03 mg/L at site MD10A in September and a maximum of 3.77 mg/L at station P8 in February (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 the highest overall 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.

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.

The lowest DON concentration was 0.1 mg/L at many stations; C3A in May, July, August and October; D19 in June and August; D26 in July, August and October; D28A in October; D4 in August and December; D41 in October; and D7 in August. A maximum concentration of 1.0 mg/L was recorded at station P8 in March (Figures 3-20 and 3-21). Peak DON during 2009 was similar, reaching 1.1 mg/L at station C3A in February (Riordan et al., 2010).

Most sites showed peak DON concentrations during February or March.

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 78 mg/L at site C3A in June to 28,980 mg/L at site D41 in October (Figures 3-22 and 3-23). The values were similar during 2009, which had a range of 63 mg/L to 29,400 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 sites D28A and MD10A in December to 149 mg/L at site D41A in August (Figures 3-24 and

3-25). During the 2009 study period the highest TSS value was recorded at site C3A (232 mg/L) in February and the lowest TSS value was below the minimum reporting limit at sites D28A in March and June and MD10A in March (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 31.0 mg/L at site D41A in August (Figures 3-26 and 3-27). These results were similar to those observed in 2009, which had a maximum value of 33.0 mg/L at site D41A in October (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 2.4 mg/L at site MD10A in May to a high of 21.6 mg/L at site C3A in January (Figures 3-28 and 3-29). Values during 2009 exhibited a similar range, from 1.5 mg/L at site D6 in February to 22.0 mg/L at site C3A in January (Riordan et al., 2010).

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 5 mg/L at site C3A in June, July and August to 16,200 mg/L at site D41 in January and September (Figures 3-30 and 3-31). These results are very similar to those observed during 2009, which recorded a low of 4 mg/L at site C3A in July and August and a high of 16,600 mg/L at site D41 in August and October (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 2009*. 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

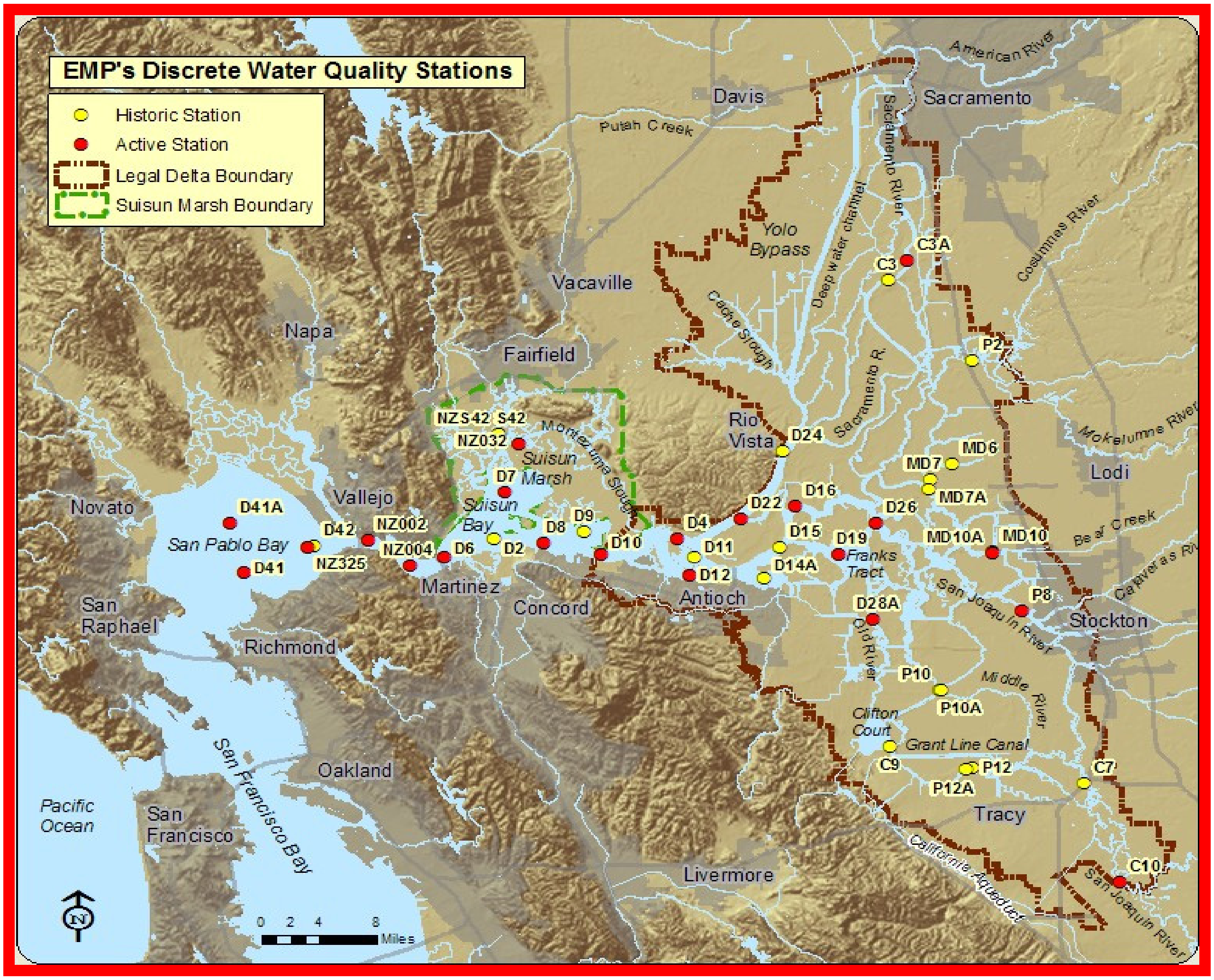

Figure 3-2 Water temperature comparisons, 2010

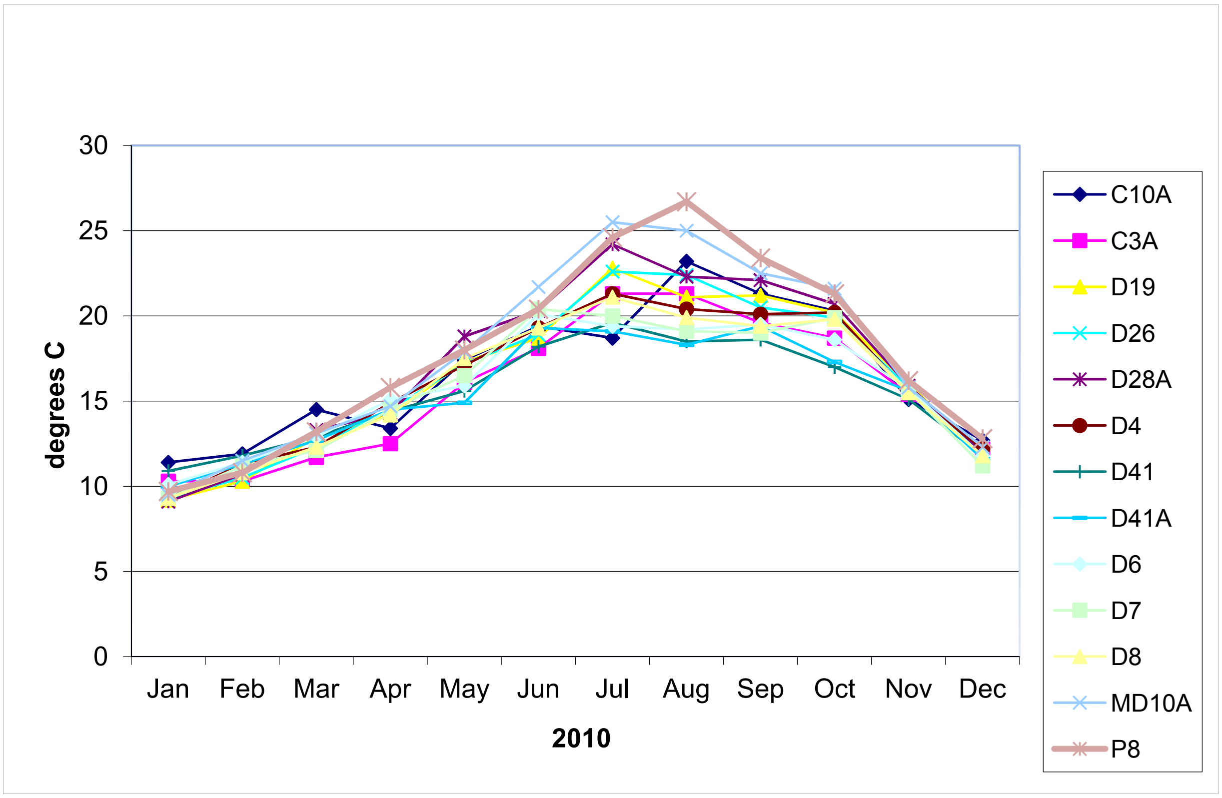

Figure 3-3 Water temperature by station, 2010

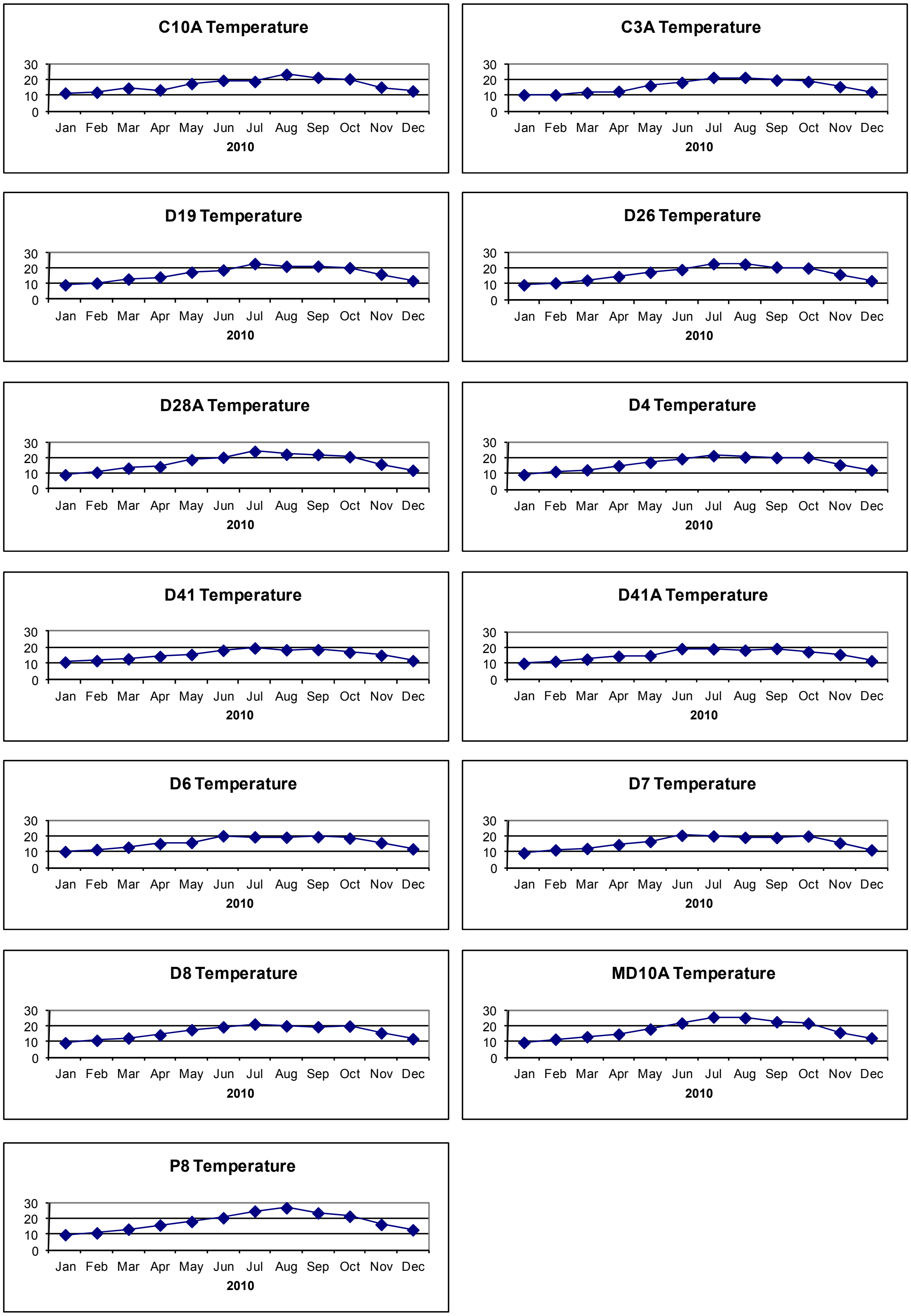

Figure 3-4 DO comparisons, 2010

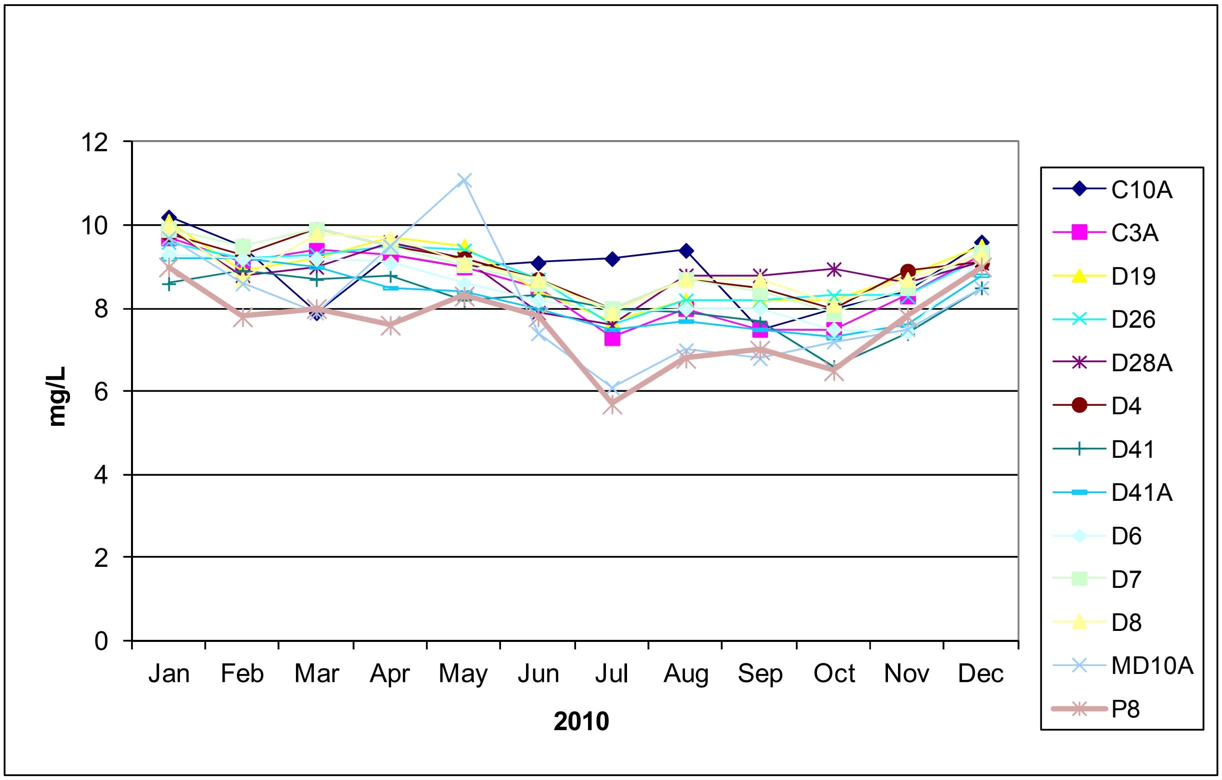

Figure 3-5 DO by station, 2010

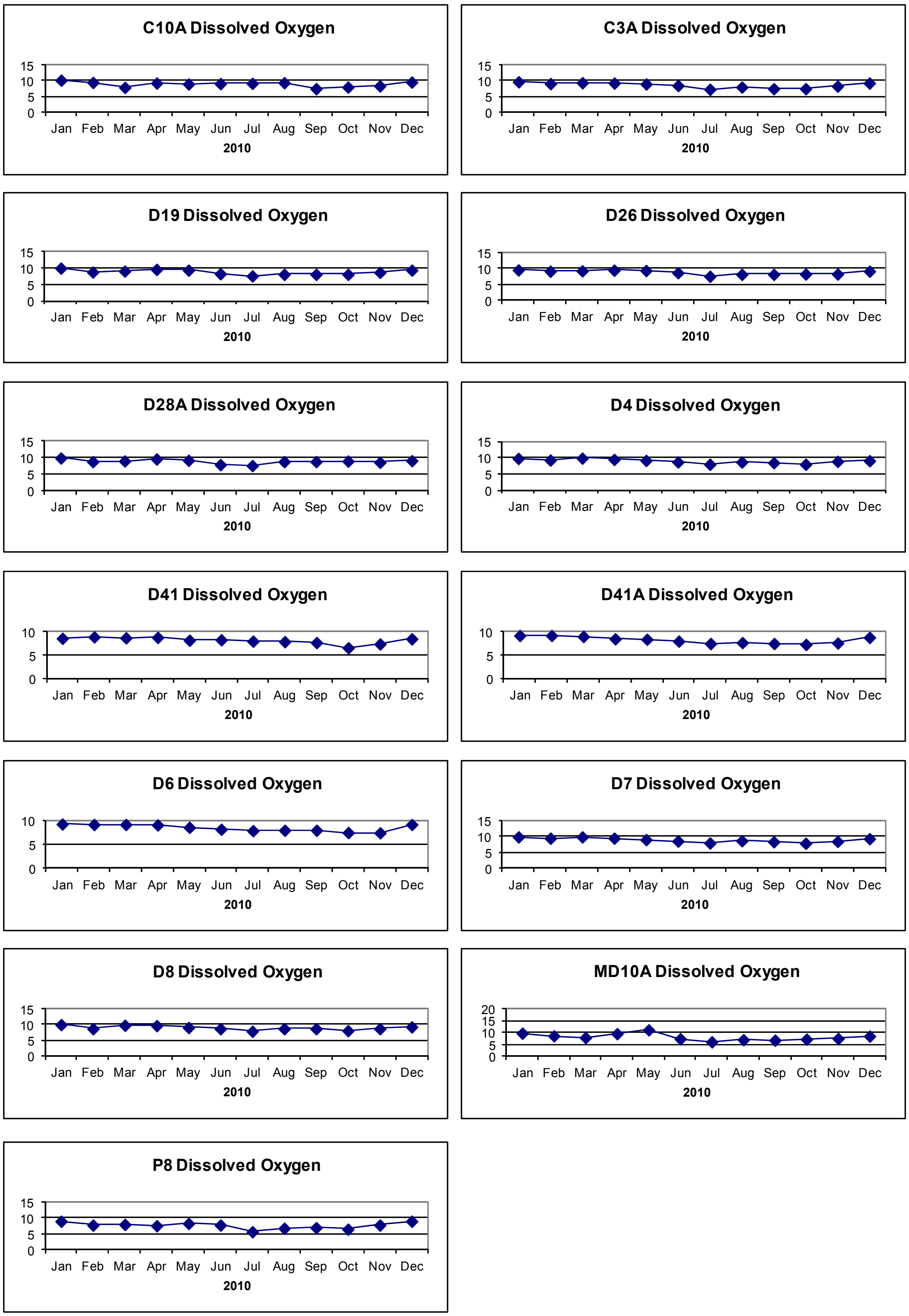

Figure 3-6 SC comparisons, 2010

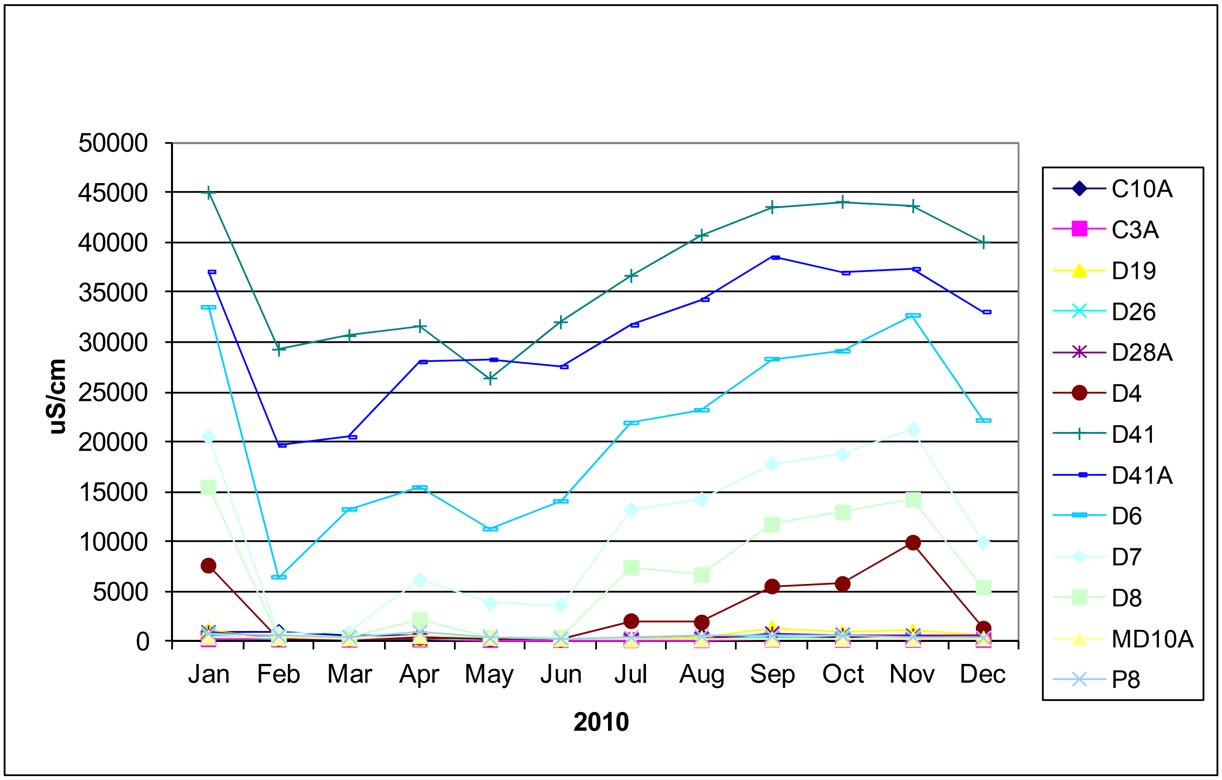

Figure 3-7 SC by station, 2010

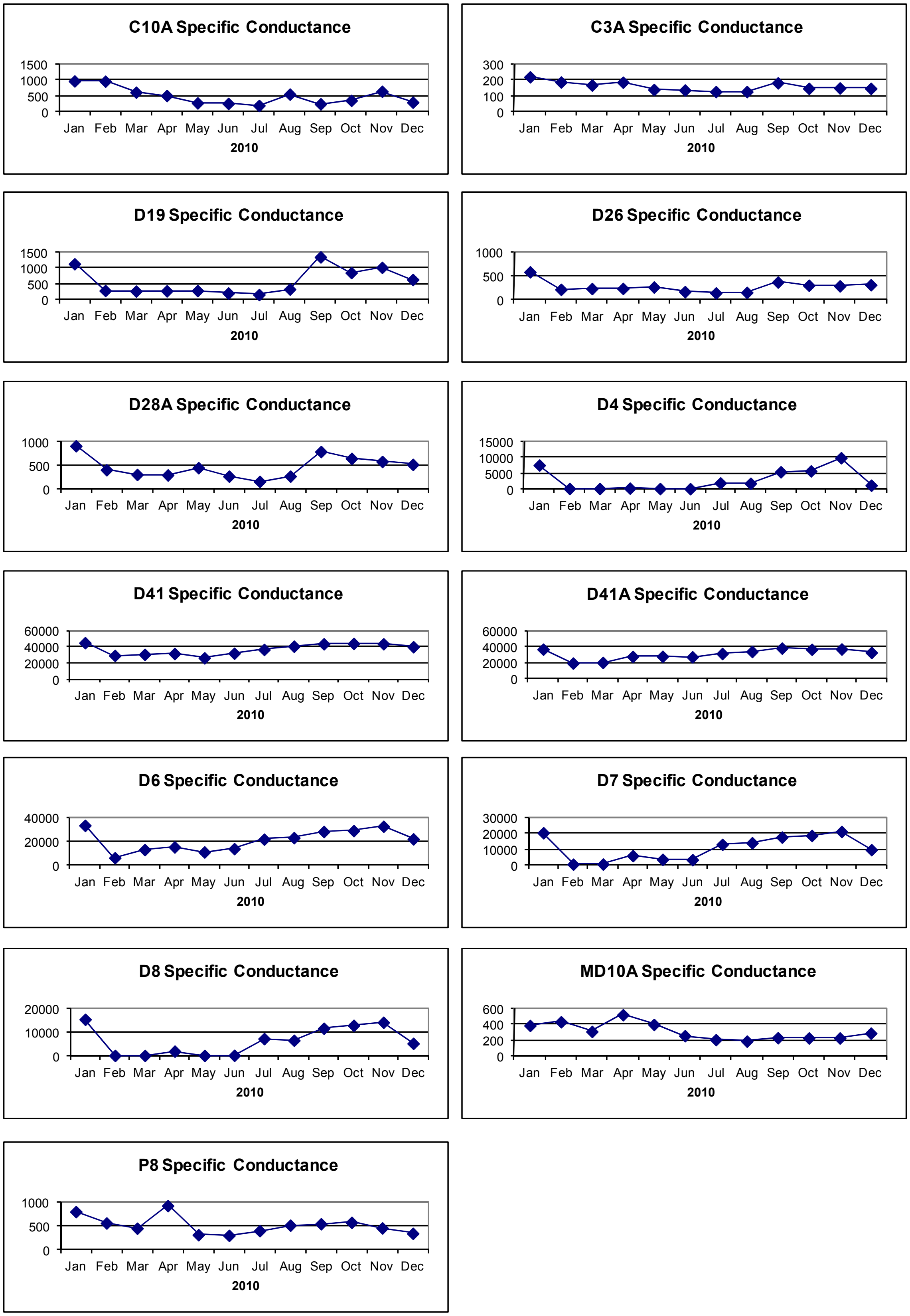

Figure 3-8 Secchi disk depth comparisons, 2010

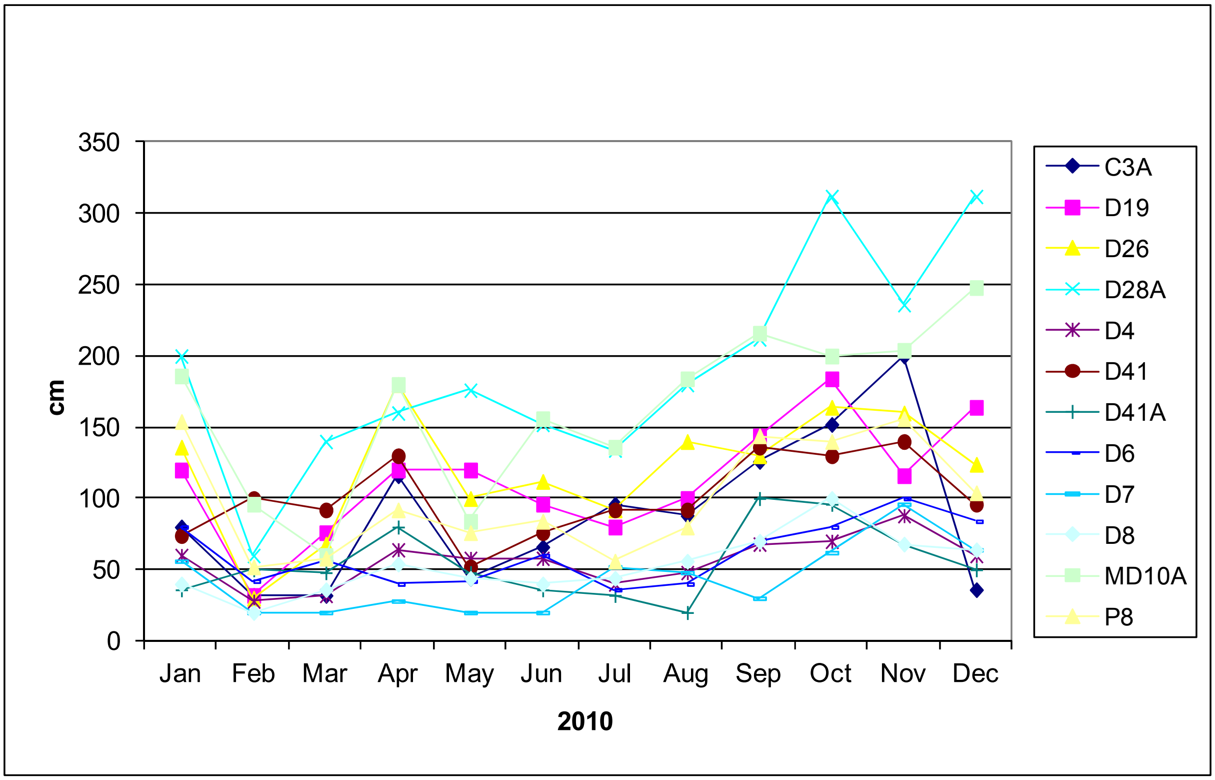

Figure 3-9 Secchi disk by station, 2010

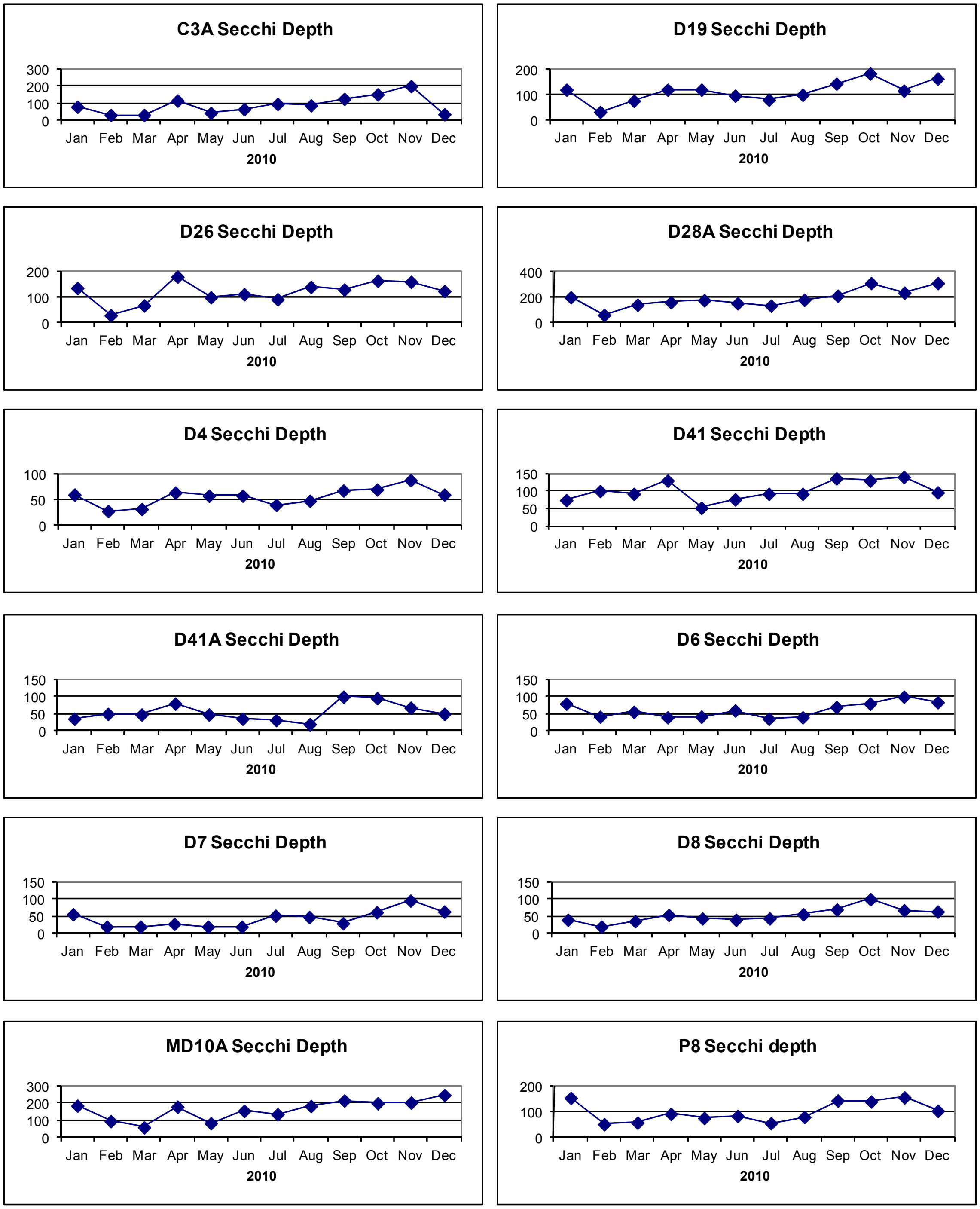

Figure 3-10 Turbidity comparisons, 2010

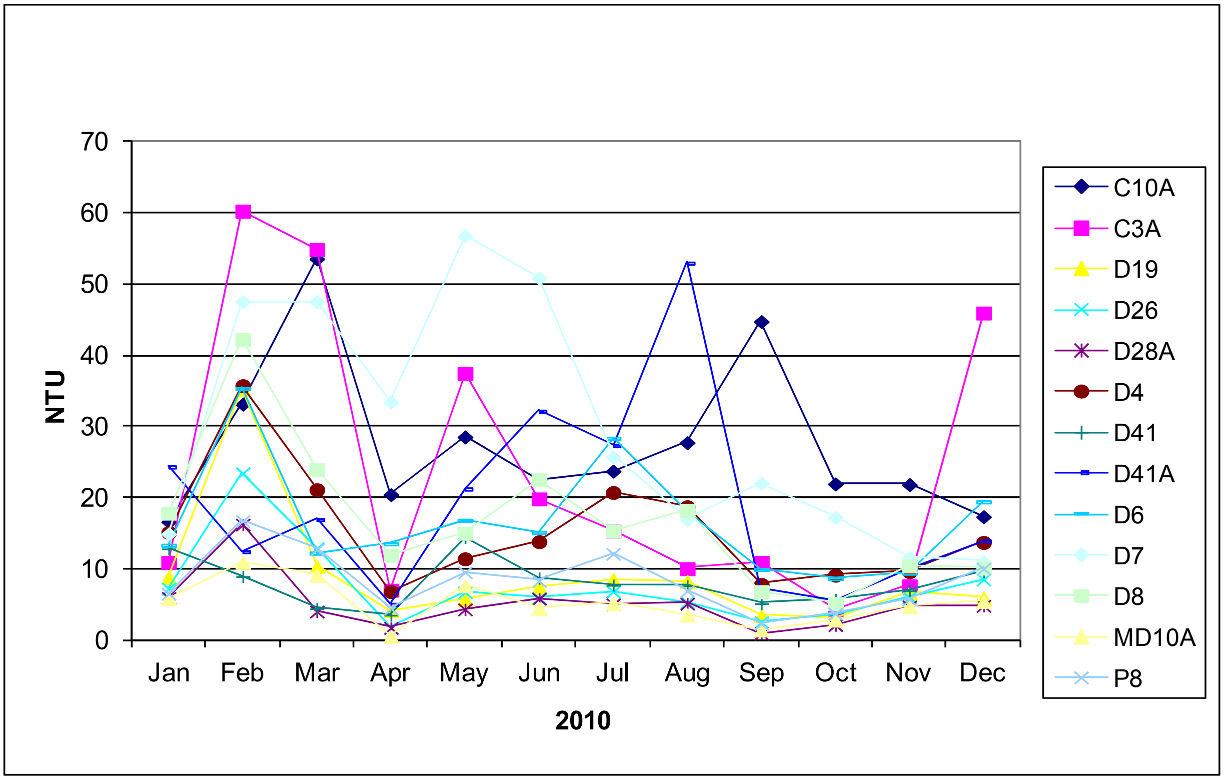

Figure 3-11 Turbidity by station, 2010

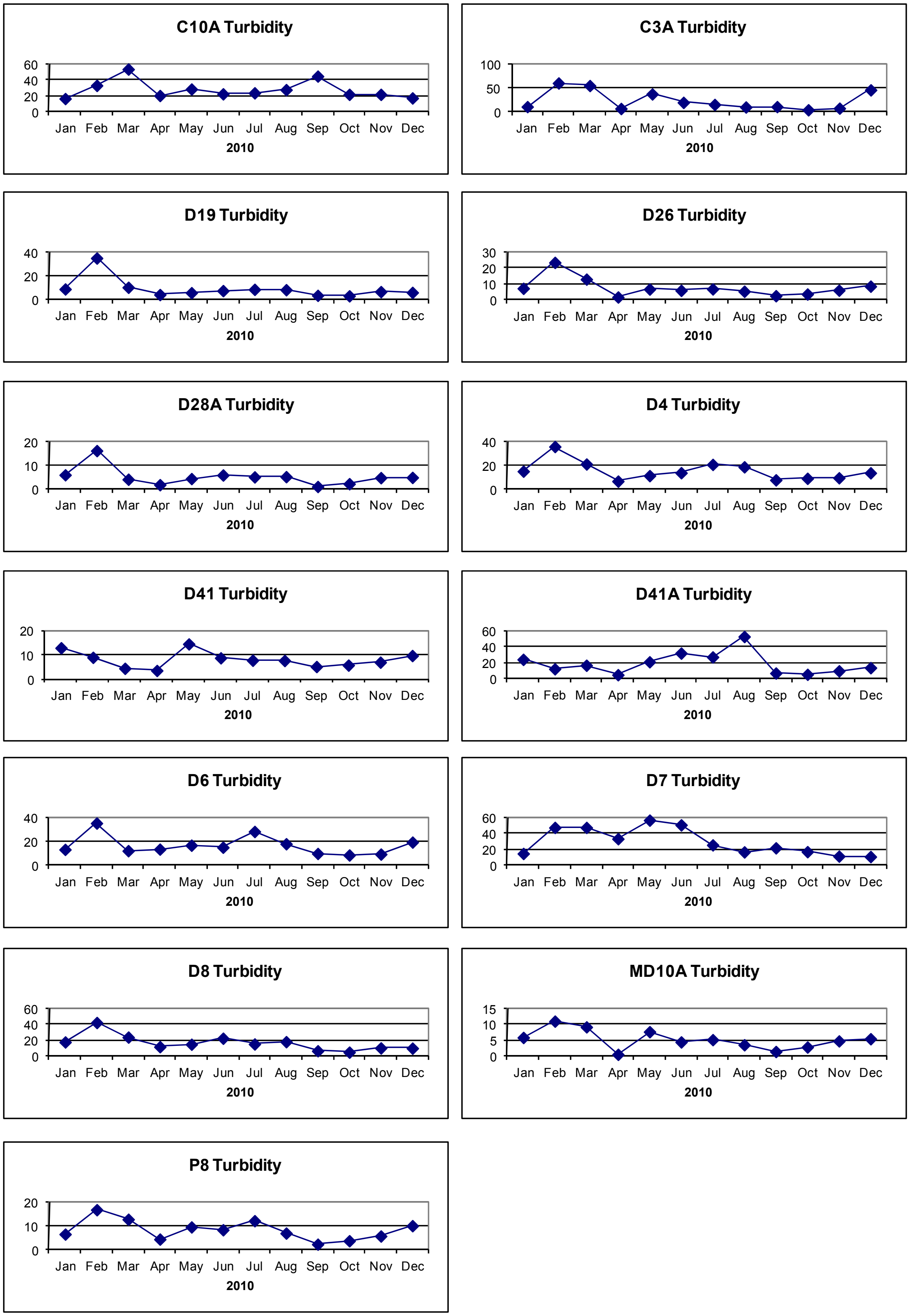

Figure 3-12 Orthophosphate comparisons, 2010

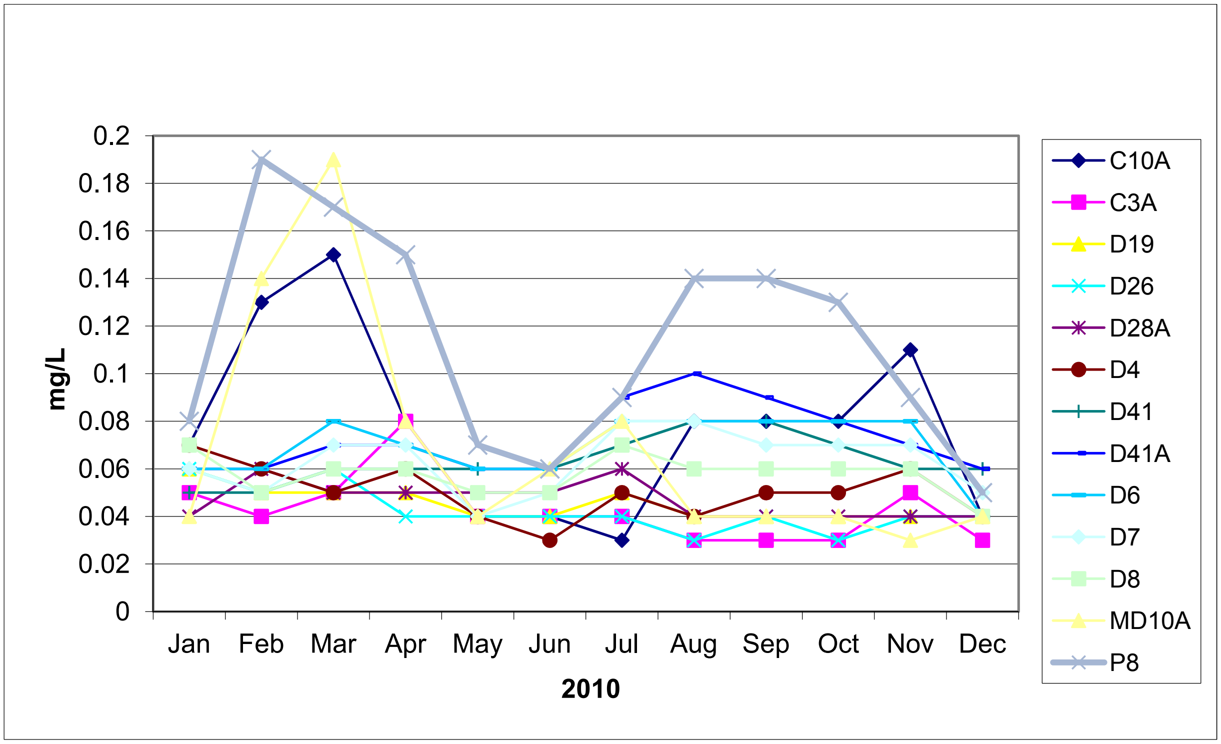

Figure 3-13 Orthophosphate by station, 2010

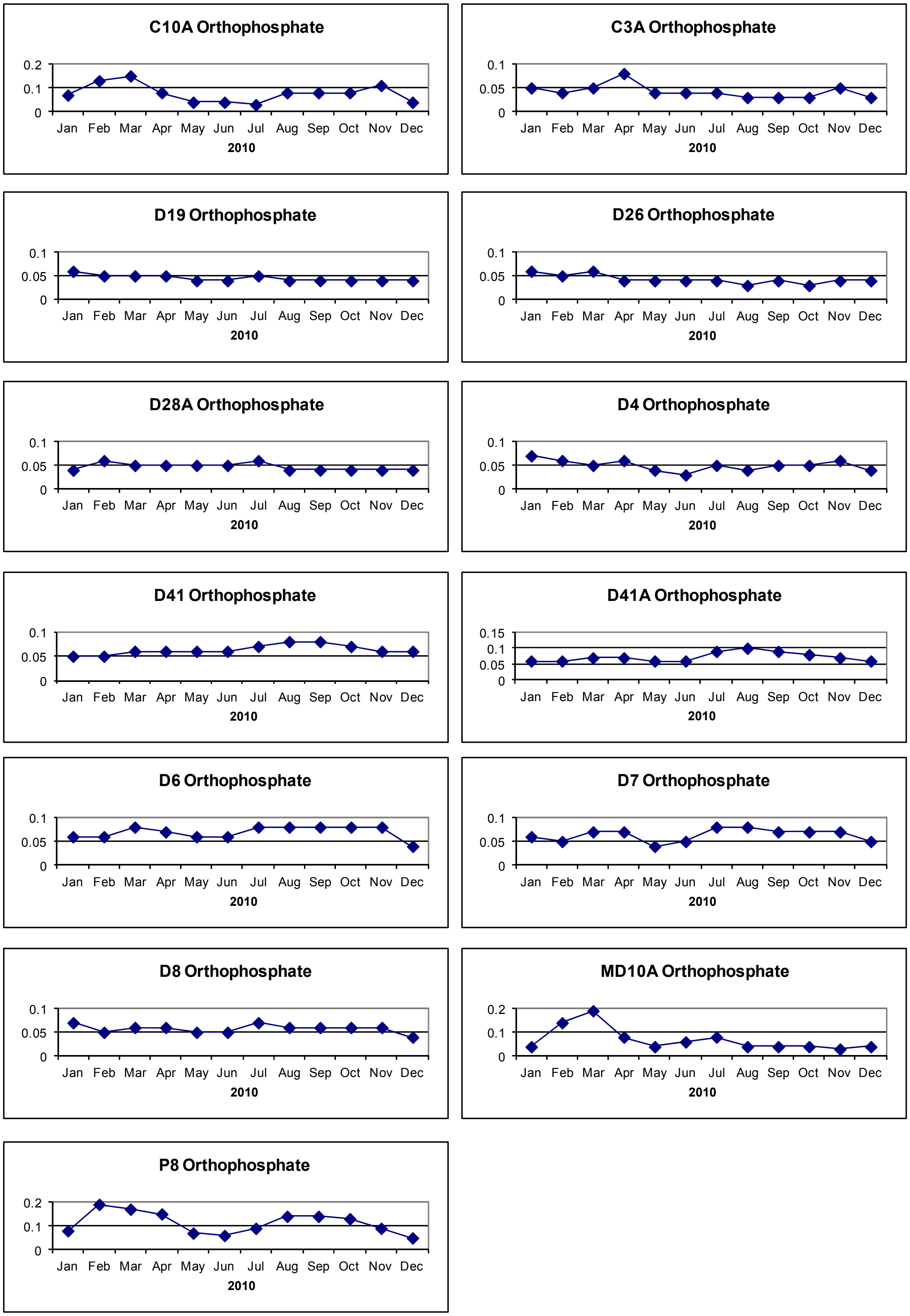

Figure 3-14 Total phosphorus comparisons, 2010

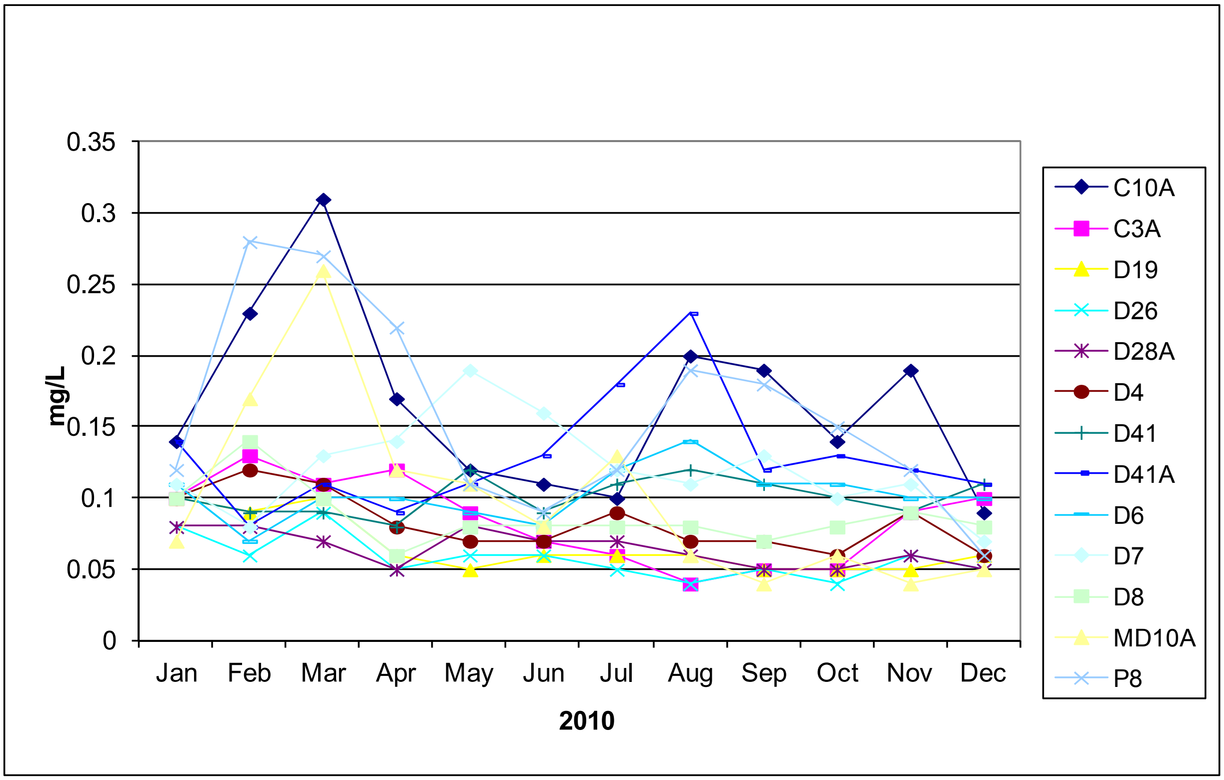

Figure 3-15 Total phosphorus by station, 2010

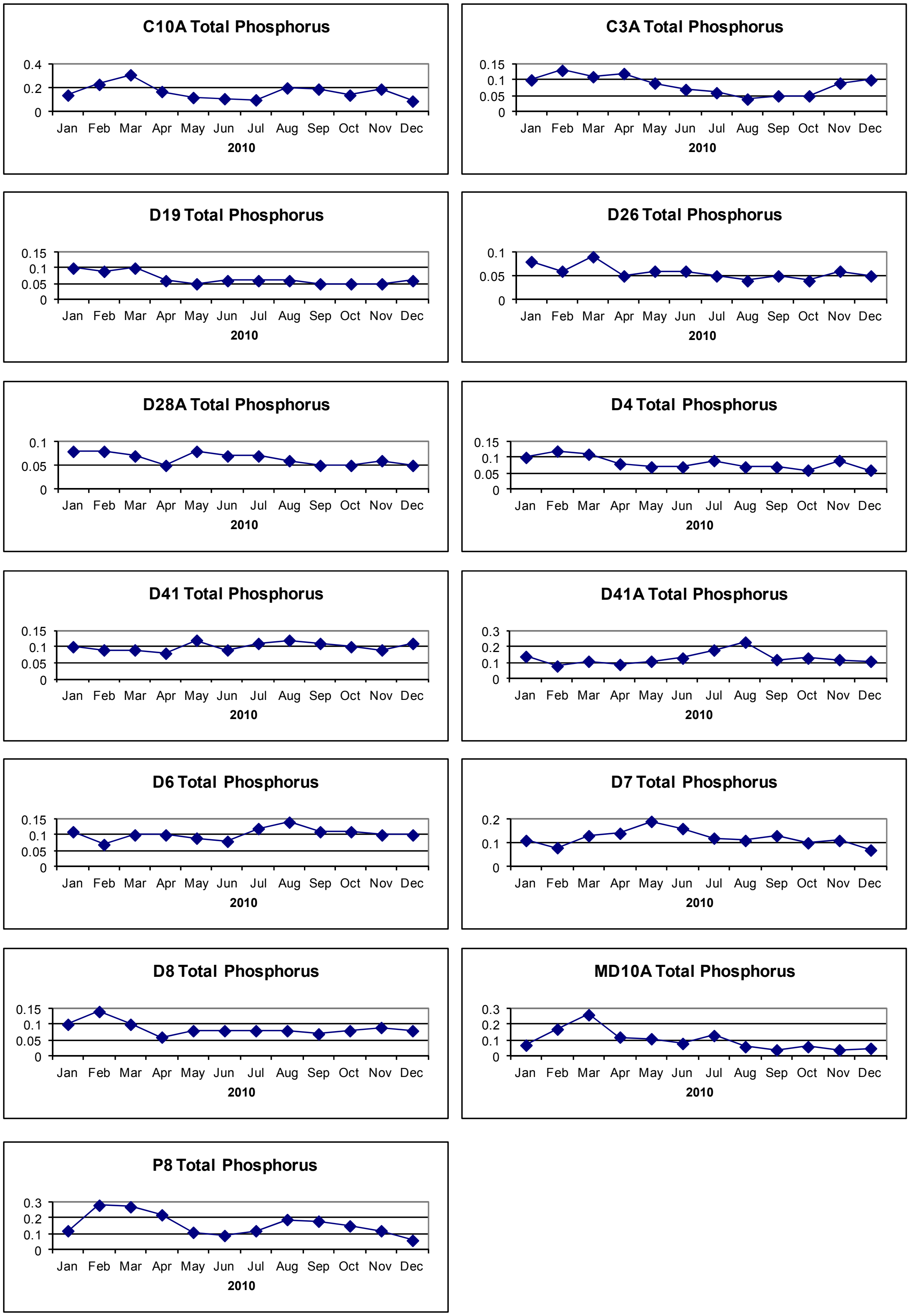

Figure 3-16 Kjeldahl nitrogen comparisons, 2010

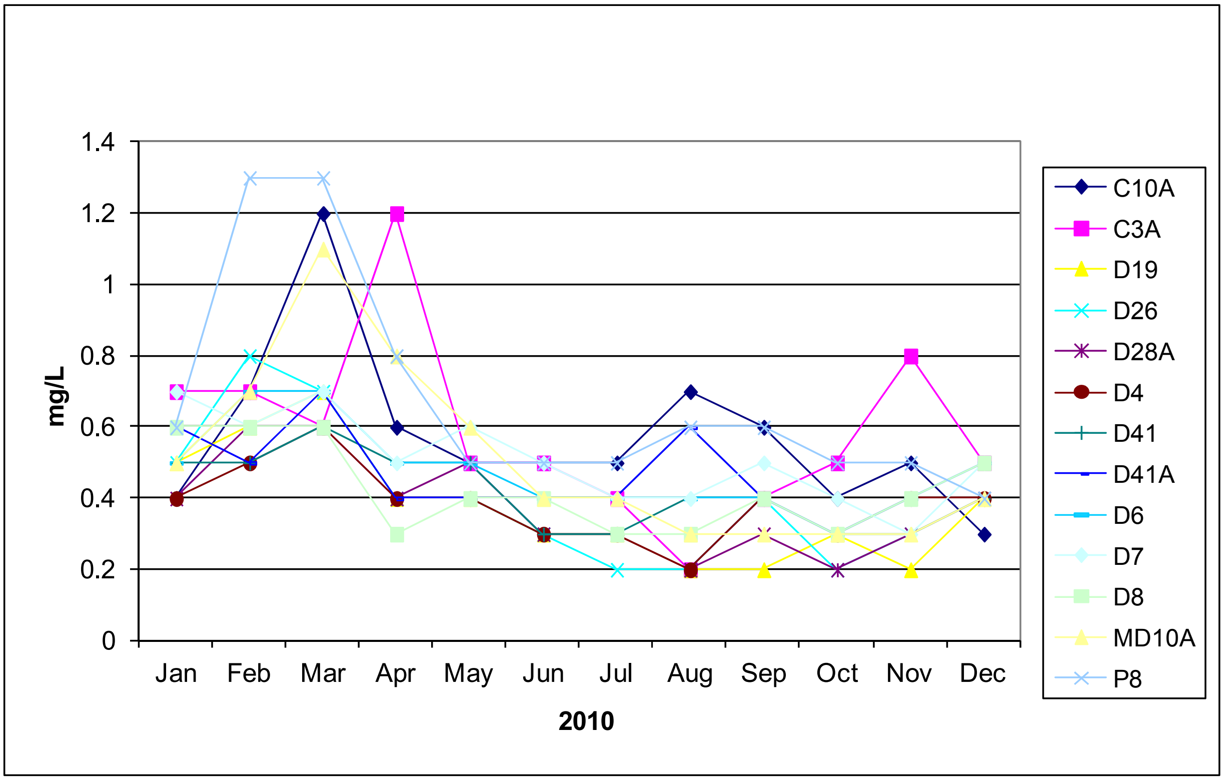

Figure 3-17 Kjeldahl nitrogen by station, 2010

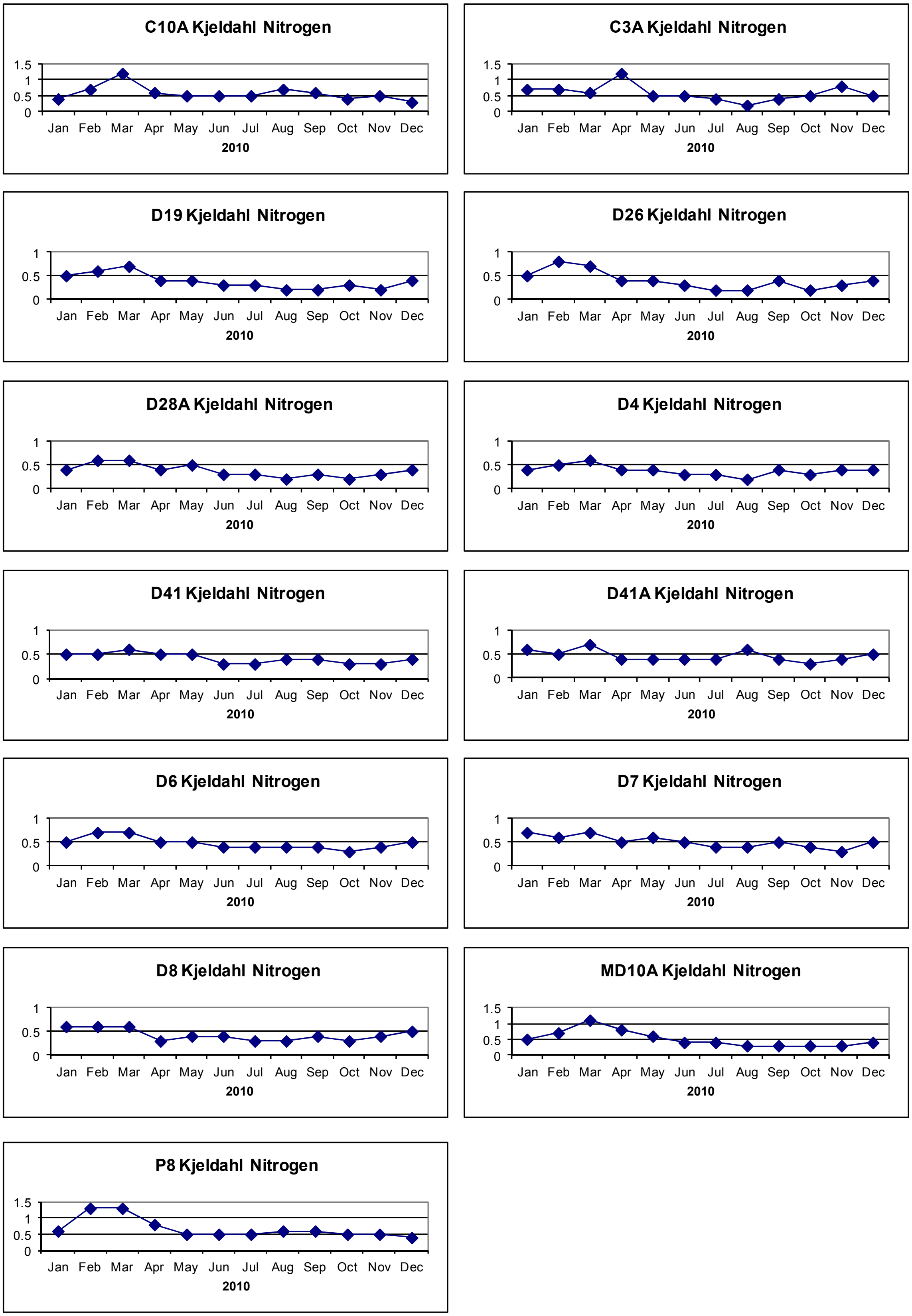

Figure 3-18 DIN comparisons, 2010

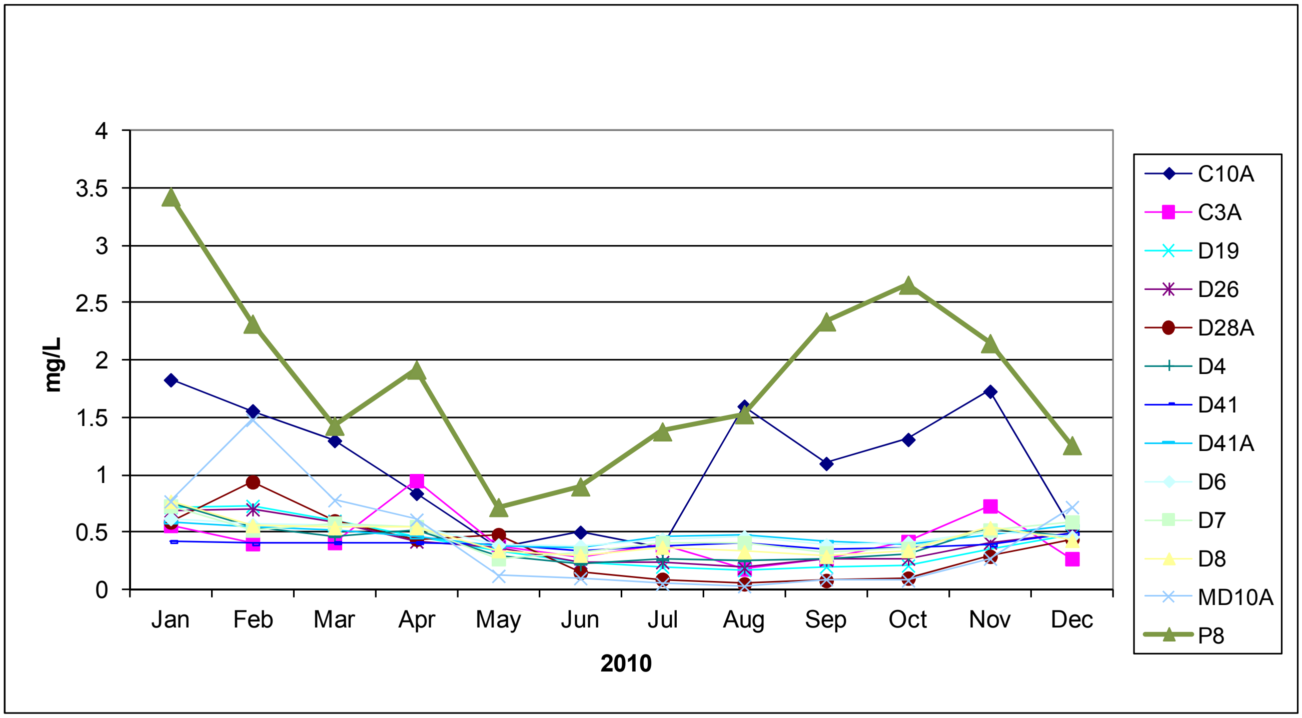

Figure 3-19 DIN by station, 2010

Figure 3-20 DON comparisons, 2010

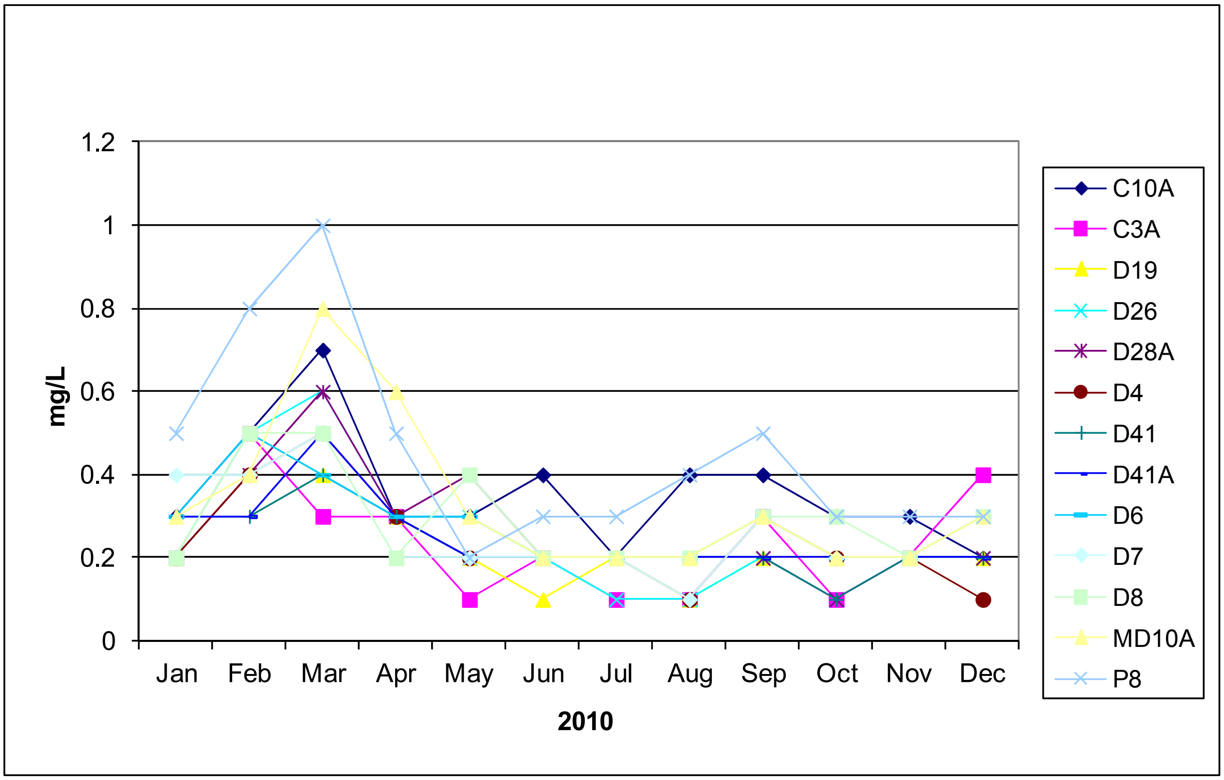

Figure 3-21 DON by station, 2010

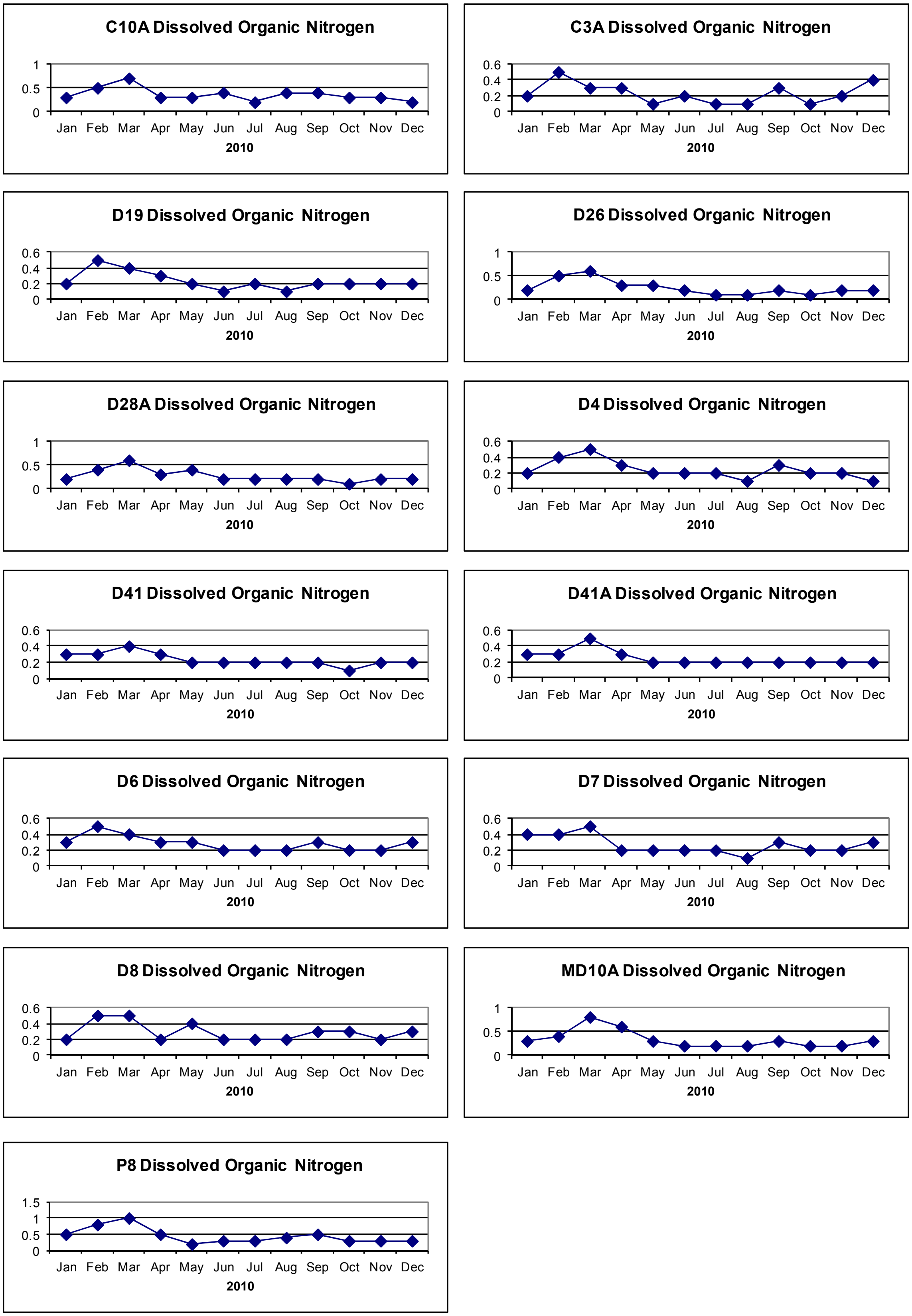

Figure 3-22 TDS comparisons, 2010

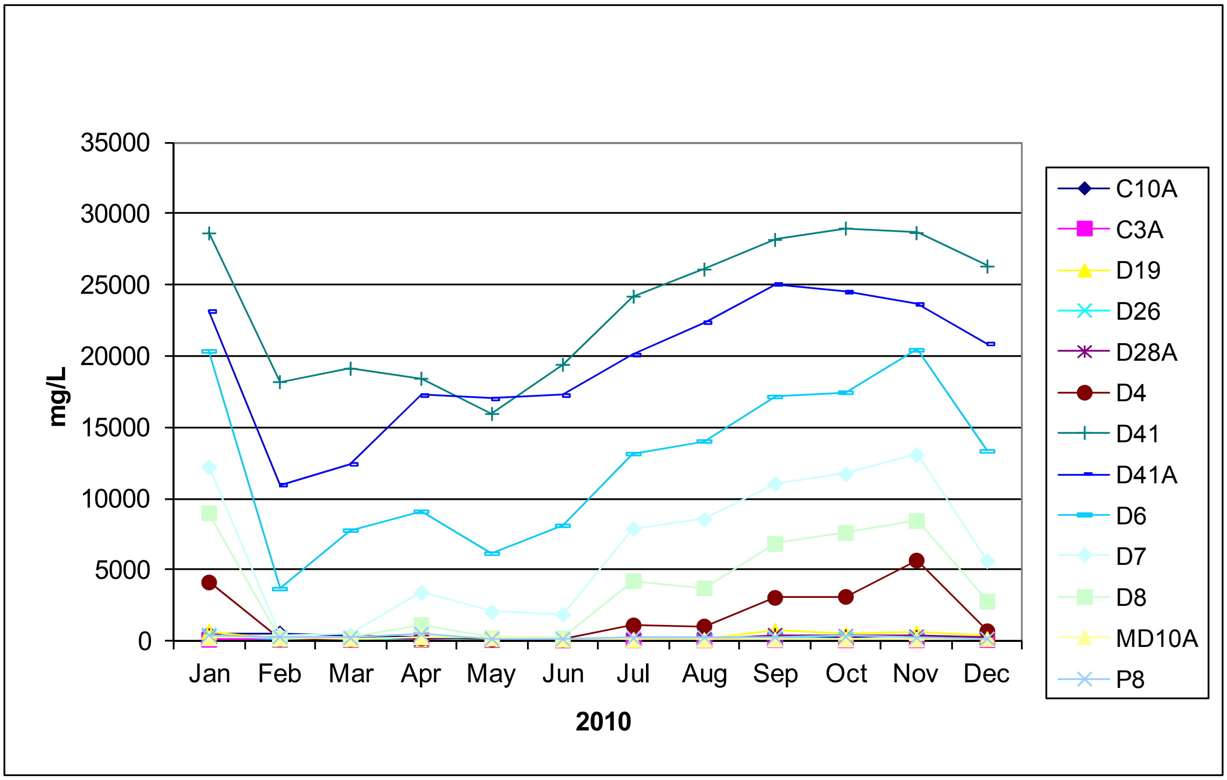

Figure 3-23 TDS by station, 2010

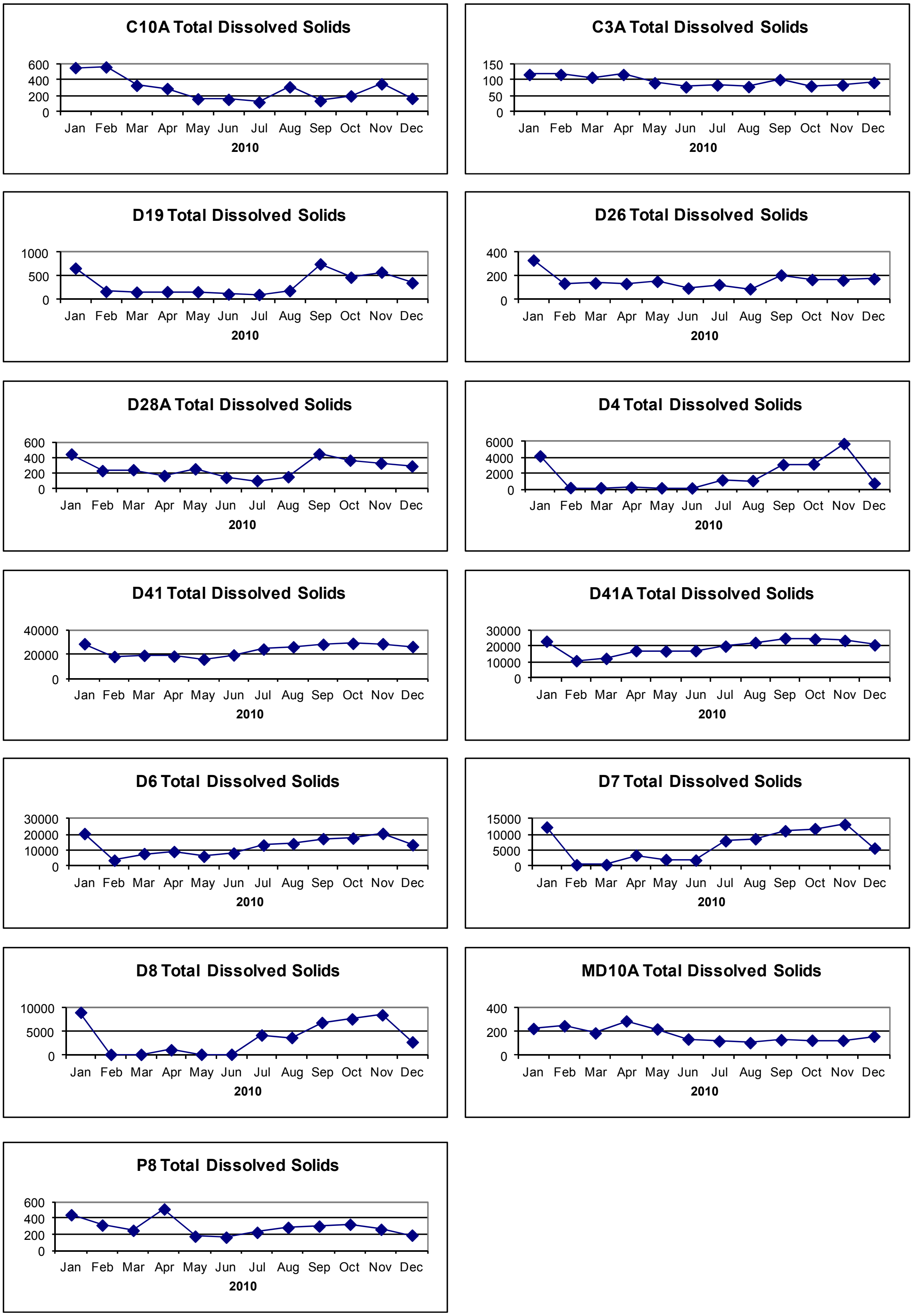

Figure 3-24 TSS comparisons, 2010

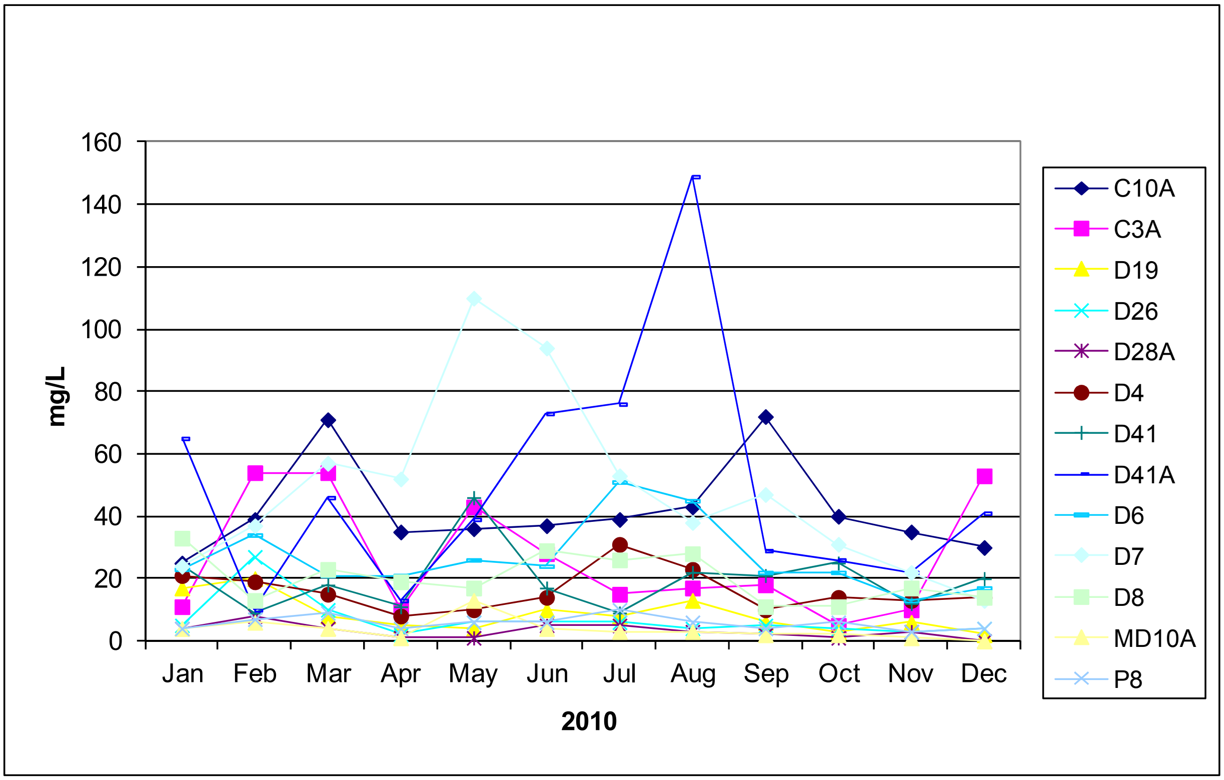

Figure 3-25 TSS by station, 2010

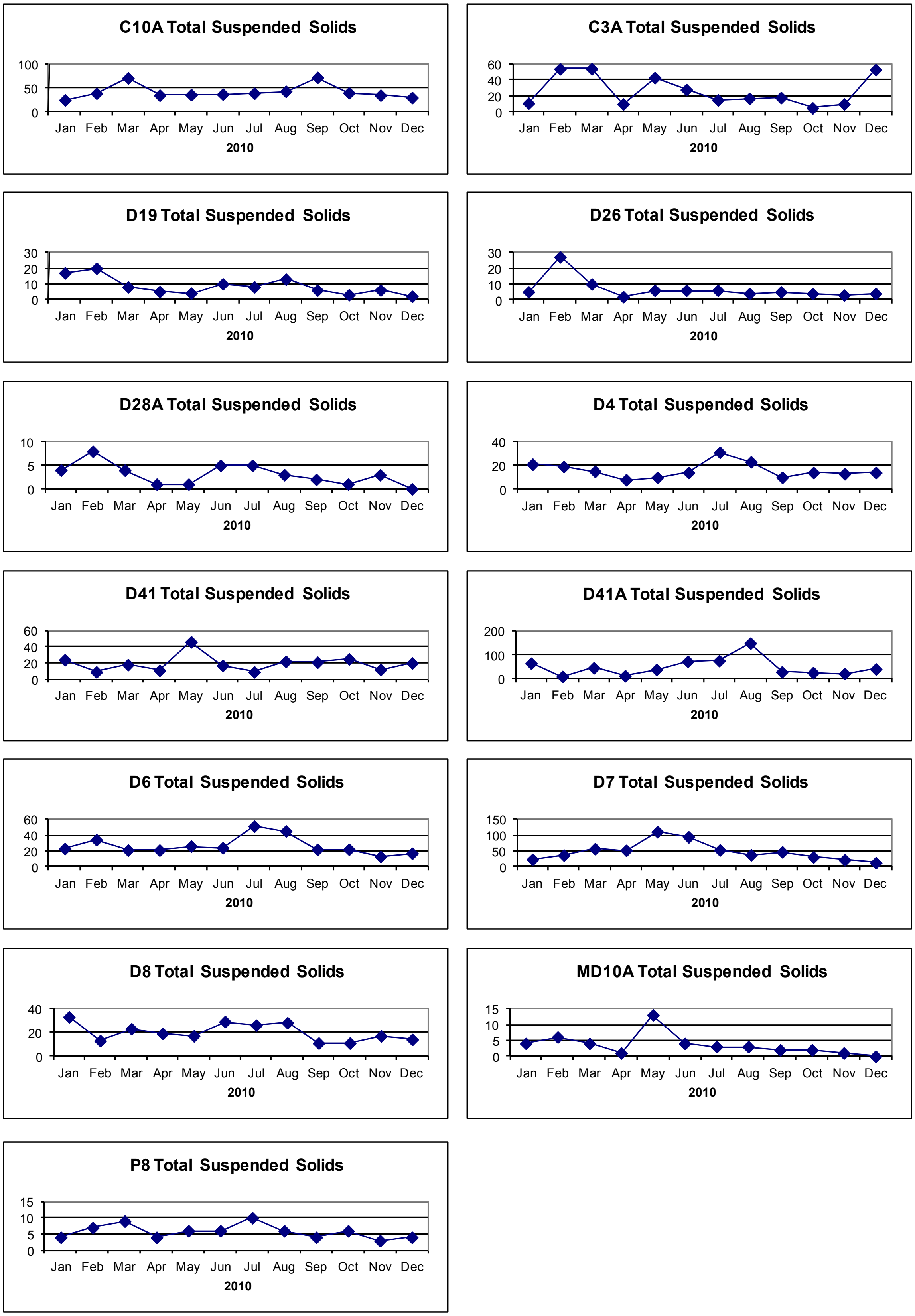

Figure 3-26 VSS comparisons, 2010

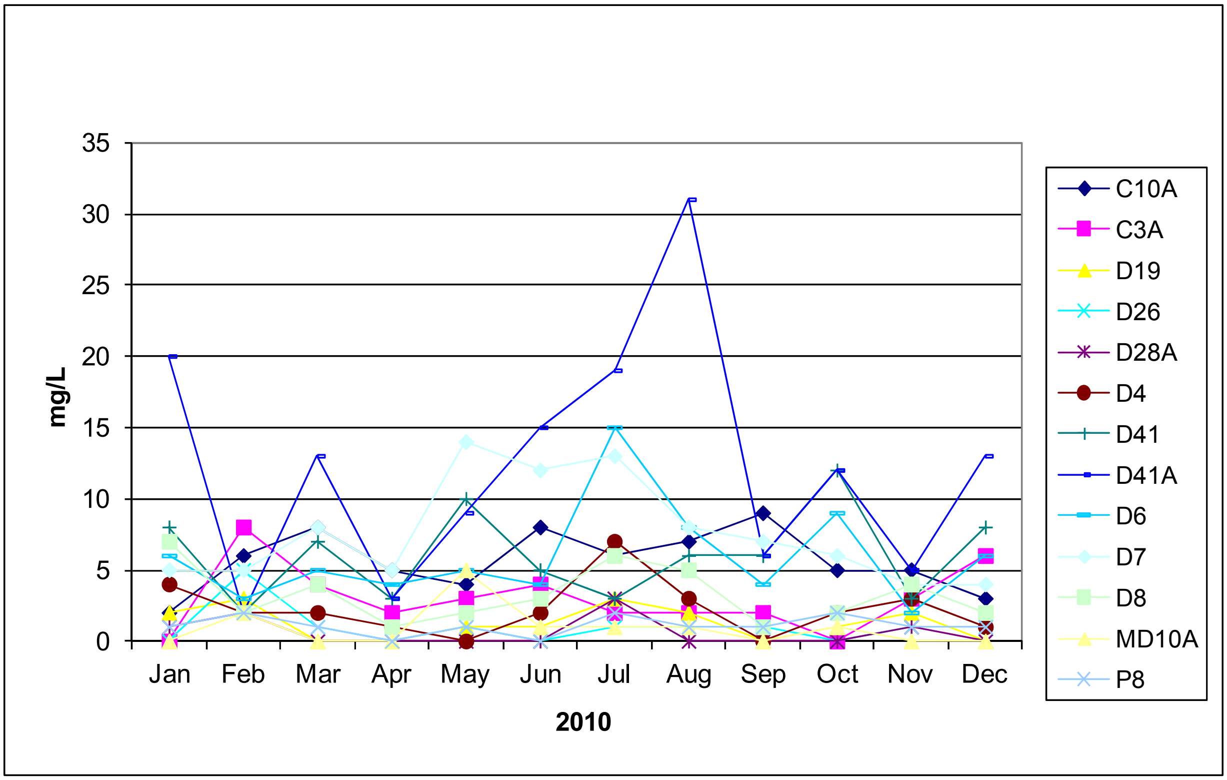

Figure 3-27 VSS by station, 2010

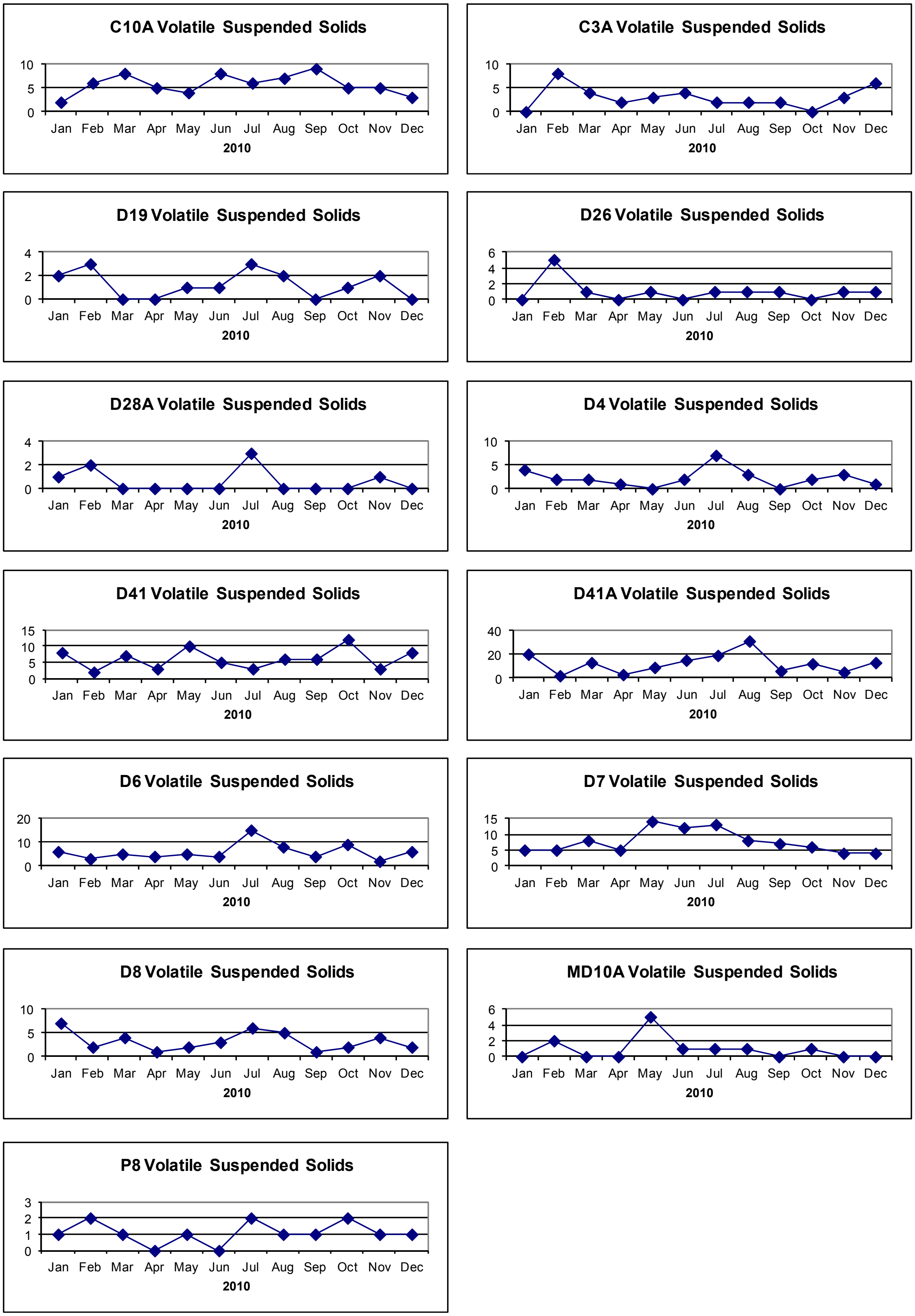

Figure 3-28 Silica comparisons, 2010

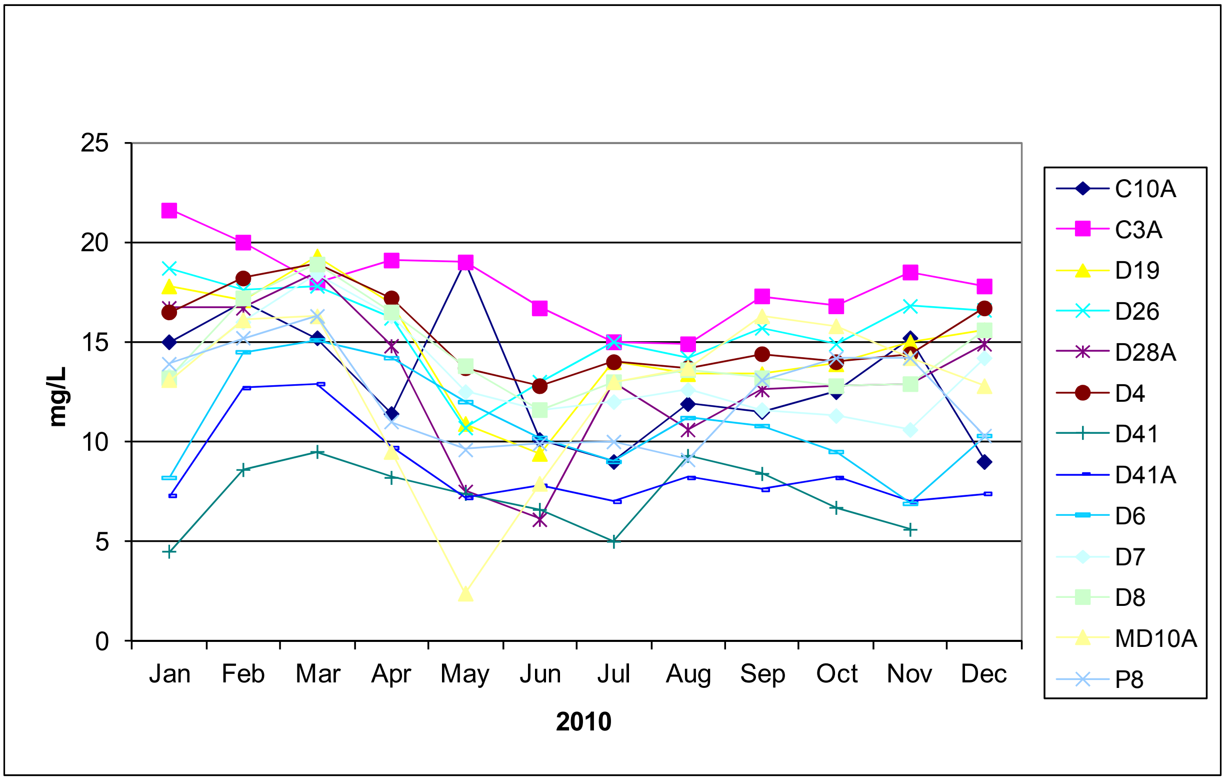

Figure 3-29 Silica by station, 2010

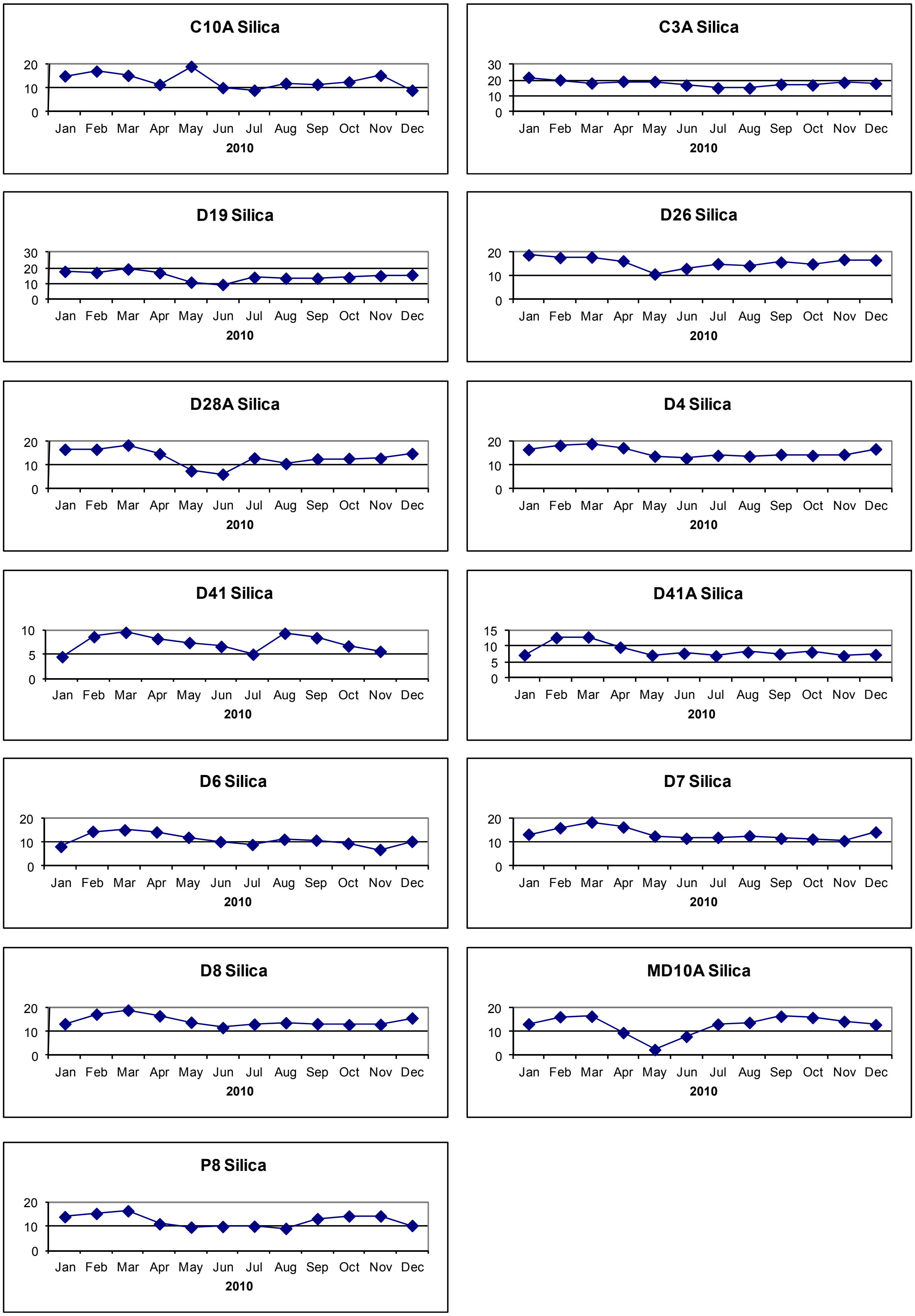

Figure 3-30 Chloride comparisons, 2010

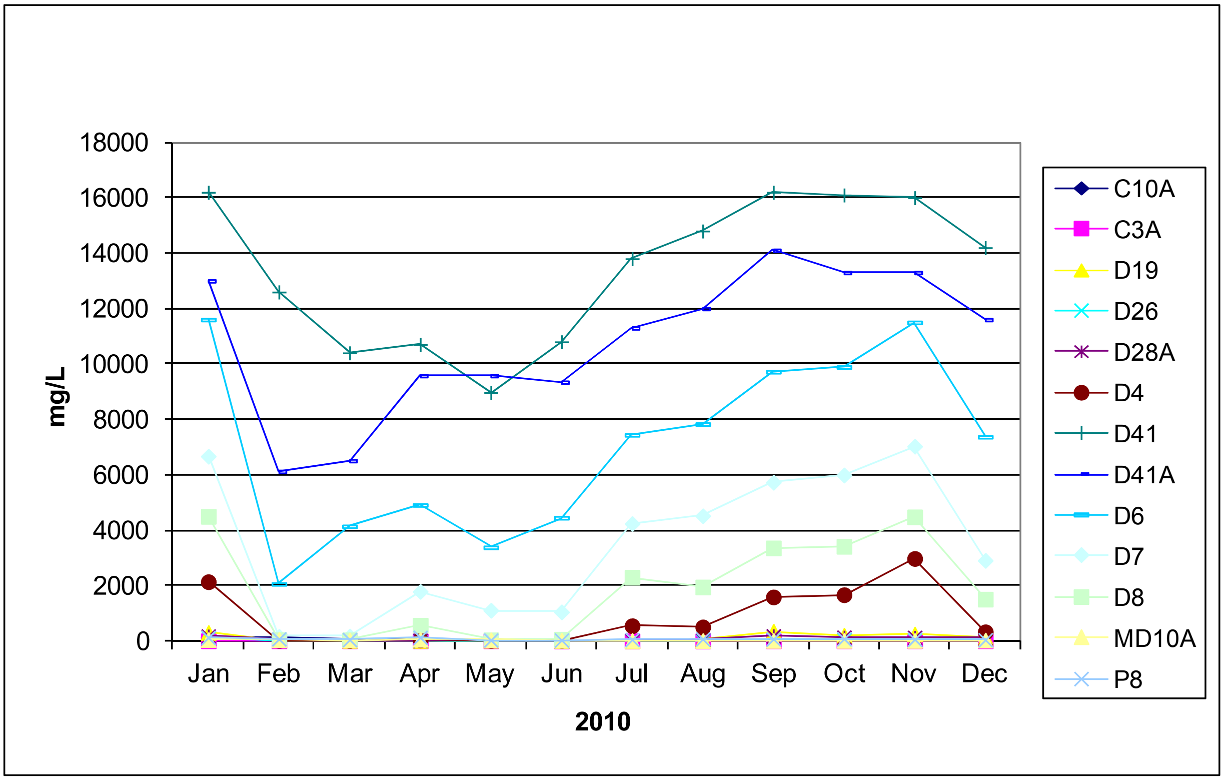

Figure 3-31 Chloride by station, 2010

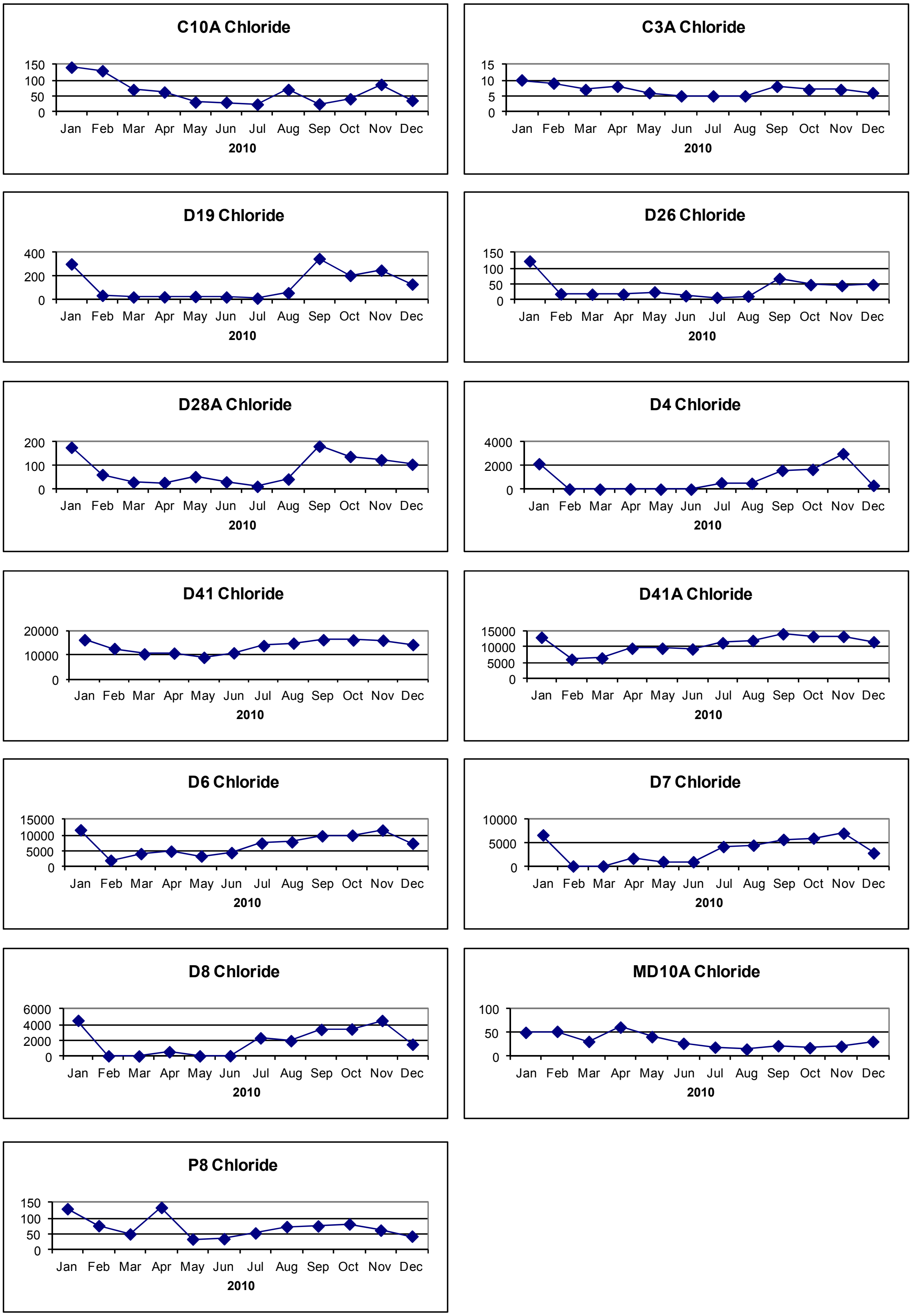

Table 3-1 Water quality parameters measured

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*

Appendix

Figures And Tables

Chapter 4. Phytoplankton and Chlorophyll *a*

Introduction

The Department of Water Resources (DWR) and the US Bureau of Reclamation (USBR) are required by Water Right Decision 1641 (D-1641) to collect phytoplankton and chlorophyll *a* samples in order to monitor algal community composition and biomass at selected sites in the upper San Francisco Estuary (estuary). The thirteen sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the estuary to broad, estuarine bays. This chapter describes the results of these monitoring efforts for calendar year 2010.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes which influence water quality in the Estuary. Phytoplankton are small, free-floating organisms that occur as unicellular, colonial or filamentous forms (Horne and Goldman 1994). Phytoplankton can affect pH, dissolved oxygen, color, taste and odor, and under certain conditions, some species can develop noxious blooms resulting in animal deaths and human illness (Carmichael, 1981). In freshwater, the cyanobacteria, or blue-green algae (class Cyanophyceae), are responsible for producing toxic blooms, particularly in waters that are polluted with phosphates (van den Hoek et al., 1995).

In addition to being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can be useful in assessing water quality (Gannon and Stemberger, 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes; hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (APHA, 1998). However, because of their transient nature, patchiness, and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited and should be interpreted in conjunction with physiochemical and other biological data (APHA, 1998).

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

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

Phytoplankton biomass and the resulting chlorophyll *a* concentrations in some areas of the Estuary may be influenced by extensive filtration of the water column by the introduced Asian clam, *Corbula amurensis* (Alpine and Cloern, 1992). Well-established benthic populations of *C. amurensis* in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll *a* concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern, 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed. Phytoplankton identification and enumeration were performed by EcoAnalysts, Inc.[1] according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and turbidity of the sample. Aliquots are enumerated at a magnification of 630X using a Leica DMIL inverted microscope. For each settled aliquot, phytoplankton in randomly chosen transects are counted. Taxa are enumerated as they appear along the transects. A minimum of 400 total algal units are counted, and a minimum of 100 algal units of the dominant taxon. For taxa that are in filaments or colonies, the number of cells per filament or colony is recorded. Organism counts for each sample can be converted to organisms/mL using the following formula:

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

where:

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

This simplifies to:

Organisms = C / cV

where:

cV = Counted volume (mL)

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

The 10 most common genera were determined by summing the number of organisms per milliliter across all stations and months for each genus.[1]

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 13 monitoring sites throughout the upper Estuary (Figure 4-1) using a submersible pump from 1 meter below the water's surface.

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

Approximately 500 mL of water was passed through a 47 mm diameter glass-fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to the Standard Methods (APHA 1998) spectrophotometric procedure. Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1998).

Results

Phytoplankton Identification

Of the thirteen groups identified, centric diatoms, pennate diatoms, green algae, cryptomonad flagellates, and cyanobacteria constituted 99.2% of the organisms collected (Figure 4-2; "Other Taxa" is the sum of the last eight groups, as they are too rare to appear individually on the graph).

All organisms collected in 2010 fell into these thirteen categories:

- Centric diatoms (class Coscinodiscophyceae)
- Pennate Diatoms (classes Bacillariophyceae and Fragilariophyceae)
- Green algae (classes Chlorophyceae, Ulvophyceae and Zygnematophyceae)
- Cryptomonad flagellates (class Cryptophyceae)
- Cyanobacteria (class Cyanophyceae)
- Haptophyte flagellates (class Haptophyceae)
- Dinoflagellates (class Dinophyceae)
- Euglenoid flagellates (class Euglenophyceae)
- Ciliates (classes Kinetofragminophora and Spirotrichea)
- Chrysophyte flagellates (class Chrysophyceae)
- Little green algal balls (class unknown)
- Kathablepharid flagellates (class Cryptophycophyta incertae sedis)
- Silico-flagellates (class Dictyochophyceae)

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

The 10 most common genera collected in 2010 were:

- *Cyclotella* (centric diatom; class Coscinodiscophyceae)
- *Melosira* (centric diatom; class Coscinodiscophyceae)
- *Fragilaria* (pennate diatom; class Fragilariophyceae)
- *Nitzschia* (pennate diatom; class Bacillariophyceae)
- *Cryptomonas* (cryptomonad flagellate; class Cryptophyceae)
- *Chroomonas* (cryptomonad flagellate; class Cryptophyceae)
- *Monoraphidium* (green alga; class Chlorophyceae)
- *Cocconeis* (pennate diatom; class Bacillariophyceae)
- *Oscillatoria* (cyanobacterium; class Cyanophyceae)
- *Chlamydomonas* (green alga; class Chlorophyceae)

A list of all phytoplankton genera identified, their shape codes, and the total number counted can be found in the Phytoplankton Dictionary available online at:
http://www.iep.ca.gov/emp/Metadata/Phytoplankton/phytoplankton_dictionary.html

Pigment Concentrations

Some stations showed seasonal patterns in chlorophyll *a* concentration, while others did not. Most maxima occurred in spring and summer, while minima usually occurred in fall or winter. (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 2010, 94.2% (147 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 9 samples with chlorophyll *a* concentrations above 10 µg/L, seven were from the south Delta (C10A), one was from the east Delta (MD10A), and one was from Suisun Bay (D7). The mean chlorophyll *a* concentration for all samples in 2010 was 3.21 µg/L, and the median value was 1.76 µg/L. The maximum chlorophyll *a* concentration in 2010 was 59.20 µg/L, recorded in August 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 December, and D6 (Suisun Bay), where the maximum occurred in September. The minimum chlorophyll *a* concentration was 0.38 µg/L, recorded in March in the lower San Joaquin River (D26). This was the only minimum recorded in the spring; the rest of the stations recorded their minima in fall and winter.

Pheophytin *a* concentrations varied among stations, with some stations remaining relatively constant, while others had peaks during one or more months (Table 4-2 and Figures 4-3 through 4-15). The mean pheophytin *a* concentration for all samples in 2010 was 1.42 µg/L, and the median value was 0.88 µg/L. The maximum pheophytin *a* concentration was 13.50 µg/L, recorded at C10A (south Delta) in August. Pheophytin *a* maxima were recorded in spring and summer at most stations except for C3A (north Delta) and D6 (Suisun Bay); both recorded their maxima in winter. The minimum pheophytin *a* concentration was 0.20 µg/L, recorded at D41 (San Pablo Bay) in November. Pheophytin *a* minima were recorded in fall and winter at all stations except D4 (lower Sacramento River), D19 (central Delta), D26 (lower San Joaquin River), and D28A (central Delta). These four stations recorded minima 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. For the phytoplankton composition graphs, very rare taxa have been lumped together as "Other Taxa" to improve the clarity of the graphs. The affected taxa are noted under each individual station's results. All chlorophyll *a* and pheophytin *a* data can be found at: http://www.iep.ca.gov/emp/data_index.html.

Site C3A: North Delta

There was no seasonality in chlorophyll *a;* values were low (below 3.5 µg/L) and stable all year. The highest concentration was recorded in December (3.31 µg/L), and the lowest was recorded in November (0.67 µg/L) (Figure 4-3a, Table 4-2). The mean and median were identical (1.70 µg/L).

Pheophytin *a* showed a pattern similar to chlorophyll *a* (Figure 4-3a). The maximum (4.31 µg/L) was recorded in December, and the minimum (0.61 µg/L) was recorded in October (Table 4-2). The mean and median were similar (1.68 µg/L and 1.71 µg/L, respectively).

Pennate diatoms dominated most of the year with extremely large blooms in January and October (Figure 4-3b; "Other Taxa" are chrysophytes, euglenoids and haptophytes). The November phytoplankton sample was not counted because the sample was damaged during shipment to the taxonomist.

Site C10A: South Delta

The maximum chlorophyll *a* concentration for this station (and the year) was recorded in August (59.20 µg/L); the minimum was in December (2.45 µg/L) (Figure 4-4a, Table 4-2). The peak in chlorophyll *a* in August skewed the mean (14.62 µg/L) higher than the median (10.90 µg/L). Chlorophyll *a* still showed a slight seasonal pattern despite this large peak (Figure 4-4a).

The largest pheophytin *a* value for the year was also recorded at this station in August (13.50 µg/L) (Figure 4-4a; Table 4-2). The minimum occurred in December (2.49 µg/L). The August peak skewed the mean (5.59 µg/L) higher than the median (5.16 µg/L)(Table 4-2). Pheophytin *a* did not show any seasonality (Figure 4-4a).

There were large blooms of centric diatoms in February and August; the August bloom also included green algae, pennate diatoms and cyanobacteria (Figure 4-4b; "Other Taxa" are chrysophytes, haptophytes, and little green algal balls).

Site P8: South Delta

Chlorophyll *a* showed a strong seasonal pattern, with highest values recorded in spring and summer (Figure 4-5a). The maximum was recorded in August (6.41 µg/L), and the minimum in February (0.54 µg/L) (Table 4-2). The mean (2.29 µg/L) was slightly higher than the median (2.02 µg/L).

Pheophytin *a* showed a slight seasonal pattern (Figure 4-5a). The mean and median were similar (1.10 and 1.01 µg/L, respectively) (Table 4-2). The maximum was 1.82 µg/L in April, and the minimum was 0.49 µg/L in September.

A large bloom of cryptomonads and green algae occurred in August; phytoplankton densities were much lower the rest of the year (Figure 4-5b; "Other Taxa" are dinoflagellates, euglenoids, haptophytes, and little green algal balls).

Site MD10A: East Delta

Chlorophyll *a* did not really show a seasonal pattern; values were low and stable all year, except for the maximum of 17.09 µg/L in May (Figure 4-6a). The May peak skewed the mean (3.49 µg/L) higher than the median (2.37 µg/L) (Table 4-2). The minimum was recorded in November (0.89 µg/L).

Pheophytin *a* was similar to chlorophyll *a*, with no clear seasonal pattern (Figure 4-6a). The maximum of 8.33 µg/L in May skewed the mean (1.76 µg/L) higher than the median (1.07 µg/L) (Table 4-2). The minimum was recorded in September (0.61 µg/L).

An extremely large bloom of centric diatoms occurred in May (Figure 4-6b; "Other Taxa" are dinoflagellates, haptophytes, and little green algal balls). A smaller bloom of green algae occurred in August. Phytoplankton densities were comparatively lower the rest of the year.

Site D26: Lower San Joaquin River

Chlorophyll *a* values were low (below 3 µg/L) at this station all year except for the maximum of 6.09 µg/L in May (Figure 4-7a). The minimum was 0.38 µg/L in March (Table 4-2). The peak in May skewed the mean (1.63 µg/L) slightly higher than the median (1.33 µg/L).

Pheophytin *a* values were extremely low (most values below 1 µg/L) all year (Figure 4-7a). The maximum was 1.61 µg/L in May, and the minimum was 0.46 µg/L in April (Table 4-2). The mean and median were similar (0.77 µg/L and 0.68 µg/L, respectively).

There was a large bloom of centric diatoms in May (Figure 4-7b: "Other Taxa" are ciliates, dinoflagellates, euglenoids, haptophytes, and little green algal balls); phytoplankton densities were low the rest of the year.

Site D19: Central Delta

Chlorophyll *a* concentrations showed a slight seasonal pattern (Figure 4-8a). The maximum of 7.61 µg/L occurred in May; the minimum was 0.61 µg/L in February (Table 4-2). The peak in May skewed the mean higher than the median (2.03 and 1.38, respectively).

Pheophytin *a* concentrations did not show a seasonal pattern, with all values below 2 µg/L (Figure 4-8a). The maximum was recorded in May (1.97 µg/L), and the minimum was recorded in March (0.41 µg/L) (Table 4-2). The mean and median were similar (1.00 µg/L and 0.92 µg/L, respectively).

A large bloom of centric diatoms occurred in May (Figure 4-8b; "Other Taxa" are ciliates, dinoflagellates, euglenoids, and little green algal balls); phytoplankton densities were low the rest of the year.

Site D28A: Central Delta

Chlorophyll *a* did not show a seasonal pattern; the peak in May was the maximum for the year (3.84 µg/L) (Figure 4-9, Table 4-2). The minimum of 0.62 µg/L was recorded in February. The May peak skewed the mean (1.40 µg/L) higher than the median (1.10 µg/L).

Pheophytin *a* values were low all year, with most values below 1 µg/L (Figure 4-9a). The mean and median were nearly identical (0.75 µg/L and 0.74 µg/L, respectively) (Table 4-2). The maximum of 1.09 µg/L was recorded in May; the minimum of 0.44 µg/L was recorded in March.

A bloom of centric diatoms in May was followed by a larger bloom of cryptomonads in October (Figure 4-9b; "Other Taxa" are euglenoids and little green algal balls). Pennate diatoms and green algae were also seen during the October cryptomonad bloom.

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 5.19 µg/L in May; the minimum was 0.94 µg/L in February (Table 4-2). The mean was higher than the median (2.34 µg/L and 2.09 µg/L, respectively).

Pheophytin *a* also showed a seasonal pattern, with peaks in spring and summer (Figure 4-10a). The maximum (2.00 µg/L) was recorded in July; the minimum (0.54 µg/L) was recorded in April (Table 4-2). The mean was 0.94 µg/L; the median was 0.83 µg/L.

A bloom of centric diatoms occurred in May; a larger bloom of pennate diatoms occurred in November, accompanied by centric diatoms (Figure 4-10b; "Other Taxa" are euglenoids, haptophytes, and little green algal balls).

Site D6: Suisun Bay

Chlorophyll *a* did not show a seasonal pattern; values were low (below 3 µg/L) all year (Figure 4-11a). The maximum was 2.69 µg/L in September; the minimum was 0.74 µg/L in February (Table 4-2). The mean and median were similar (1.52 µg/L and 1.49 µg/L, respectively).

Pheophytin *a* also did not show a seasonal pattern; values were extremely low (excepting the maximum, all below 1 µg/L) (Figure 4-11a). The maximum was recorded in February (1.00 µg/L) and the minimum was recorded in January (0.24 µg/L) (Table 4-2). The mean and median were nearly identical (0.65 µg/L and 0.68 µg/L, respectively).

Here, a centric diatom bloom occurred in September, with a larger bloom of cryptomonads in November (Figure 4-11b; "Other Taxa" are cyanobacteria, euglenoids, haptophytes, silico-flagellates, and little green algal balls). Phytoplankton densities were extremely low (less than 500 organisms per mL) the rest of the year.

Site D7: Suisun Bay

Chlorophyll *a* showed a strong seasonal pattern, with higher values in spring and summer. The maximum was 12.28 µg/L in June, and the minimum was 0.64 µg/L in December (Figure 4-12a, Table 4-2). The peaks in spring and summer skewed the mean (3.57 µg/L) much higher than the median (1.62 µg/L).

Pheophytin *a* showed a seasonal pattern as well; the maximum was 5.78 µg/L in May (Figure 4-12a, Table 4-2). The minimum (0.41 µg/L) was recorded in December (Table 4-2). The mean was 1.82 µg/L; the median was 1.26 µg/L.

There was a large bloom of pennate diatoms in June; phytoplankton densities were low the rest of the year (Figure 4-12b; "Other Taxa" are cyanobacteria, euglenoids, haptophytes, and little green algal balls).

Site D8: Suisun Bay

Chlorophyll *a* showed a strong seasonal pattern; the maximum of 6.84 µg/L was recorded in May, and the minimum was 0.57 µg/L in December (Figure 4-13a, Table 4-2). The peak in May skewed the mean (2.43 µg/L) higher than the median (1.34 µ/L).

Pheophytin *a* showed no pattern; values were extremely low (below 2 µg/L) all year (Figure 4-13a). The maximum (1.76 µg/L) was recorded in May; the minimum (0.32 µg/L) was recorded in November (Table 4-2). The mean was higher than the median (0.78 µg/L and 0.67 µg/L, respectively).

A large bloom of centric diatoms in May was accompanied by smaller blooms of pennate diatoms and green algae (Figure 4-13b; "Other Taxa" are cyanobacteria, haptophytes, and little green algal balls).

Site D41: San Pablo Bay

Chlorophyll *a* did not show a seasonal pattern; values were stable, and below 4 µg/L all year (Figure 4-14a). The maximum occurred in June (3.72 µg/L) (Table 4-2). The minimum of 1.93 µg/L was recorded in January. The mean and median were nearly identical (2.78 µg/L and 2.80 µg/L, respectively) (Table 4-2).

Pheophytin *a* also did not show a pattern; the maximum of 1.28 in May was the only value above 1 µg/L (Figure 4-14a, Table 4-2). The minimum of 0.20 µg/L was recorded in November (Table 4-2). The mean and median were very close (0.64 µg/L and 0.61 µg/L, respectively).

Blooms of cryptomonads occurred in February, September and November (Figure 4-14b; "Other Taxa" are cyanobacteria, euglenoids, silico-flagellates, and little green algal balls). Smaller blooms of other phytoplankton occurred throughout the year.

Site D41A: San Pablo Bay

Chlorophyll *a* showed a slight seasonal pattern; there were peaks in spring and summer. The maximum (4.13 µg/L) occurred in May (Figure 4-15a, Table 4-2). The minimum of 0.78 µg/L was recorded in February. The mean (1.97 µg/L) was slightly higher than the median (1.73 µg/L) (Table 4-2).

Pheophytin *a* also showed a slight seasonal pattern; the maximum of 2.07 was recorded in June (Figure 4-15a, Table 4-2). The minimum of 0.21 µg/L was recorded in November (Figure 4-15a, Table 4-2). The mean was slightly higher than the median (0.99 µg/L and 0.82 µg/L, respectively).

A large bloom of cryptomonads in November was accompanied by centric diatoms, dinoflagellates, and pennate diatoms (Figure 4-15b; "Other Taxa" are cyanobacteria, euglenoids, haptophytes, kathablepharids, silico-flagellates, and little green algal balls). Phytoplankton densities were low the rest of the year.

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at 13 sites in 2010. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following thirteen categories: centric diatoms, pennate diatoms, green algae, cryptomonad flagellates, cyanobacteria, haptophyte flagellates, dinoflagellates, euglenoid flagellates, ciliates, chrysophytes, little green algal balls, kathablepharid flagellates, and silico-flagellates. The ten most common genera were *Cyclotella, Melosira, Fragilaria, Nitzschia, Cryptomonas, Chroomonas, Monoraphidium, Cocconeis, Oscillatoria,* and *Chlamydomonas.*

Chlorophyll *a* concentrations showed a seasonal pattern at some stations, but not others; values ranged from 0.38 µg/L to 59.20 µg/L. Pheophytin *a* concentrations mainly did not show a seasonal pattern; values ranged from 0.20 µg/L to 13.50 µg/L. Despite sporadic peaks at some stations, chlorophyll *a* concentrations overall were relatively low when compared with the historical data.

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Chapter 4 Appendix

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

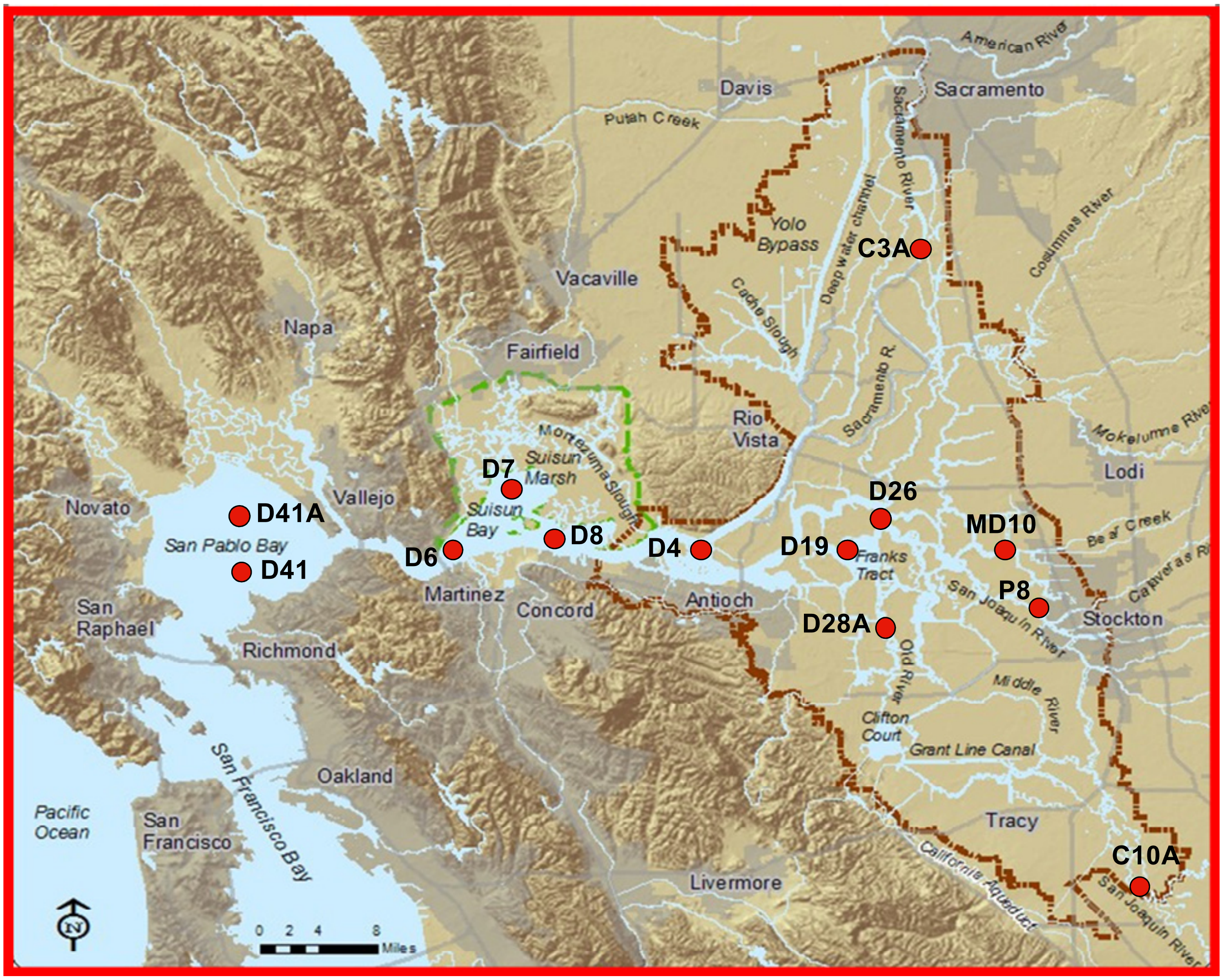

Figure 4-2 Percent of phytoplankton composition by group, 2010

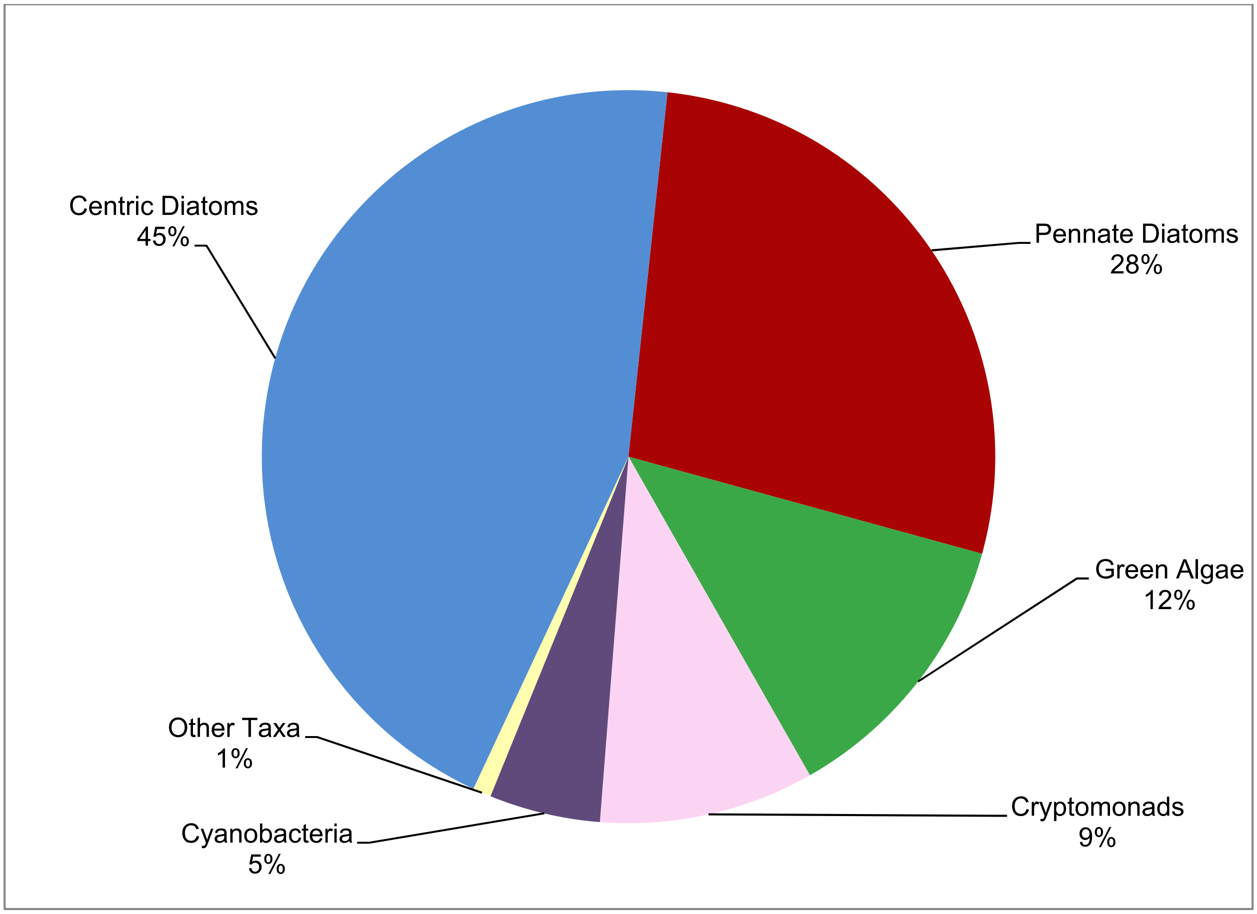

Figure 4-3a. Pigment concentrations at C3A, 2010

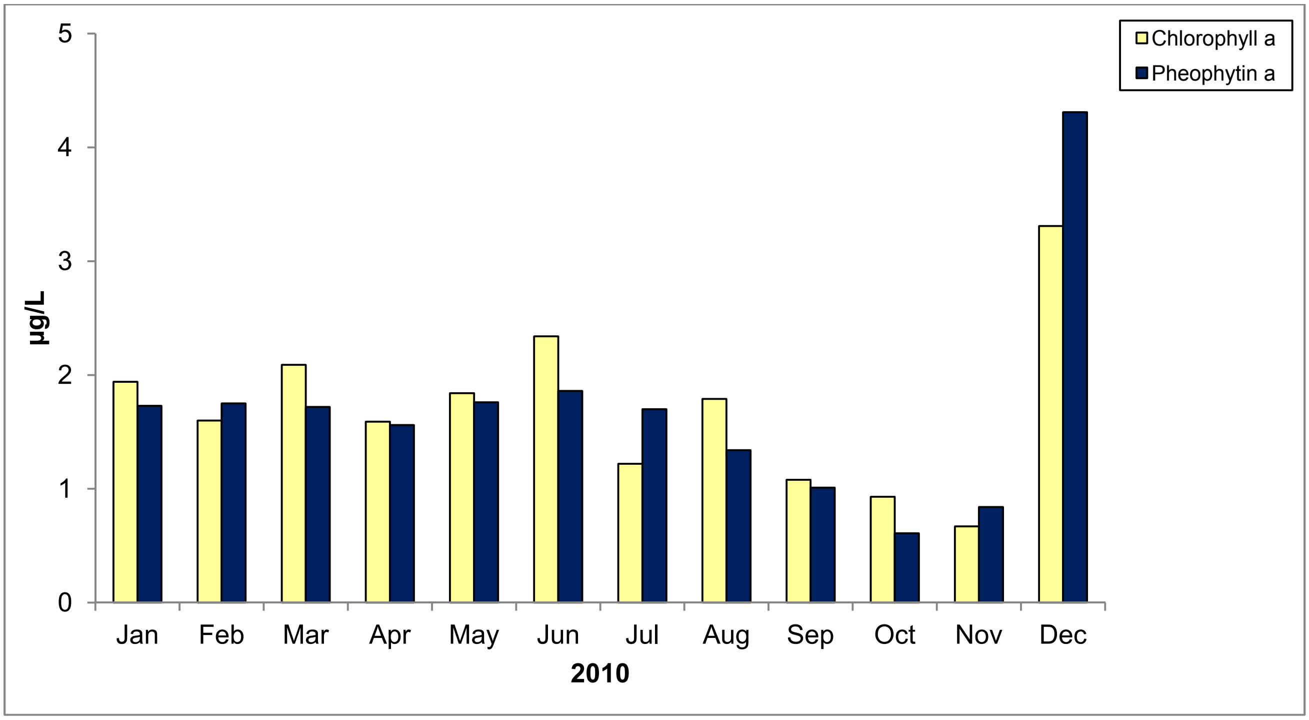

Figure 4-3b. Phytoplankton composition at C3A, 2010

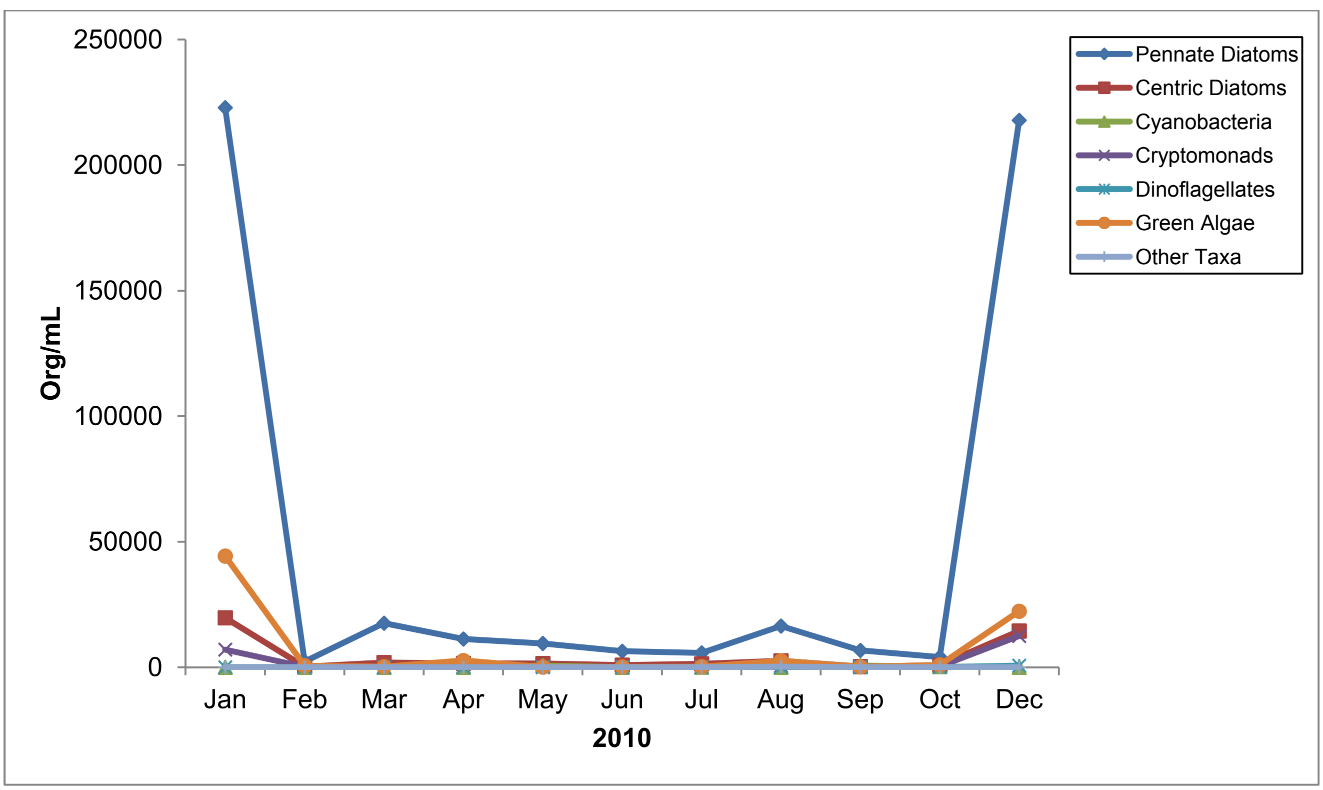

Figure 4-4a. Pigment concentrations at C10A, 2010

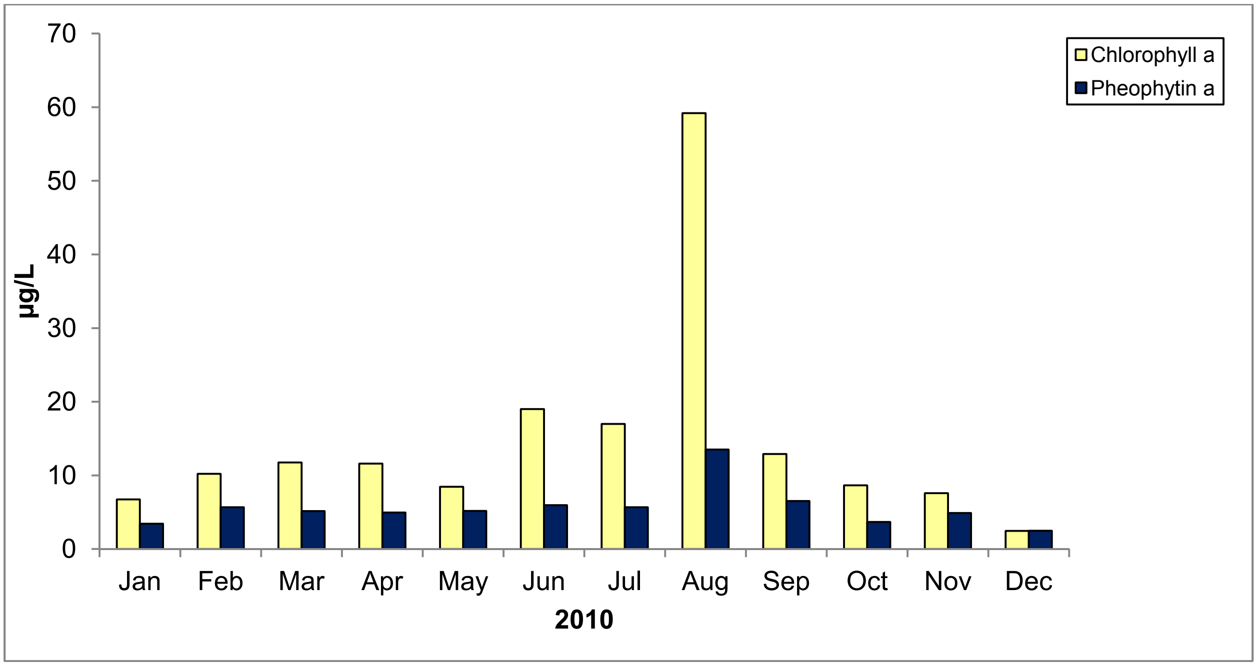

Figure 4-4b. Phytoplankton composition at C10A, 2010

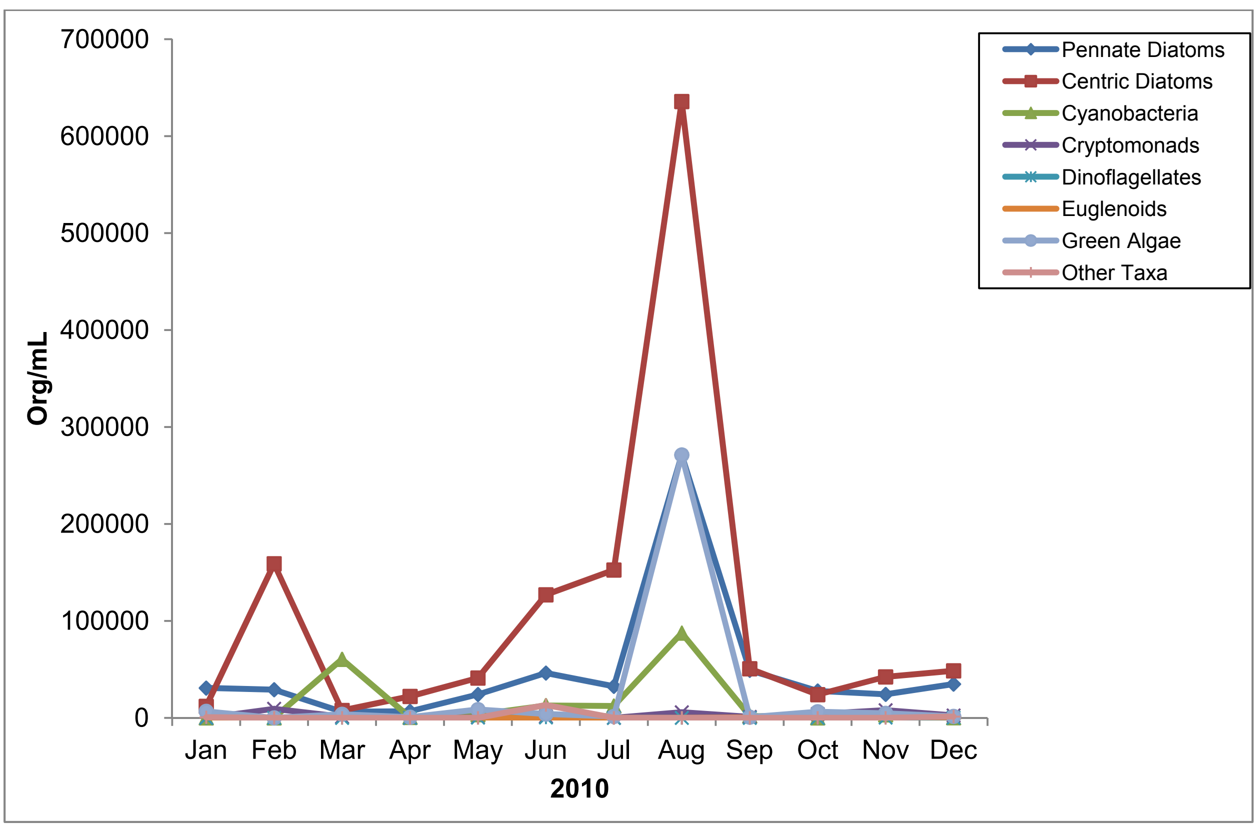

Figure 4-5a. Pigment concentrations at P8, 2010

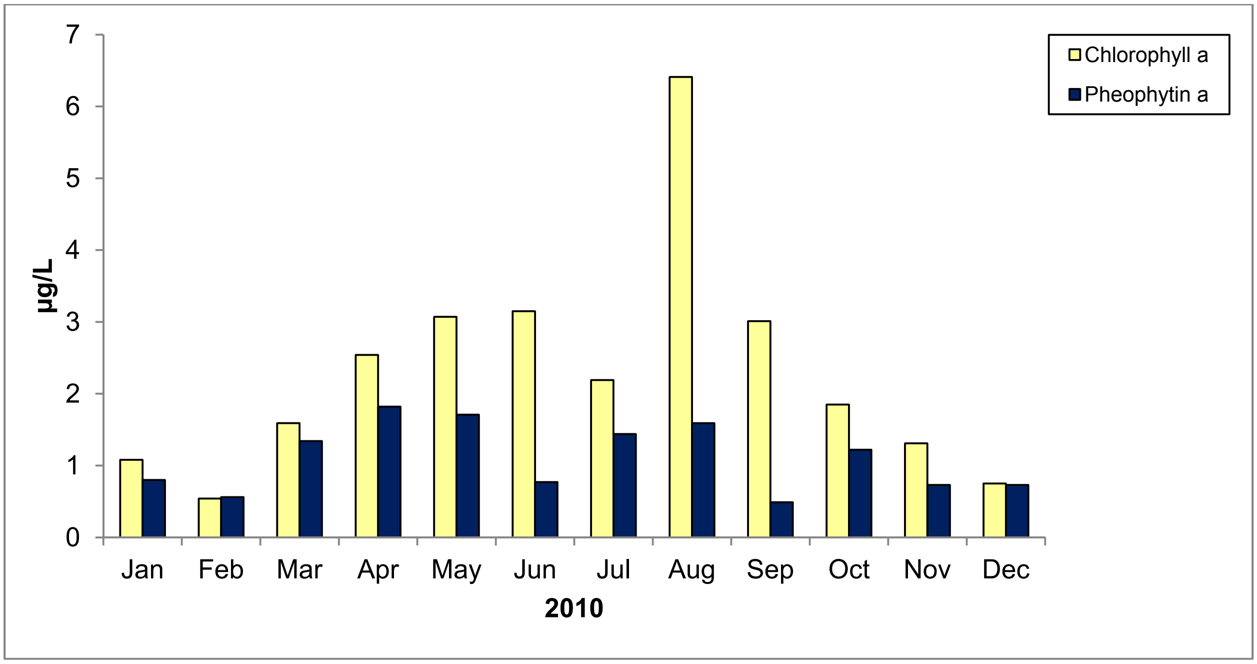

Figure 4-5b. Phytoplankton composition at P8, 2010

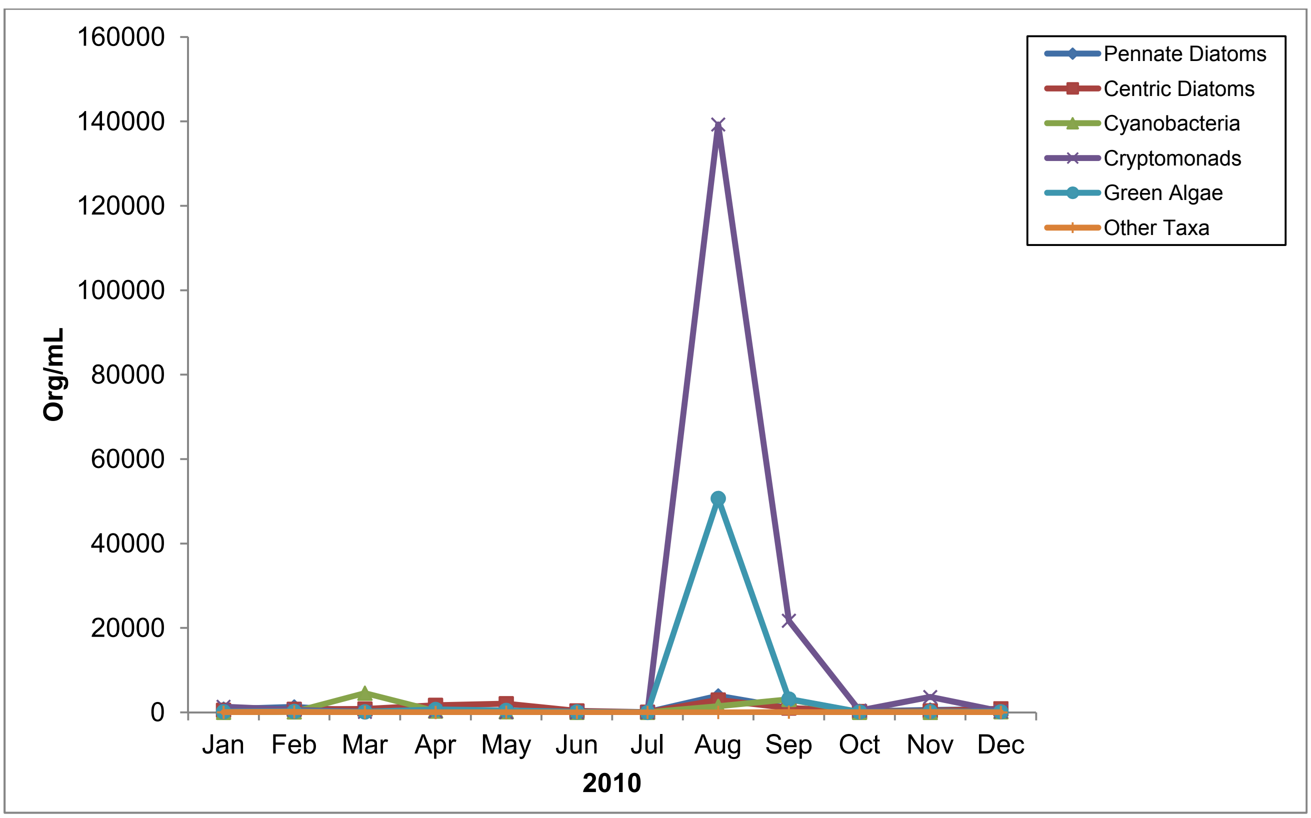

Figure 4-6a. Pigment concentrations at MD10A, 2010

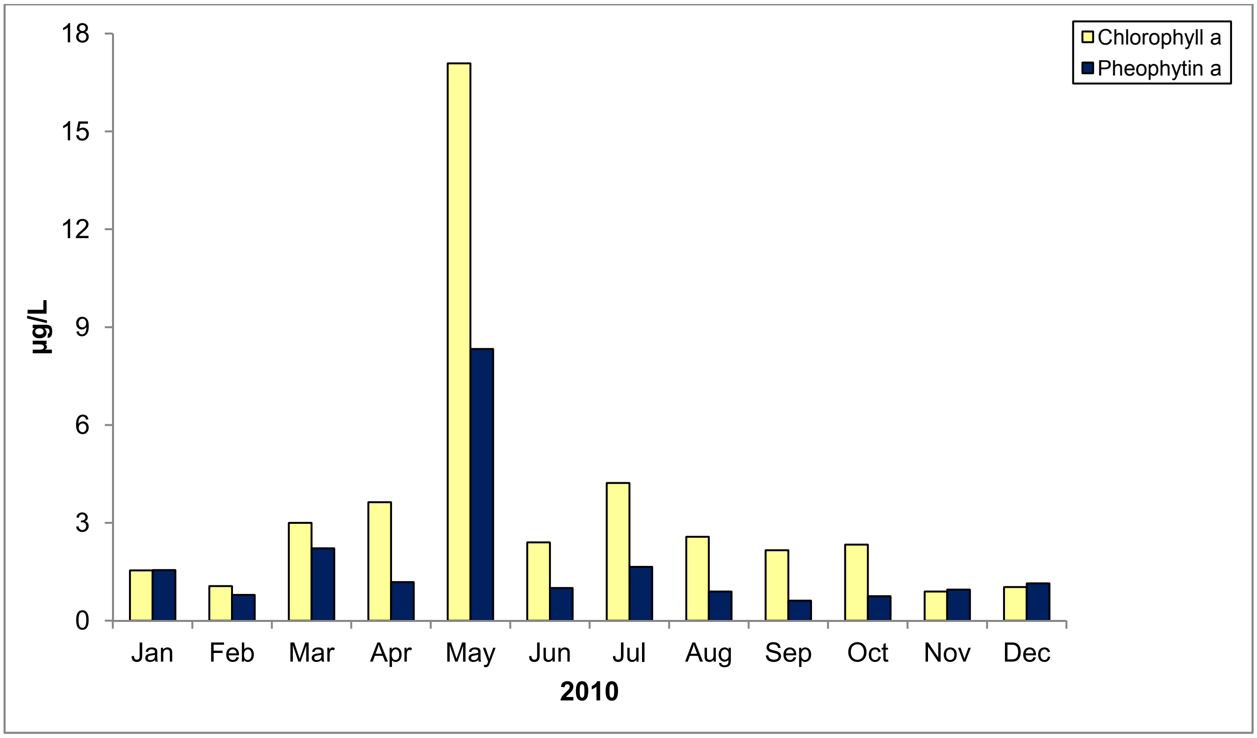

Figure 4-6b. Phytoplankton composition at MD10A, 2010

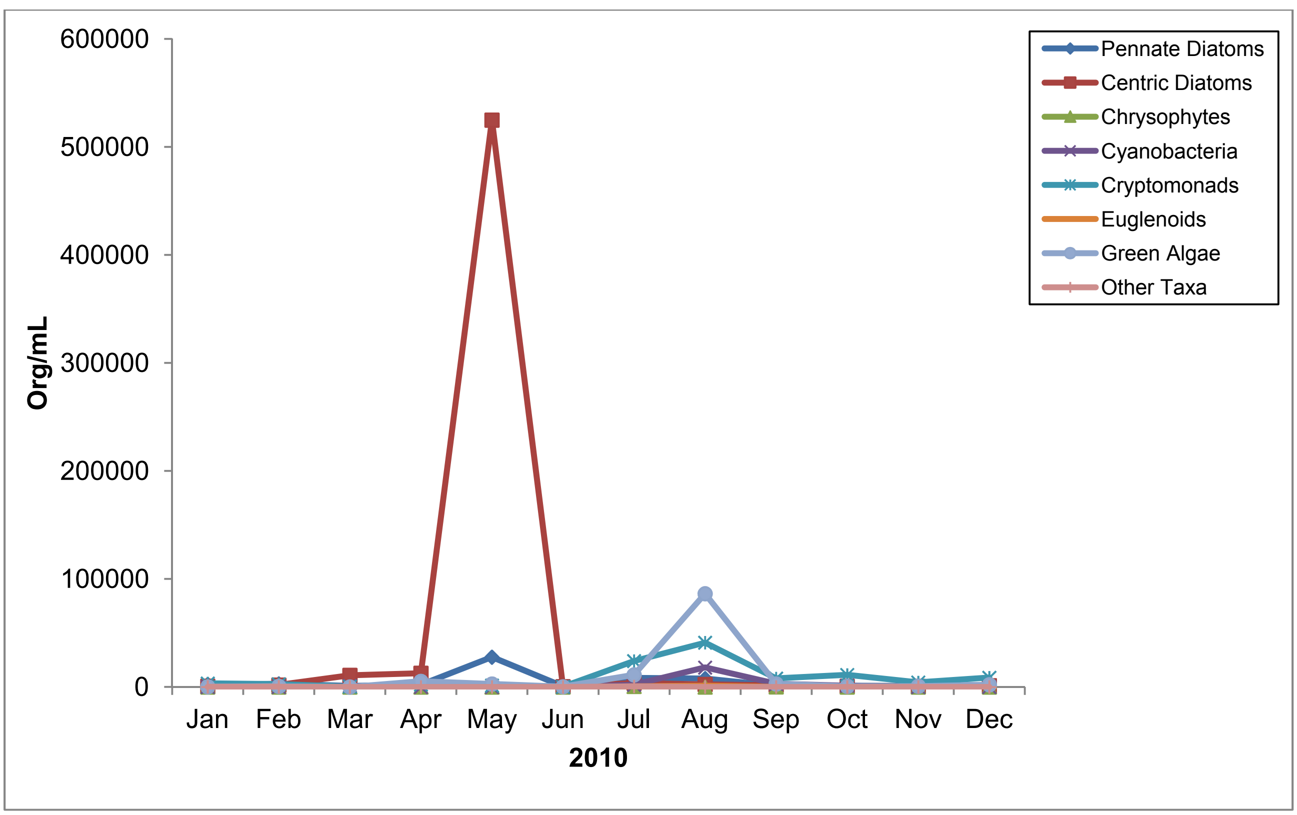

Figure 4-7a. Pigment concentrations at D26, 2010

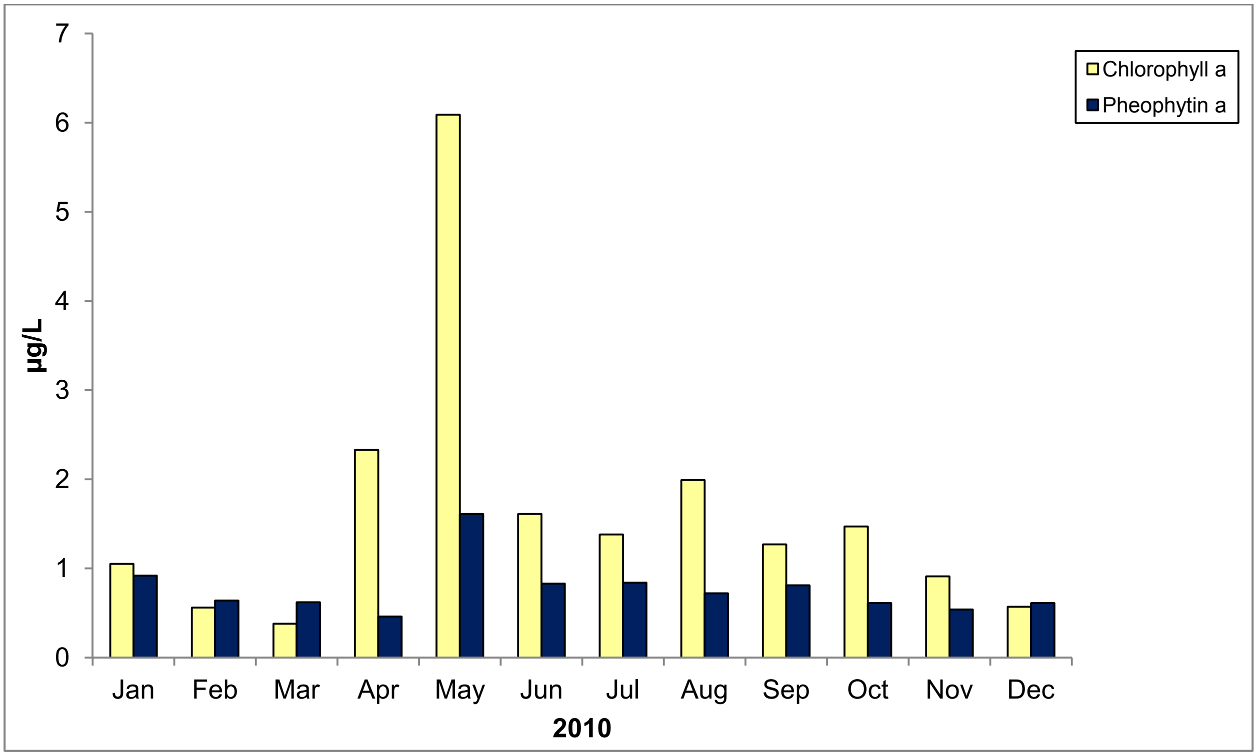

Figure 4-7b. Phytoplankton composition at D26, 2010

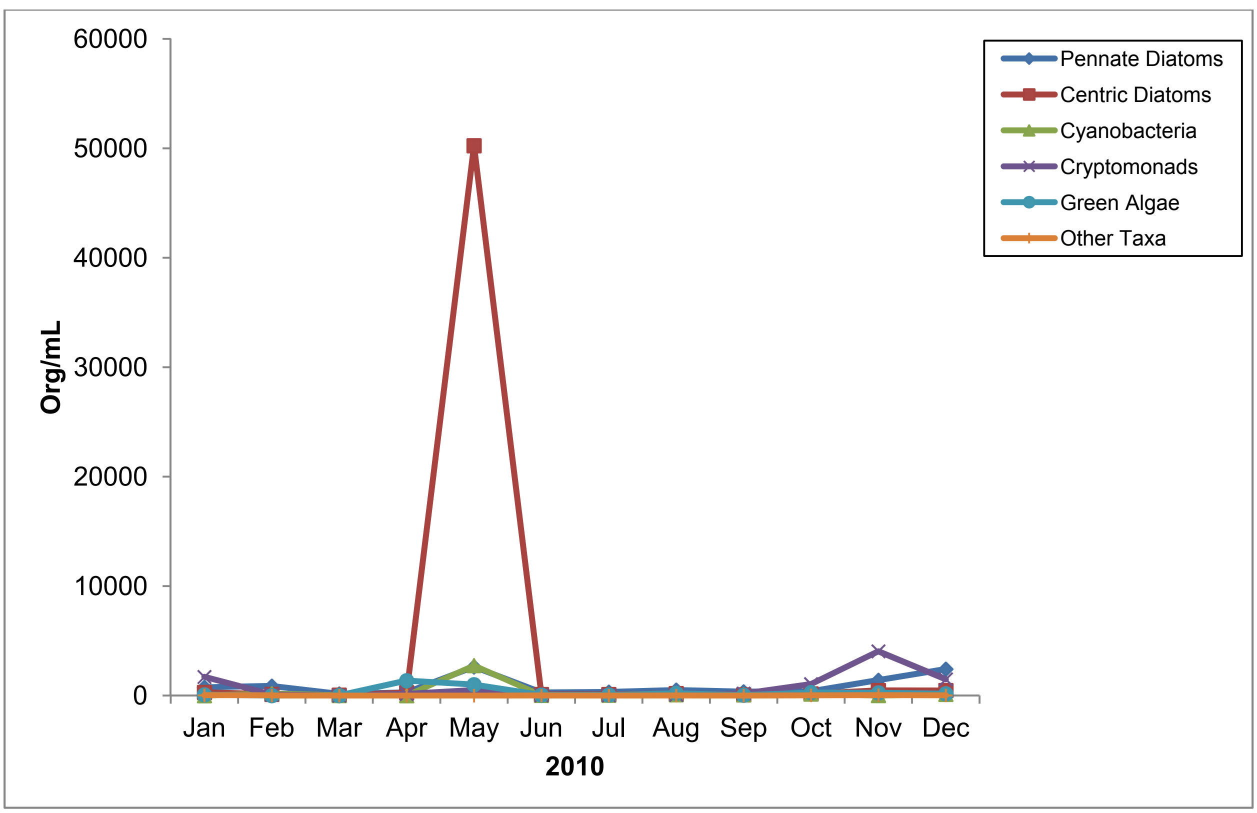

Figure 4-8a. Pigment concentrations at D19, 2010

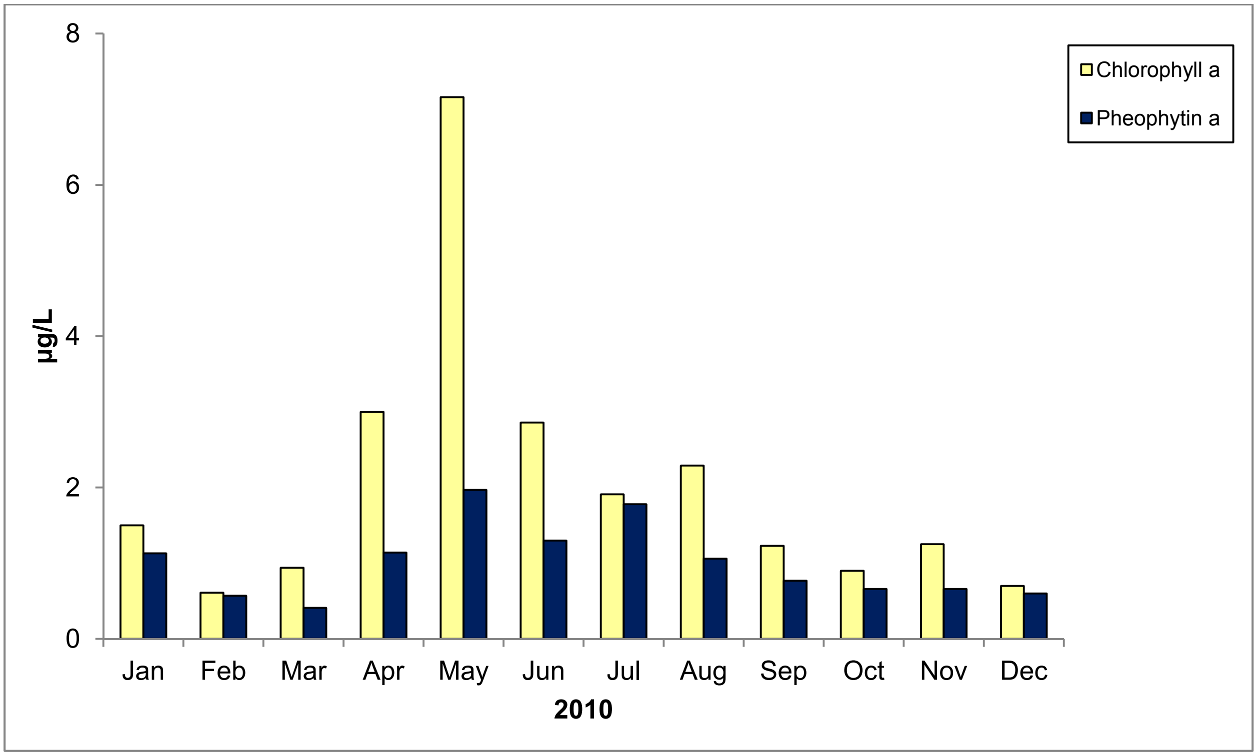

Figure 4-8b. Phytoplankton composition at D19, 2010

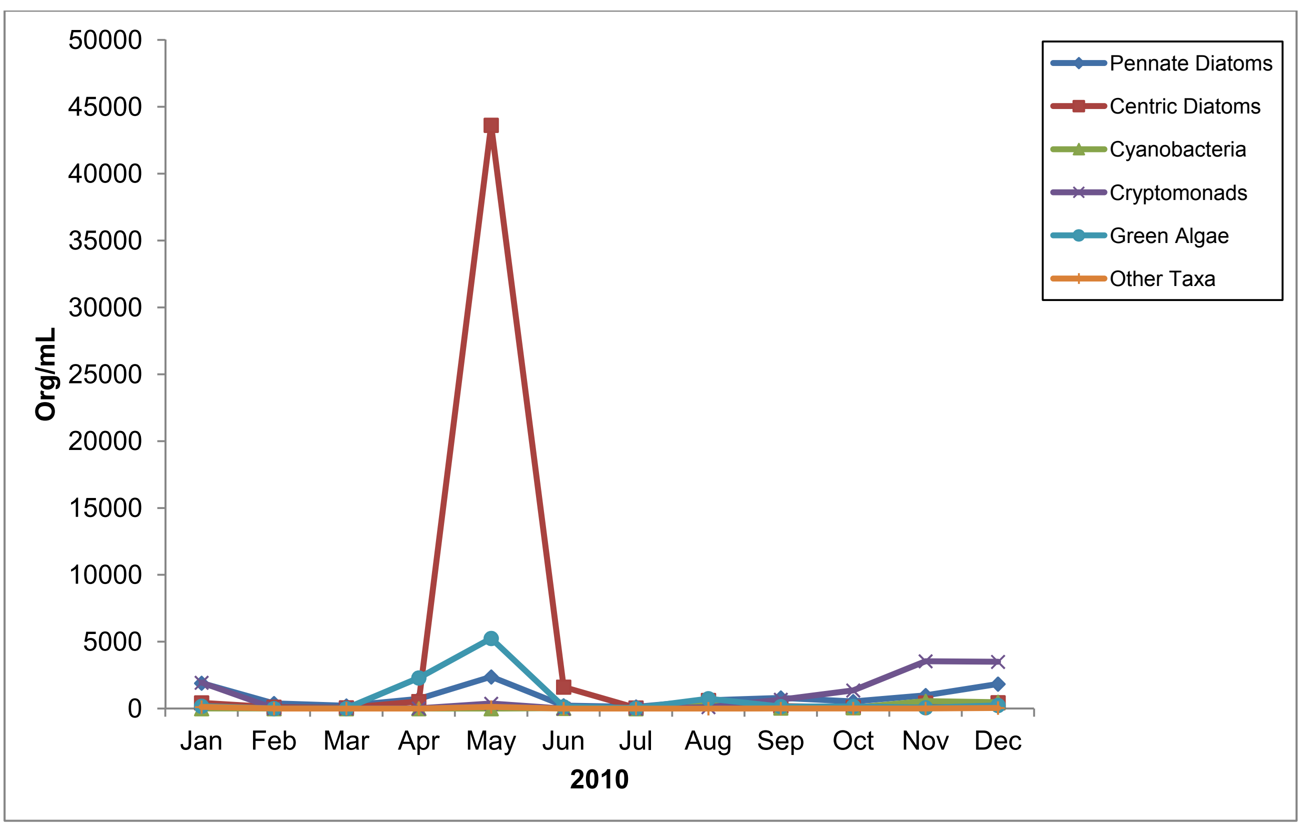

Figure 4-9a. Pigment concentrations at D28A, 2010

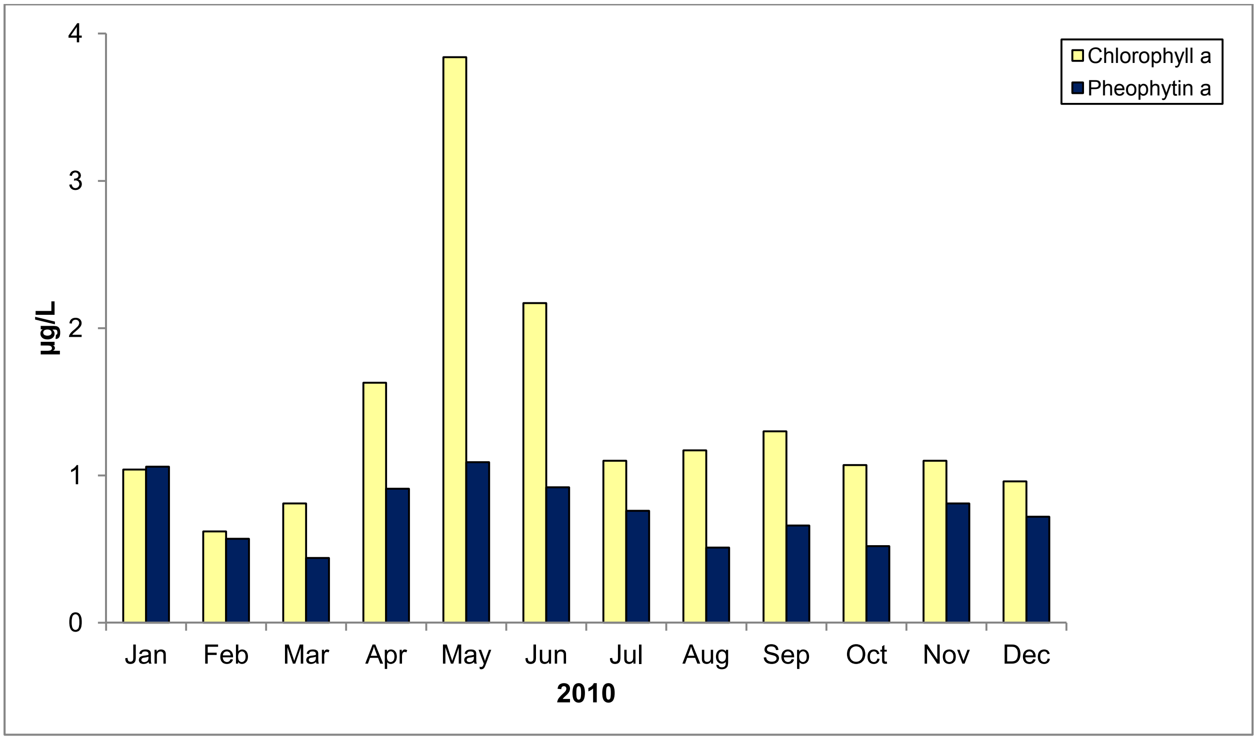

Figure 4-9b. Phytoplankton composition at D28A, 2010

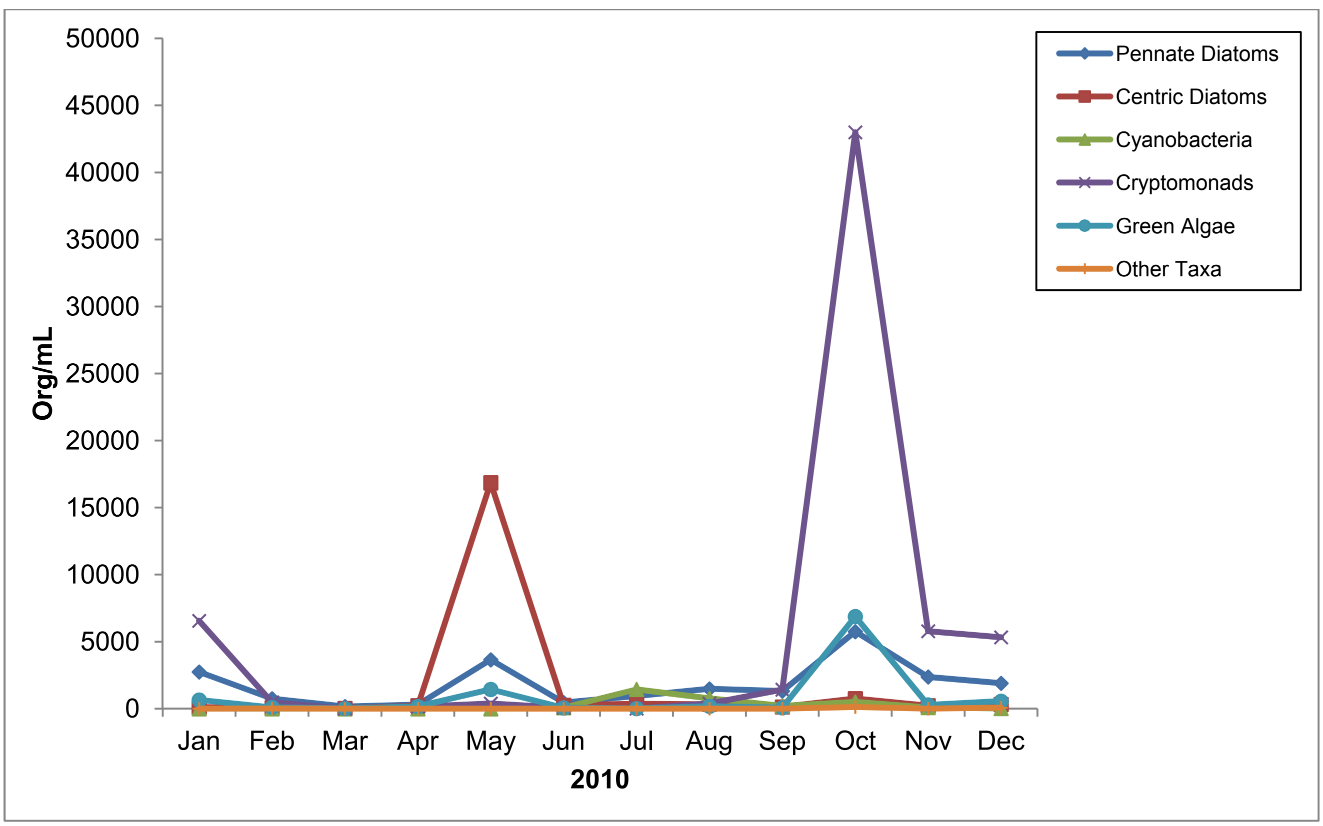

Figure 4-10a. Pigment concentrations at D4, 2010

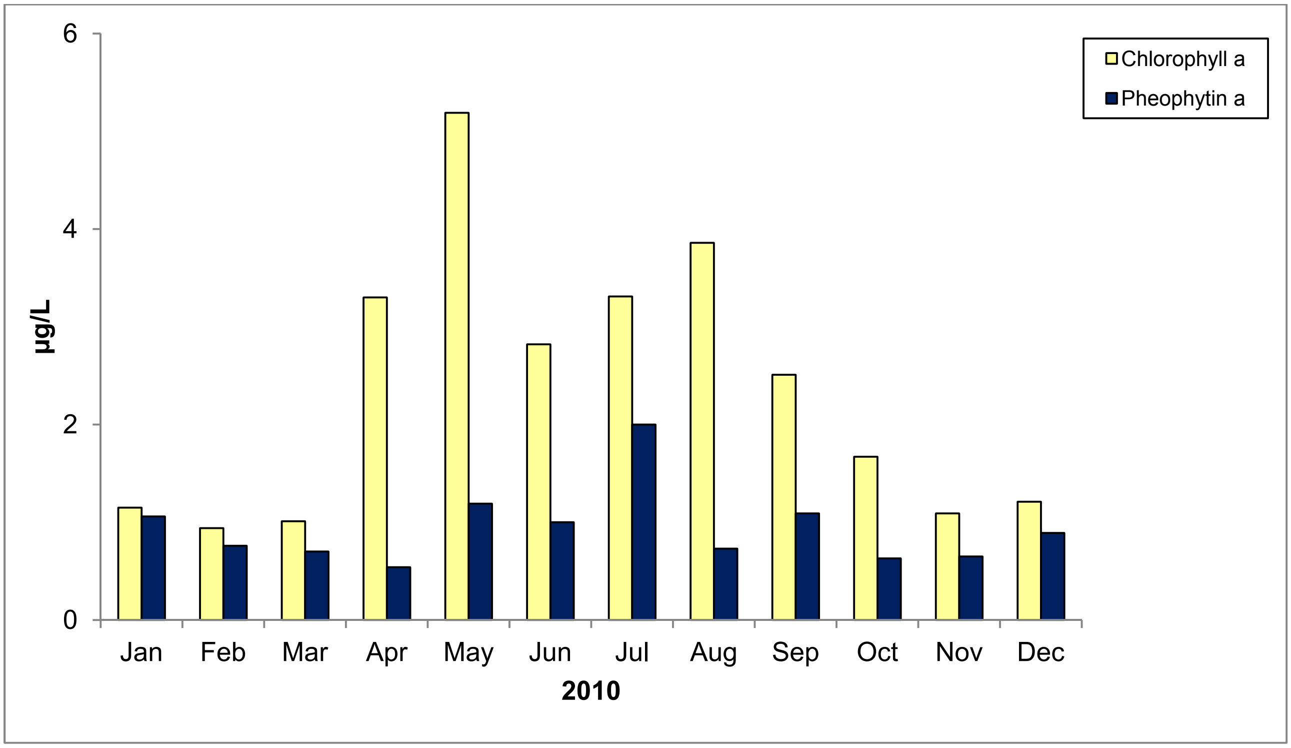

Figure 4-10b. Phytoplankton composition at D4, 2010

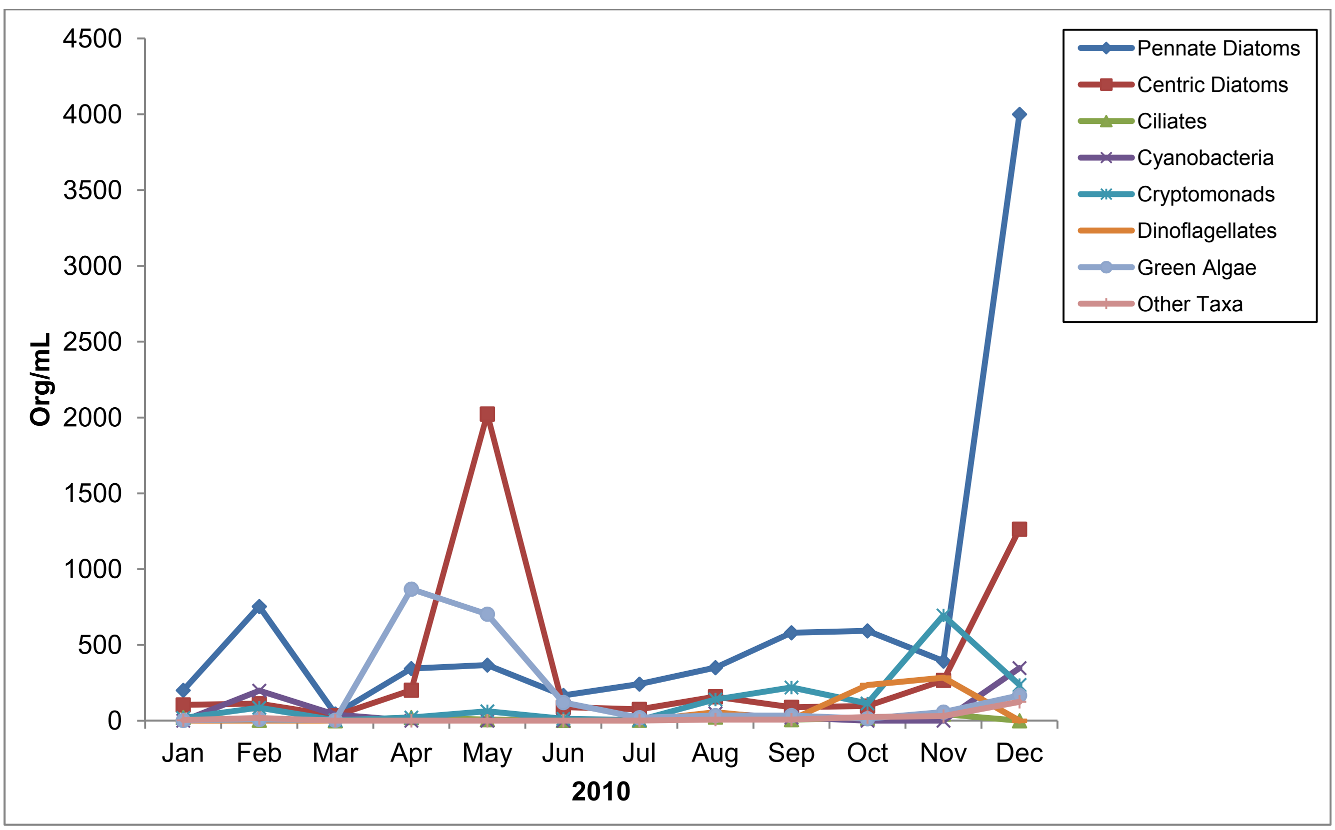

Figure 4-11a. Pigment concentrations at D6, 2010

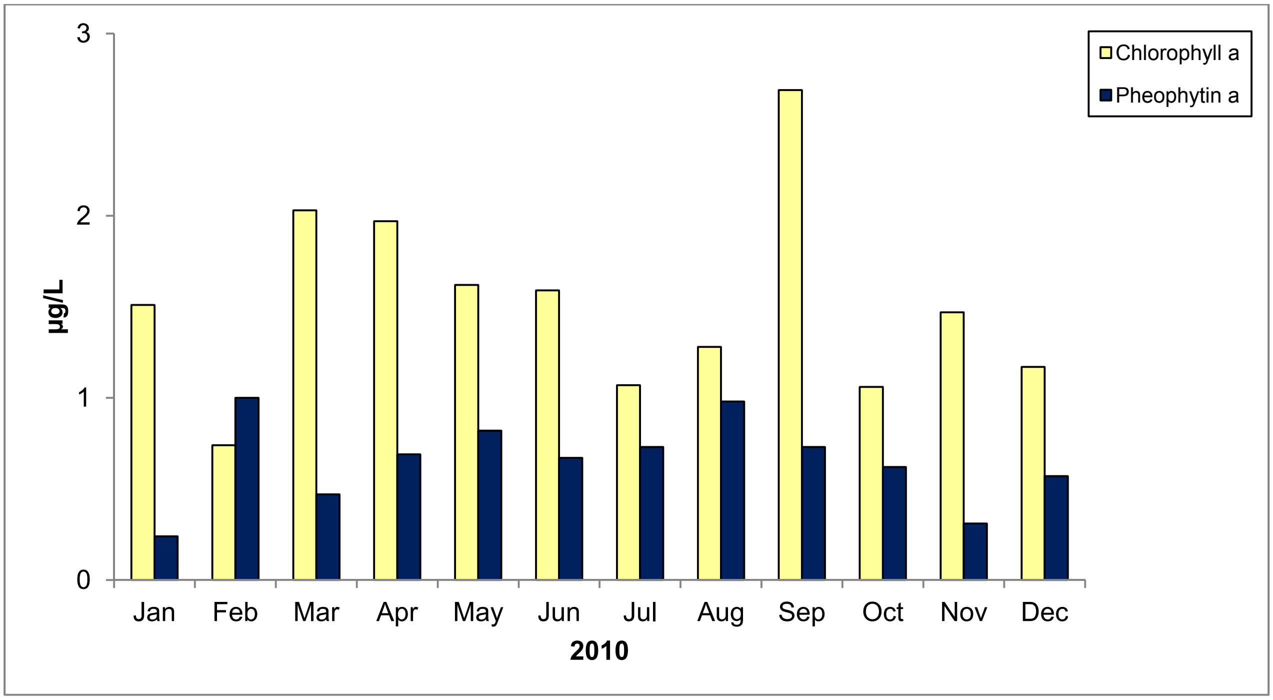

Figure 4-11b. Phytoplankton composition at D6, 2010

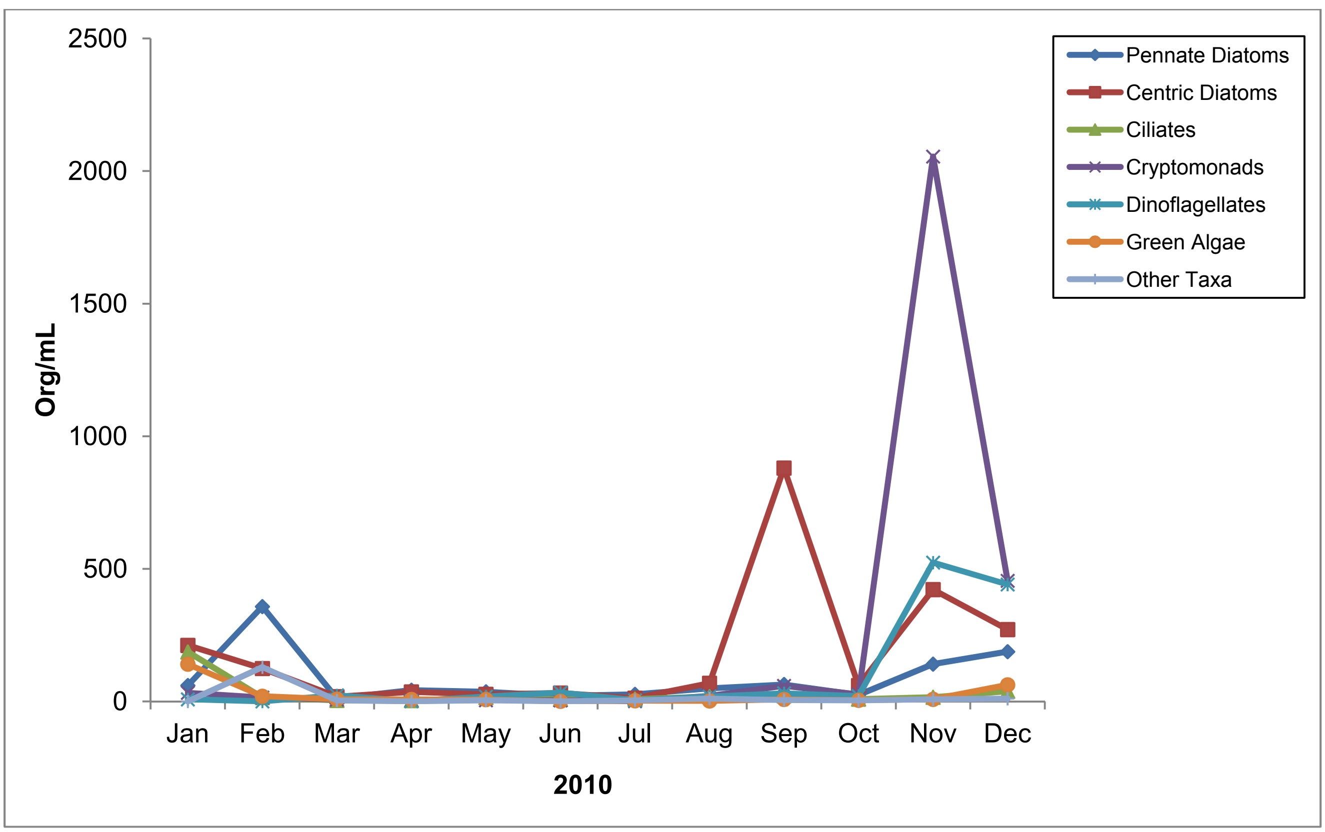

Figure 4-12a. Pigment concentrations at D7, 2010

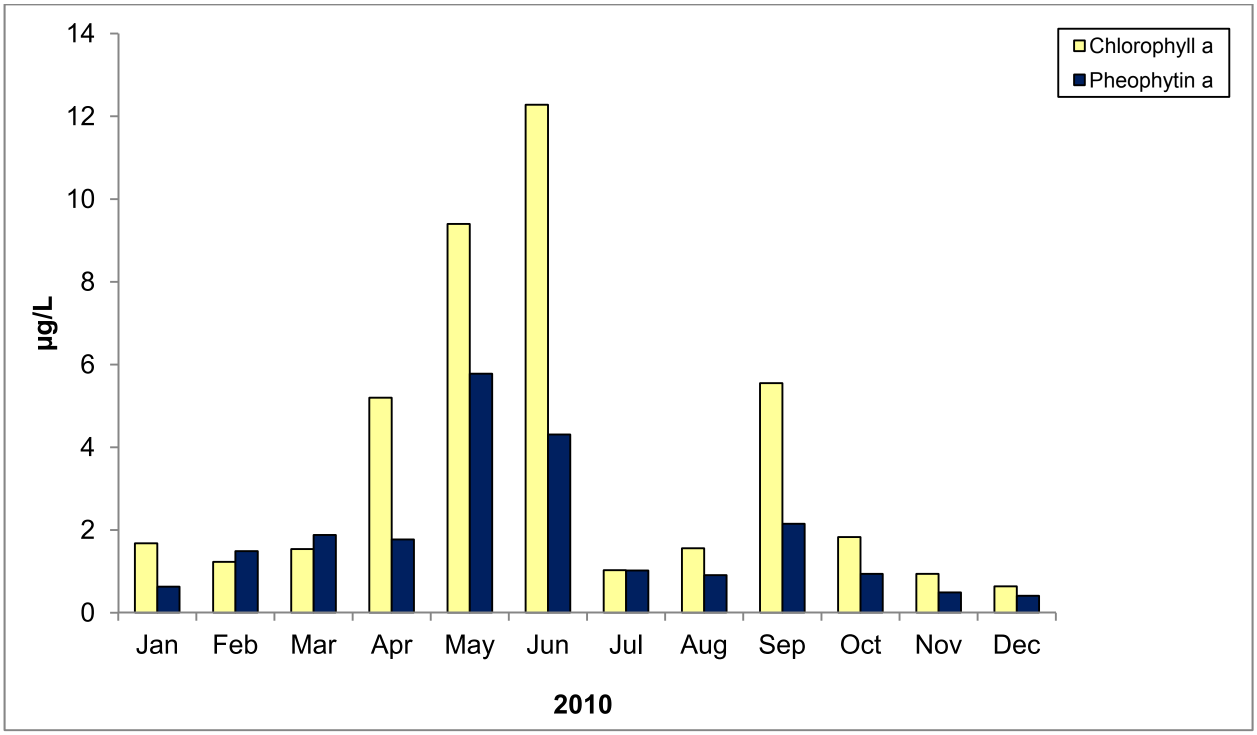

Figure 4-12b. Phytoplankton composition at D7, 2010

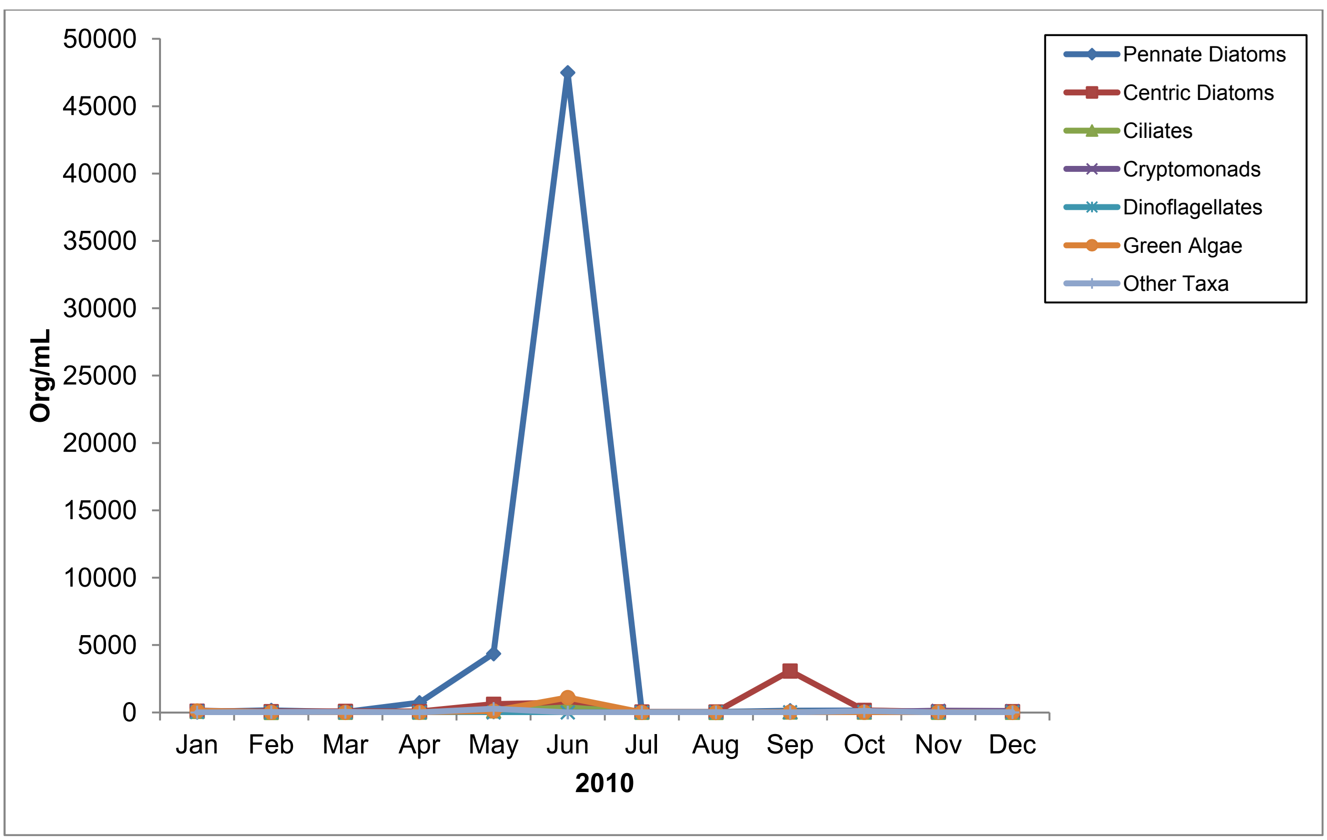

Figure 4-13a. Pigment concentrations at D8, 2010

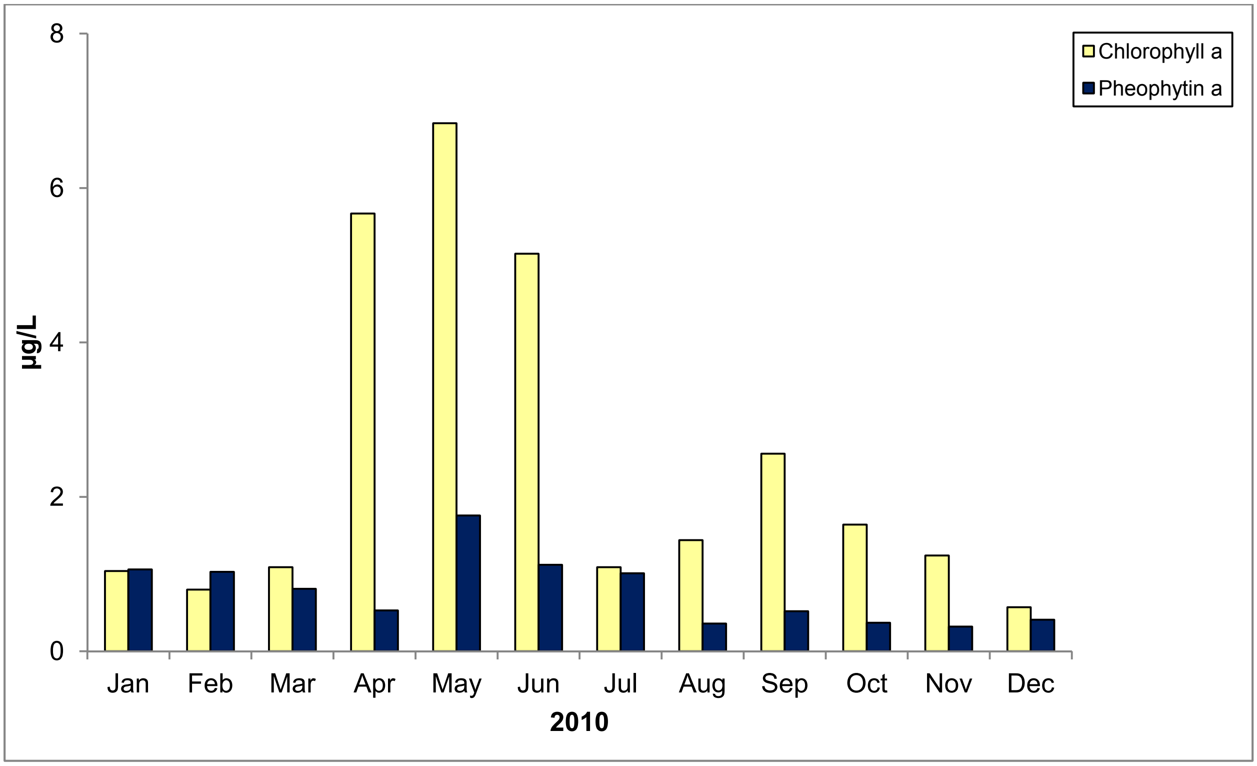

Figure 4-13b. Phytoplankton composition at D8, 2010

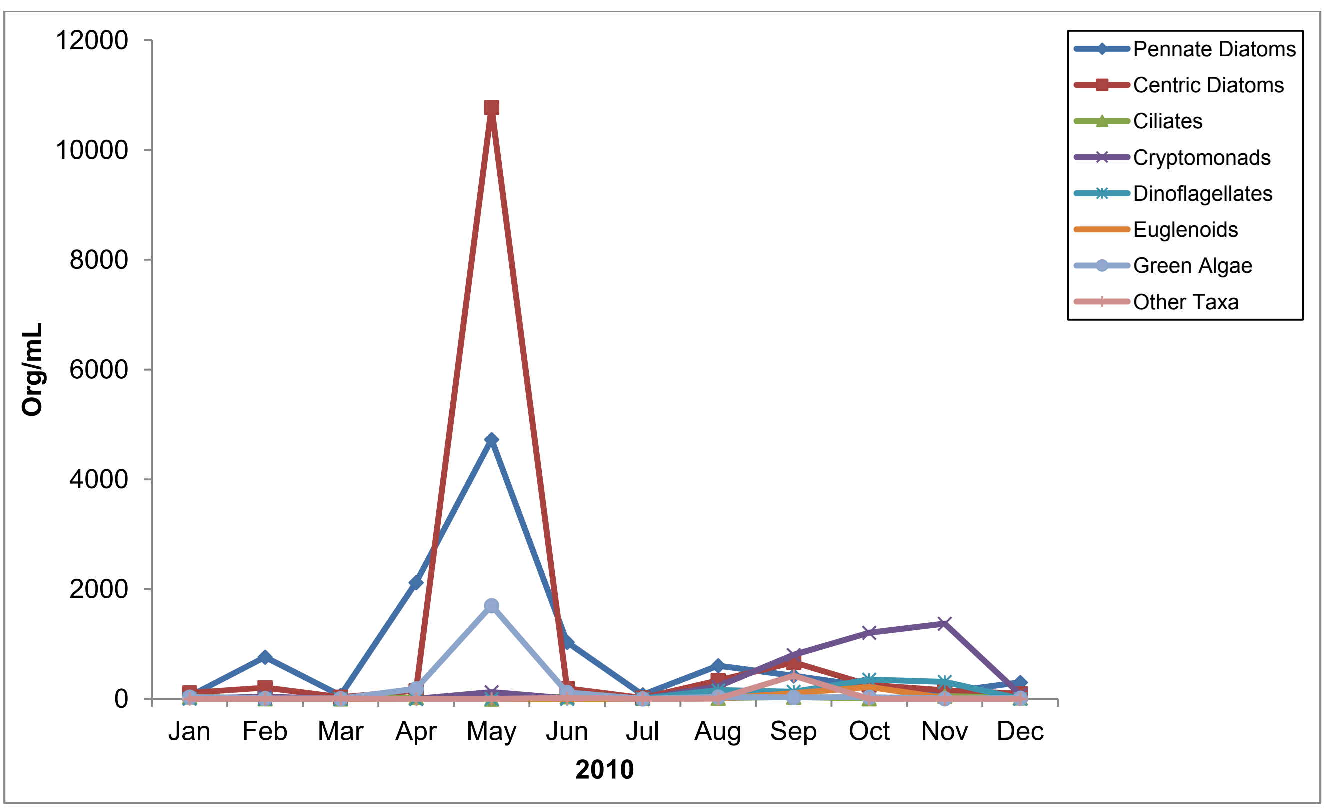

Figure 4-14a. Pigment concentrations at D41, 2010

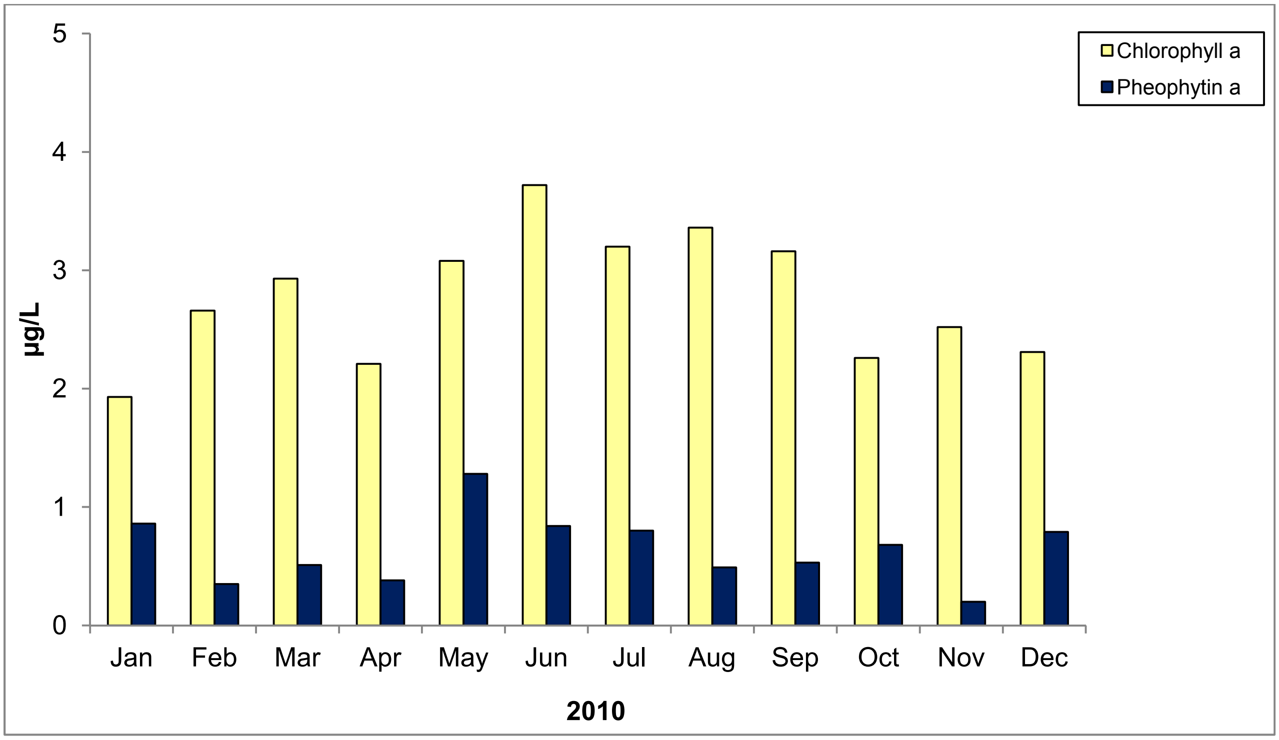

Figure 4-14b. Phytoplankton composition at D41, 2010

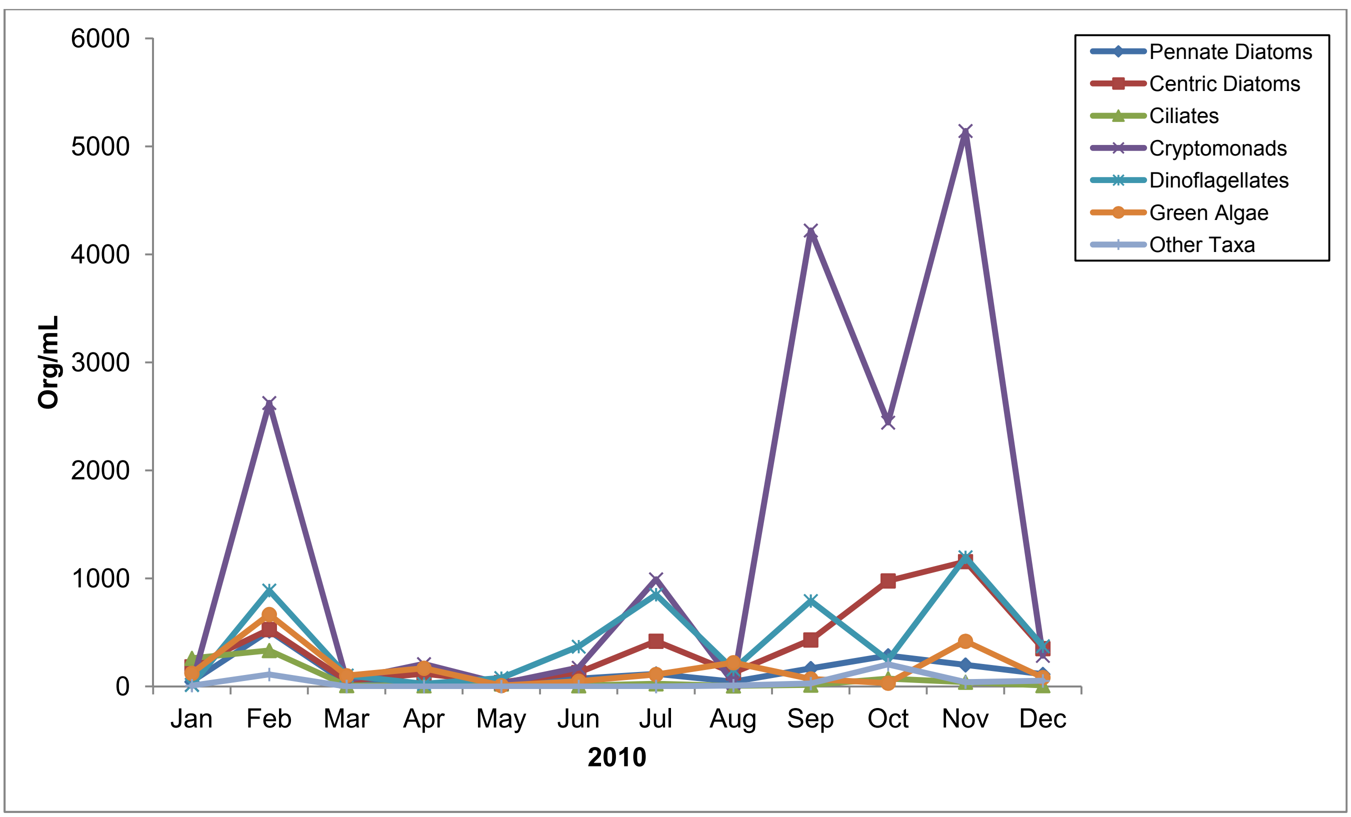

Figure 4-15a. Pigment concentrations at D41A, 2010

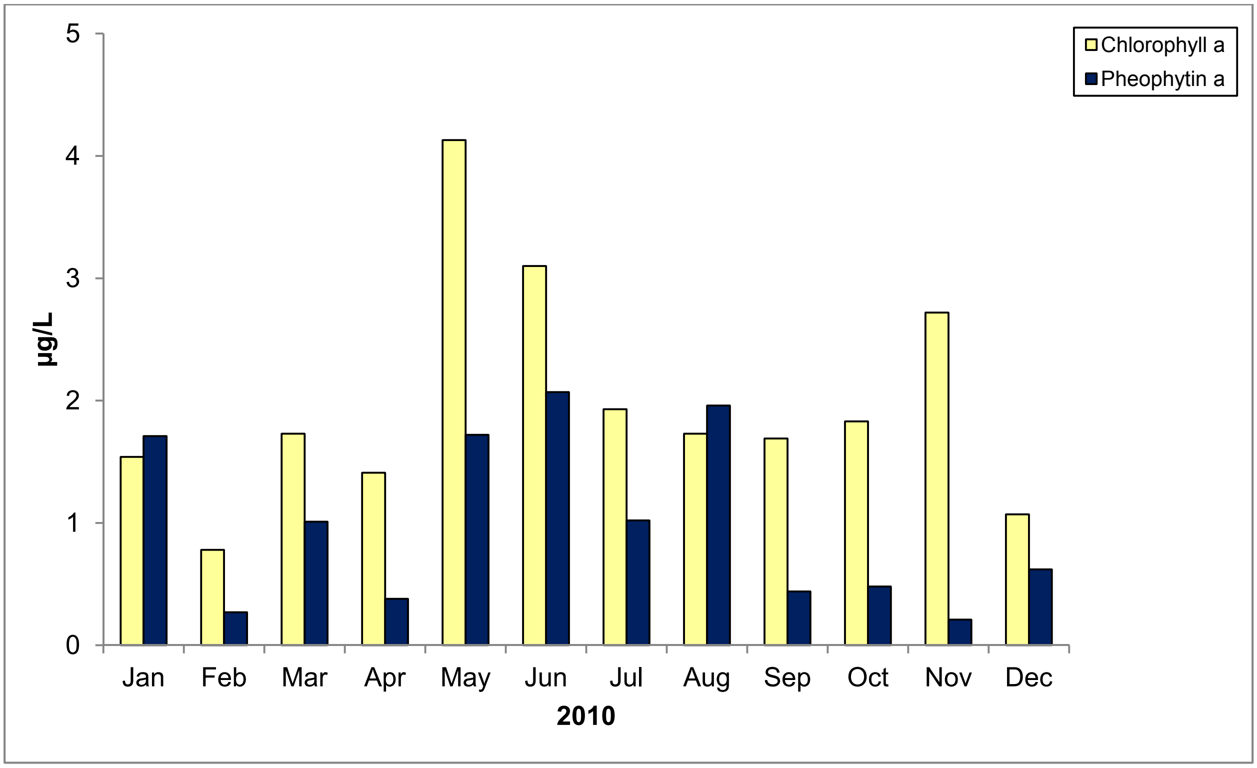

Figure 4-15b. Phytoplankton composition at D41A, 2010

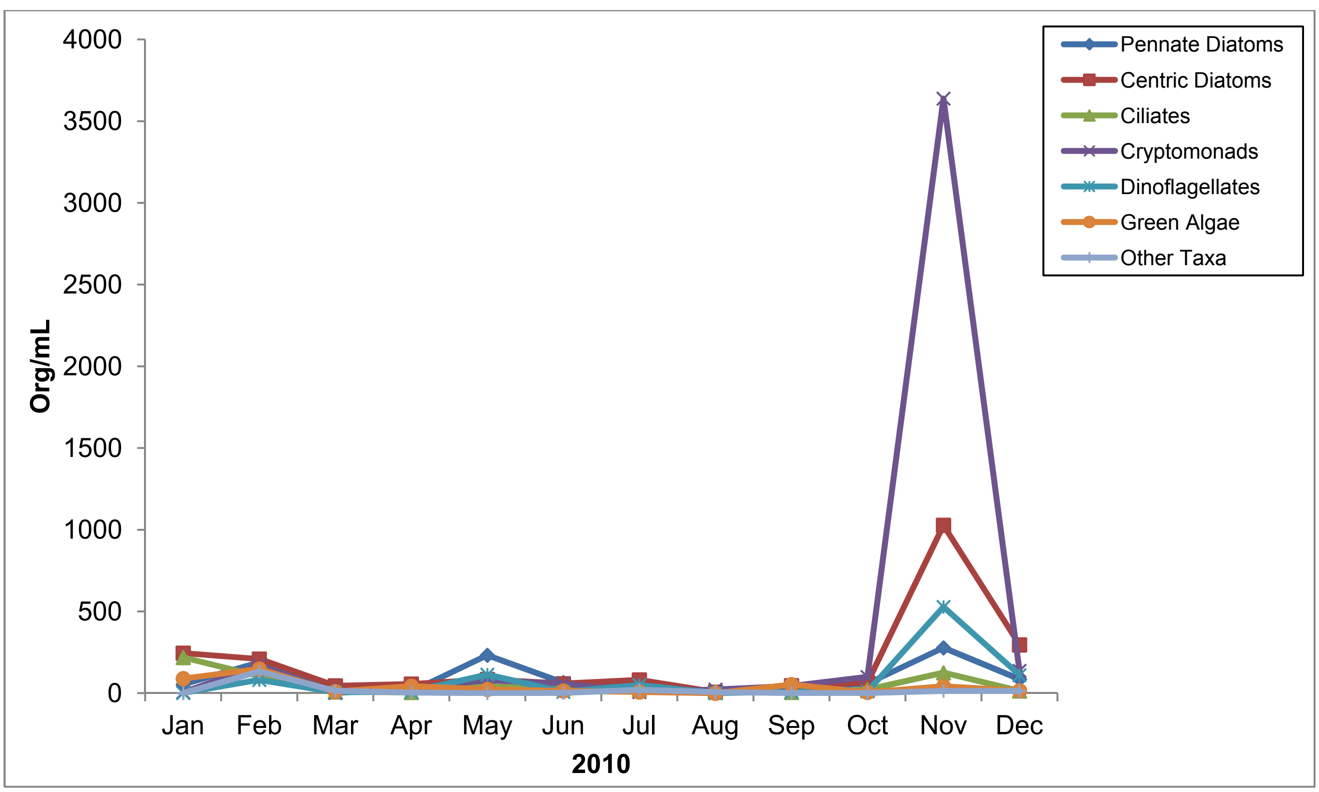

Table 4-1. Phytoplankton genera by group, 2010

Green Algae	Pennate Diatoms	Centric Diatoms	Dinoflagellates
Actinastrum	Achnanthes	Aulacoseira	Alexandrium
Carteria	Amphipleura	Biddulphia	Ceratium
Chlamydomonas	Amphora	Coscinodiscus	Crypthecodinium
Chlorella	Asterionella	Cyclotella	Dinophysis
Chlorococcum	Bacillaria	Eucampia	Dissodinium
Closterium	Caloneis	Hydrosera	Gonyaulax
Coelastrum	Campylodiscus	Melosira	Gymnodinium
Cosmarium	Cocconeis	Odontella	Katodinium
Crucigenia	Cymatopleura	Rhizosolenia	Oxyphysis
Dunaliella	Cymbella	Terpsinoe	Peridinium
Gonium	Diatoma	Thalassiosira	Prorocentrum
Keratococcus	Diploneis	Triceratium	Protoperidinium
Kirchneriella	Entomoneis	**Cyanobacteria**	Pyrophacus
Lagerheimia	Epithemia	Anabaena	Scrippsiella
Micractinium	Eunotia	Aphanocapsa	Warnowia
Microspora	Fragilaria	Chroococcus	Woloszynskia
Monoraphidium	Gomphonema	Coelosphaerium	**Euglenoids**
Mougeotia	Gyrosigma	Leptolyngbya	Euglena
Oocystis	Navicula	Merismopedia	Monomorphina
Palmella	Nitzschia	Oscillatoria	Phacus
Pediastrum	Pinnularia	Phormidium	Trachelomonas
Pyramimonas	Rhoicosphenia	Pseudanabaena	**Ciliates**
Scenedesmus	Rhopalodia	**Cryptomonads**	Mesodinium
Schroederia	Stauroneis	Chroomonas	Salpingella
Spirogyra	Surirella	Cryptomonas	**Chrysophytes**
Staurastrum	Synedra	Komma	Dinobryon
Stigeoclonium	**Haptophytes**	Rhodomonas	**Kathablepharids**
Tetraedron	Chrysochromulina	Teleaulax	Leucocryptos
Tetrastrum	Phaeocystis	**Silico-flagellates**	**Unknown**
	Prymnesium	Dictyocha	Little green algal balls

Table 4-2. Chlorophyll *a* and pheophytin *a* concentrations, 2010

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	3.31	0.67	1.70	1.70	0.71
C10A	59.20	2.45	10.90	14.62	14.73
P8	6.41	0.54	2.02	2.29	1.58
MD10A	17.09	0.89	2.37	3.49	4.40
D26	6.09	0.38	1.33	1.63	1.52
D19	7.16	0.61	1.38	2.03	1.80
D28A	3.84	0.62	1.10	1.40	0.87
D4	5.19	0.94	2.09	2.34	1.38
D6	2.69	0.74	1.49	1.52	0.53
D7	12.28	0.64	1.62	3.57	3.80
D8	6.84	0.57	1.34	2.43	2.17
D41	3.72	1.93	2.80	2.78	0.55
D41A	4.13	0.78	1.73	1.97	0.93

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	4.31	0.61	1.71	1.68	0.92
C10A	13.50	2.49	5.16	5.59	2.74
P8	1.82	0.49	1.01	1.10	0.47
MD10A	8.33	0.61	1.07	1.76	2.12
D26	1.61	0.46	0.68	0.77	0.30
D19	1.97	0.41	0.92	1.00	0.49
D28A	1.09	0.44	0.74	0.75	0.22
D4	2.00	0.54	0.83	0.94	0.39
D6	1.00	0.24	0.68	0.65	0.23
D7	5.78	0.41	1.26	1.82	1.64
D8	1.76	0.32	0.67	0.78	0.44
D41	1.28	0.20	0.61	0.64	0.29
D41A	2.07	0.21	0.82	0.99	0.70

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Chapter 5. Zooplankton

Introduction

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

Methods

Zooplankton were sampled monthly at 17 to 22 stations in the Delta and Suisun Bay (Figure 5-1). Twenty of these stations were at fixed locations and two were "floating" entrapment zone (EZ) stations located where bottom electrical conductance (EC) was 2 mS/cm and 6 mS/cm, +/-10%. Station 325 in San Pablo Bay and stations 2 and 4 in Carquinez Strait were sampled only when their surface EC was less than 20 mS/cm. Monthly sampling was scheduled such that each station was sampled at approximately high slack tide.

At each station three types of gear were deployed: 1) a mysid net for macrozooplankton; 2) a modified Clarke-Bumpus (CB) net for mesozooplankton; and 3) a pump sampler for microzooplankton. The mysid net was 1.48 m long with a 28 cm interior mouth diameter and a mesh size of 505 µm. A General Oceanics model 2030 flowmeter was mounted at the center of the net mouth. The net was attached to a ski-mounted towing frame made of steel tubing. The CB net was 75 cm long with an interior mouth diameter of 12.4 cm and a mesh size of 154 µm. The CB frame was a 19.1 cm long, clear acrylic pipe with an inside diameter of 12.0 cm with a General Oceanics model 2030 flowmeter suspended in the center. The CB net and frame were mounted on top of the mysid frame, and the nets were deployed together. The pump sampler consisted of a 15-liter/minute-capacity Teel marine pump connected to a 15 m intake hose that discharged into a 35 µm plankton net with a cod-end.

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

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

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

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

Monthly and annual abundance indices for each taxon were calculated as the mean number per cubic meter (catch-per-unit-effort or CPUE) for each gear type and EC zone. The number of stations in each zone varied monthly (Table 5-1) 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 2010 CPUE for all stations sampled. Monthly abundance trends are presented for the top three to five ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Results

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*) is an introduced mysid first collected in the upper estuary in 1993, and has been the most abundant mysid in the upper estuary since 1995. In 2010, *H. longirostris* was again the most abundant mysid in all zones (Table 5-2). Abundance was highest in the entrapment zone. Downstream of the entrapment zone abundance was 33% of entrapment zone abundance. Upstream abundance was much lower at only 8% of entrapment zone abundance. Seasonality was similar among zones, with abundance peaks in summer and early fall (Figure 5-2). Entrapment zone abundance rose steadily starting in March and peaked in June. Although entrapment zone abundance declined steadily after June, *H. longirostris* remained relatively abundant in the entrapment zone through early fall. Abundance declined in fall in all zones.

Alienacanthomysis macropsis is a native brackish-water mysid that was the second most abundant mysid in 2010 for the second year in a row, although numbers were very low (Table 5-2). From 2009 to 2010, *A. macropsis* abundance increased, although this apparent increase may be due in part to lower salinities in 2010 that resulted in more stations sampled in Carquinez Strait and San Pablo Bay than in 2009. *A. macropsis* was not collected upstream of the entrapment zone in 2010 (Figure 5-3). In the entrapment zone, *A. macropsis* was only collected in January, February, April, and December in 2010; and only at one station in each of these months in very low numbers. Downstream of the entrapment zone, *A. macropsis* was collected during every month of 2010. *A. macropsis* abundance peaked in February in Carquinez Strait and San Pablo Bay, where densities were $12m^{-3}$. After the February peak, densities decreased downstream of the entrapment zone and remained low throughout the summer before increasing again in fall.

The native brackish-water mysid *Neomysis kadiakensis* is very similar to *Neomysis japonica,* a freshwater mysid that may be present in the estuary. Until we are able to distinguish between the two species, they will be grouped together as *Neomysis kadiakensis/japonica*. *N. kadiakensis/japonica* was the third most abundant mysid overall in 2010, for the second year in a row (Table 5-2). Upstream of the entrapment zone *N. kadiakensis/japonica* was only caught twice, at one station in Suisun Marsh in March and at one station in the lower Sacramento River in April and in very low numbers; indicating that if *N. japonica* is present in the estuary, abundance was very low in 2010 (Figure 5-4). Abundance was highest downstream of the entrapment zone, with peaks in May and August. Entrapment zone abundance, slightly lower than abundance downstream, was highest in May and June.

Neomysis mercedis moved from the fifth most abundant mysid in 2009 to the fourth most abundant mysid in 2010, and was collected mainly within and upstream of the entrapment zone (Table 5-2). Until the mid-1990s, this native species had been the most common mysid in the estuary. Since 1993 however, *N. mercedis* abundance has been very low. In 2010, *N. mercedis* abundance was highest in the entrapment zone. Upstream of the entrapment zone abundance was lower at only 50% of the entrapment zone abundance. In 2010, entrapment zone abundance peaked in June in Suisun Marsh, but abundance was very low in all zones in every month (Figure 5-5). Upstream of the entrapment zone, *N. mercedis* was caught in low numbers during most months of 2010; except during February, April, October, and November when none were caught. Upstream abundance was highest in June and July in the lower Sacramento and San Joaquin rivers. Downstream of the entrapment zone, *N. mercedis* was only caught May through July and in very low numbers.

Acanthomysis aspera is an introduced mysid that was first collected from the upper estuary in 1992, although it has never been very abundant. In 2010 *A. aspera* was the fifth most abundant mysid, switching ranks with *Neomysis mercedis* which was the fifth most abundant in 2009 (Table 5-2). *A. aspera* was only found downstream of the entrapment zone in 2010, as is typical for this brackish water species. Although *A. aspera* was only found in low numbers, small peaks occurred in May and August in San Pablo Bay (Figure 5-6).

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in 2010, switching ranks with *Acartia* spp., which was the most abundant in 2009 (Table 5-3). *P. forbesi* was most abundant upstream of the entrapment zone, with the highest abundance during summer and fall in the eastern delta (Figure 5-7). Entrapment zone abundance was lower at only 58% of upstream abundance. Downstream abundance was much lower at only 7% of upstream abundance. Seasonality was similar among the zones with lower abundances January through April, after which abundance gradually increased and was higher for the remainder of the year.

The genus *Acartia* consists of three native brackish water species and was the second most abundant calanoid copepod in 2010 (Table 5-3). *Acartia* spp. was the most common calanoid copepod collected downstream of the entrapment zone. In 2010, *Acartia* spp. was not collected upstream of the entrapment zone (Figure 5-8). Within the entrapment zone, it was collected in January, February, and September, in very low numbers. Downstream abundance was highest January through April in San Pablo Bay, and lowest during early fall. After a small peak in August, downstream abundance decreased slightly in September and remained lower in October, before increasing again in November and December.

Sinocalanus doerrii was the third most abundant calanoid copepod in 2010, switching ranks with *Acartiella sinensis* which was the third most abundant from 2007 through 2009 (Table 5-3). *S. doerrii* was most common within the entrapment zone, where abundance peaked in May and June in Suisun Marsh and eastern Suisun Bay (Figure 5-9). Upstream abundance was 64% of entrapment zone abundance with a similar seasonal trend. In 2010, in the entrapment zone and upstream, abundance increased through spring, peaked in May and June, and decreased in late summer and early fall before increasing again in December. Downstream abundance was much lower and was only 11% of entrapment zone abundance. Downstream abundance was also highest in May and June, but was much lower in the spring and fall than the other zones.

The introduced *Acartiella sinensis* was the fourth most abundant calanoid copepod in 2010 (Table 5-3). *A. sinensis* abundance was highest in the entrapment zone from July through December, with a peak in September in the lower Sacramento River (Figure 5-10). Downstream abundance was 77% of entrapment zone abundance, and was also highest late summer and fall. Upstream of the entrapment zone, abundance was much lower at only 7% of entrapment zone abundance. February through June abundance upstream of the entrapment zone was low, but began increasing in July and peaked in September before declining again in October, November, and December.

Eurytemora affinis was the fifth most abundant calanoid copepod in 2010 (Table 5-3), as it was in 2008 and 2009. *E. affinis* was most common in the entrapment zone in 2010, where abundance was highest February through June and declined sharply thereafter (Figure 5-11). In 2010, abundance peaked in May in Suisun Marsh. Upstream abundance was 71% of entrapment zone abundance, and was also higher in spring and declined in summer. However, fall abundance was much higher upstream than it was in the entrapment zone and downstream. Downstream abundance was lower at only 26% of entrapment zone abundance, and was higher January through May, declined in summer and early fall before increasing again in November and December. This seasonal decline in summer and fall has been typical since 1987, when *Corbula 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, *Limnoithona tetraspina* has become the most abundant copepod in the study area. *L. tetraspina* was abundant in all three zones in 2010, with the highest abundance in the entrapment zone and downstream (Table 5-4). Abundance was highest throughout the year in the pump samples (Figure 5-12). Pump abundance was highest downstream of the entrapment zone in 2010; followed by the entrapment zone, which was 88% of downstream abundance. Upstream pump abundance was much lower at only 3% of downstream abundance. In all zones, pump abundance was highest July through November. Pump abundance peaked in September and October in the lower Sacramento River. CB abundance was highest in the entrapment zone in 2010; followed closely by downstream abundance, which was 95% of entrapment zone abundance. Upstream CB abundance was much lower at only 2% of entrapment zone abundance. In the entrapment zone, CB abundance was relatively stable throughout the year and increased steadily February to July, then decreased thereafter. CB abundance peaked in the entrapment zone in July in eastern Suisun Bay. Downstream of the entrapment zone, pump abundance was relatively stable, except for a low in February, and small peaks in May, July, and September. Upstream CB abundance was low throughout the year with a small peak in September.

Another introduced species, *Oithona davisae*, was the most abundant cyclopoid copepod in the CB samples in 2010 and the second most abundant cyclopoid copepod in the pump samples for the third year in a row (Table 5-4). *O. davisae* was most common downstream of the entrapment zone in both the CB and pump samples during summer and fall (Figure 5-13). Both CB and pump abundance peaked in San Pablo Bay, although pump abundance peaked in August, whereas CB abundance peaked later in October. Within and upstream of the entrapment zone, pump abundance was zero all year, whereas CB abundance was zero during most months with small peaks in September.

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod in the CB net in 2010, for the fifth year in a row, and was most abundant in and upstream of the entrapment zone (Table 5-4). In and upstream of the entrapment zone, *A. vernalis* abundance was highest in spring and early summer, besides a small dip in April, but declined to zero in August in all zones (Figure 5-14). Upstream abundance started increasing again in September through December, whereas entrapment zone abundance remained zero through October and started increasing again in November and December. In 2010, *A. vernalis* abundance was highest in Suisun Marsh in March. Downstream abundance was much lower but had a similar seasonal trend, except a higher increase in November and December than the other zones, with a peak in December.

Cladocerans

The cladocerans most commonly collected by this study are freshwater, and therefore are mainly found upstream of the entrapment zone. *Diaphanosoma* was the most abundant cladoceran genera in 2010, switching rankings with *Bosmina* which was most abundant in 2008 and 2009. *Daphnia* was the third most abundant cladoceran genera for the third year in a row.

The most abundant cladoceran in 2010 was *Diaphanosoma* spp. (Table 5-5). It was most common upstream of the entrapment zone where abundance steadily increased spring through summer, and peaked in July and August, before starting to decline again in fall (Figure 5-15). *Diaphanosoma* abundance was highest in July in the eastern delta in 2010. Entrapment zone abundance was zero all year except a small peak in July. Downstream of the entrapment zone, *Diaphanosoma* was only present in July and August, and in very low numbers.

Bosmina spp. was the second most abundant cladoceran in 2010 (Table 5-5). Upstream abundance was relatively high all year with a lot of fluctuation (Figure 5-16). Upstream abundance was low January through March, peaked in April and May, and then declined in summer, before peaking again in September and declining thereafter. In 2010, *Bosmina* abundance was highest in September in the eastern delta. In the entrapment zone, *Bosmina* abundance was higher January through May, but declined to zero in late summer and early fall, before increasing in late fall and peaking again in December. Downstream of the entrapment zone, abundance was much lower and peaked in April and May before declining to zero in June and July. Downstream abundance remained low through the summer and fall before increasing again in December.

Daphnia spp. was the third most abundant cladoceran in 2010, and was also most common upstream of the entrapment zone (Table 5-5). Upstream abundance was relatively high most of the year with a lot of fluctuation (Figure 5-17). After a small dip in March, upstream abundance increased steadily through spring and early summer, and peaked in July, before declining sharply in August. In 2010, *Daphnia* abundance was highest in July in the eastern delta. Abundance was lower in the entrapment zone with small peaks in February, May, and December. Downstream abundance was even lower and also peaked in February and May. No *Daphnia* were found July through November in and downstream of the entrapment zone.

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 most common taxa, as well as their relative rankings, have been the same since 2008.

Synchaeta spp., which includes the brackish-water species *Synchaeta bicornis*, was the most common rotifer in 2010, as it was in 2008 and 2009 (Table 5-6). It was most abundant downstream of the entrapment zone, where abundance was relatively high most of the year, but was highest March through June (Figure 5-18). In 2010, *Synchaeta* abundance was highest in June in San Pablo Bay. Entrapment zone abundance increased steadily January through April, declined in late spring and summer, before slightly increasing again in fall. Upstream of the entrapment zone, abundance increased steadily January through April, and declined in May and June before crashing to zero in July, after which abundance increased in late summer and fall. *Polyarthra* spp. was again the second most abundant rotifer in 2010 (Table 5-6). It was most abundant upstream of the entrapment zone, where abundance was relatively stable most of the year and was highest in August (Figure 5-19). In 2010, *Polyarthra* abundance was highest in the eastern delta in August. In the entrapment zone, abundance was highest in January and February and again in December, but was highly variable in other months. During July, August, and November, 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 2010 (Table 5-6). It was most abundant upstream of the entrapment zone, where abundance was also relatively stable throughout the year (Figure 5-20). In 2010, *Keratella* abundance was highest in May in the eastern delta. Entrapment zone abundance was also relatively stable, with the highest abundance in February and March, and small peaks in July and December. Downstream abundance was higher in spring and late fall, but was lower in summer.

Summary

In 2010, the most common zooplankton taxa were the same as previous years, although some of their relative rankings changed. Monthly abundance patterns in 2010 were slightly different than in 2008 and 2009, presumably due to higher flows in 2010. While abundance of some taxa was higher in 2010 than 2009, others were lower. *H. longirostris, A. macropsis,* and *N. kadiakensis* were again the most abundant mysids in 2010, as they were in 2009. Both *H. longirostris* and *A. macropsis* abundance increased, while *N. kadiakensis* abundance decreased in 2010 from 2009. *N. mercedis* abundance increased while *A. aspera* abundance decreased in 2010 from 2009, causing them to switch rankings, making *N. mercedis* the fourth most abundant mysid and *A. aspera* the fifth most abundant. *P. forbesi* abundance increased and *Acartia* spp. abundance decreased in 2010 from 2009, causing them to switch rankings, making *P. forbesi* the most abundant calanoid copepod of 2010 and *Acartia* spp. the second most abundant. *S. doerrii* and *A. sinensis* also switched rankings in 2010 and were the third and fourth most abundant calanoid copepods respectively. *S. doerrii* abundance increased in 2010 from 2009, whereas *A. sinensis* abundance decreased. *E. affinis* abundance increased in 2010 from 2009, and remained the fifth most abundant calanoid copepod. *O. davisae, L. tetraspina,* and *A. vernalis* were again the most abundant cyclopoid copepods in the CB samples; *O. davisae* and *L. tetraspina* abundance increased in 2010 from 2009, whereas *A. vernalis* abundance decreased. In the pump samples, *L. tetraspina* was again the most abundant cyclopoid copepod and *O. davisae* the second most abundant, although abundance of each decreased in 2010 from 2009. *Diaphanosoma* spp. abundance increased while *Bosmina* spp. abundance decreased in 2010 from 2009, causing them to switch rankings in 2010, making *Diaphanosoma* spp. the most abundant cladoceran and *Bosmina* spp. the second most abundant. *Daphnia* spp. remained the third most abundant cladoceran and abundance increased slightly in 2010 from 2009. *Synchaeta* spp., *Polyarthra* spp., and *Keratella* spp. remained the most abundant rotifers in 2010 and relative rankings were unchanged from 2009. Both *Synchaeta* spp. and *Polyarthra* spp. abundance increased in 2010 from 2009, whereas *Keratella* spp. abundance decreased.

Chapter 5 Appendix

Figure 5-1 Zooplankton monitoring stations

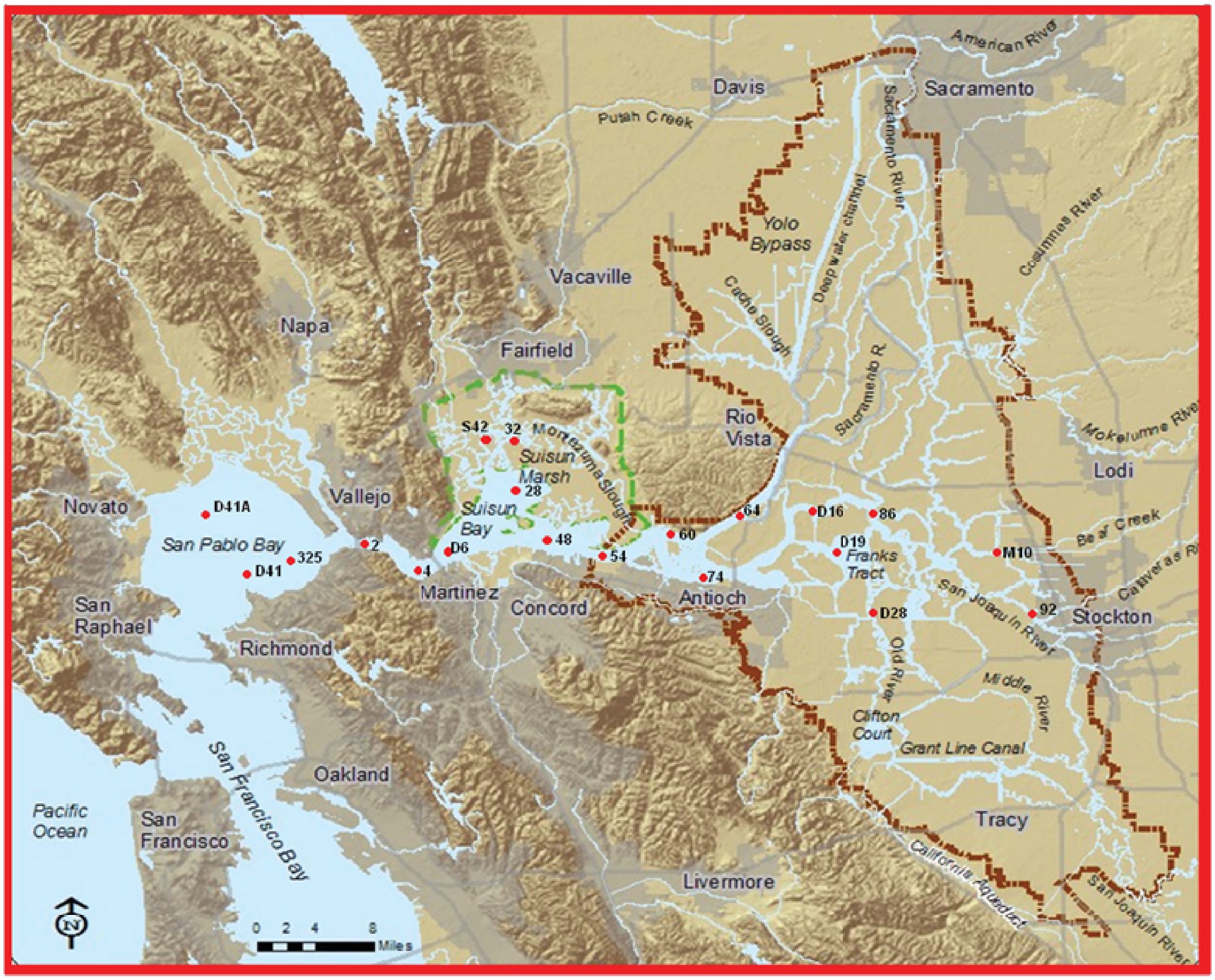

Figure 5-2 Monthly Hyperacanthomysis longirostris (Acanthomysis bowmani) abundance upstream, within, and downstream of the entrapment zone in 2010

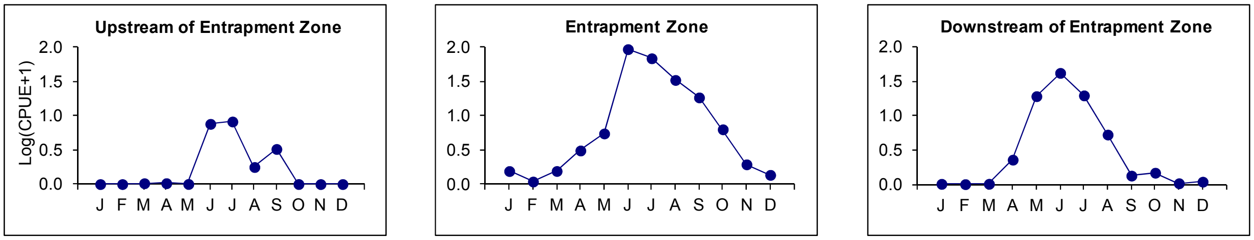

Figure 5-3 Monthly *Alienacanthomysis macropsis* abundance upstream, within, and downstream of the entrapment zone in 2010

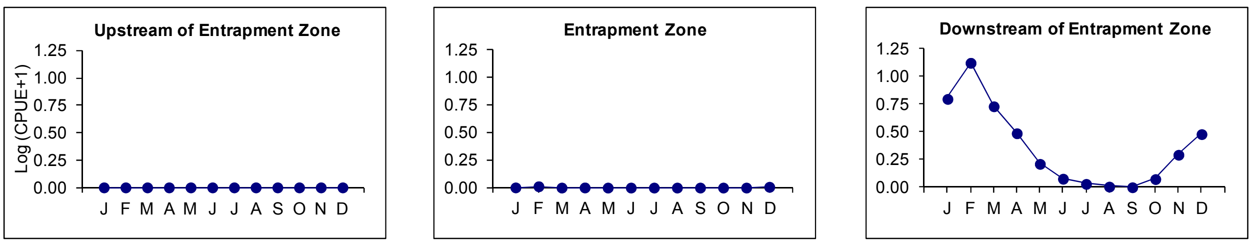

Figure 5-4 Monthly *Neomysis kadiakensis/japonica* abundance upstream, within, and downstream of the entrapment zone in 2010

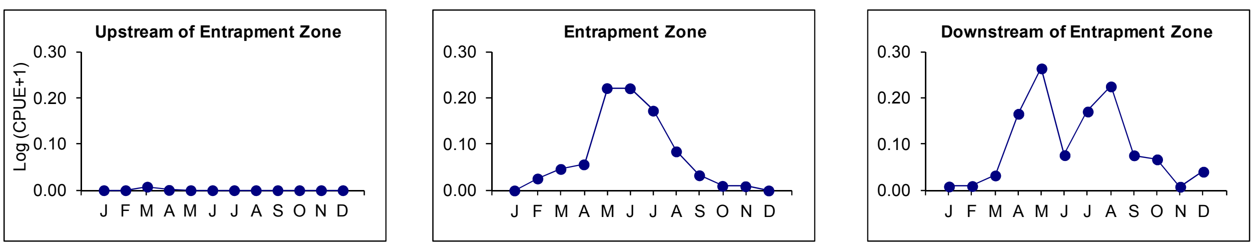

Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, within, and downstream of the entrapment zone in 2010

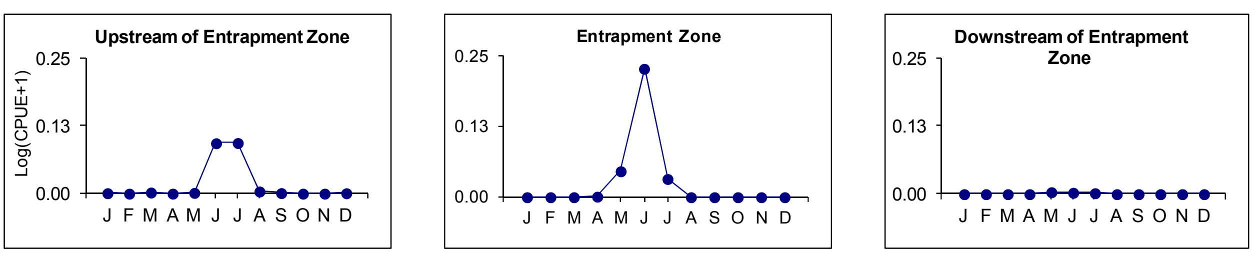

Figure 5-6 Monthly *Acanthomysis aspera* abundance upstream, within, and downstream of the entrapment zone in 2010

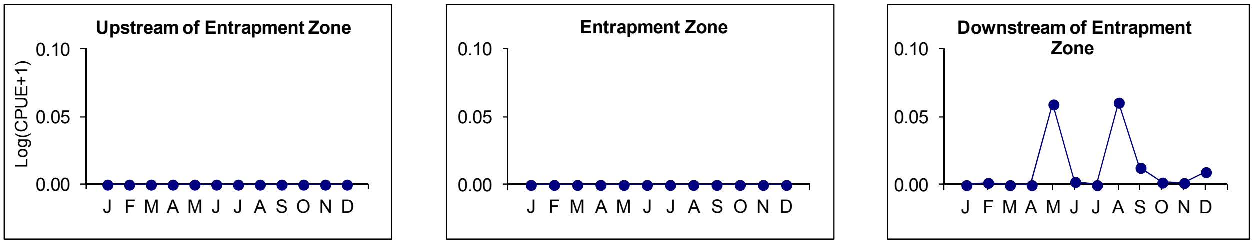

Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, within, and downstream of the entrapment zone in 2010

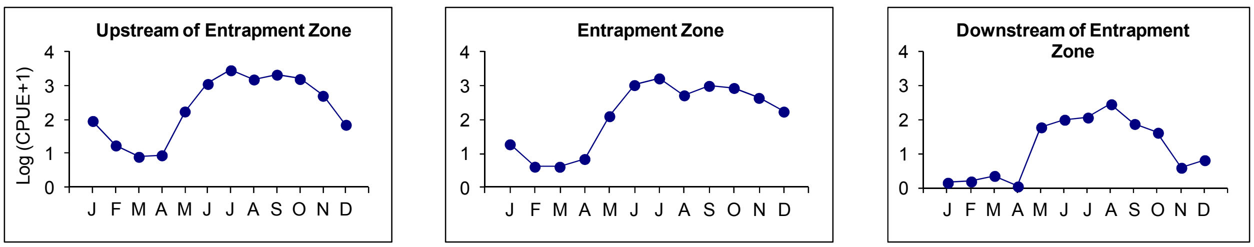

Figure 5-8 Monthly *Acartia* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

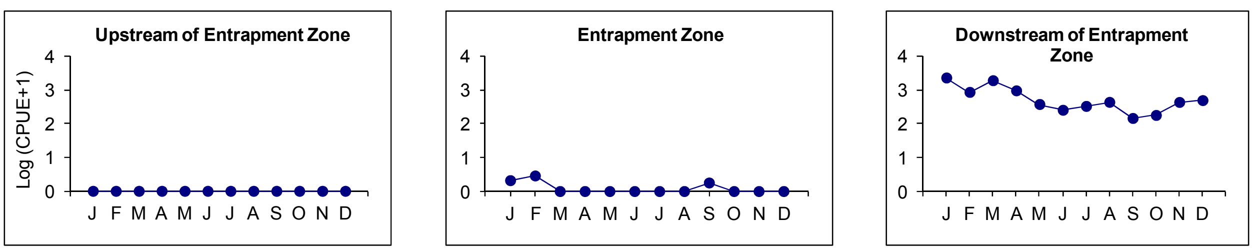

Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, within, and downstream of the entrapment zone in 2010

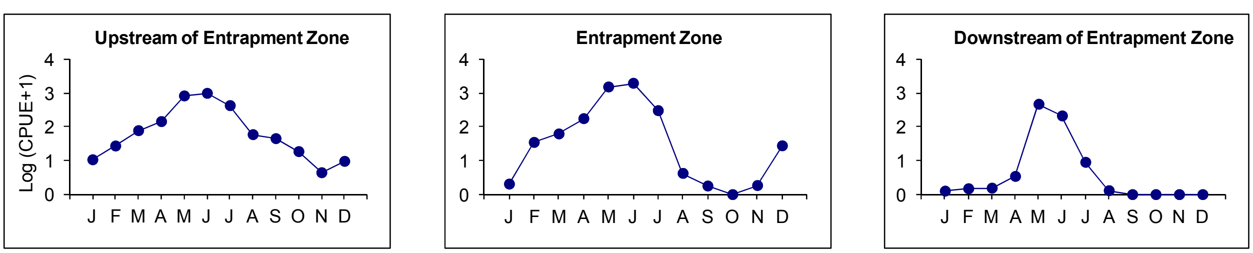

Figure 5-10 Monthly *Acartiella sinensis* abundance upstream, within, and downstream of the entrapment zone in 2010

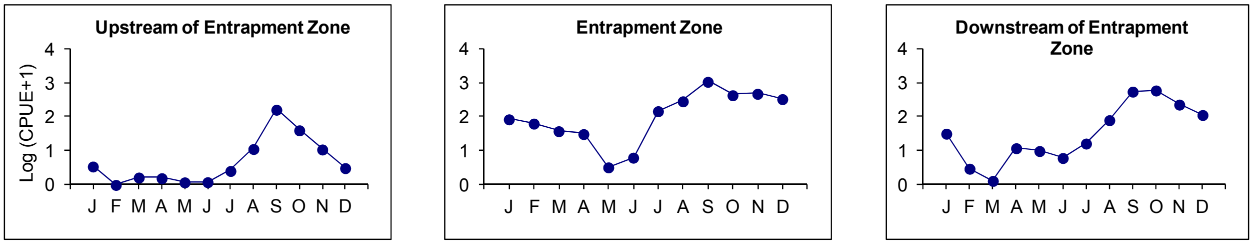

Figure 5-11 Monthly *Eurytemora affinis* abundance upstream, within, and downstream of the entrapment zone in 2010

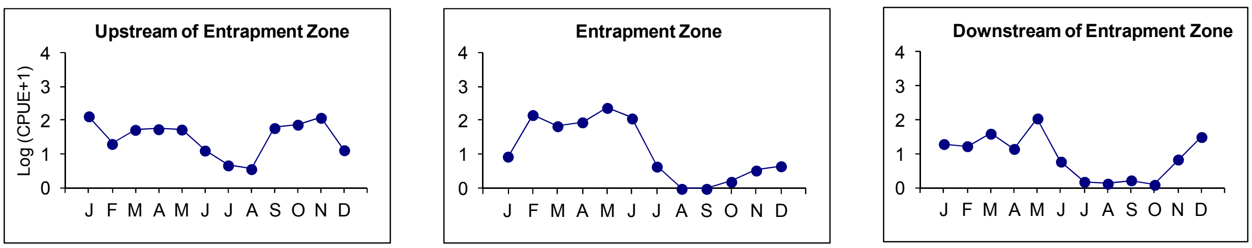

Figure 5-12 Monthly *Limnoithona tetraspina* abundance upstream, within, and downstream of the entrapment zone in 2010. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

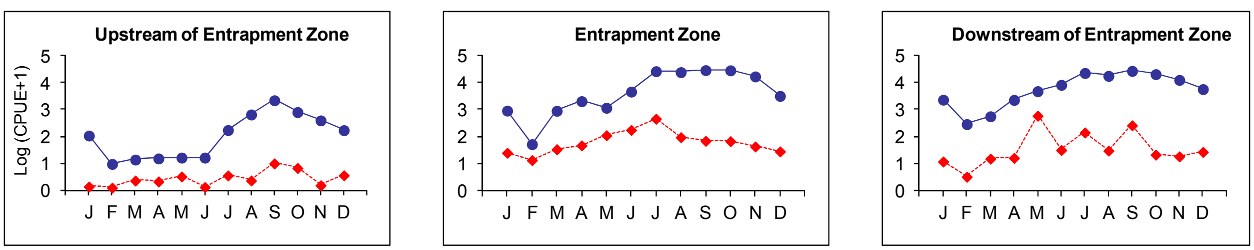

Figure 5-13 Monthly *Oithona davisae* abundance upstream, within, and downstream of the entrapment zone in 2010. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

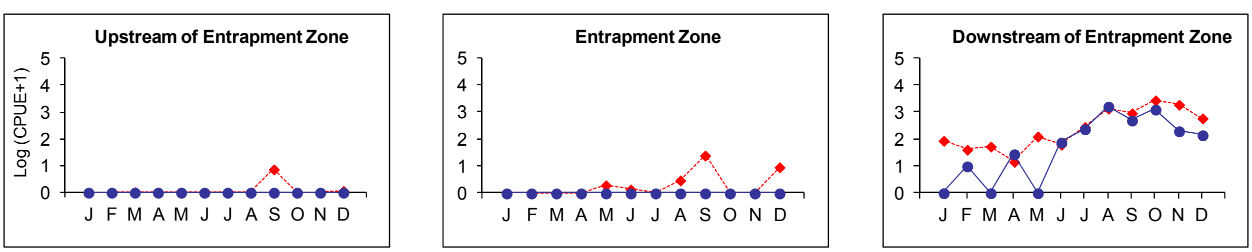

Figure 5-14 Monthly *Acanthocyclops vernalis* abundance upstream, within, and downstream of the entrapment zone in 2010

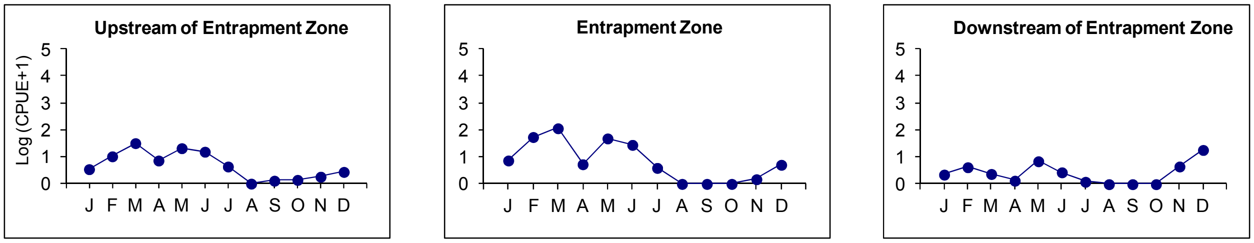

Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

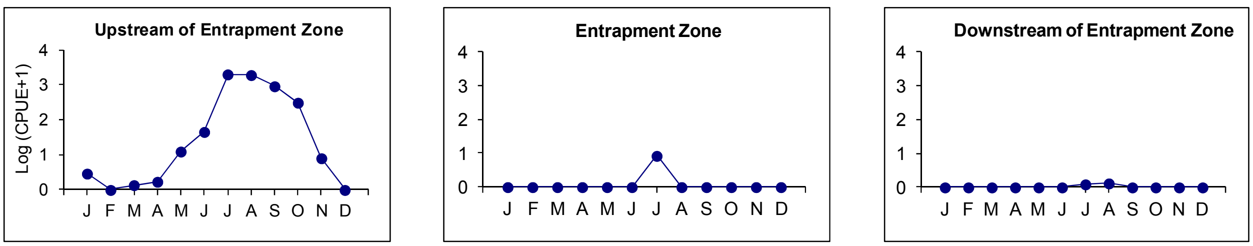

Figure 5-16 Monthly *Bosmina* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

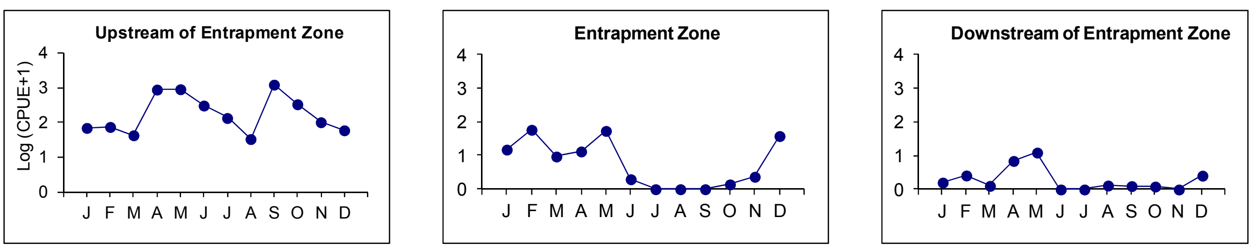

Figure 5-17 Monthly *Daphnia* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

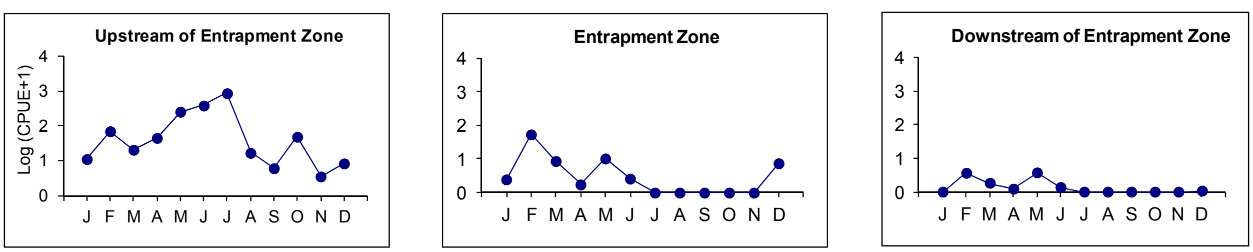

Figure 5-18 Monthly *Synchaeta* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

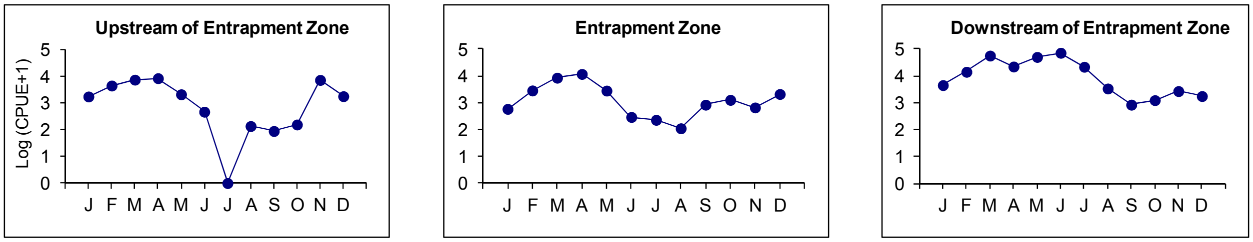

Figure 5-19 Monthly *Polyarthra* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

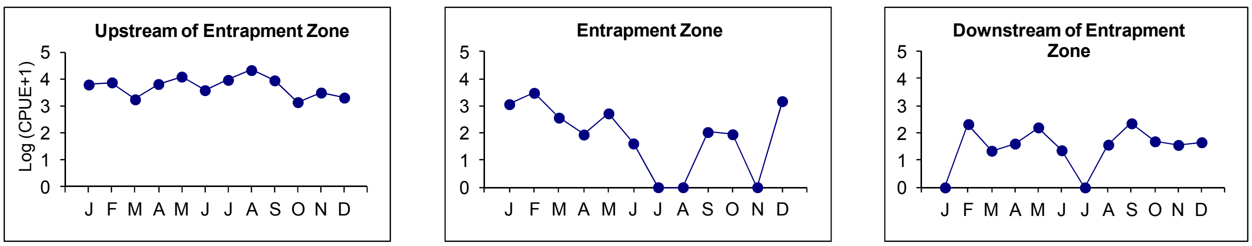

Figure 5-20 Monthly *Keratella* spp. abundance upstream, within, and downstream of the entrapment zone in 2010

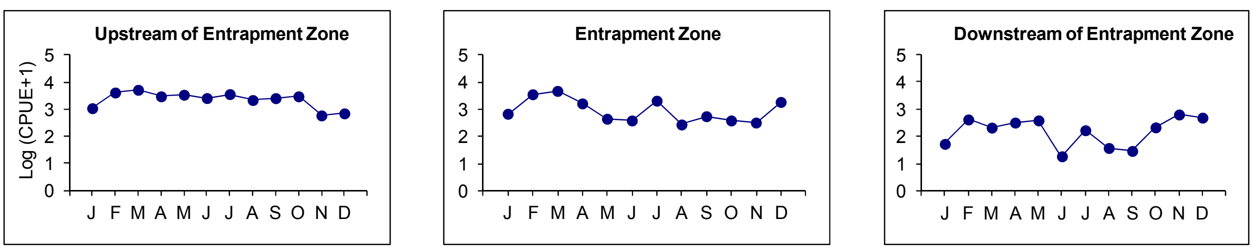

Table 5-21 Number of stations sampled monthly in each zone in 2010

Survey Month	Upstream	Entrapment Zone	Downstream	All Zones
January	6	4	9	19
February	12	3	6	21
March	12	3	5	20
April	9	6	5	20
May	10	4	6	20
June	10	4	6	20
July	8	3	6	17
August	8	2	7	17
September	7	3	9	19
October	6	3	9	18
November	6	4	9	19
December	8	3	8	19
All Months	102	42	85	229

Table 5-22 Mysid abundance upstream, within, and downstream of the entrapment zone in 2010

Mysids	Upstream	Entrapment Zone	Downstream	All Zones
Hyperacanthomysis longirostris	1.44	17.76	5.90	6.087
Alienacanthomysis macropsis	0.00	<0.01	2.24	0.826
Neomysis kadiakensis	<0.01	0.21	0.24	0.129
Neomysis mercedis	0.04	0.08	<0.01	0.036
Acanthomysis aspera	0.00	0.00	0.03	0.010

Table 5-23 Calanoid copepod abundance upstream, within, and downstream of the entrapment zone in 2010

Calanoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
Pseudodiaptomus forbesi	764.1	446.3	56.2	444.8
Acartia spp.	0.0	0.3	689.5	254.1
Sinocalanus doerrii	244.3	381.2	43.3	195.4
Acartiella sinensis	15.7	226.1	175.0	113.1
Eurytemora affinis	45.4	64.0	16.5	38.1

Table 5-24 Cyclopoid copepod abundance upstream, within, and downstream of the entrapment zone in 2010

Cyclopoid Copepods CB net:	Upstream	Entrapment Zone	Downstream	All Zones
Oithona davisae	0.5	2.5	814.8	300.9
Limnoithona tetraspina	2.2	95.8	90.6	52.0
Acanthocyclops vernalis	9.4	21.0	3.0	9.2
Pump:				
Limnoithona tetraspina	326	10218	11602	6326
Oithona davisae	0	0	375	139

Table 5-25 Cladoceran abundance upstream, within, and downstream of the entrapment zone in 2010

Cladocerans	Upstream	Entrapment Zone	Downstream	All Zones
Diaphanosoma spp.	403.5	0.5	<0.1	180.6
Bosmina spp.	342.2	15.8	1.5	156.5
Daphnia spp.	151.1	6.1	0.4	68.9

Table 5-26 Rotifer abundance upstream, within, and downstream of the entrapment zone in 2010

Rotifers	Upstream	Entrapment Zone	Downstream	All Zones
Synchaeta spp.	3045	3253	17139	8315
Polyarthra spp.	6995	540	72	3241
Keratella spp.	2891	1348	247	1627

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 2010, field sampling was conducted monthly at 10 sites throughout the estuary. Figure 6-1 shows the location of each site, and Table 6-1 summarizes latitude, longitude, salinity range, and substrate composition for each site. The research vessels *Endeavor* and *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 taken using the Ponar at each benthic monitoring site each month. Four of these grabs were used for organism identification and enumeration 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 contract with DWR, identified and enumerated organisms in the macrofaunal samples. A

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

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.

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

Results

Benthic Composition and Abundance

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 195 species collected in 2010, 10 represented 78% of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods

Ampelisca abdita

Americorophium spinicorne

Corophium alienense

Gammarus daiberi

Asian Clams

Corbula amurensis

Corbicula fluminea

Cumacean

Nippoleucon hinumensis

Sabellidae Polychaete

Manayunkia speciosa

Tubificidae Worms

Limnodrilus hoffmeisteri

Varichaetadrilus angustipenis

Of the 10 dominant species, *C. amurensis, A. abdita, and N. hinumensis* represent macrofauna that inhabit a typically higher saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *C. alienense 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 2010 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 93% 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 2010 ranged from 62,770 org/m^2 in May at D4 to 2,836 org/m^2 in May at D16. Minimum abundances ranged from 8,835 org/m^2 in March at D4 to 95 org/m^2 in April at D16.

Site C9: South Delta

Maximum abundance in 2010 occurred in June with a total of 15,187 org/m^2 (Figure 6-3). *L. hoffmeisteri* (4,247 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in December with a total of 3,363 org/m^2. *V. angustipenis* (2,470 org/m^2) was the dominant species.

Site P8: South Delta

The maximum abundance in 2010 occurred in April with a total of 13,143 org/m^2 (Figure 6-4). *M. speciosa* (9462 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in December with a total of 394 org/m^2. *C. fluminea* (841 org/m^2) was the most abundant species.

Site D28A: Central Delta

Maximum abundance in 2010 occurred in February with a total of 22,053 org/m^2 (Figure 6-5). *Cyprideis* sp. *A* (11,690 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in January with a total of 2,600 org/m^2. *Cyprideis* sp. *A* (1,135 org/m^2) was the dominant species.

Site D16: Lower San Joaquin River

Maximum abundance in 2010 occurred in May with a total of 2,836 org/m^2 (Figure 6-6). *A. spinicorne* (1,430 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in April with a total of 95 org/m^2, there was no dominant species.

Site D24: Lower Sacramento River

Maximum abundance in 2010 occurred in December with a total of 3,327 org/m^2 (Figure 6-7). *C. fluminea* (2,423 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in February with a total of 1,449 org/m^2. *C. fluminea* (860 org/m^2) was the dominant species.

Site D4: Lower Sacramento River

Maximum abundance in 2010 occurred in May with a total of 62,770 org/m^2 (Figure 6-8). *G. daiberi* (25,584 org/m^2) and *A. spinicorne* (23,826 org/m^2) were the dominant species. The minimum abundance in 2010 occurred in March with a total of 8,835 org/m^2. *A. spinicorne* (2,974 org/m^2) and *V. angustipenis* (2,627 org/m^2) were the dominant species.

Site D6: Suisun Bay

Maximum abundance in 2010 occurred in October with a total of 13,146 org/m^2 (Figure 6-9). *C. amurensis* (12,151 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in December with a total of 2,703 org/m^2. *C. amurensis* (2,024 org/m^2) was the dominant species.

Site D7: Suisun Bay

Maximum abundance in 2010 occurred in June with a total of 17,531 org/m^2 (Figure 6-10). *N. hinumensis* (7,538 org/m^2) and *C. amurensis* (7,329 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in February with a total of 4,617 org/m^2. *C. alienense* (2,570 org/m^2) was the dominant species.

Site D41: San Pablo Bay

Maximum abundance in 2010 occurred in September with a total of 14,640 org/m^2 (Figure 6-11). *Phoronopsis harmeri* (10,507 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in April with a total of 1,094 org/m^2. *Sabaco elongatus* (128 org/m^2) was the most abundant species.

Site D41A: San Pablo Bay

Maximum abundance in 2010 occurred in May with a total of 17,835 org/m^2 (Figure 6-12). *N. hinumensis* (8,916 org/m^2) was the dominant species. The minimum abundance in 2010 occurred in November with a total of 3,895 org/m^2. *A. abdita* (2,071 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 2010, organic content ranged from 0.2% at site D16 to 23.3% at site D4.

Site C9: South Delta

Sand with silt dominated the sediment content at C9 in most of 2010, except for January through April, which was mainly silty sand (Figure 6-13), except in March which composed of 50% of both sand and silt. The percentage of organic content ranged from 0.9% to 2.4%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

Site P8: South Delta

All through 2010 the sediment at P8 was consistently about four-fifths silt with sand, with a large increase of sand in August (Figure 6-14). The organic matter ranged from 2.3% to 5.3%, with the higher organic values typically coinciding with finer sediments.

Site D28A: Central Delta

Sandy sediment was dominant most months at site D28A for 2010 with the exception of March, June, September, and October when there was slightly more fine sediment (Figure 6-15). The organic matter ranged from 1.5% to 12.4%. Larger quantities of organic matter coincided with an abundance of fine sediment.

Site D16: Lower San Joaquin River

Silt dominated the sediment type at site D16 for 2010 with the exception of January, April, June, July, and December when sand greatly increased (Figure 6-16). The amount of organic matter at this site ranged from 0.2% to 3.8% with higher values coinciding with higher percentages of fine sediment.

Site D24: Lower Sacramento River

Sand dominated the sediment at site D24 during 2010 (Figure 6-17). The amount of organic matter ranged from 0.5% to 1.3%.

Site D4: Lower Sacramento River

Silt with sand dominated at site D4 during 2010. Large increases in sand were seen during February, May, and October through November (Figure 6-18). The percent of organic matter at this site was high during August and December but low for the rest of the year, and ranged from 2.1% to 23.3%.

Site D6: Suisun Bay

Silty clay dominated site D6 throughout 2010 (Figure 6-19). Organic matter at this site remained quite constant ranging from 3.1% to 5.9%.

Site D7: Suisun Bay

Silty clay dominated site D7 for all of 2010 (Figure 6-20). The organic matter at this site was stable throughout the year ranging from 2.3% to 4.4%.

Site D41: San Pablo Bay

The majority of the months at site D41 in 2010 contained higher percentages of sandy sediment with the exception of January, May, July, and November, which generally contained a slightly higher percent of silty fines; however, November was dominated by silty sand (Figure 6-21). The organic matter ranged from 1.5% to 16.1% with a high during September, but lower and stable during the rest of the year.

Site D41A: San Pablo Bay

Fine clay and silt sediments dominated site D41A for all of 2010 (Figure 6-22). The percent organic matter at this site evenly ranged from 1.9% to 4.1%.

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 2010 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida, and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda, and Mollusca constituted 93% of the organisms collected during the study period. Ten species represent 78% of all organisms collected during this period. These species are: (1) The amphipods—*A. abdita*, *A. spinicorne*, *C. alienense,* and *G. daiberi*; (2) The S. polychaete—*M. speciosa* (3) the Tubificidae worms—*V. angustipenis and L. hoffmeisteri*; (4) the cumacean—*N. hinumensis* and (5) the Asian clams—*C. amurensis* and *C. fluminea*.

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Chapter 6 Appendix

Figure 6-1 Location of macrobenthic monitoring stations

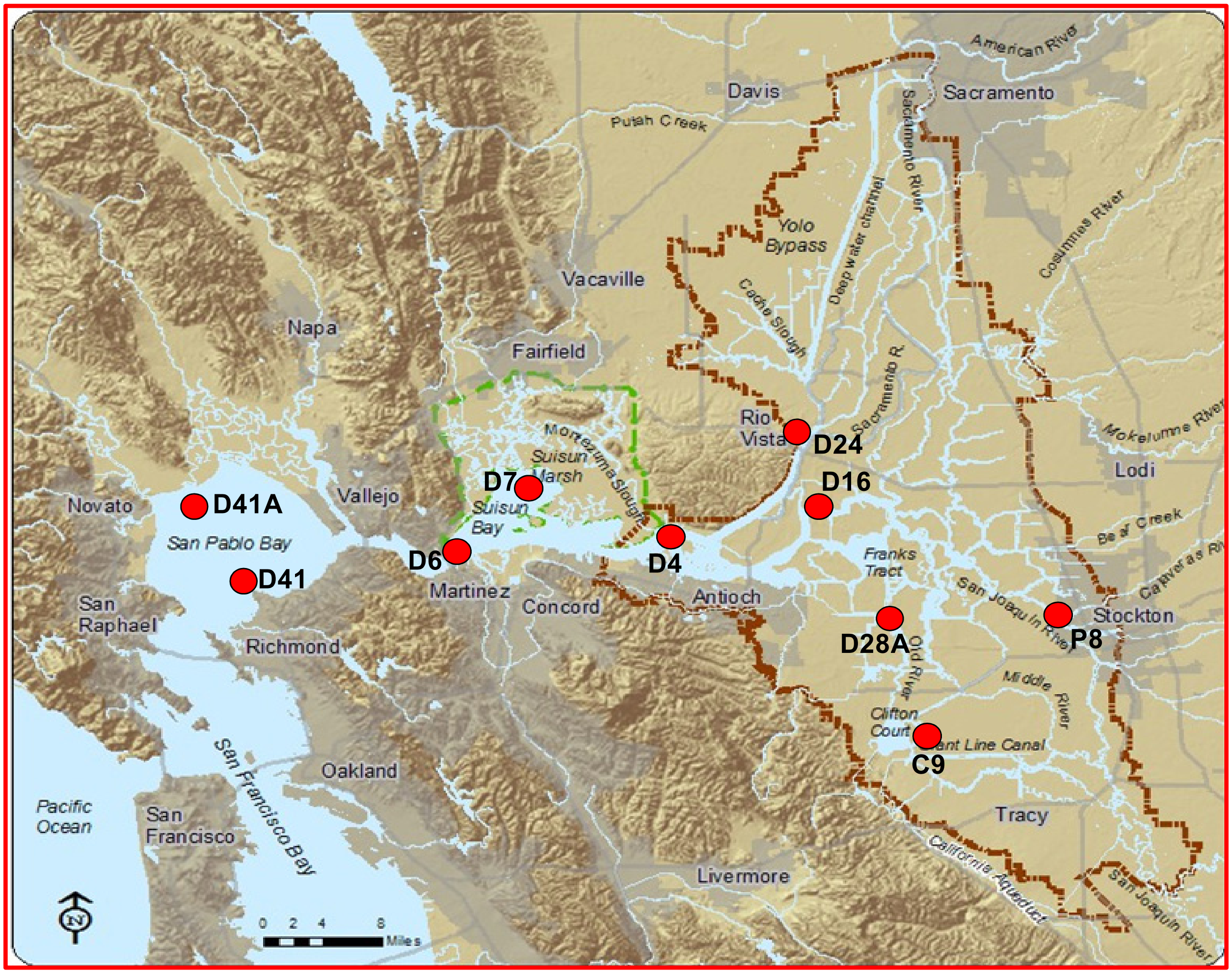


Figure 6-2 Total contribution by phyla for all stations, 2010

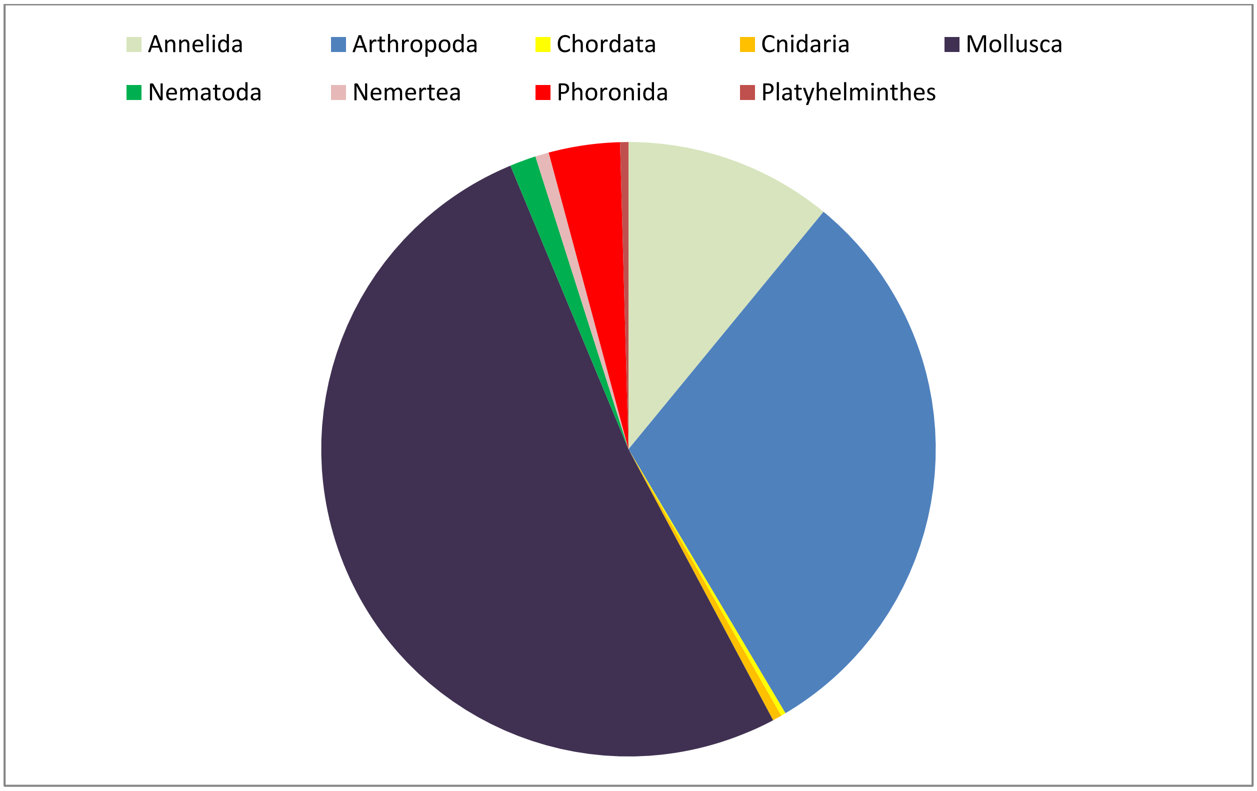


Figure 6-3 Total abundance at C9, 2010

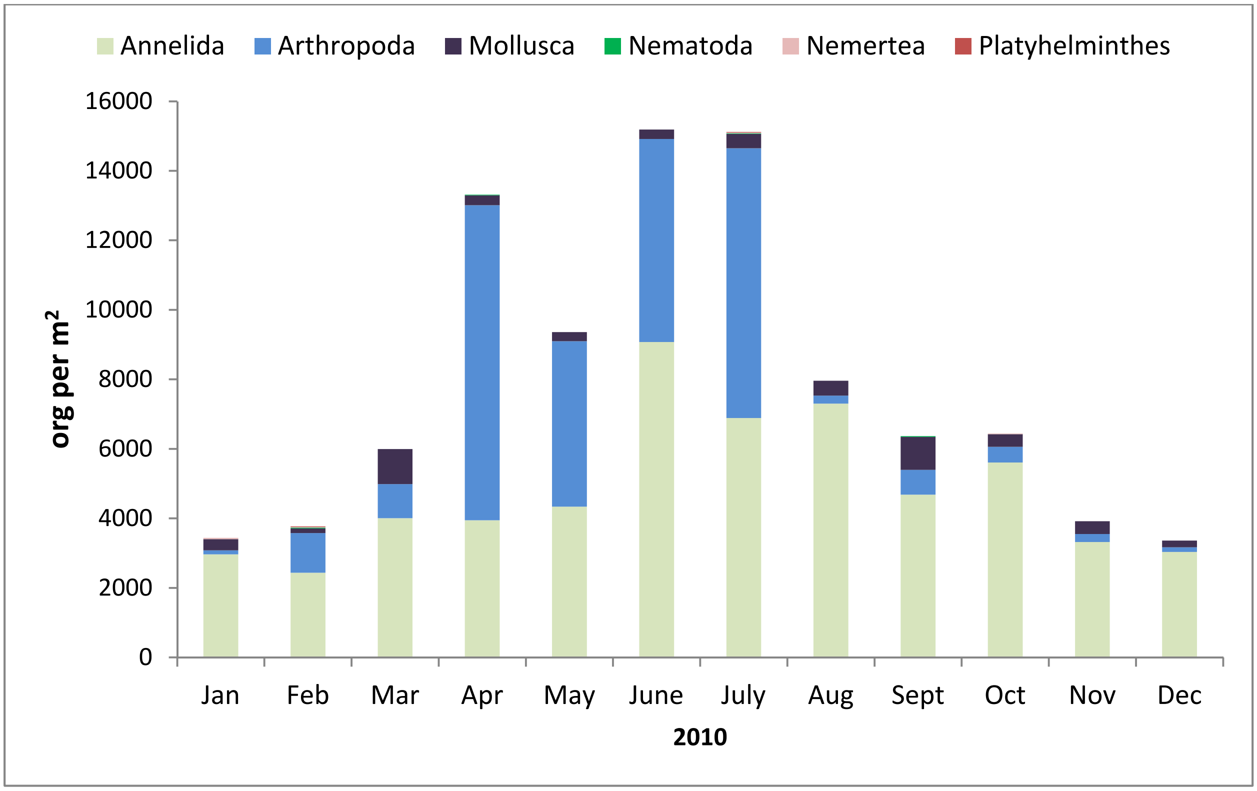


Figure 6-4 Total abundance at P8, 2010

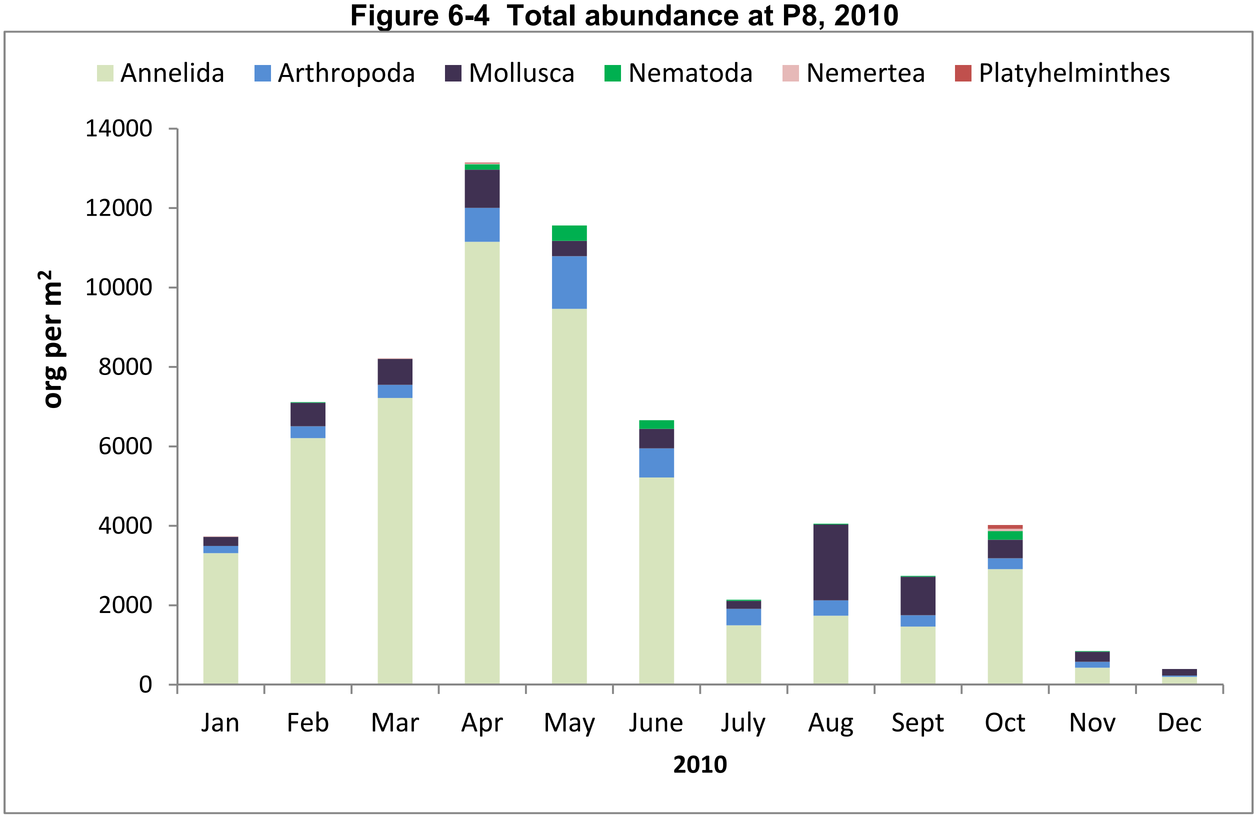


Figure 6-5 Total abundance at D28A, 2010

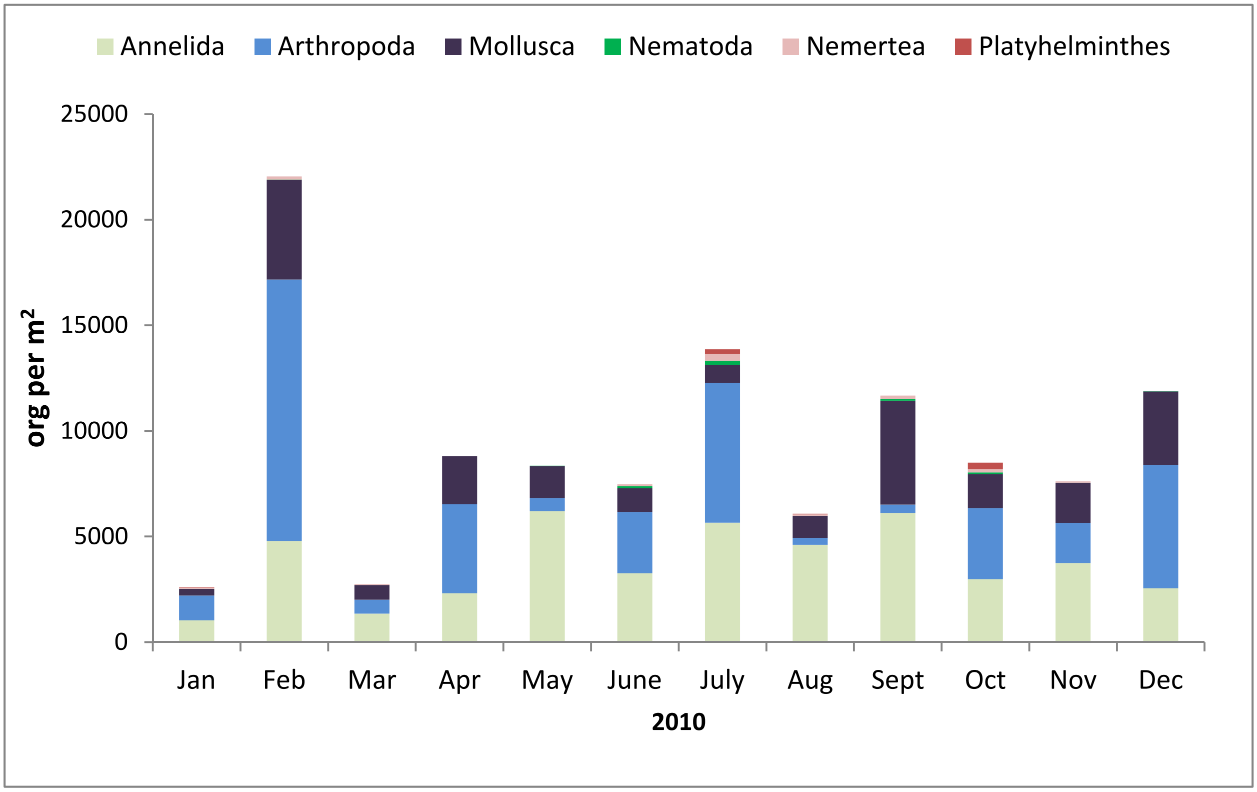


Figure 6-6 Total abundance at D16, 2010

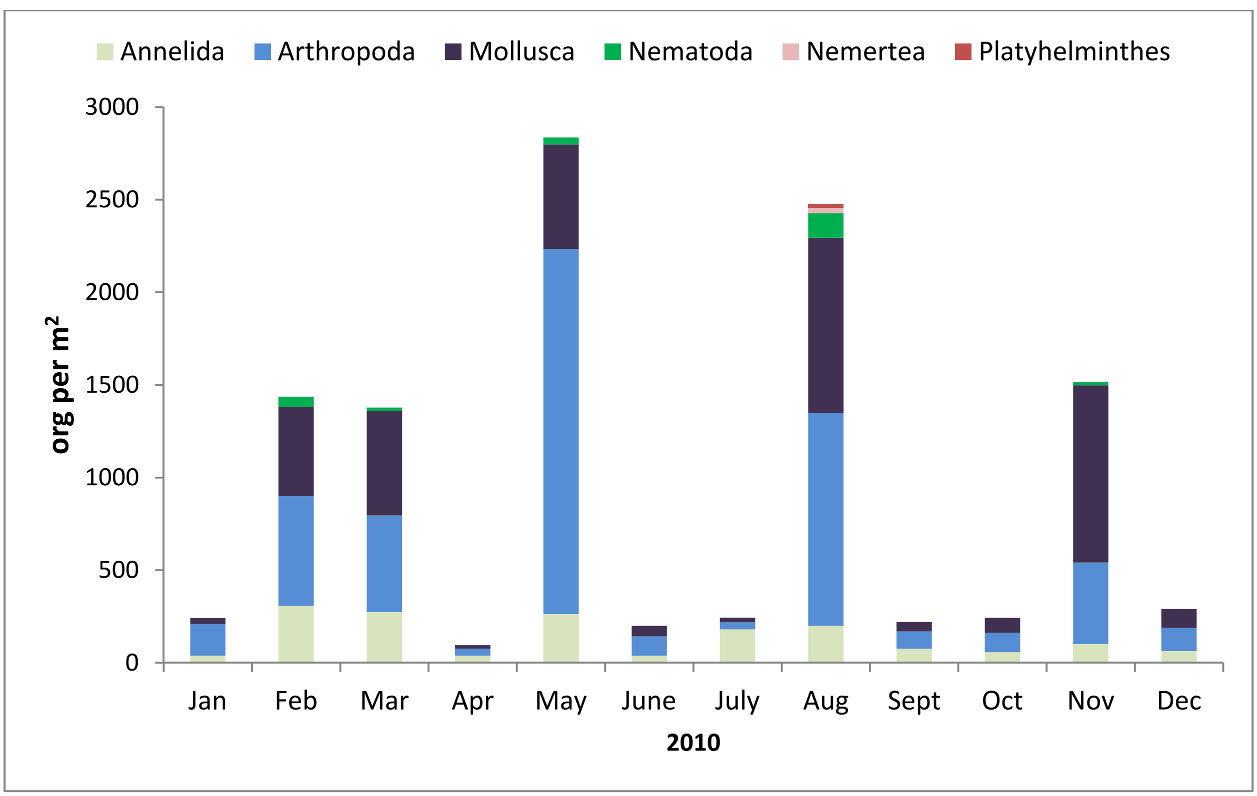


Figure 6-7 Total abundance at D24, 2010

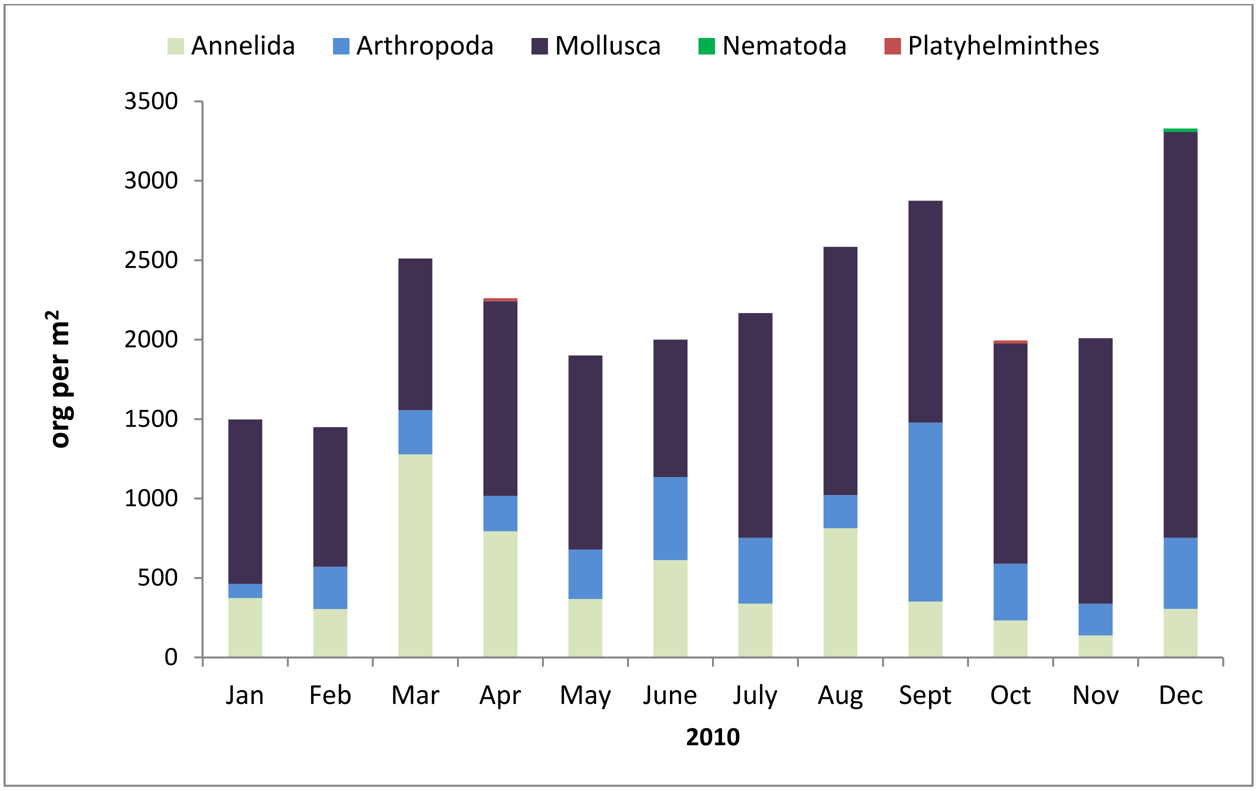


Figure 6-8 Total abundance at D4, 2010

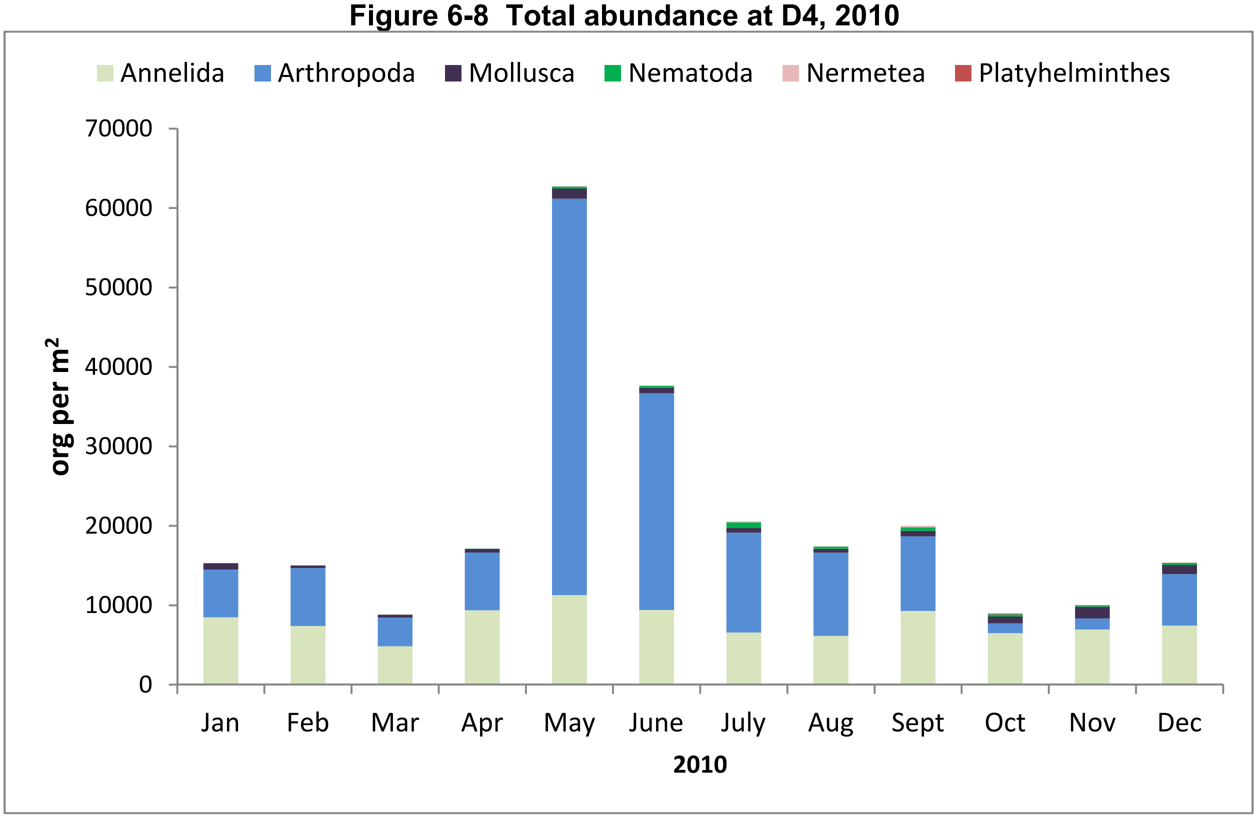


Figure 6-9 Total abundance at D6, 2010

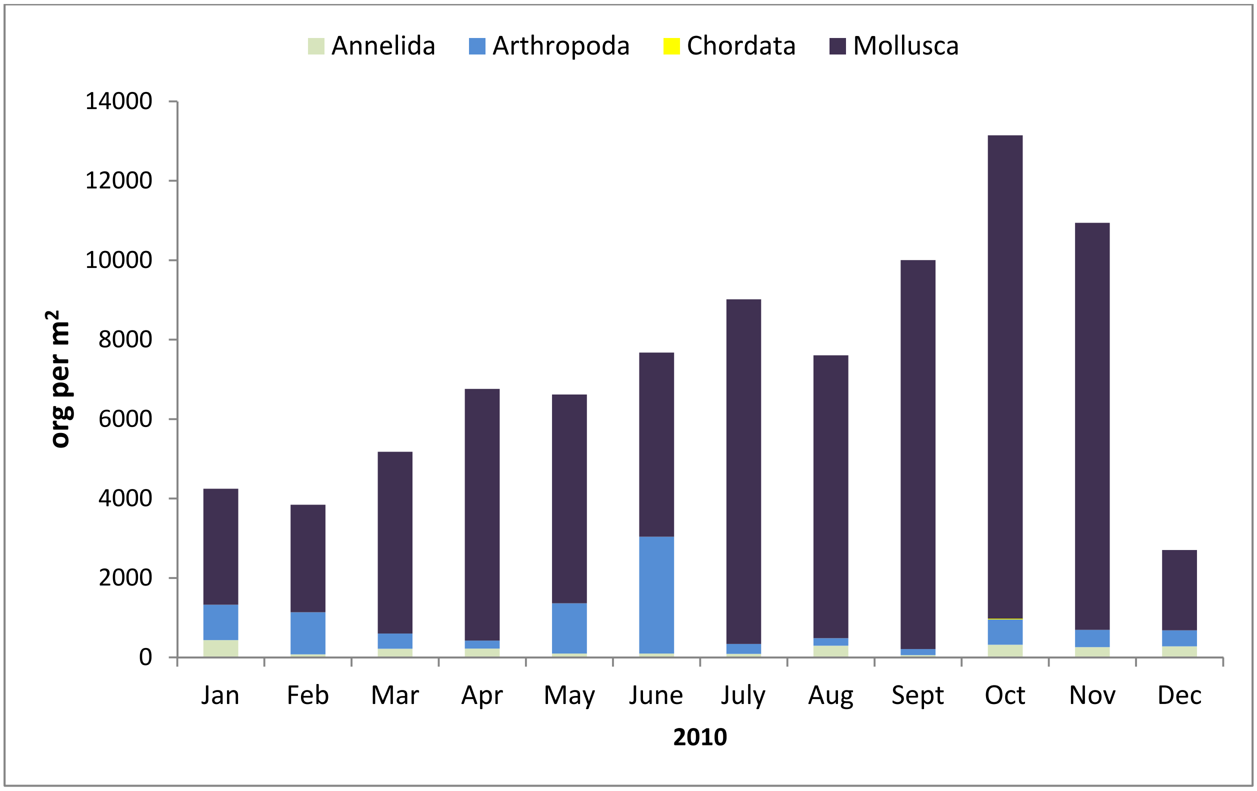


Figure 6-10 Total abundance at D7, 2010

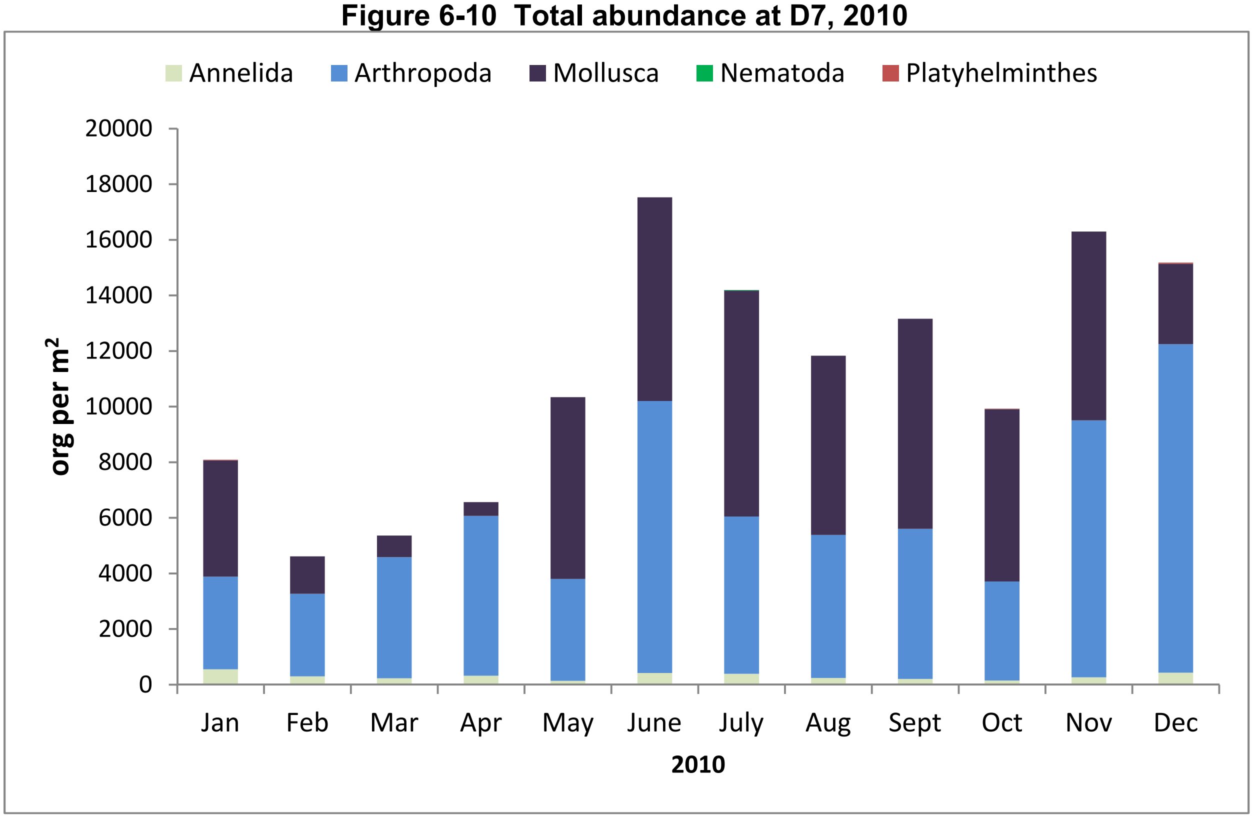


Figure 6-11 Total abundance at D41, 2010

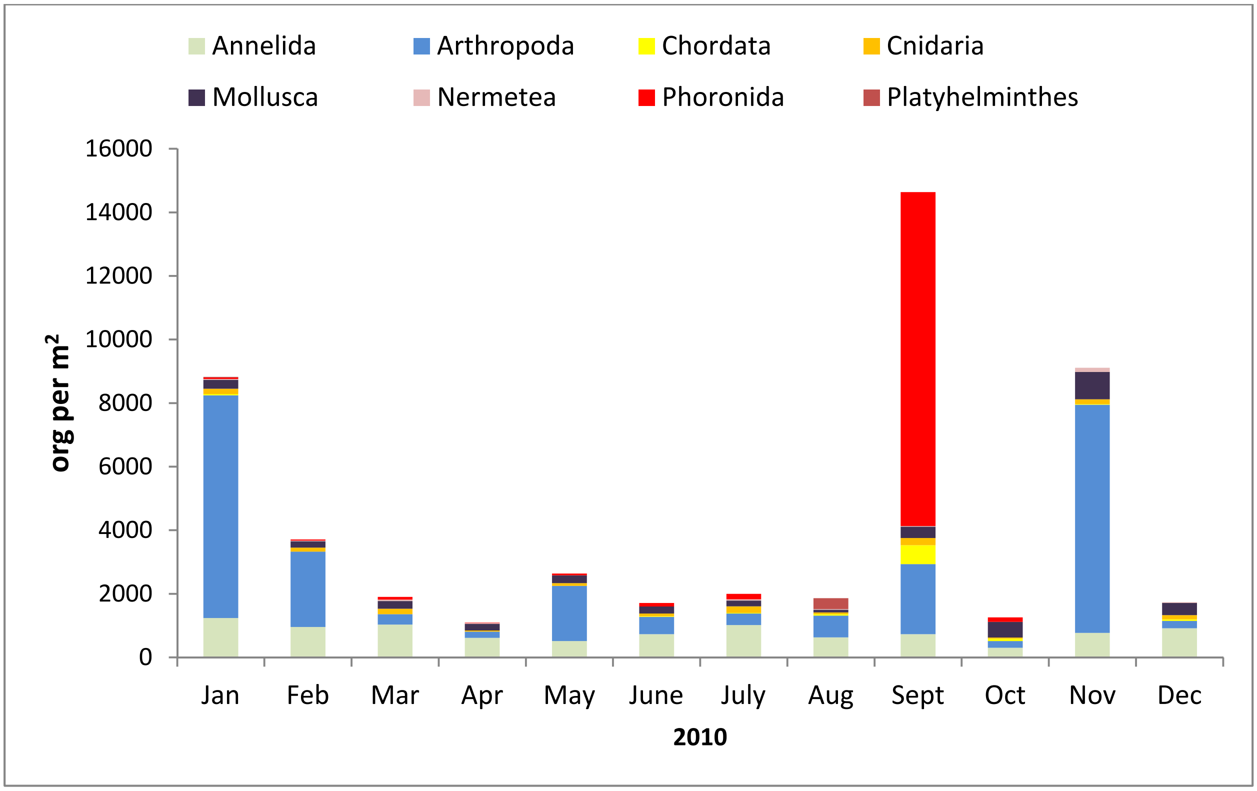


Figure 6-12 Total abundance at D41A, 2010

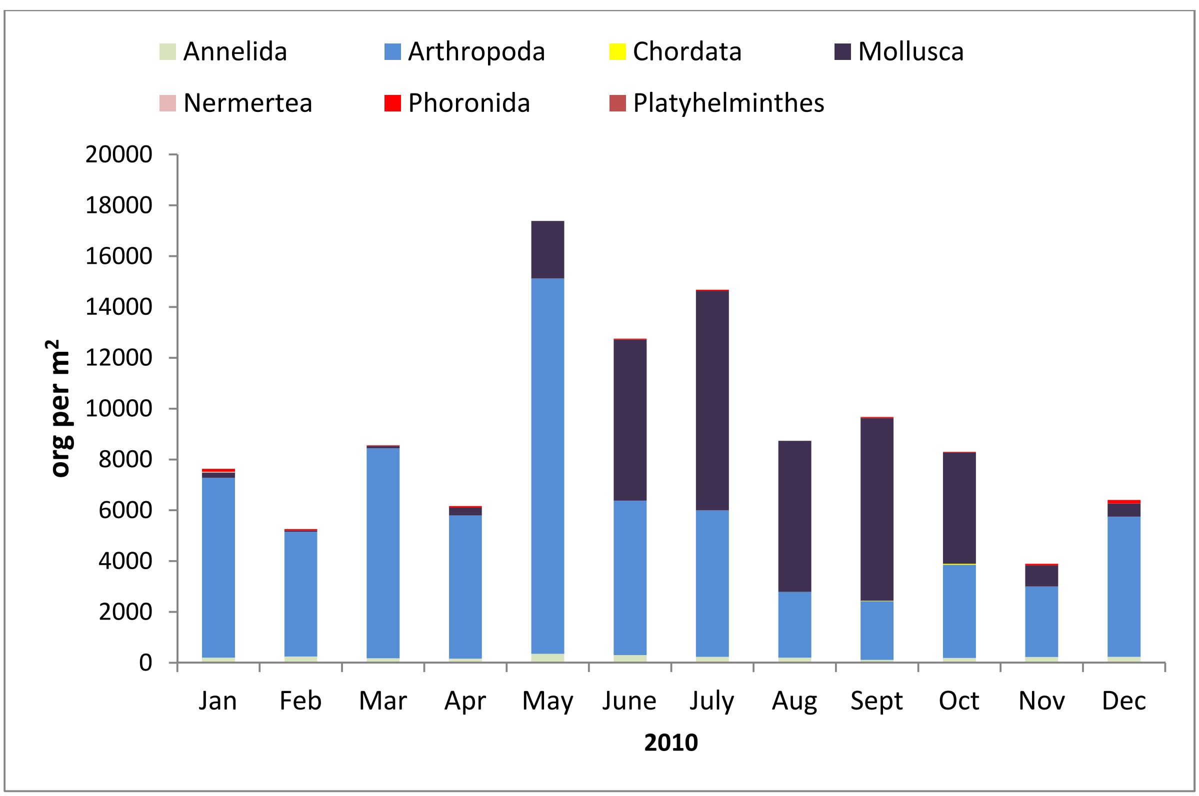
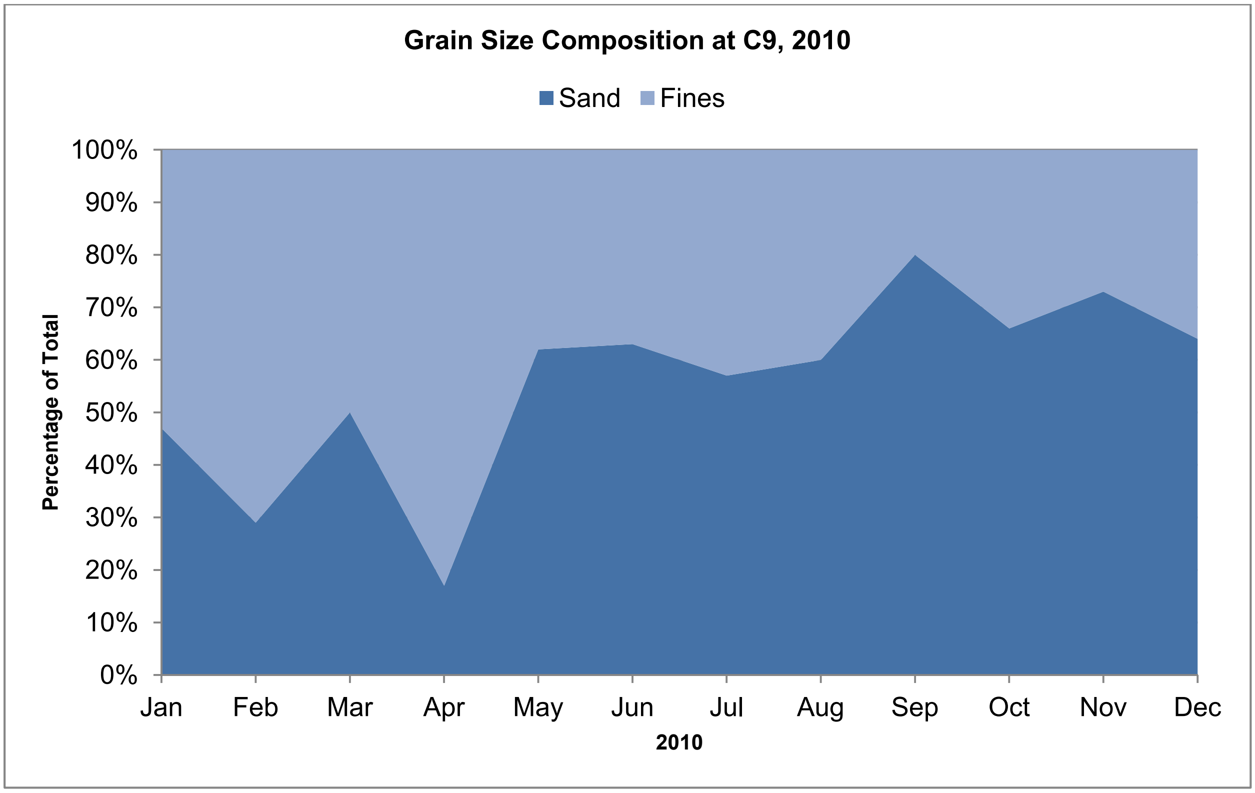


Figure 6-13 Sediment grain size and organic content at C9, 2010



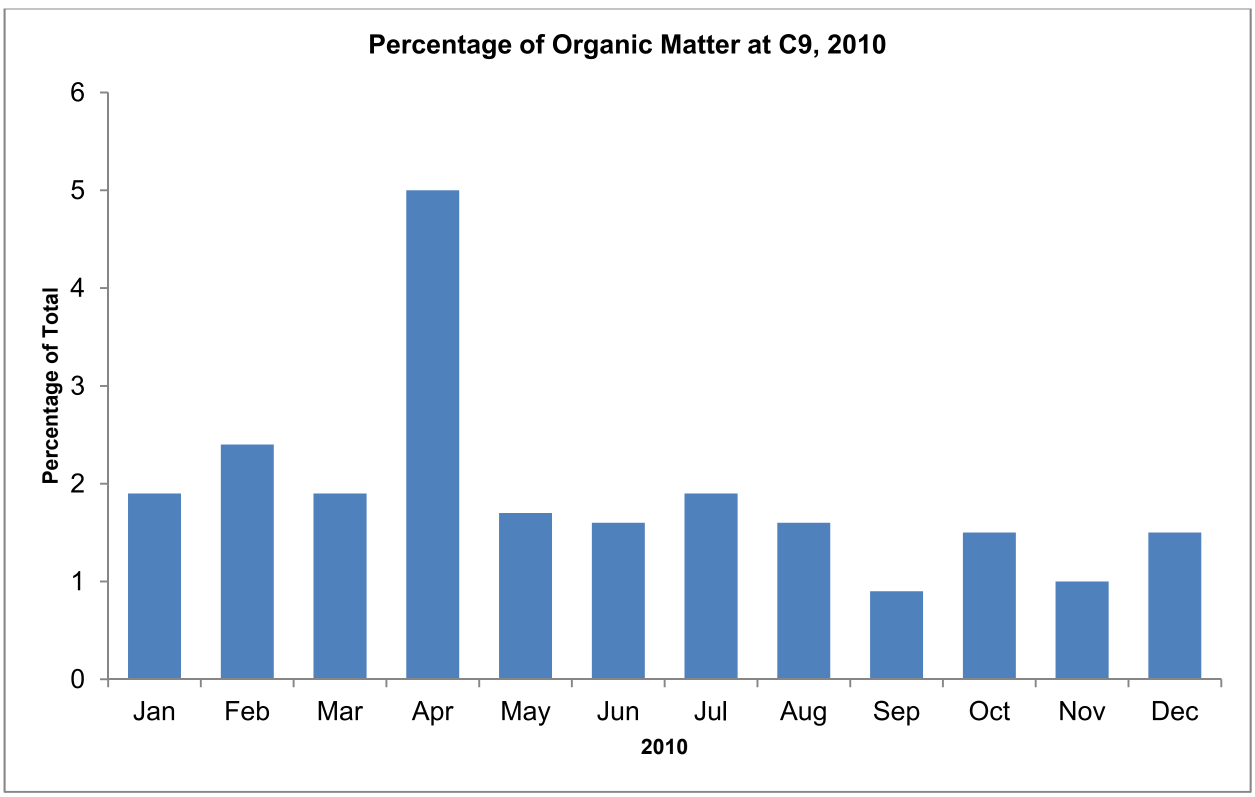
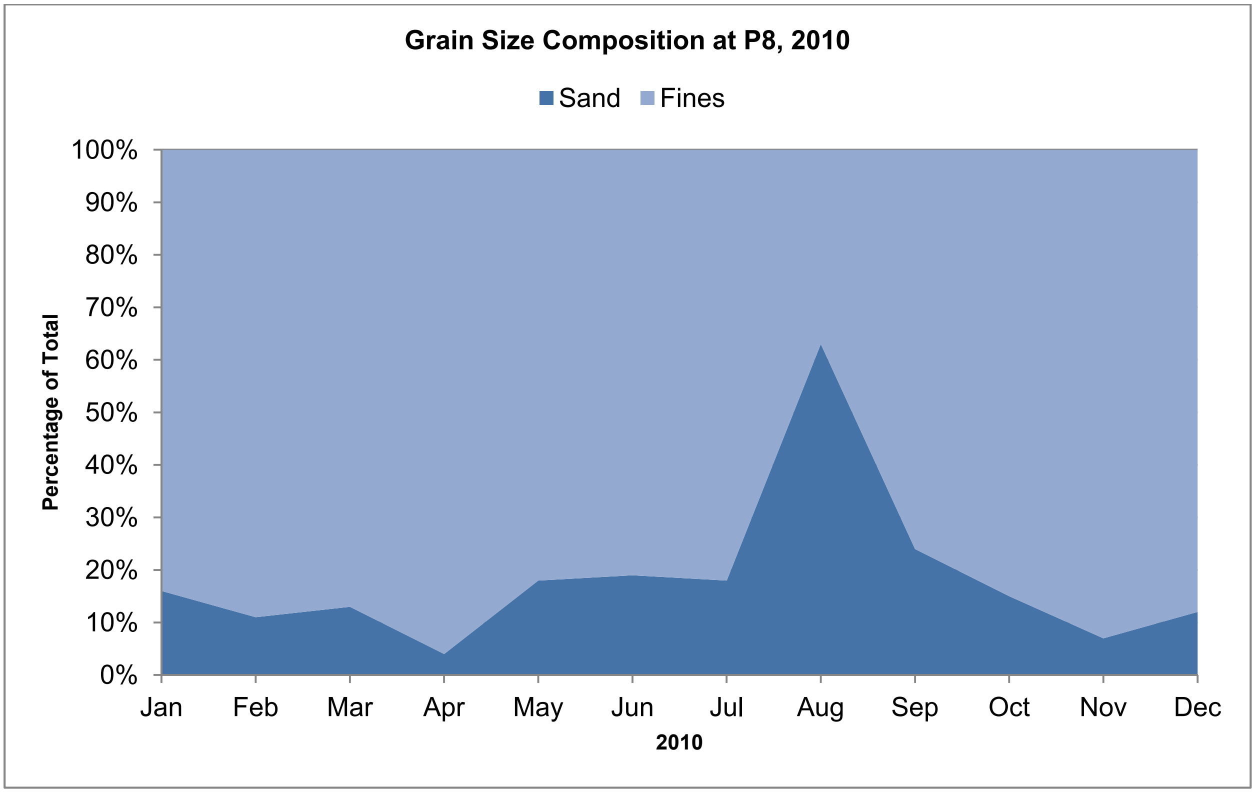


Figure 6-14 Sediment grain size and organic content at P8, 2010



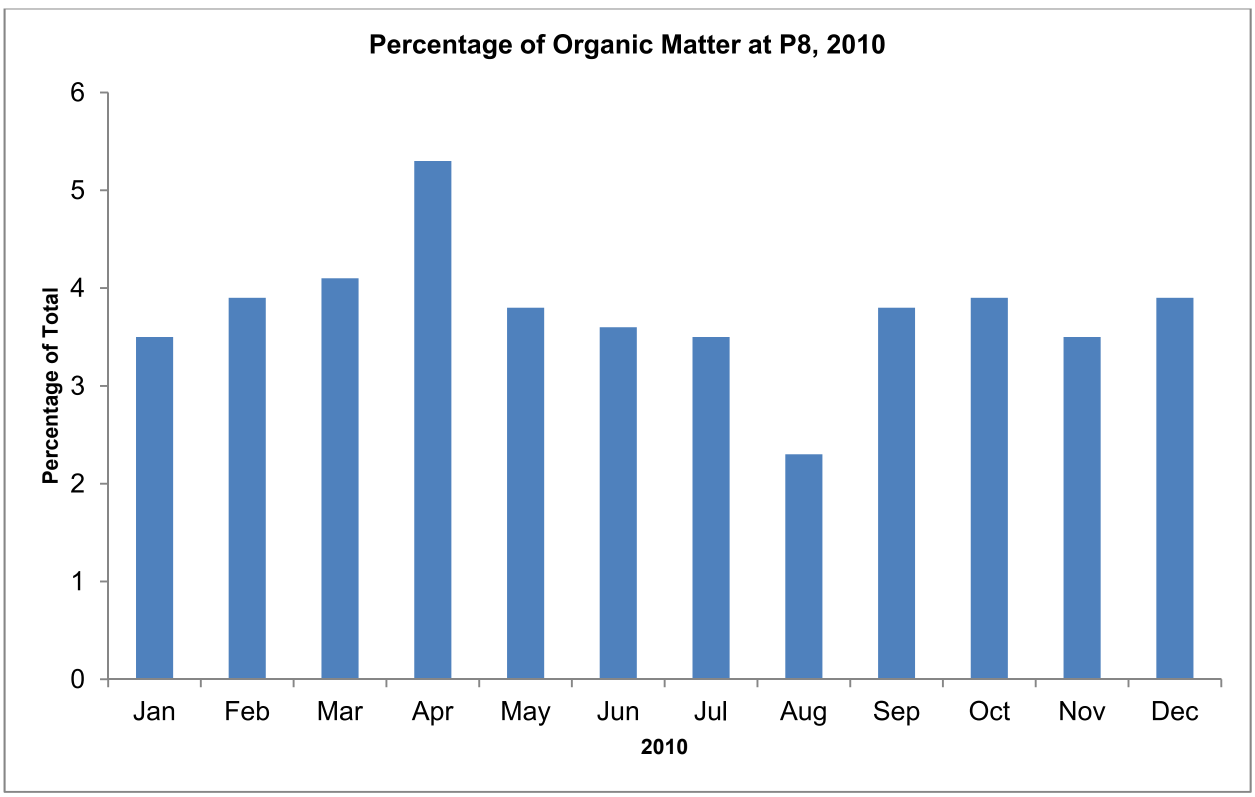
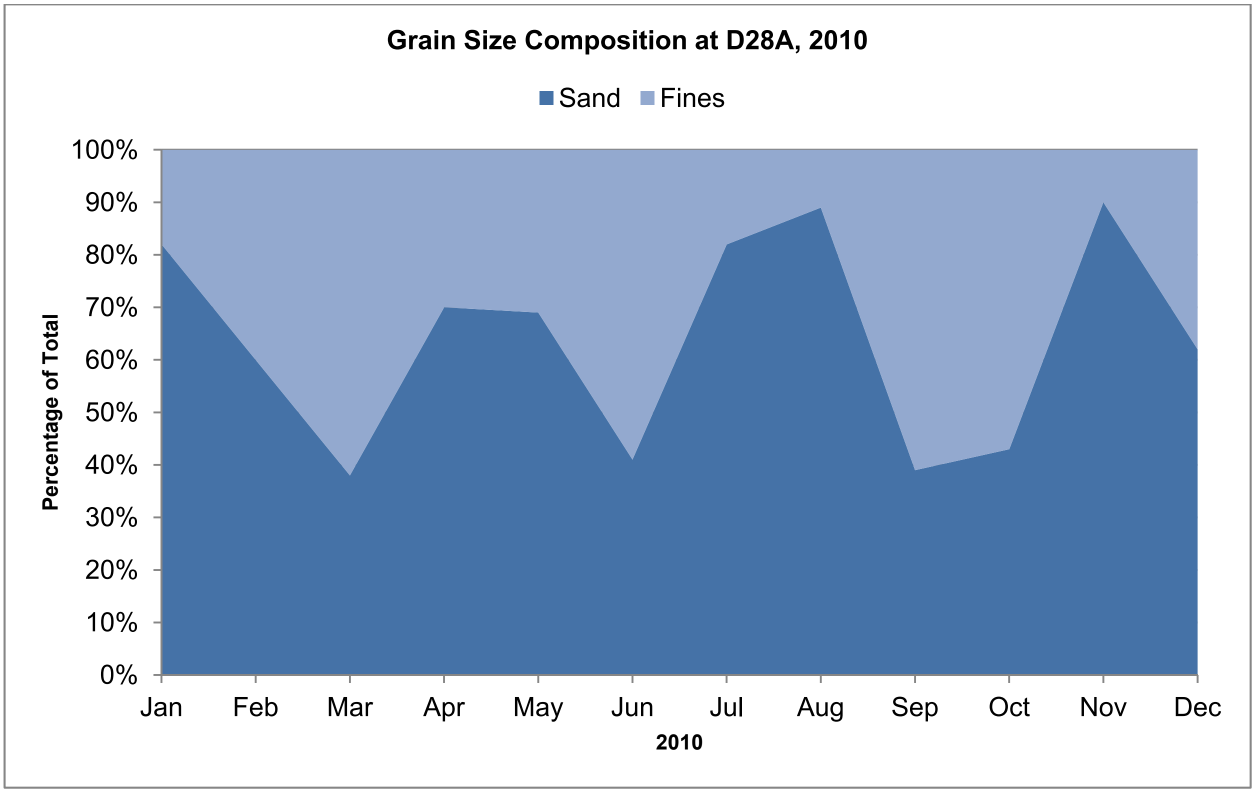


Figure 6-15 Sediment grain size and organic content at D28A, 2010



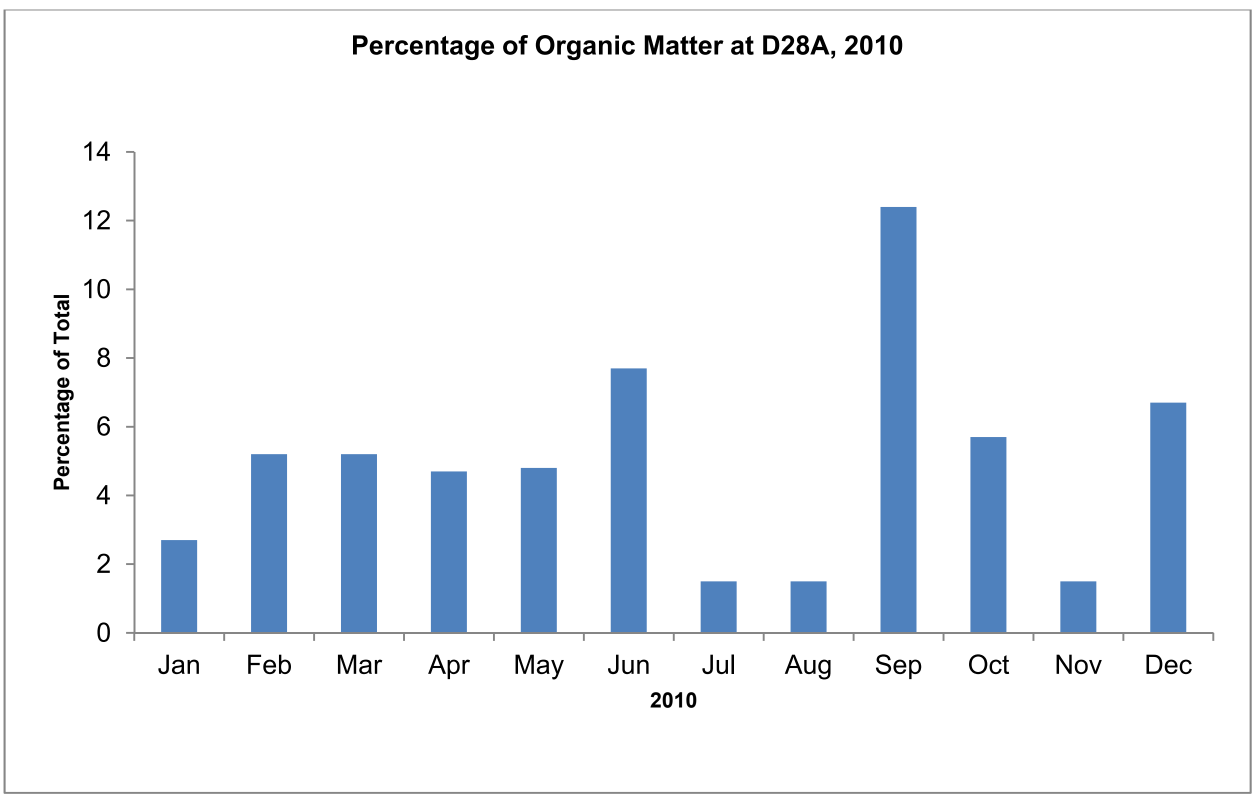
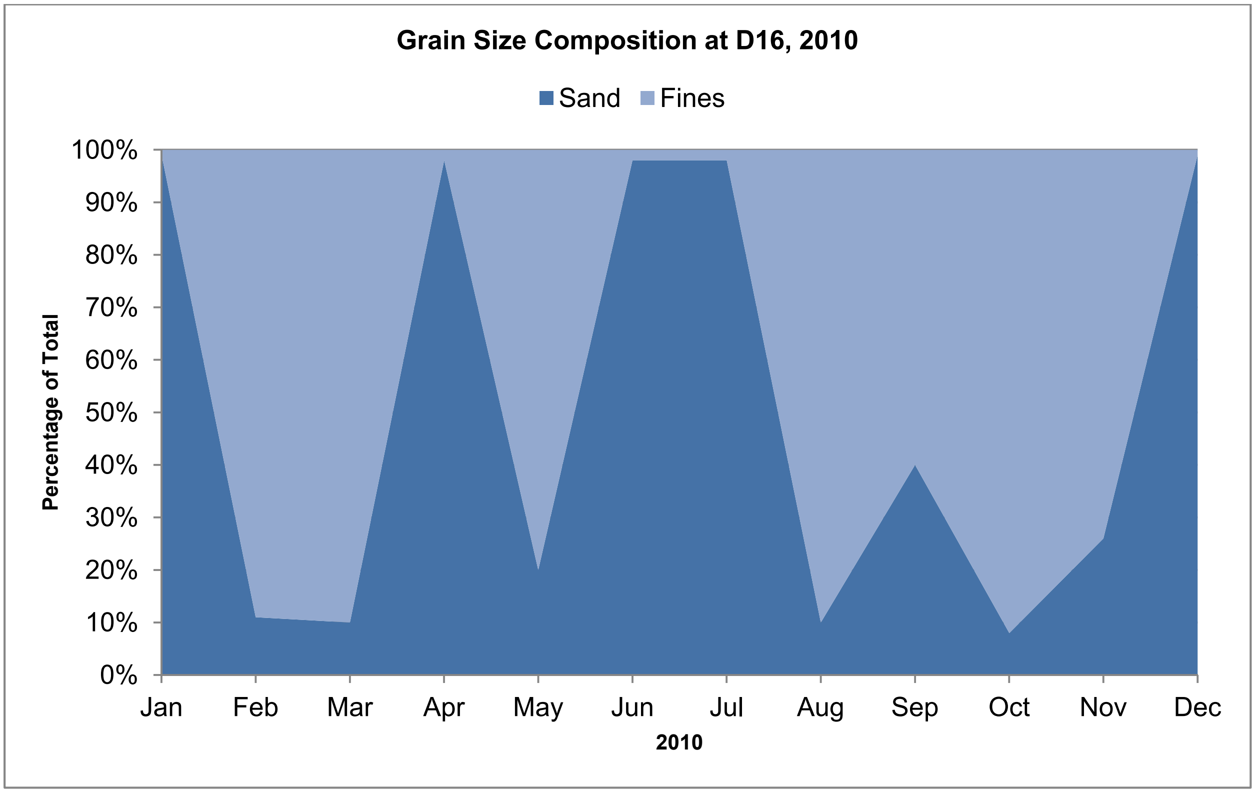


Figure 6-16 Sediment grain size and organic content at Station D16, 2010



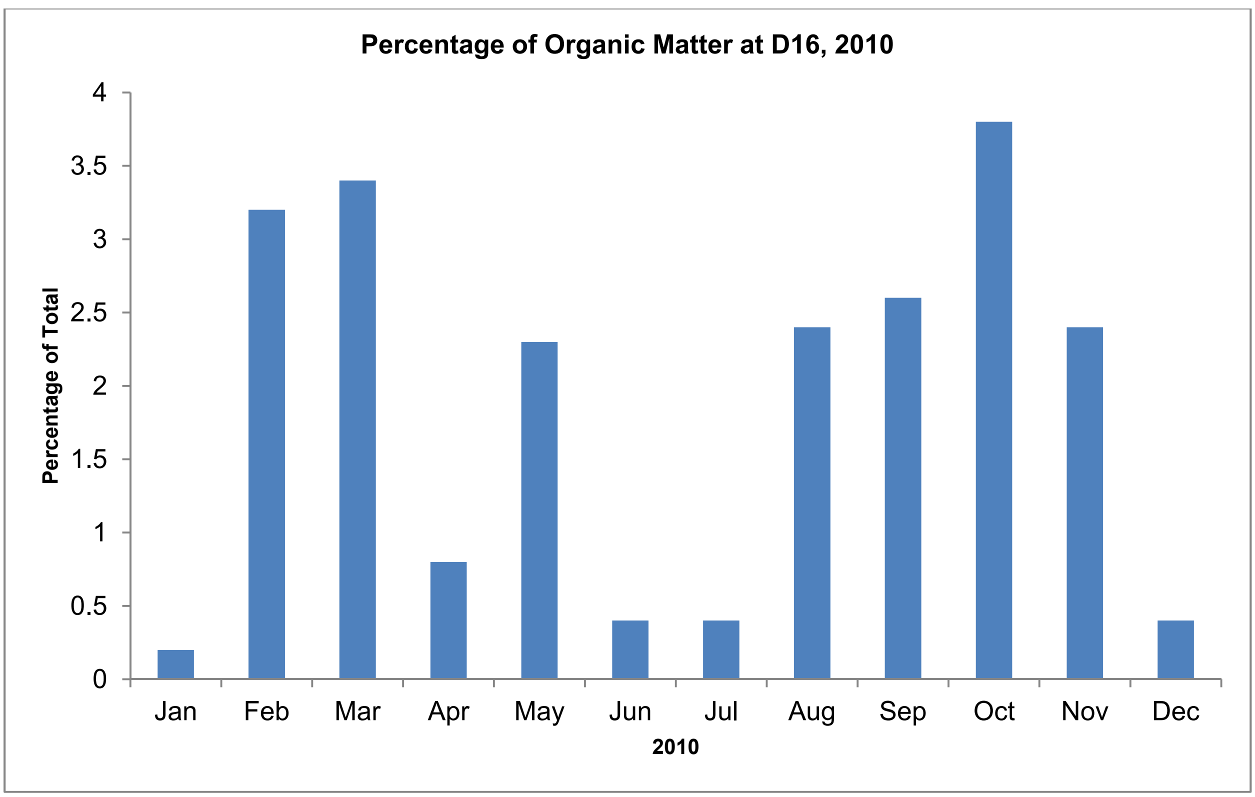
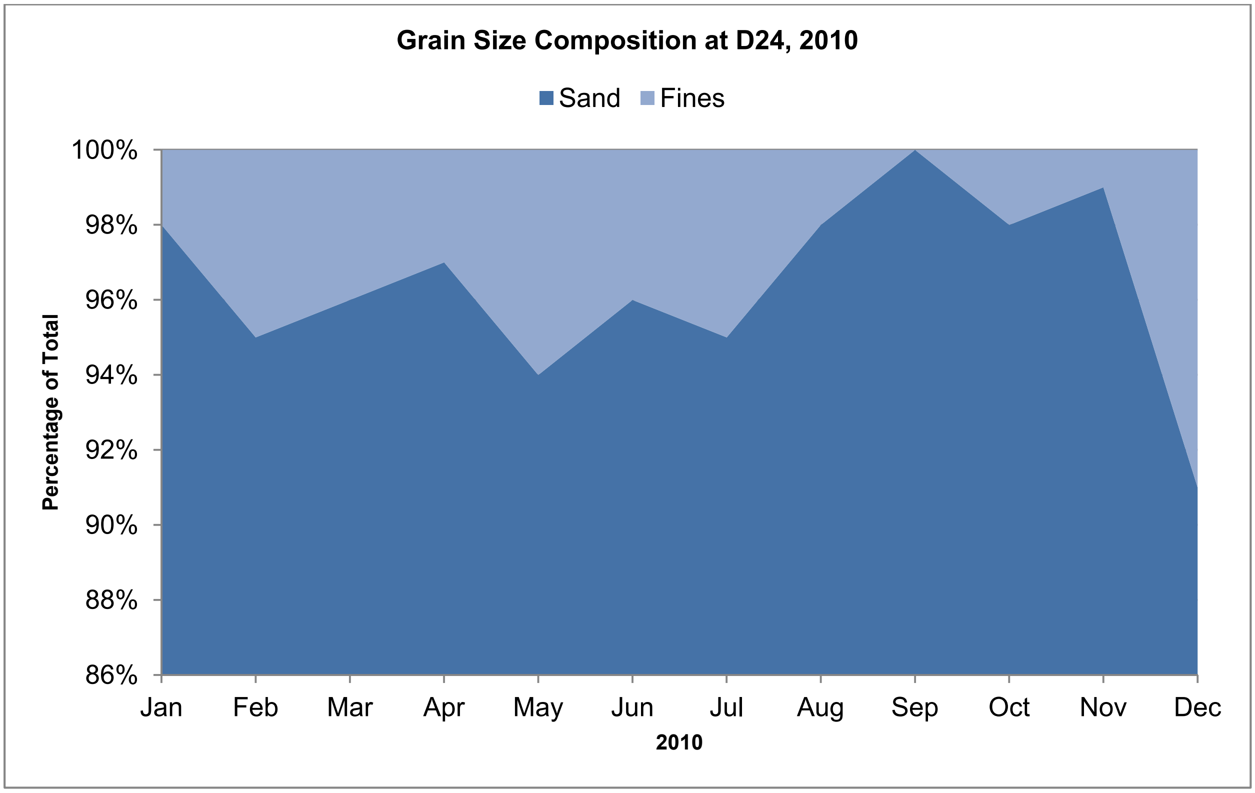


Figure 6-17 Sediment grain size and organic content at D24, 2010



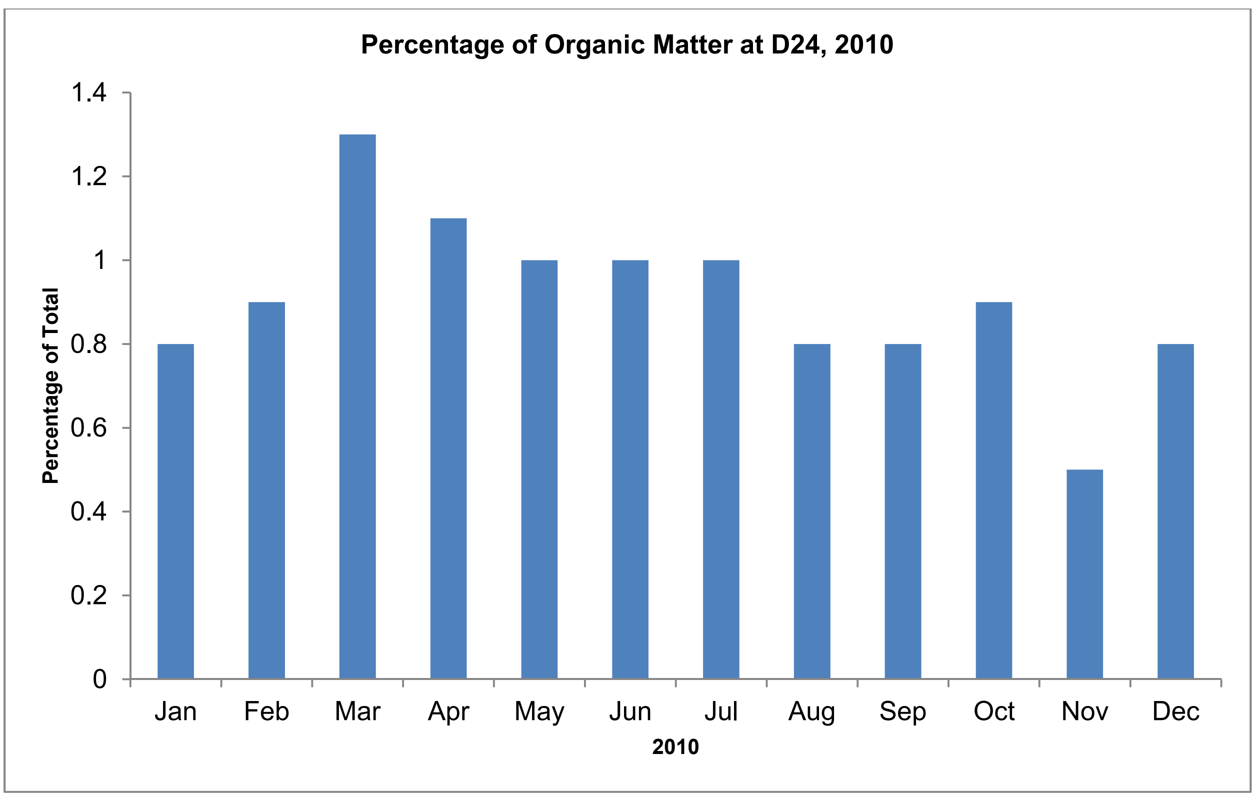
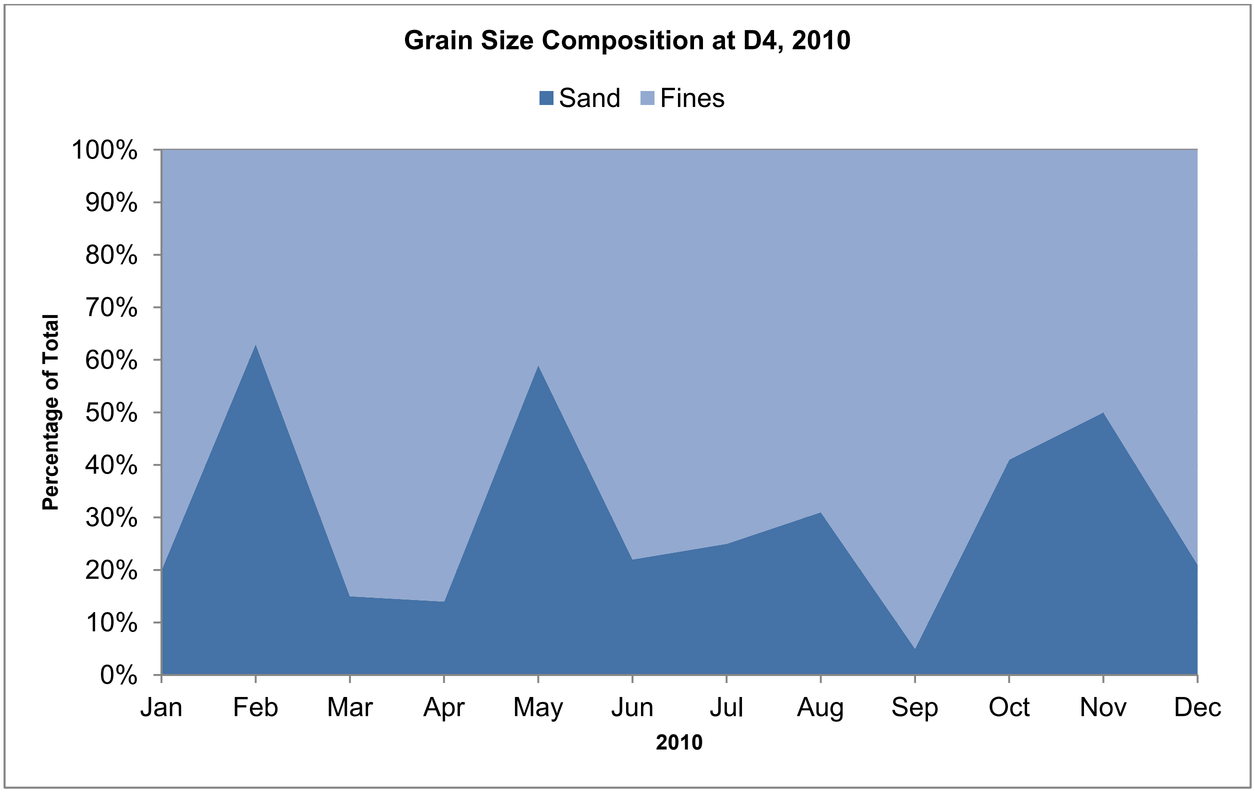


Figure 6-18 Sediment grain size and organic content at Station D4, 2010



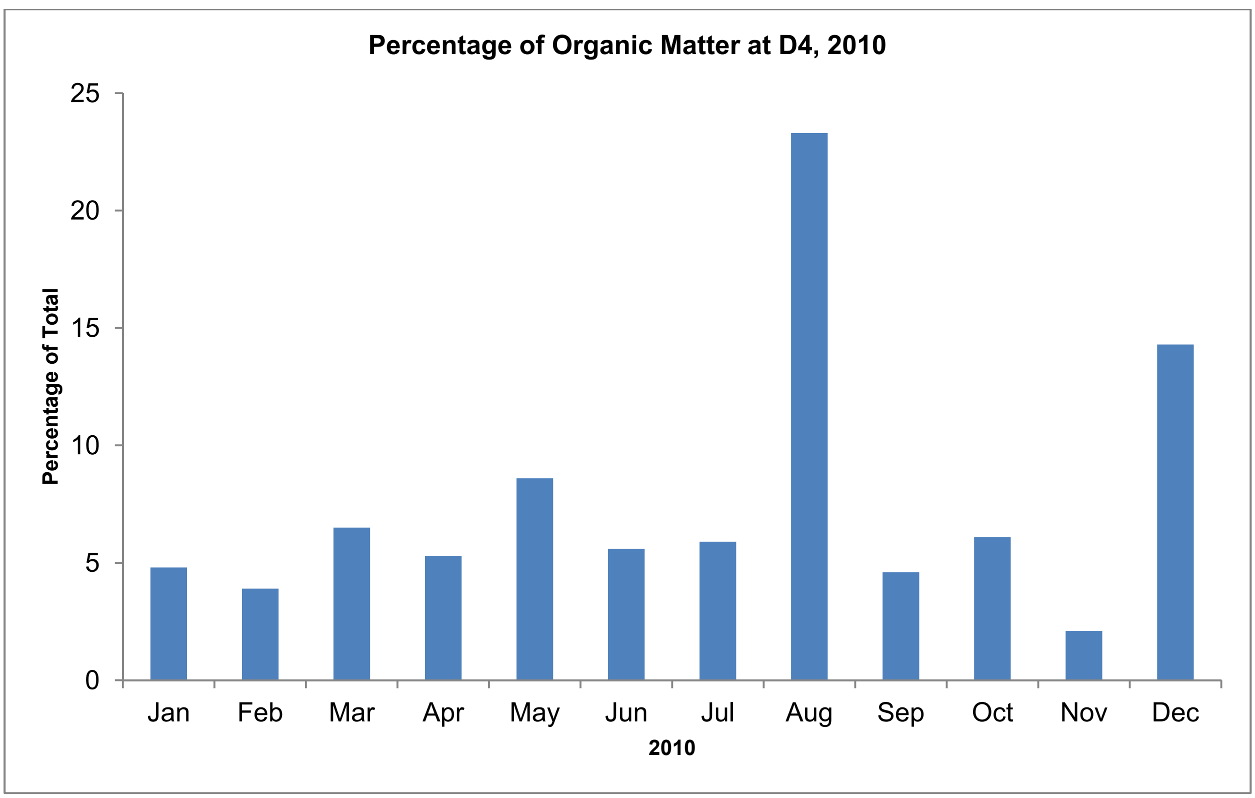
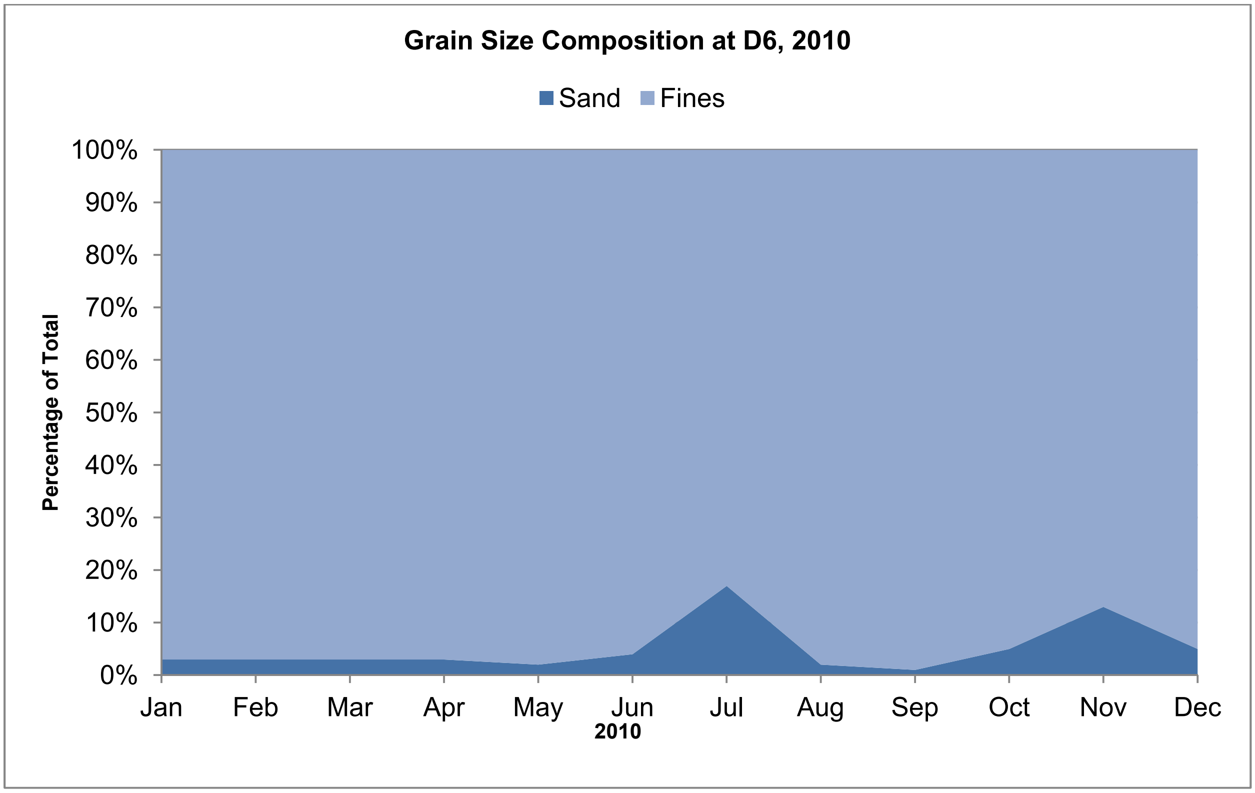


Figure 6-19 Sediment grain size and organic content at D6, 2010



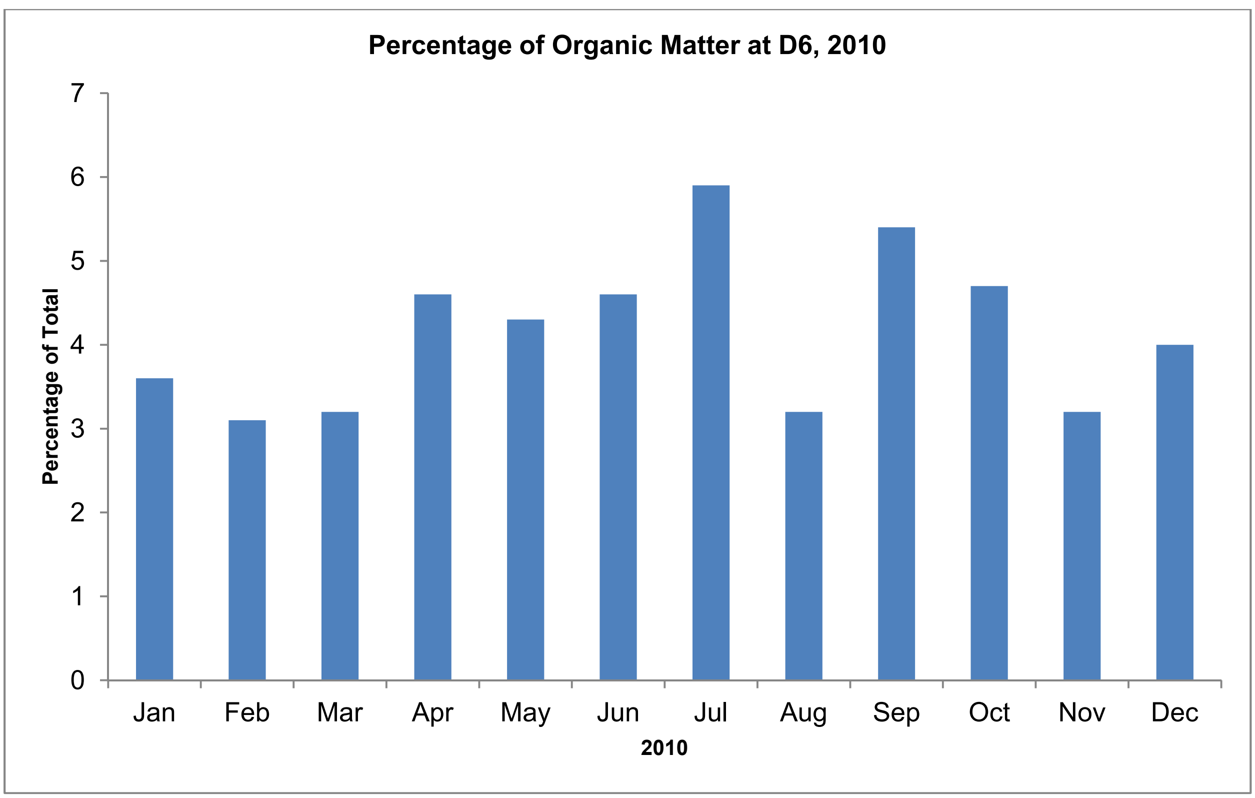
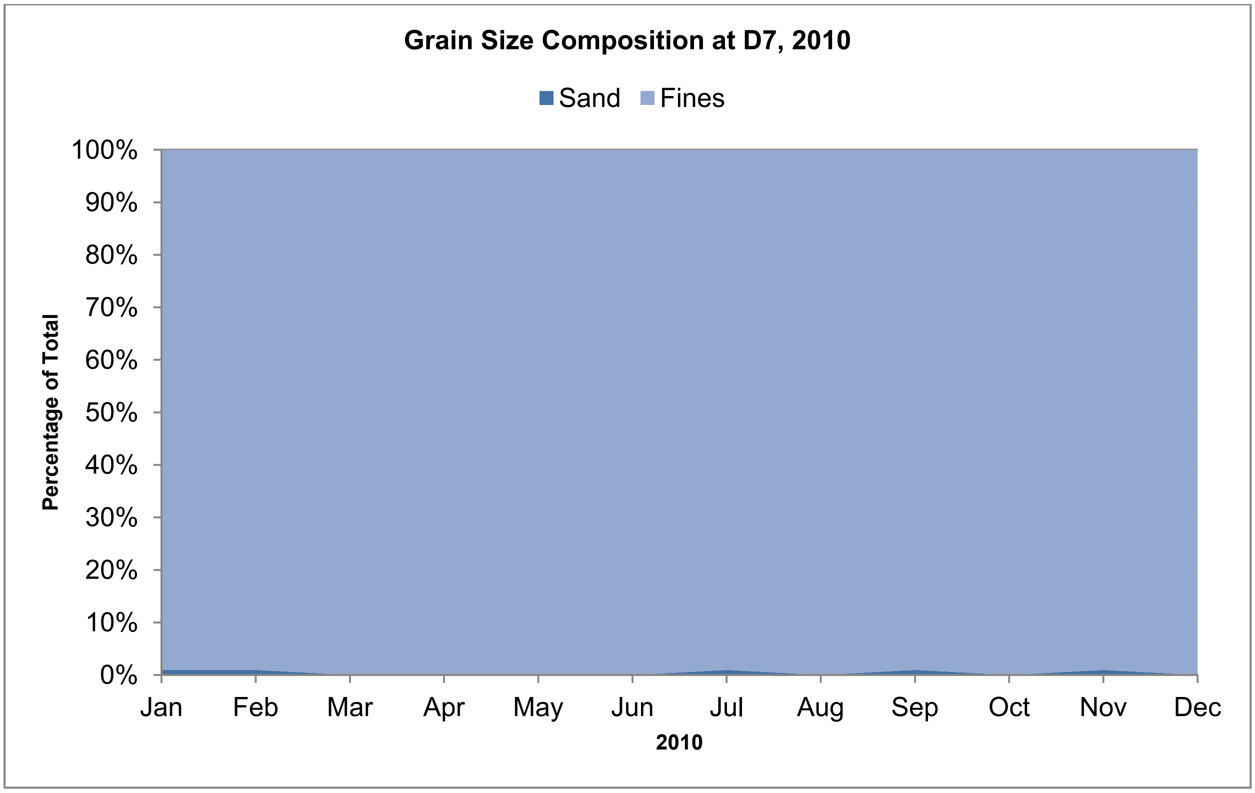


Figure 6-20 Sediment grain size and organic content at D7, 2010



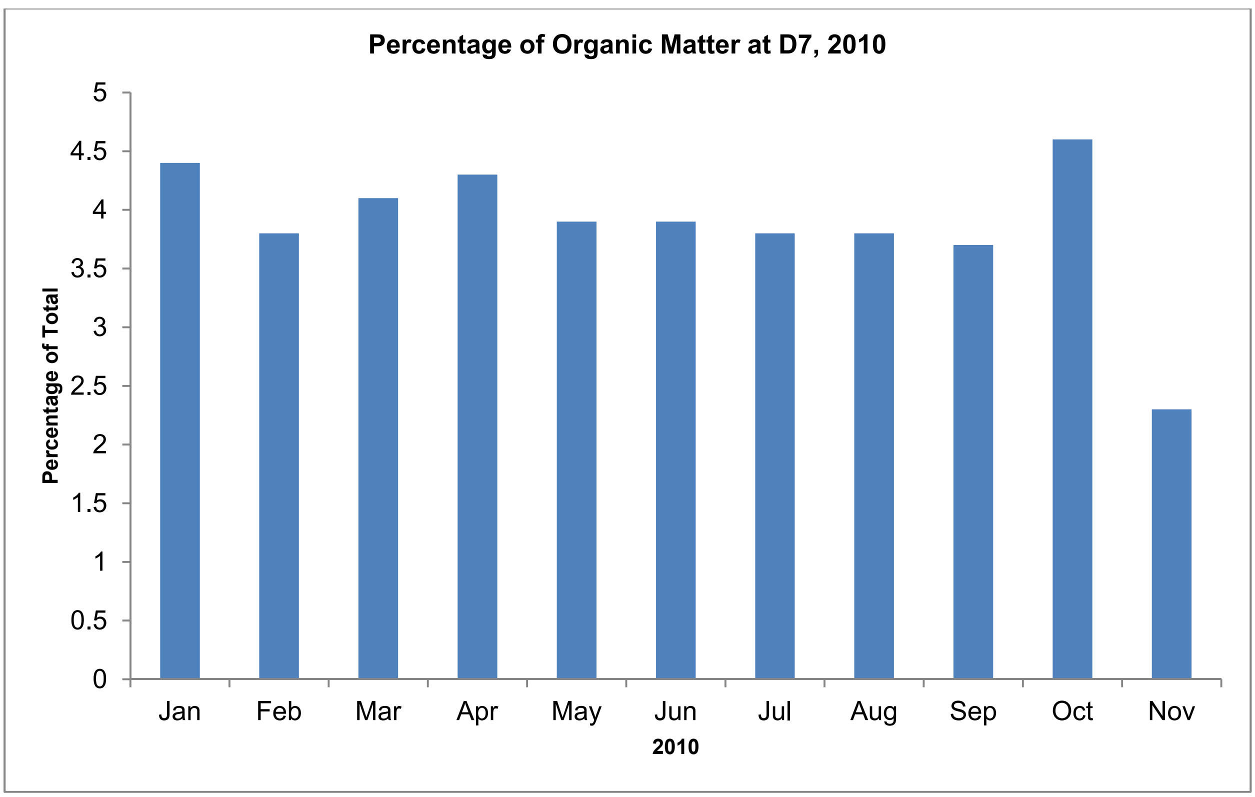
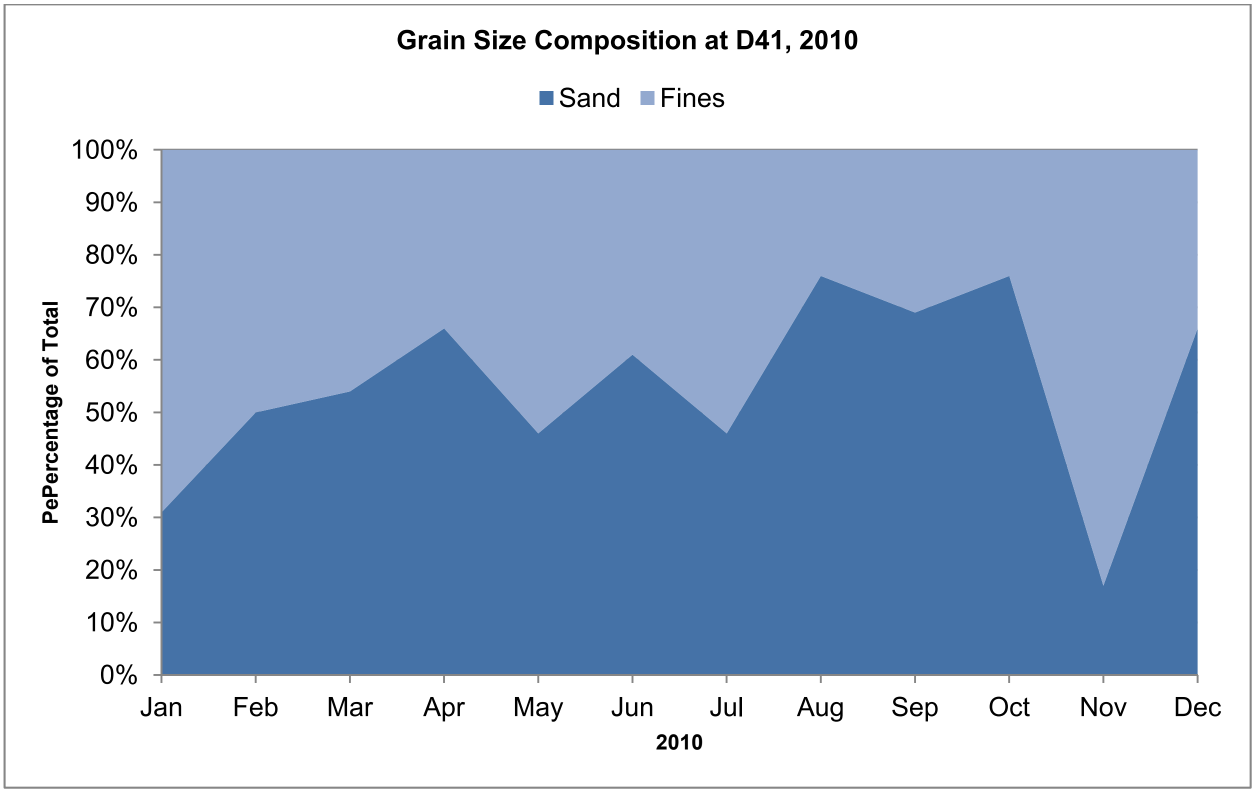


Figure 6-21 Sediment grain size and organic content at D41, 2010



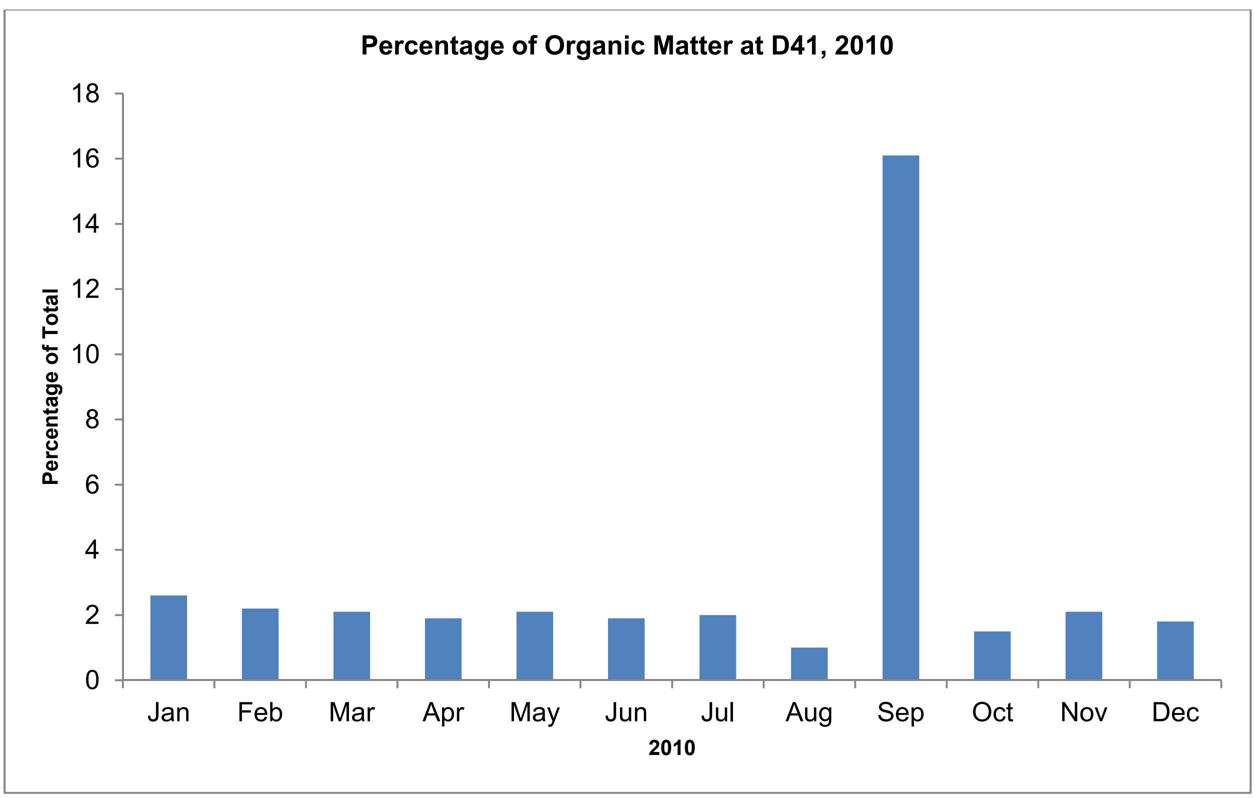
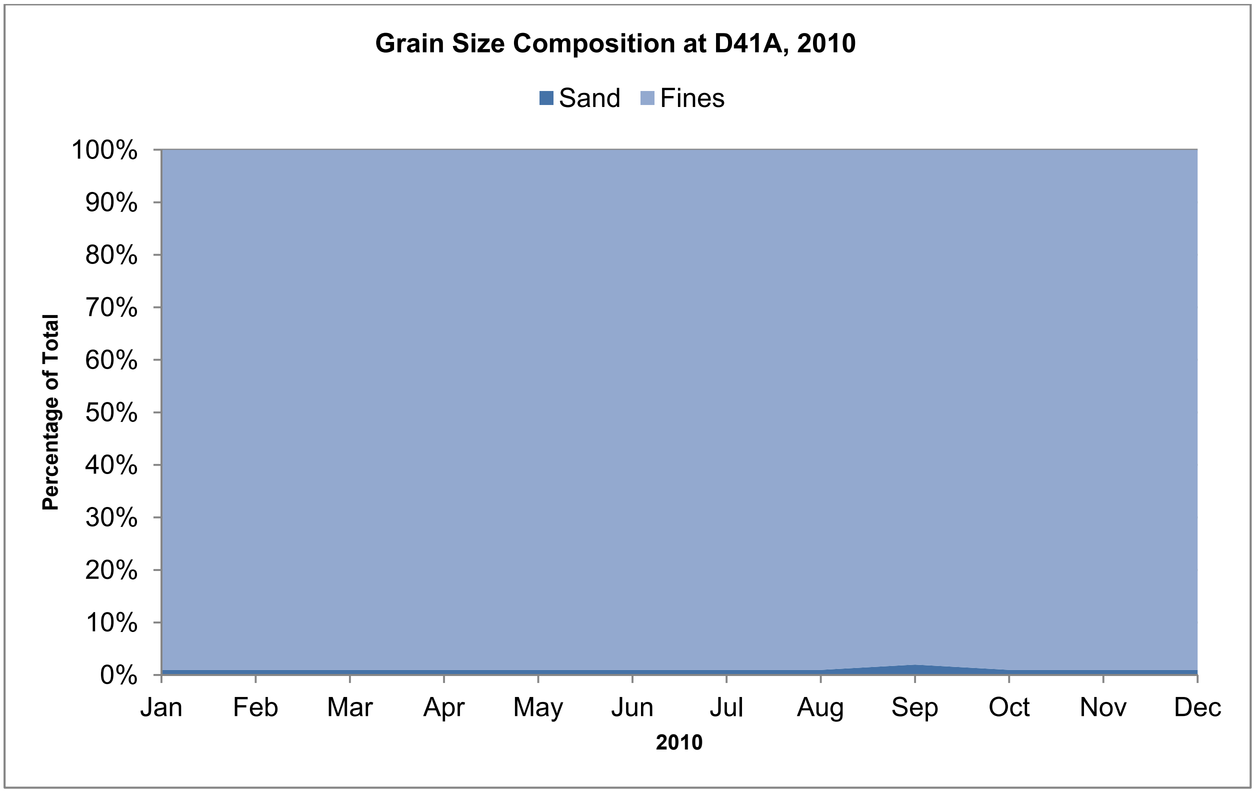


Figure 6-22 Sediment grain size and organic content at D41A, 2010



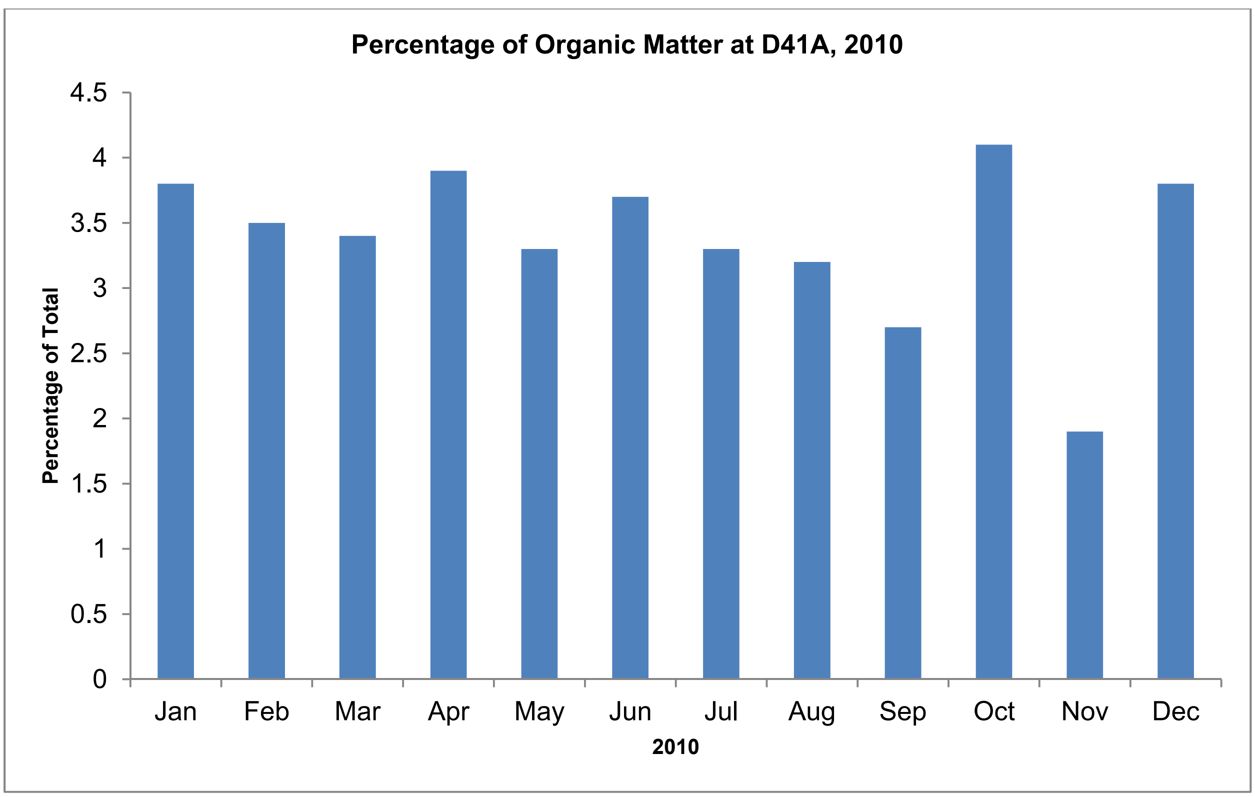


Table 6-1 Macrobenthic monitoring station characteristics, 2010

Station Region	Latitude Longitude	Substrate composition	Approx. salinity range (uS/cm)
C9 Delta-Old River	37° 49' 50" 121° 33' 09"	Mostly sand in late spring through fall. Winter and early spring bring silty clay.	272 - 907
P8 Delta San Joaquin River	37° 58' 42" 121° 22' 55"	Consistent. High silt content (≈80%) except in August.	436 - 754
D28A Delta Old River	37° 58' 14" 121° 34' 19"	Usually high sand (≈70%) content. Can vary to lower (≈40%) amounts.	283 - 851
D16 Delta San Joaquin River	38° 05' 50" 121° 40' 05"	Variable. Sand high (≈95%) in some months and low (≈10%) in others.	263 - 1,190
D24 Delta Sacramento River	38° 09' 27" 121° 41' 01"	Consistent. High sand content (≈95%).	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 (≈90%).	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 rarely organic material.	33,305 - 45,179
D41A San Pablo Bay	38° 03' 75" 122° 24' 40"	Consistent. High fines content (≈99%).	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 estuary, 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 2010, the spring barrier was not installed; instead, a non-physical "bubble barrier" was installed to prevent salmon from entering Old River. 2010 also marked the final year of the Port of Stockton Aeration Demonstration project. The aeration facility was undergoing operational testing, which included injecting oxygen, intermittently throughout the DO monitoring study period. The aeration facility is located on Rough and Ready Island near station 11. For more information about this project visit http://baydeltaoffice.water.ca.gov/sdb/af/index_af.cfm.

This report describes DO monitoring results during the period of June through November 2010.

Methods

Monitoring was conducted approximately every 2 weeks by vessel on 12 monitoring cruises from June 11 to November 19, 2010. During each of the monitoring cruises, 14 sites were sampled at low water slack tide, 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 August 2010, net flow at Stockton reached a minimum of -282 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 4.6 to 9.1 mg/L at the surface and 4.2 to 9.2 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 7.2 to 9.1 mg/L at the surface and 7.0 to 9.2 mg/L at the bottom. In the central portion of the channel, DO concentrations were variable, ranging from 5.6 to 9.0 mg/L at the surface and 5.1 to 8.9 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 4.6 to 8.4 mg/L at the surface and 4.2 to 8.4 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 6,109 cfs in June to a low of 1,025 cfs in August. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 2,240 cfs in June to a low of -282 cfs in August (Figure 7-2).

The findings for the summer and fall of 2010 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.

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[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.

June

Monitoring was conducted on June 11 and 24. Surface DO levels ranged from 6.7 mg/L at station 11 to 8.4 mg/L at station 1. Bottom DO levels ranged from 6.2 mg/L at station 12 to 8.3 mg/L at station 1 (Figure 7-3).

Water temperatures ranged from 20.1 ^{o}C (station 1) to 22.9 ^{o}C (station 12) at the surface and 19.8^{o}C (station 1) to 22.3 ^{o}C (station 4) at the bottom (Figure 7-3).

Flows on the San Joaquin River near Vernalis during the month of June ranged from 2,563 to 6,109 cfs. Net flow in the San Joaquin River near Stockton during June ranged from -554 to 2,240 cfs (Figure 7-2).

July

Monitoring cruises were conducted on July 9 and 23. Surface DO levels ranged from 4.6 mg/L at station 13 to 7.8 mg/L at station 1. Bottom DO levels ranged from 4.2 mg/L at stations 12 and 13 to 8.1 mg/L at station 1 (Figure 7-4). DO fell below the 5.0 mg/L water quality objective at 4 stations on the July 23rd monitoring cruise.

Water temperatures ranged from 21.4 ^{o}C (station 1) to 26.8 ^{o}C (station 12) at the surface and 21.3 ^{o}C (station 1) to 26.3 ^{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 1,267 to 3,918 cfs. Net flow in the San Joaquin River near Stockton during July ranged from 65 to 1,200 cfs (Figure 7-2).

August

Monitoring cruises were conducted on August 9 and 23. Surface DO levels ranged from 5.2 mg/L at station 13 to 8.1 mg/L at station 2. Bottom DO levels ranged from 4.8 mg/L at station 13 to 8.2 mg/L at station 1 (Figure 7-5). DO fell below the 5.0 mg/L water quality objective at one station on the August 9th monitoring cruise.

Water temperatures ranged from 21.5 ^{o}C (station 1) to 26.0 ^{o}C (station 12) at the surface and 21.4 ^{o}C (station 1) to 25.3 ^{o}C (station 12) at the bottom (Figure 7-5).

Flows on the San Joaquin River near Vernalis during the month of August ranged from 1,025 to 1,369 cfs. Net flow in the San Joaquin River near Stockton during August ranged from -282 to 399 cfs (Figure 7-2).

September

Monitoring cruises were conducted on September 9 and 21. Surface DO levels ranged from 6.3 mg/L at station 13 to 8.3 mg/L at station 1. Bottom DO levels ranged from 6.4 mg/L at stations 8, 9 and 11 to 8.3 mg/L at stations 1 and 3 (Figure 7-6). Water temperatures ranged from 20.6 ^{o}C (station 1) to 23.8 ^{o}C (stations 10 and 11) at the surface and 20.6 ^{o}C (station 1) to 23.1 ^{o}C (stations 10 - 12) at the bottom (Figure 7-6).

Flows on the San Joaquin River near Vernalis during the month of September ranged from 1,226 to 2,573 cfs. Net flow in the San Joaquin River near Stockton during September ranged from 110 to 991 cfs (Figure 7-2).

October

Monitoring cruises were conducted on October 2 and 16. Surface DO levels ranged from 6.3 mg/L at stations 9 and 10 to 8.3 mg/L at station 1. Bottom DO levels ranged from 6.0 mg/L at station 11 to 8.2 mg/L at station 1 (Figure 7-7).

Water temperatures ranged from 18.5 ^{o}C (station 2) to 22.1 ^{o}C (station 10) at the surface and 18.5 ^{o}C (stations 1 and 2) to 21.9 ^{o}C (station 10) at the bottom (Figure 7-7).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 1,512 to 3,234 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 317 to 937 cfs (Figure 7-2).

November

Monitoring cruises were conducted on November 3 and 18. Surface DO levels ranged from 7.9 mg/L at station 9 to 9.1 mg/L at station 4. Bottom DO levels ranged from 7.82 mg/L at stations 8 and 9 to 9.2 mg/L at station 1 (Figure 7-8).

Water temperatures ranged from 14.0 ^{o}C (station 1) to 17.0 ^{o}C (station 7) at the surface and 14.1 ^{o}C (stations 1, 3 and 4) to 16.8 ^{o}C (station 7) at the bottom (Figure 7-8).

Flows on the San Joaquin River near Vernalis during the month of November ranged from 1, 589 to 2,727 cfs. Net flow in the San Joaquin River near Stockton during November ranged from -192 to 654 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 July through October. DO levels in June ranged from 8.9 mg/L at the surface to 5.2 mg/L at the bottom (Figure 7-9). DO levels in July ranged from 9.1 mg/L at the surface to 3.1 mg/L at the bottom. DO levels in August ranged from 6.9 mg/L at the surface to 1.6 mg/L at the bottom. September DO levels at the surface and bottom ranged from 7.8 to 4.4 mg/L, respectively. DO levels in October ranged from 6.8 mg/L at the surface to 5.9 mg/L at the bottom. November DO readings ranged from 12.4 mg/L at the surface to 7.3 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 4 stations (excluding the Stockton turning basin) during 2 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 1,025 cfs in August to a high of 6,109 cfs in June. Net daily flow on the San Joaquin River past Stockton ranged from a low of -282 cfs in August to a high of 2,240 cfs in June. The head of Old River barrier was not installed during this sampling season.

Further monitoring operations for the summer and fall 2010 special study were suspended after November 19, 2010.

References

[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.

[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.

Chapter 7 Appendix

Figure 7-1 Monitoring sites in the channel

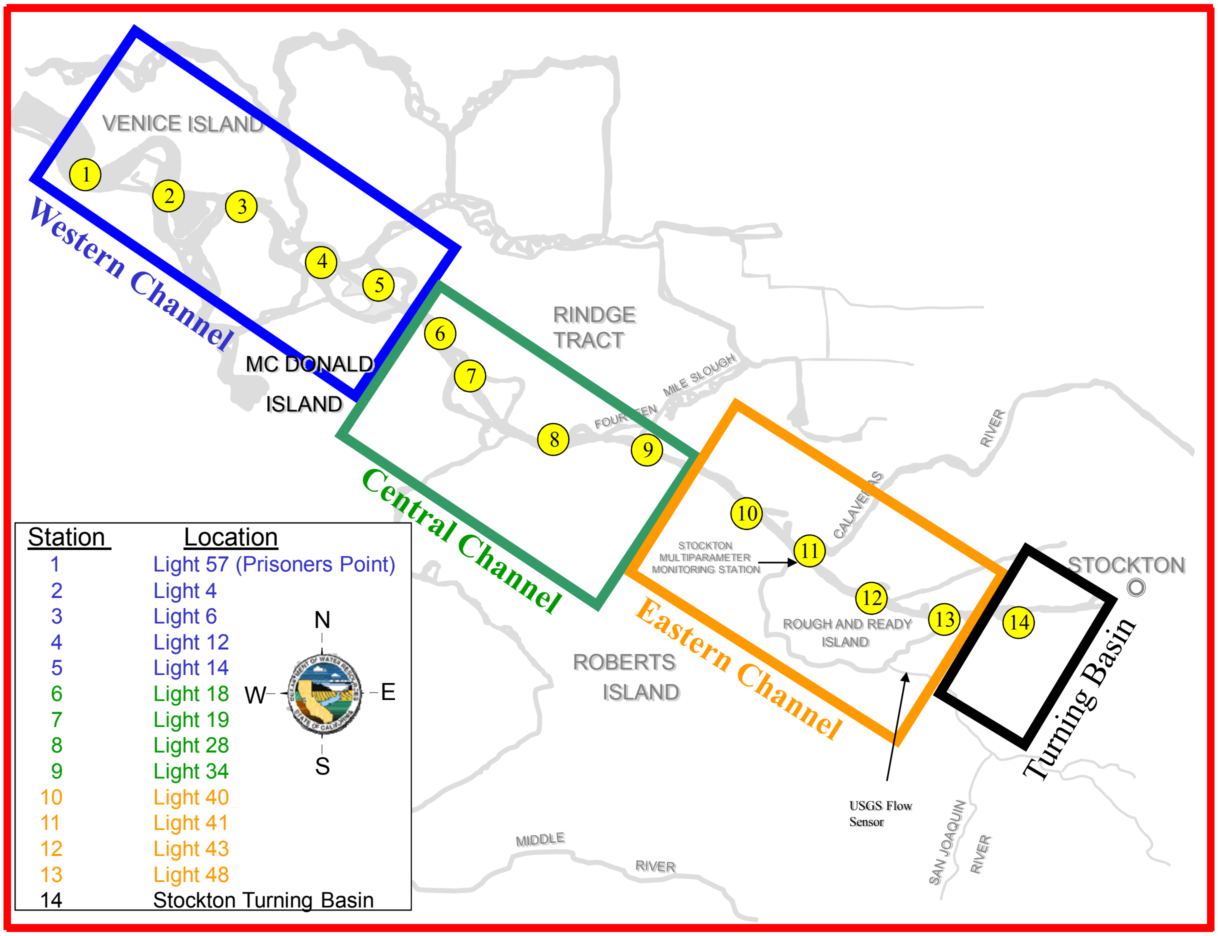


Figure 7-2 San Joaquin River's mean daily flow during summer/fall 2010

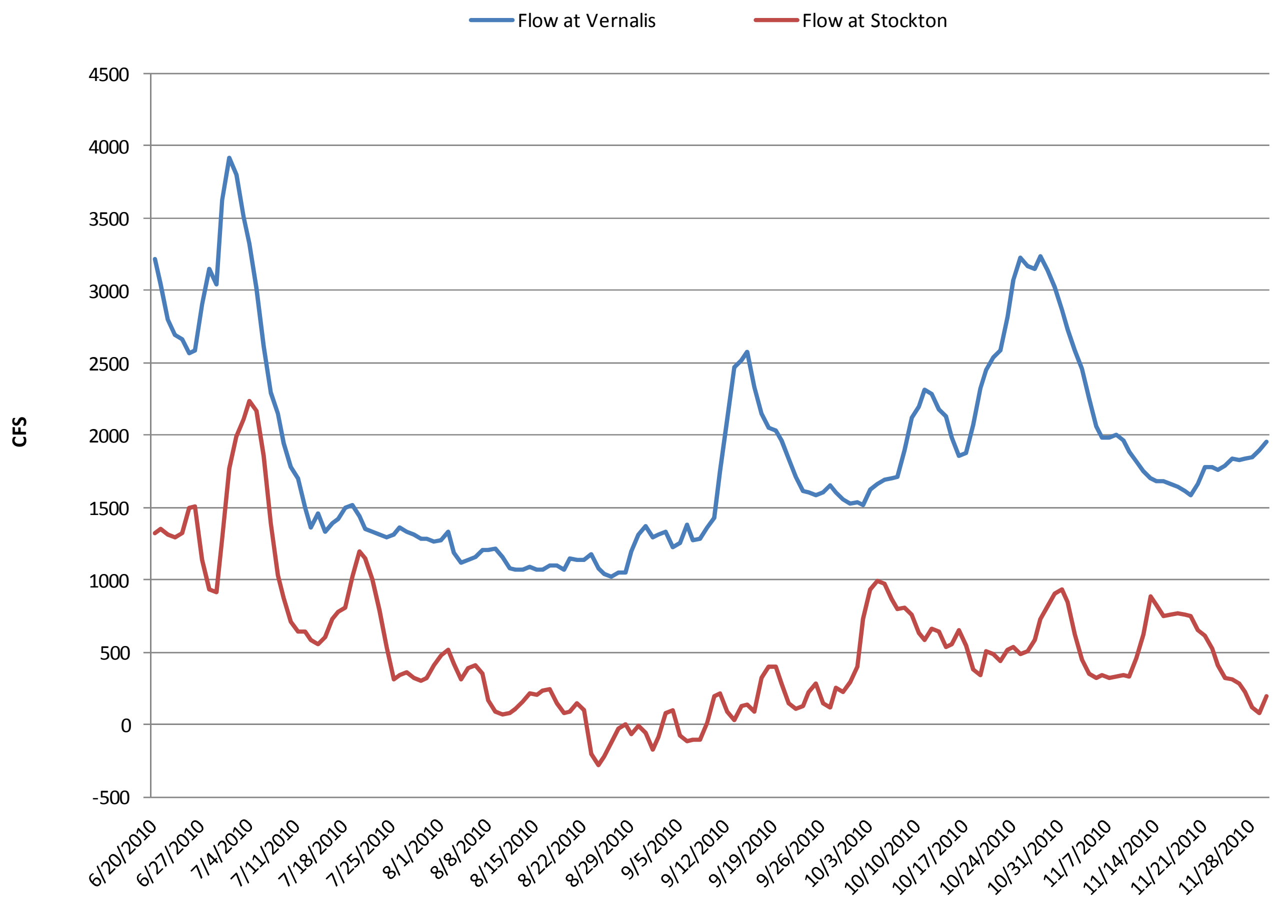
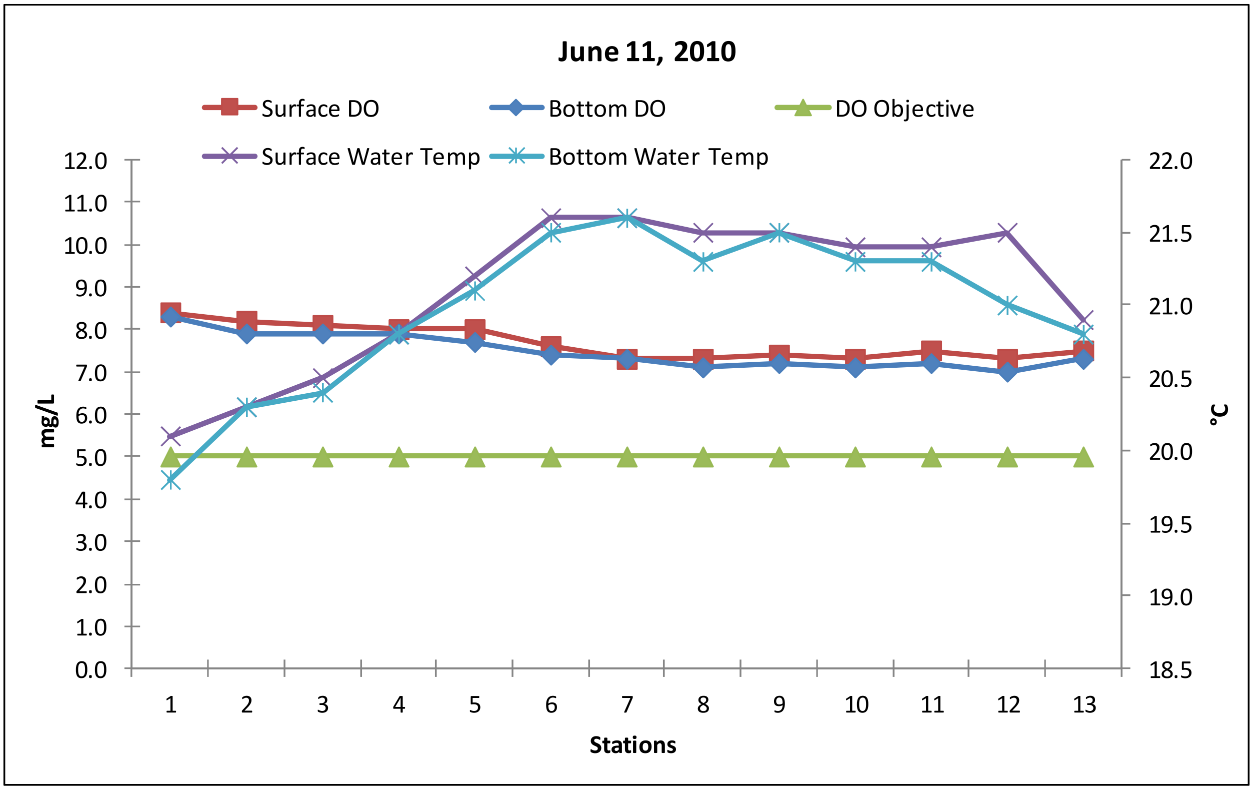


Figure 7-3 Surface and bottom DO and water temperature values in the channel, June 2010



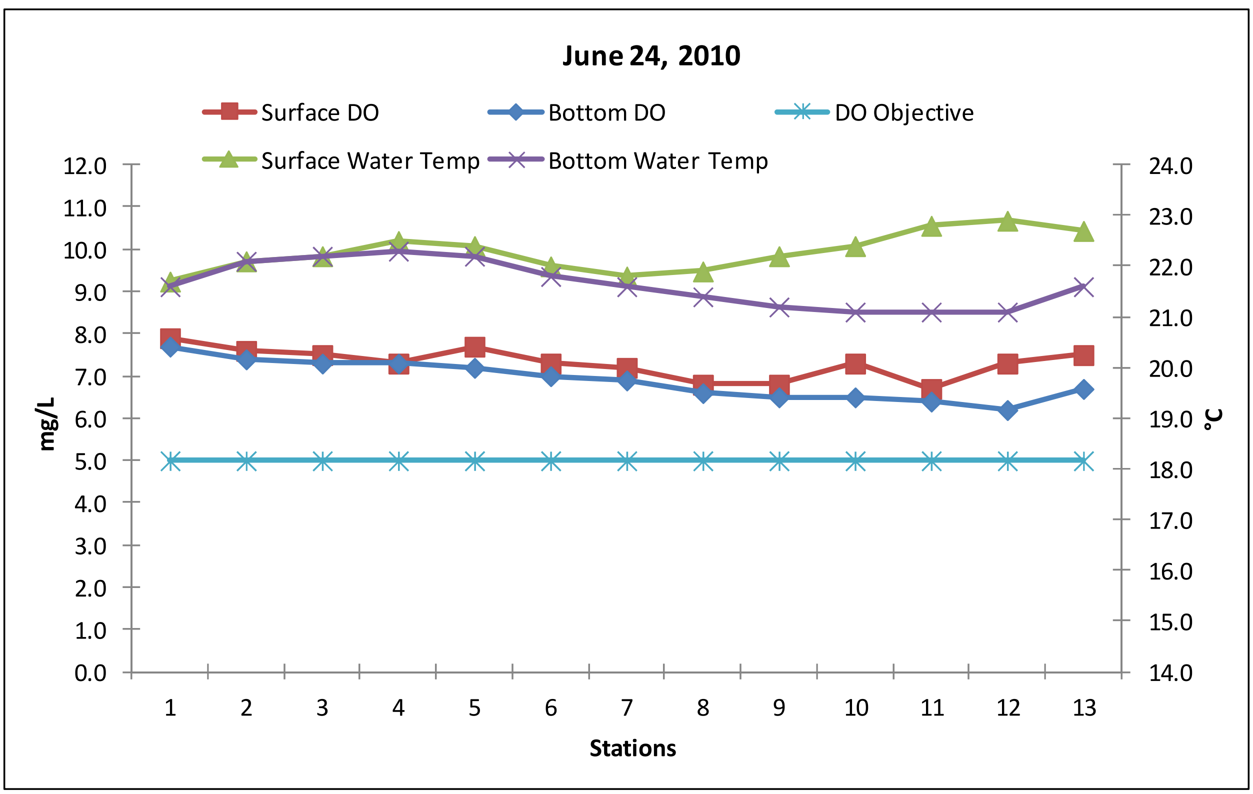
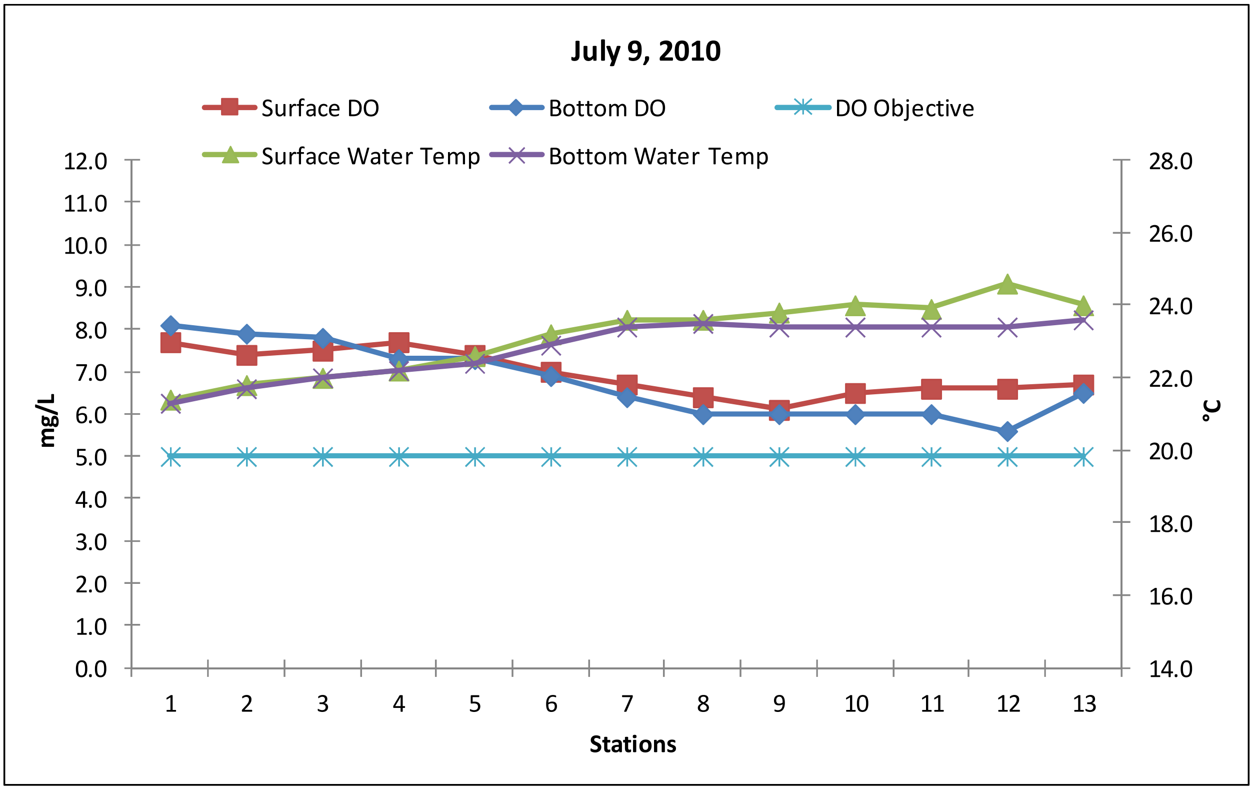


Figure 7-4 Surface and bottom DO and water temperature values in the channel, July 2010



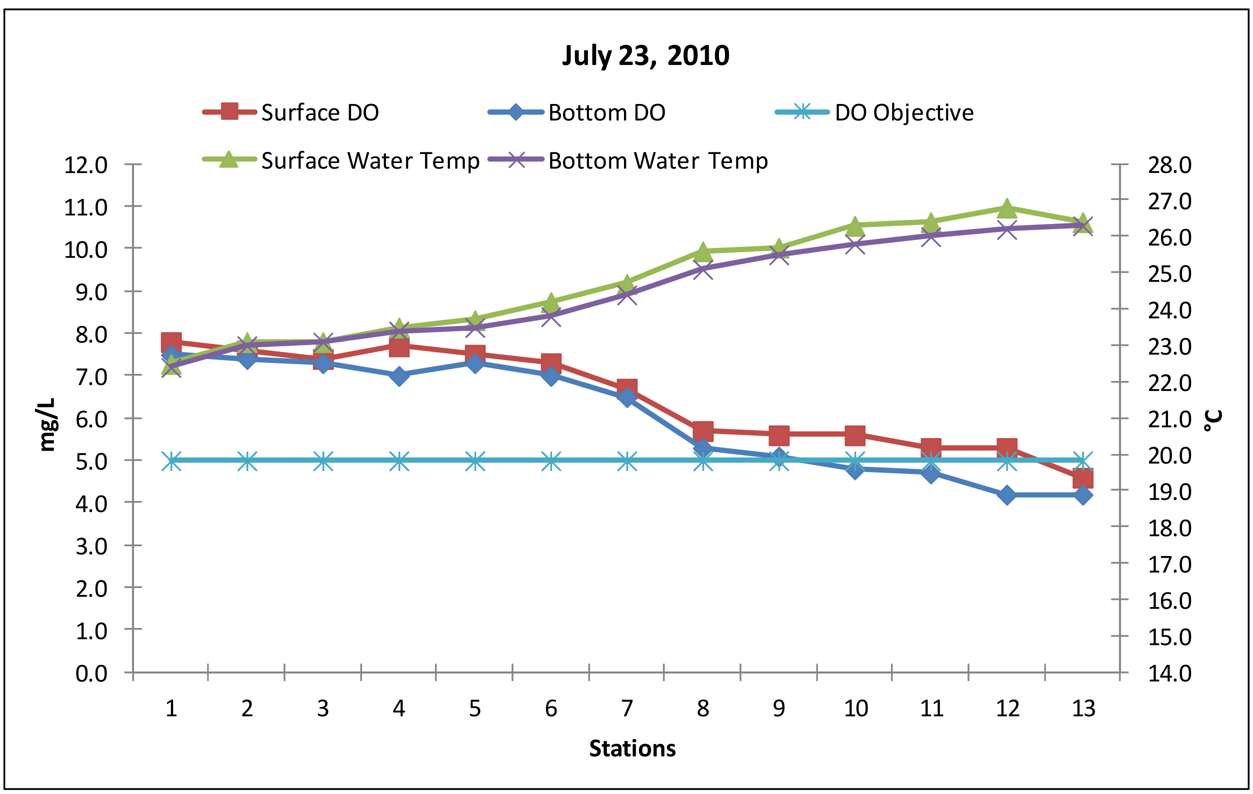
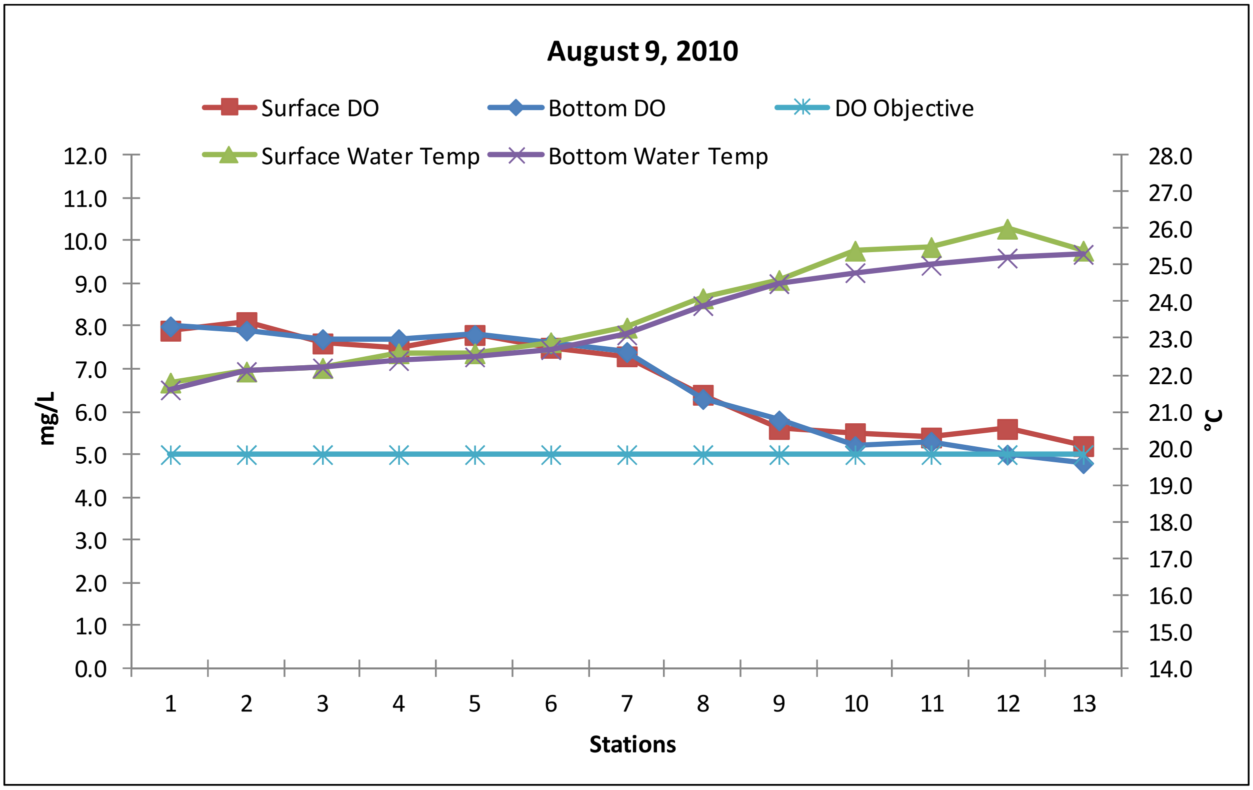


Figure 7-5 Surface and bottom DO and water temperature values in the channel, August 2010



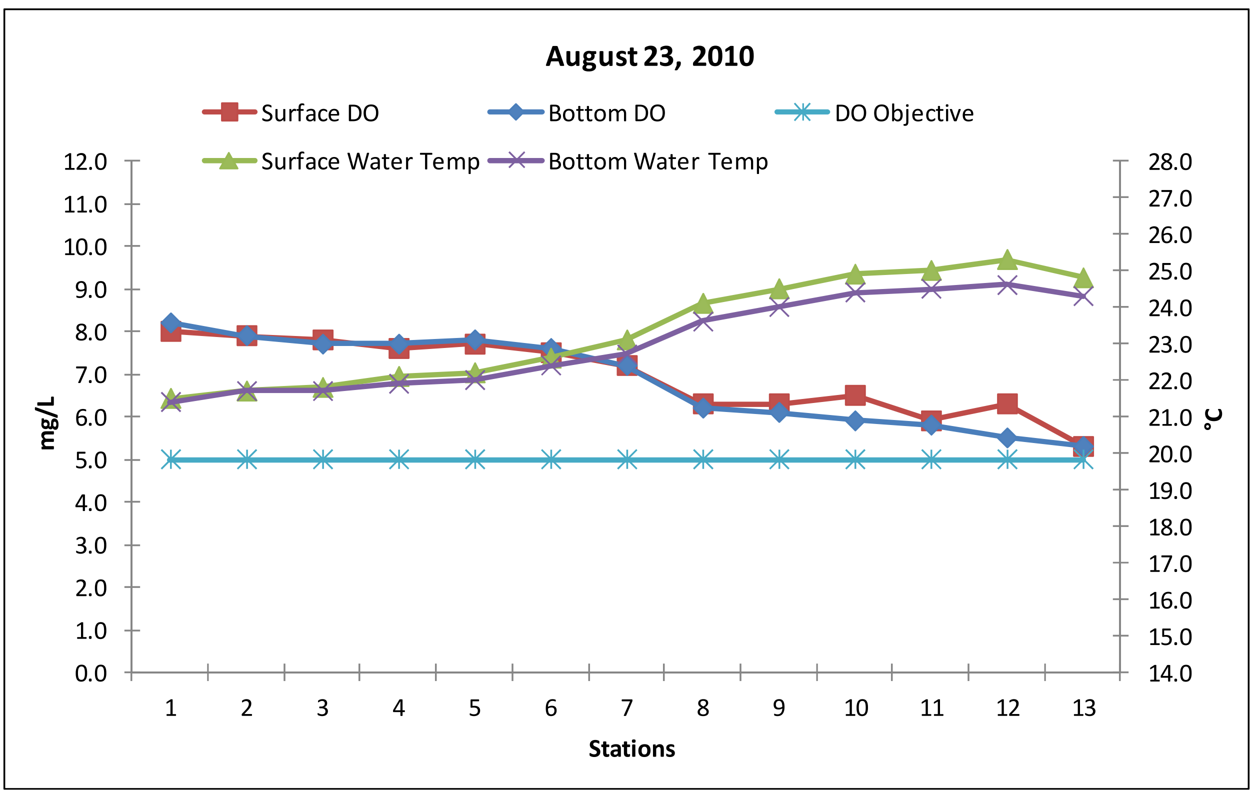
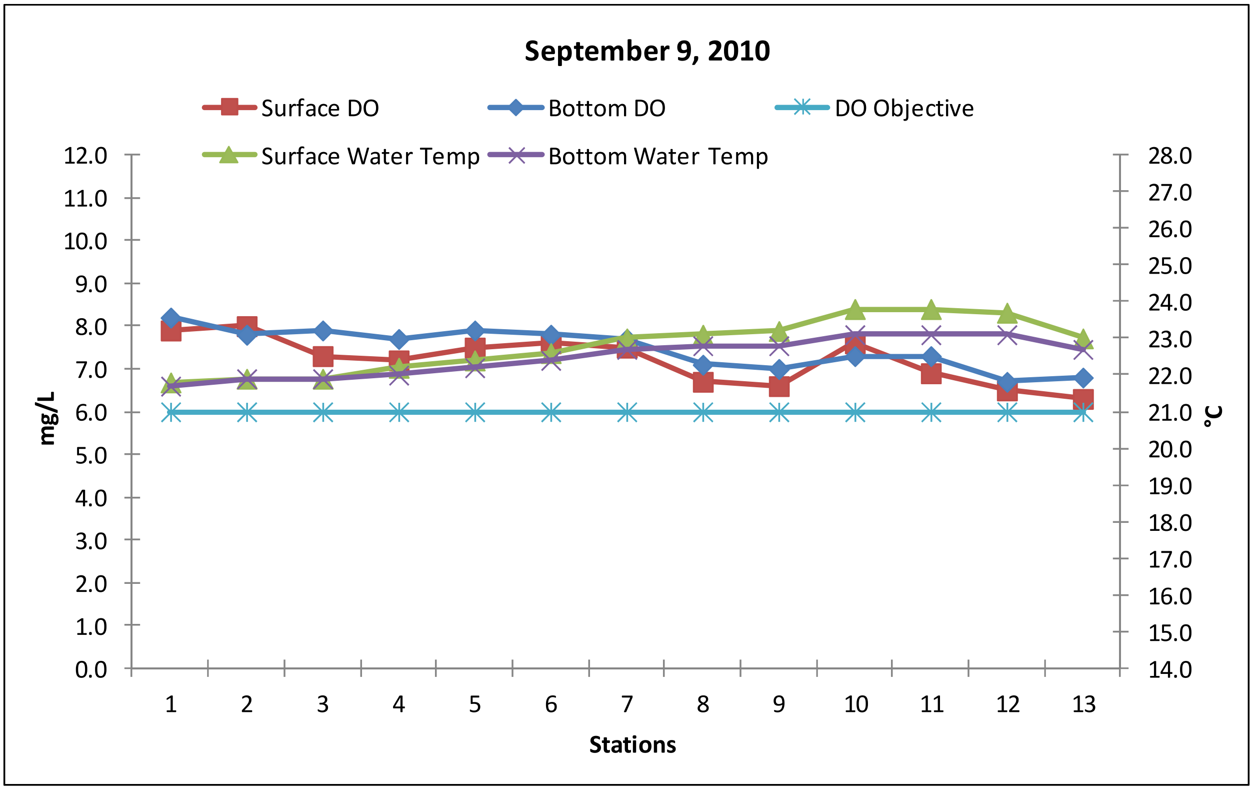


Figure 7-6 Surface and bottom DO and water temperature values in the channel, September 2010



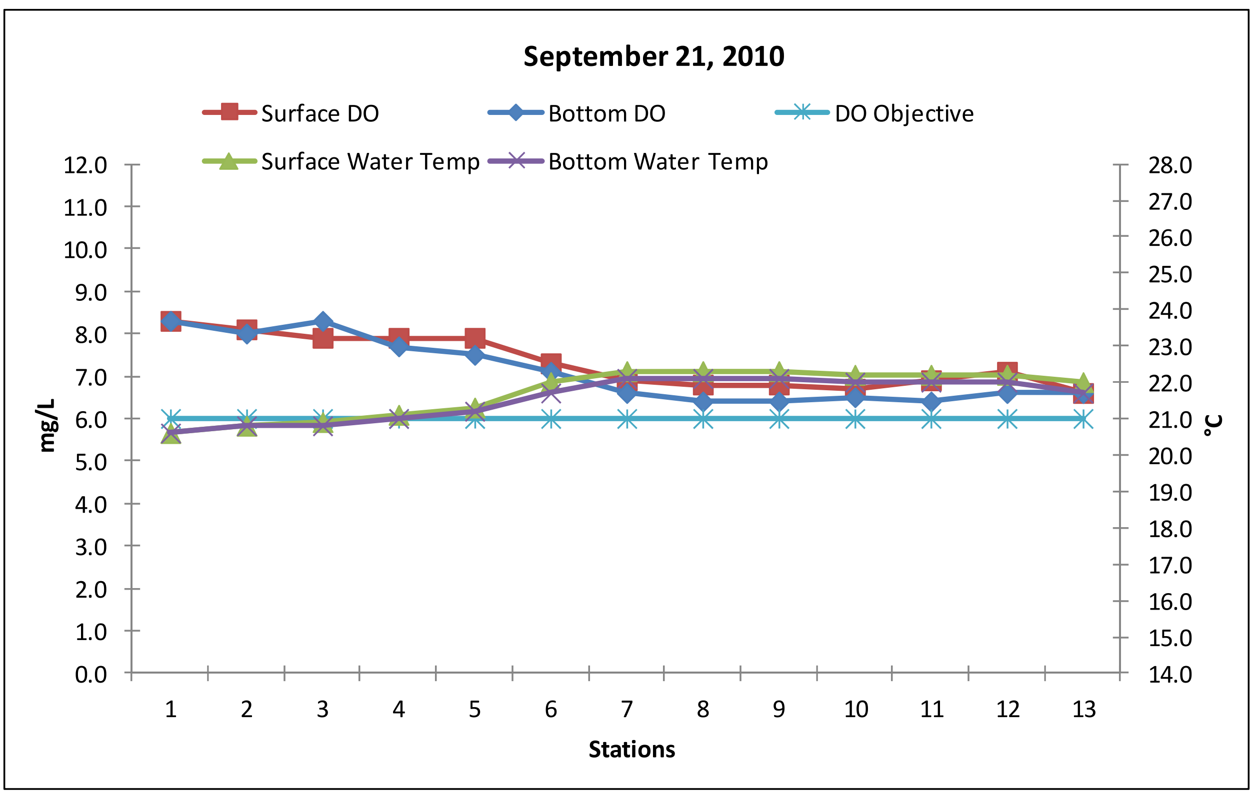
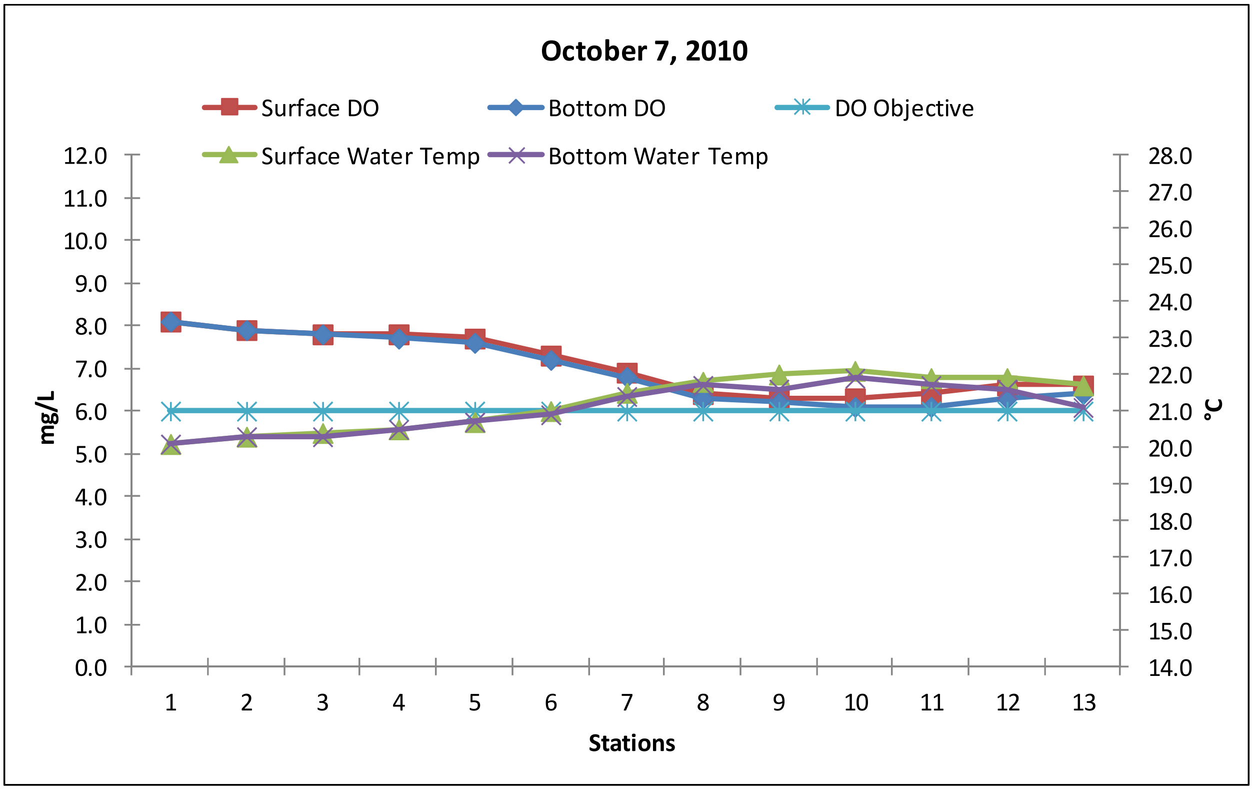


Figure 7-7 Surface and bottom DO and water temperature values in the channel, October 2010



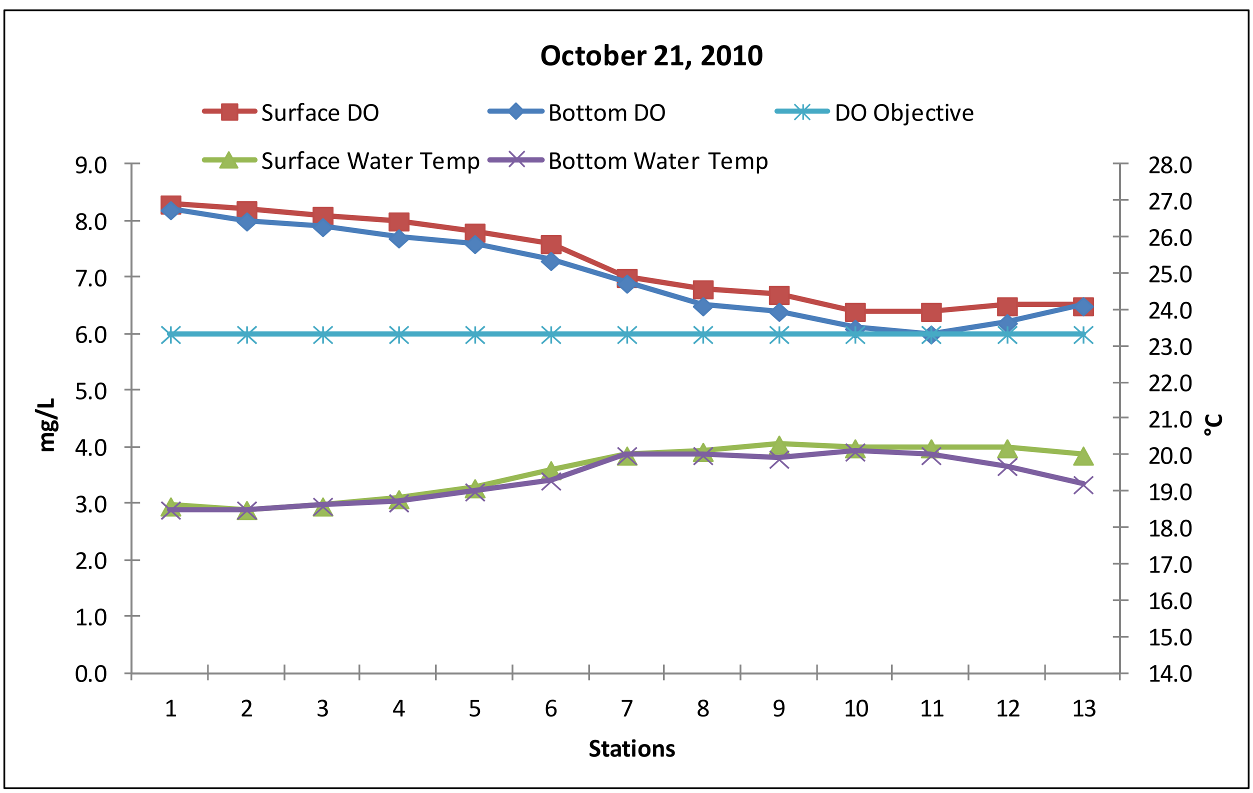
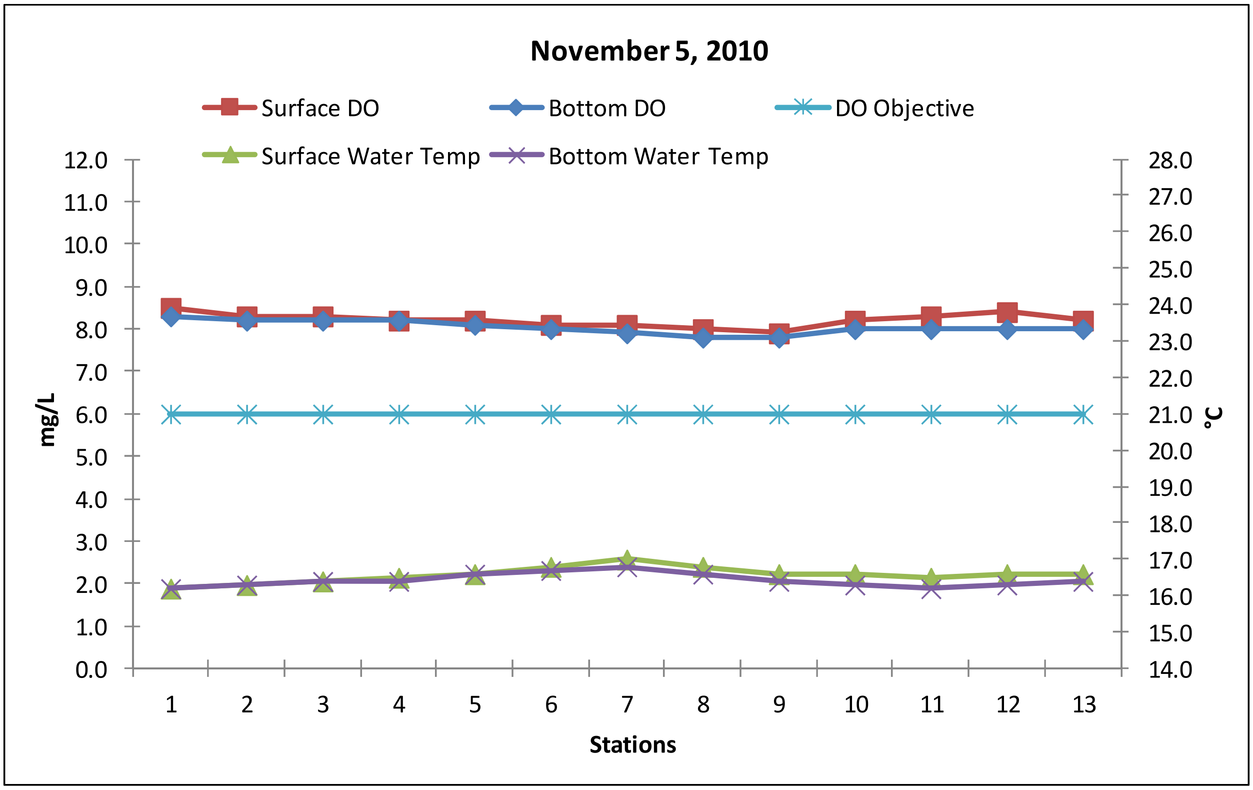


Figure 7-8 Surface and bottom DO and water temperature values in the channel, November 2010



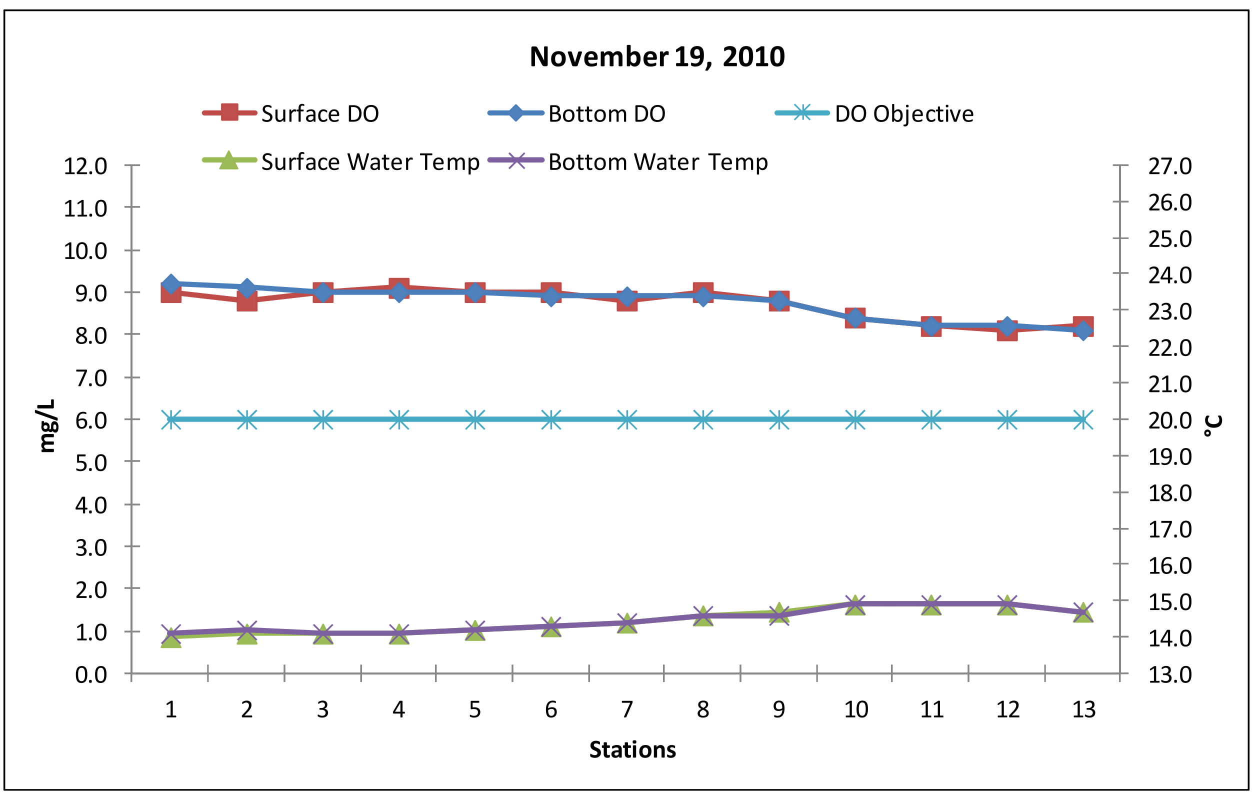
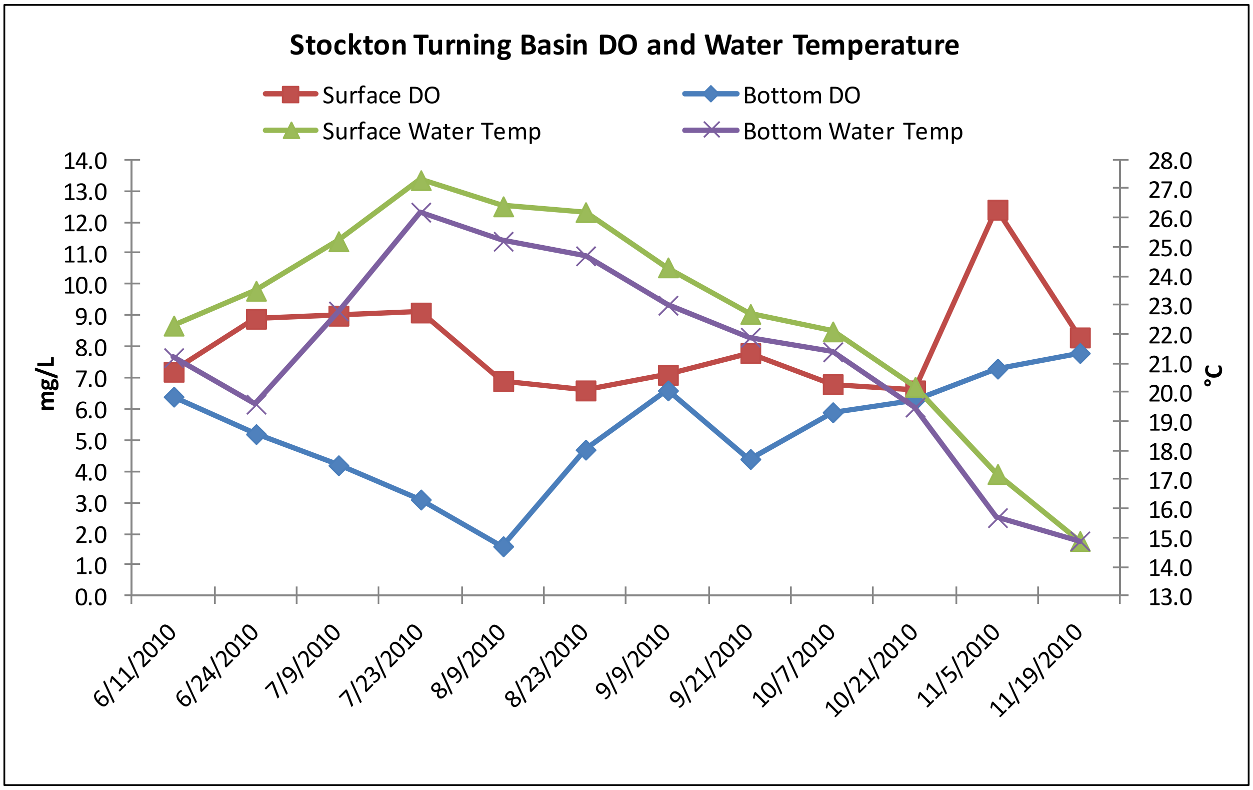


Figure 7-9 Surface and bottom DO and water temperature values in the Stockton turning basin from June through November 2010



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 2010. The stations are 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 (Prisoners Point), C10A (Vernalis), and P8A (Stockton)
Tidally influenced stations:	D11 (Antioch), D10A (Mallard Island), and D6A (Martinez)

Methods

Continuous data were collected for the water quality and environmental parameters shown in Table 8-1. Each of the 9 monitoring stations collected continuous data for water temperature, pH, DO, surface SC, chlorophyll *a* fluorescence, and turbidity. Additional sensors were installed at the Antioch, Mallard Island, and Martinez stations to monitor bottom SC. These measurements, along with river stage data measured at the Mallard Island and Martinez stations, were needed to determine compliance with the salinity standard (also known as X2) that was mandated by the *Bay-Delta Plan* (SWRCB, 1995).

Environmental data, such as air temperature, solar radiation, wind speed, and wind direction, were measured at all stations except the Mossdale (only air temperature measured), Prisoners Point, Vernalis, and Hood stations as part of D-1641's Table 3 objectives (SWRCB, 1999). The only environmental parameter analyzed for this chapter was air temperature from a MET-1 Instrument Mod. 062 sensor.

Except for bottom SC, all water samples were collected at 1 m below the water surface using a float-mounted YSI 6600 multi-parameter water quality sonde. In contrast, bottom SC was measured at 1.5 m above the channel bottom using a Foxboro sensor. Water quality data and environmental data were recorded at 15-minute intervals. Afterwards, quality assurance and control measures were applied using field verification data sheets. Data affiliated with instrument issues were flagged and excluded from the analysis.

Results

The daily 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 2010 are shown in Figures 8-2 to 8-9d. The range of monthly DO values at the Stockton station is shown in Figure 8-10. Data gaps in the daily plots result from days where more than 34% of the 15-minute data are flagged or unavailable.

Water Temperature

Average daily water temperatures in the estuary ranged from 8.1 °C in January, 2010 at the Hood station on the Sacramento River to 26.8 °C in July 2010 at the Stockton station on the San Joaquin River (Figure 8-2). The range of water temperature values was similar to the same time period in 2009.

Average daily water temperatures at the Sacramento River stations were usually lower in comparison to the San Joaquin River stations, with the greatest divergence occurring in the months of July through August at the San Joaquin River stations of Stockton, Mossdale, and Vernalis.

DO

Average daily DO values for the 9 monitoring stations ranged from 4.8 mg/L to 14.1 mg/L (Figure 8-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton, Mossdale, and Vernalis. These 3 stations ranged from a daily average of 4.8 mg/L at the Stockton station in July, 2010 to a value of 14.1 mg/L at the Mossdale station in July, 2010. All other stations showed daily averages between 7.3 mg/L and 11.7 mg/L.

All compliance monitoring stations, except the Stockton station, recorded daily averages above the standard of 5.0 mg/L that was set by the CVRWQCB in the *Basin Plan* (CVRWQCB, 1998). The Stockton station, located in ship channel, started recording lower values that approached the baseline standard of 5.0 mg/L in June, 2010. The Stockton station showed a DO sag to 4.8 mg/L in July, 2010, which was similar to the sag in 2009.

During the summer of 2010, daily average DO values at the Mossdale and Vernalis stations showed a familiar pattern of increase from June to August that was similar to 2009. For example, the DO increase to a maximum of 14.1 mg/L at the Mossdale station in July, 2010 occurred around the same time as the 2009 increase. The high summer DO averages seen at the Mossdale and Vernalis stations in 2010 coincided with high chlorophyll *a* fluorescence during the same period (Figure 8-8a).

SC

Daily average surface SC for the estuary ranged from 106 µS/cm to 30,675 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). Overall, 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 the Hood and Rio Vista stations on the Sacramento River upstream of the confluence of the Sacramento and San Joaquin rivers (Figure 8-4b).

All stations showed a decrease in SC in late January that coincided with the rapid increase of turbidity during the first flush of surface water from rainfall events (Figure 8-4a and 8-9a). In addition, the Vernalis, Mossdale, and Stockton stations on the San Joaquin River showed a significant decrease in surface SC in April, 2010 after the April VAMP pulse (Figure 8-4b). SC from these 3 stations would remain low until the beginning of July.

The SC values recorded at the stations in 2010 were very similar to the values recorded in 2009. As seen in previous years, bottom SC measured in 2010 at the Antioch, Mallard Island, and Martinez stations exhibited seasonal patterns and ranges similar to the surface SC (Figure 8-5).

pH

Daily average pH levels at all stations in the estuary ranged from 6.8 to 9.4 (Figure 8-6). In 2010, the Stockton station on the San Joaquin River showed a slight decrease in pH starting in late May and continuing until late July.

In comparison, the Antioch, Mallard Island, and Prisoners Point stations saw an increase in pH values from the beginning to the end of May. Furthermore, the Mossdale and Vernalis stations on the San Joaquin River showed a significant increase in pH values from July through August. This was somewhat similar to 2009, where the Mossdale and Vernalis stations saw higher pH levels than the other stations from June through August. The rapid increase in pH during these periods corresponded to the rapid increase of chlorophyll *a* fluorescence (Figure 8-8a).

Air Temperature

Daily average air temperatures in the estuary ranged from 4.5 °C in December 2010 at the tidally influenced Martinez station to 28.7 °C in July 2010 at the Mossdale station on the San Joaquin River (Figure 8-7). The range of daily average air temperature values for 2010 was similar to the values from 2009.

Chlorophyll *a* Fluorescence

Daily average chlorophyll *a* fluorescence recorded at all the stations ranged from a low of 0.85 FU in May, 2010 at the Hood station on the Sacramento River to a high of 109.68 FU in July, 2010 at the Mossdale station on the San Joaquin River (Figure 8-8, a-d). In general, the values recorded in 2010 exhibited a similar data range as the values from 2009. However, the maximum recorded in 2010 was much higher than the maximum recorded in 2009.

For most of the 2010 calendar year, daily chlorophyll *a* fluorescence averages at the Vernalis and Mossdale stations were typically higher than the other stations (Figure 8-8a). Major algal blooms at the Mossdale and Vernalis stations were observed in March, June, July, and August. Moderate blooms were observed at the Antioch, Mallard Island, and Prisoners Point stations in May.

Algal blooms at the stations were detected by the presence of highly elevated chlorophyll *a* fluorescence values that often coincided with a rapid increase in pH or DO. However, high turbid conditions often interfered with chlorophyll *a* fluorescence measurements and resulted in a rapid increase of chlorophyll *a* fluorescence when bloom activities were not occurring. For example, there was a rapid increase of chlorophyll *a* fluorescence at most stations in late January, but it did not coincide with the rapid increase of pH or DO (Figures 8-3, 8-6, and 8-8a). Instead, the rapid increase of chlorophyll *a* fluorescence coincided with the elevation of turbidity (Figures 8-8a and 8-9a). As a result, there were no algal blooms in late January despite the increase in chlorophyll *a* fluorescence at most of the stations.

Turbidity

Daily average turbidity in the estuary ranged from a low of 1 NTU at the Hood station on the Sacramento River in October, 2010 to a high of 324 NTU at the Mossdale station on the San Joaquin River in January, 2010 (Figure 8-9, a-d). These results are very similar to those observed in 2009, which also recorded the minimum at a Sacramento River station in the fall and the maximum at a San Joaquin River station in the winter. In 2010, turbidity was at its highest for all stations in late January or early February due to the first flush of surface water from rainfall events (Figure 8-9a).

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 did not drop below the state-mandated standards of 5.0 mg/L for 2010 at the Stockton station on the San Joaquin River (Figure 8-10). Like in 2009, the range of average monthly DO values at the Stockton station was more consistent from month to month when compared to the 10-unit swing seen in 2008. Unlike 2008, monthly average DO values from 2010 only showed a 3.1 unit swing from high to low values of 5.9 mg/L to 9.0 mg/L. The lowest DO value occurred in August 2010 at the Stockton station, while the highest value occurred in January 2010.

The quarter-hourly values for the Stockton station ranged from 4.3 mg/L to 10.9 mg/L. The minimum value of 4.3 mg/L was recorded in July, 2010, while the maximum value of 10.9 mg/L was recorded in January 2010. As seen in previous years, the DO levels dropped during the summer in June and recovered by September.

DWR's oxygen aeration facility did not operate in 2010, with only minimal testing occurring from June to September 2010. For 2010, average monthly DO values at the Stockton station did not drop below the standard 6.0 mg/L from September through November (Figure 8-10).

The box plots (Figure 8-10) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal "whiskers" indicate the range of hourly DO values for each month. Boxes represent monthly medians and averages. Open boxes indicate that the monthly median is greater than the monthly average, with the top of the box indicating the median, and the bottom of the box indicating the average. Filled boxes indicate that the monthly average is greater than the median, with the top of the box indicating the average and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the average are equal.

Summary

Water quality conditions in the estuary for calendar year 2010 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 usually showed higher chlorophyll *a* fluorescence values than the other stations. In addition, the Mossdale station showed higher DO values in July and August than any other station in the estuary, while the Stockton station showed the lowest values for DO in July. Lastly, the pH values at the Mossdale and Vernalis stations on the San Joaquin River increased during the months of July through August, and returned near or lower than the other pH values measured at the other estuary stations by the end of the year.

The monthly average DO levels at the Stockton station did not fall below the 5.0 mg/L standard that was set by the CVRWQCB (1998). The monthly average 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 the September through November 2010 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

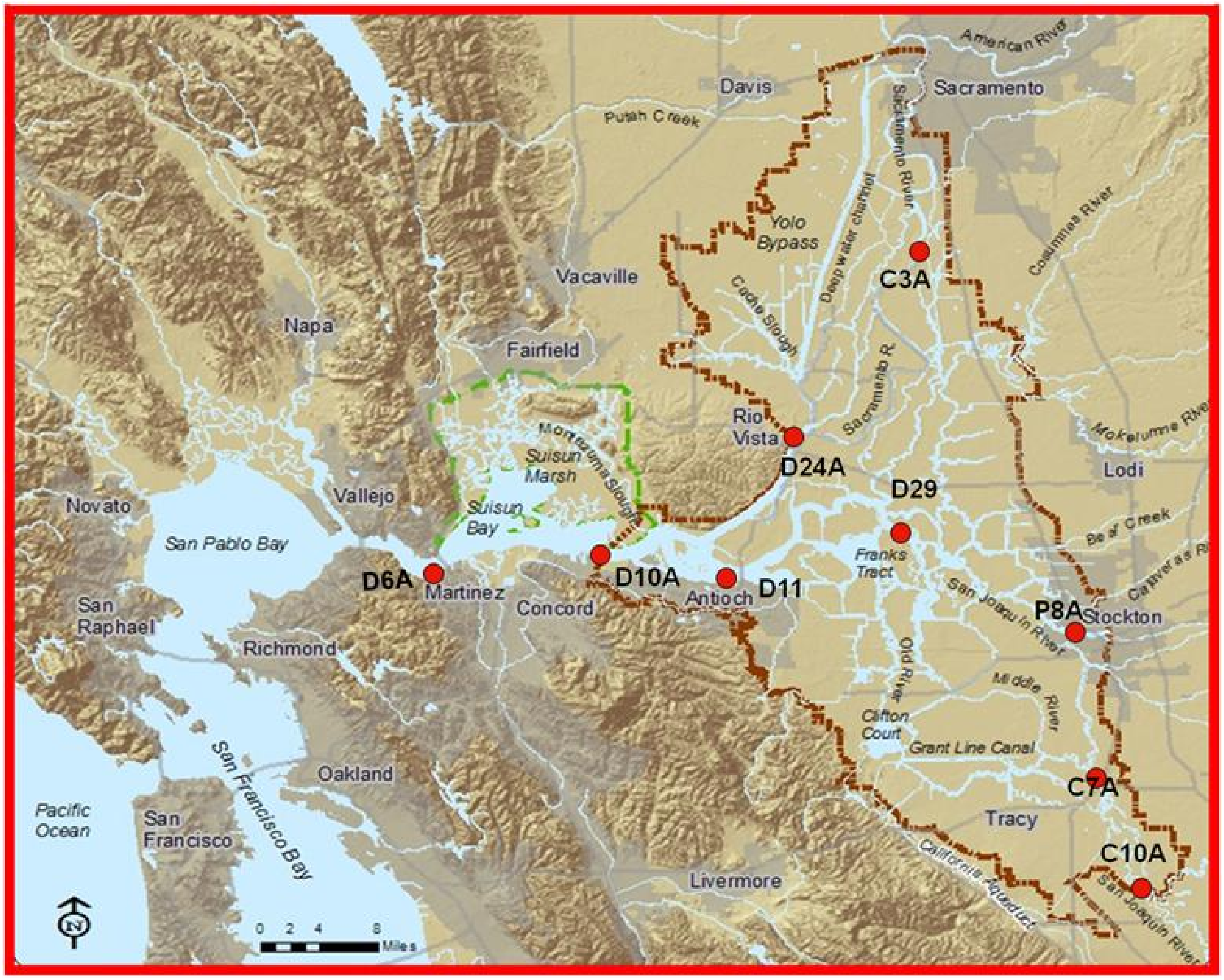


Figure 8-2 Average daily water temperature at 9 stations, 2010

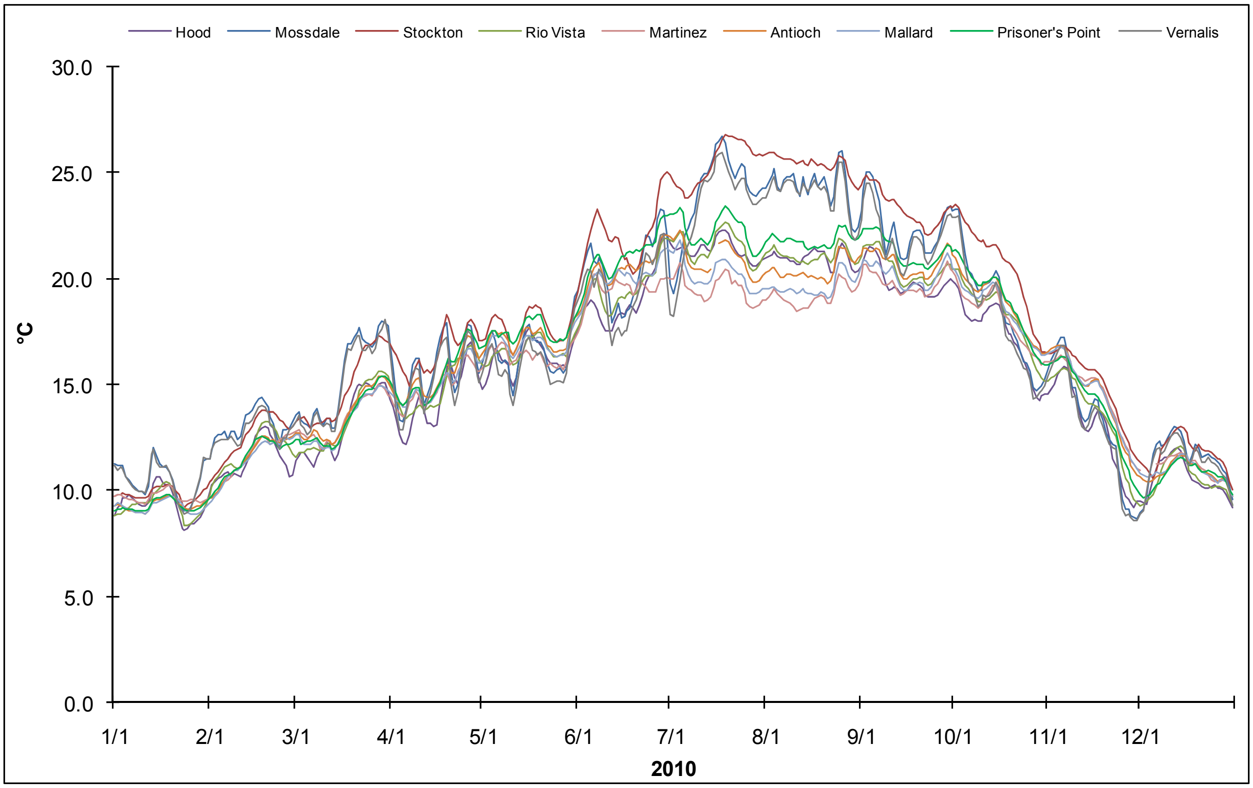


Figure 8-3 Average daily DO at 9 stations, 2010

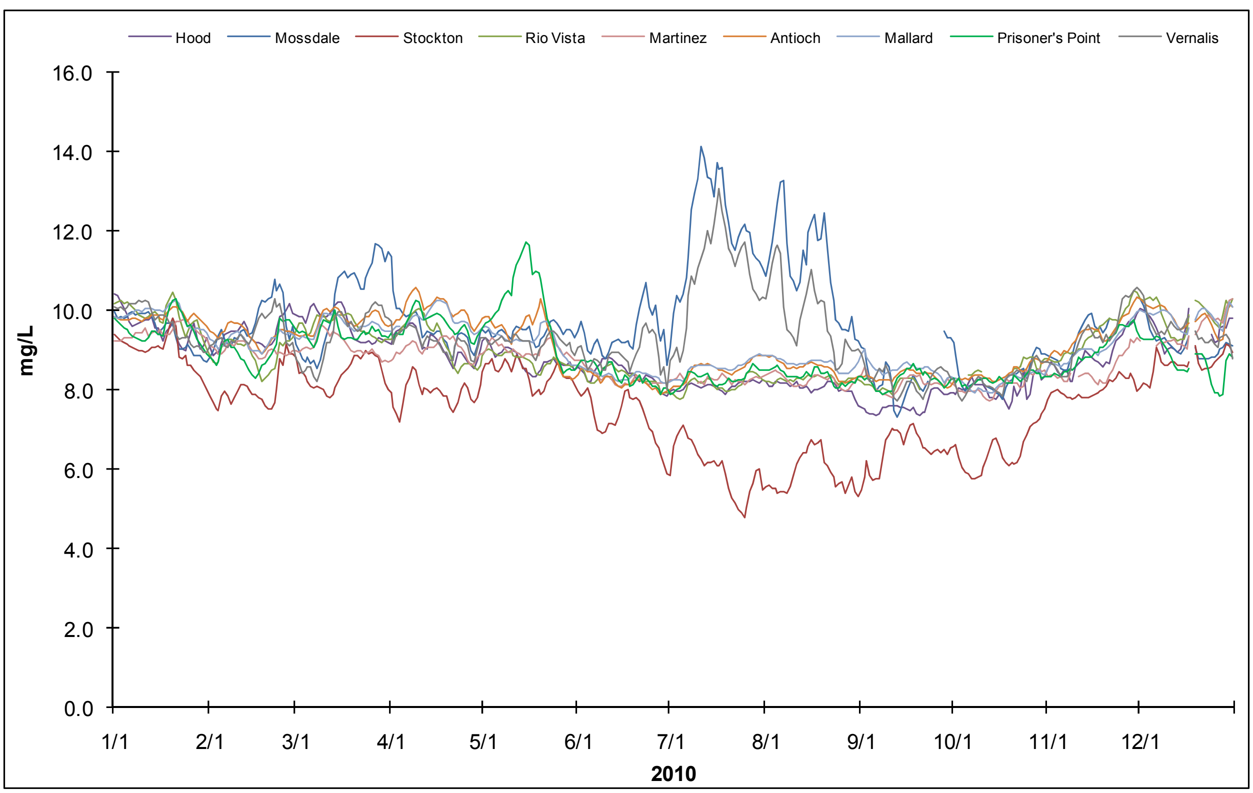


Figure 8-4a Average daily surface SC at 9 stations, 2010

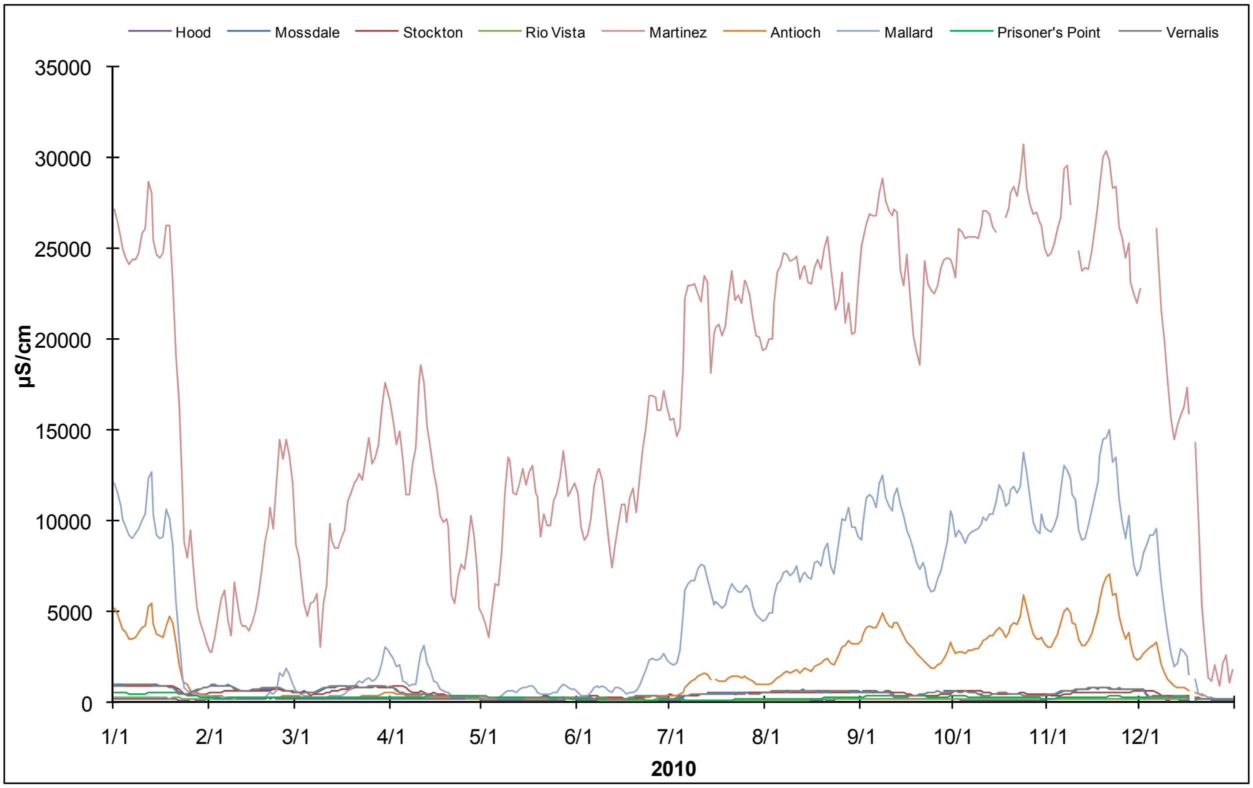


Figure 8-4b Average daily surface SC at 6 stations, 2010

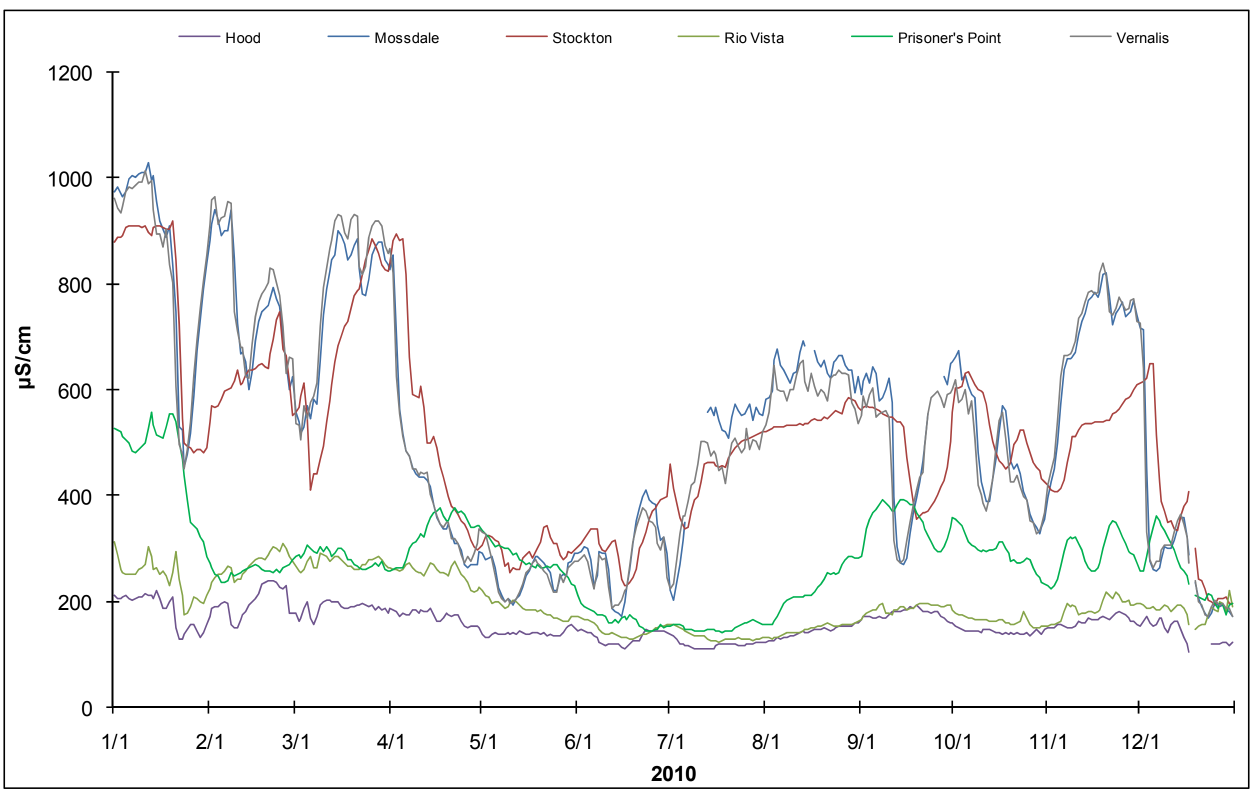


Figure 8-5 Average daily surface and bottom SC at 3 tidally influenced stations, 2010

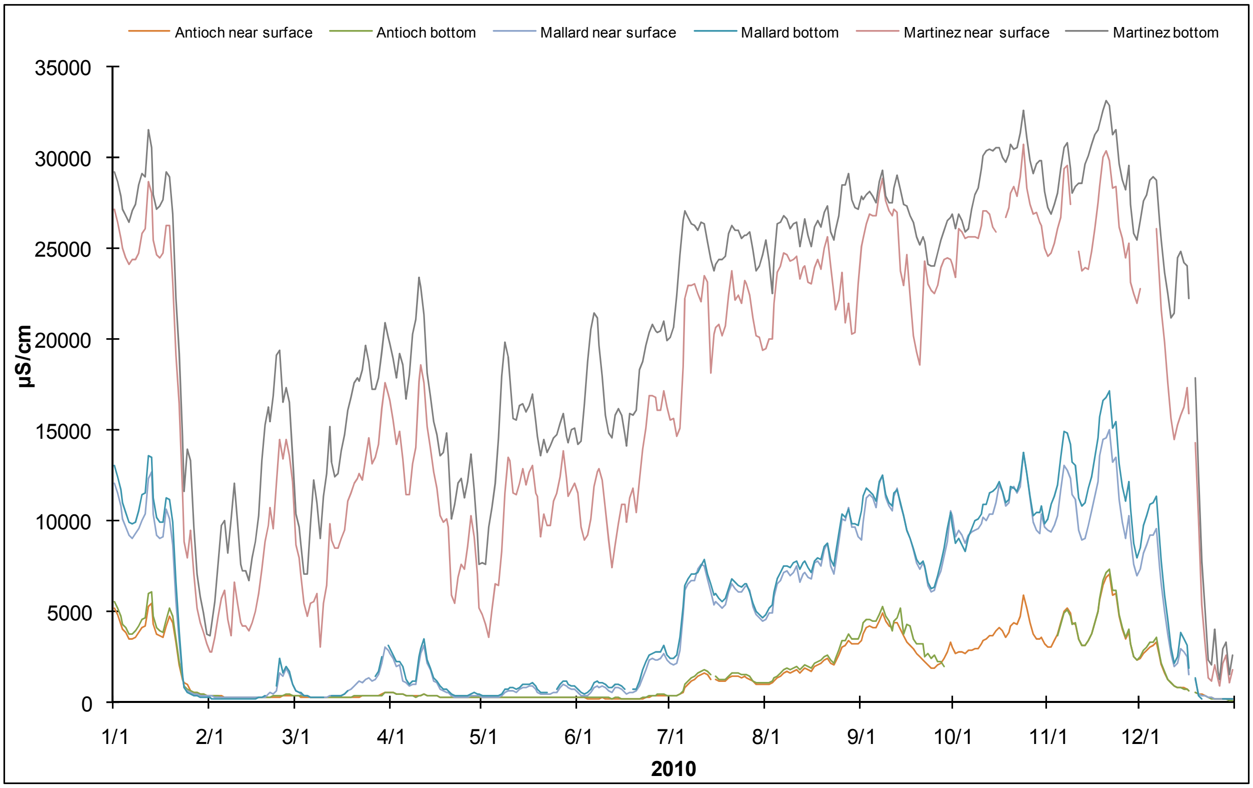


Figure 8-6 Average daily pH at 9 stations, 2010

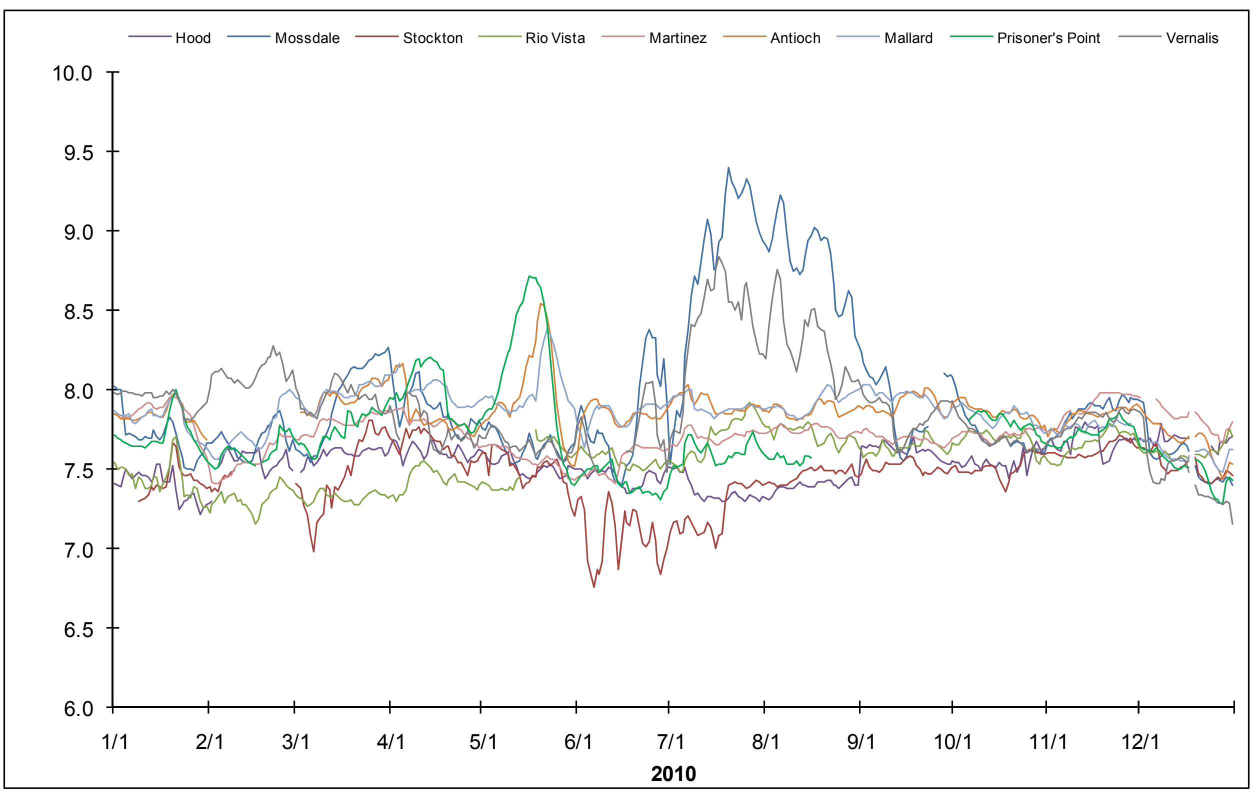


Figure 8-7 Average daily air temperature at 6 stations, 2010

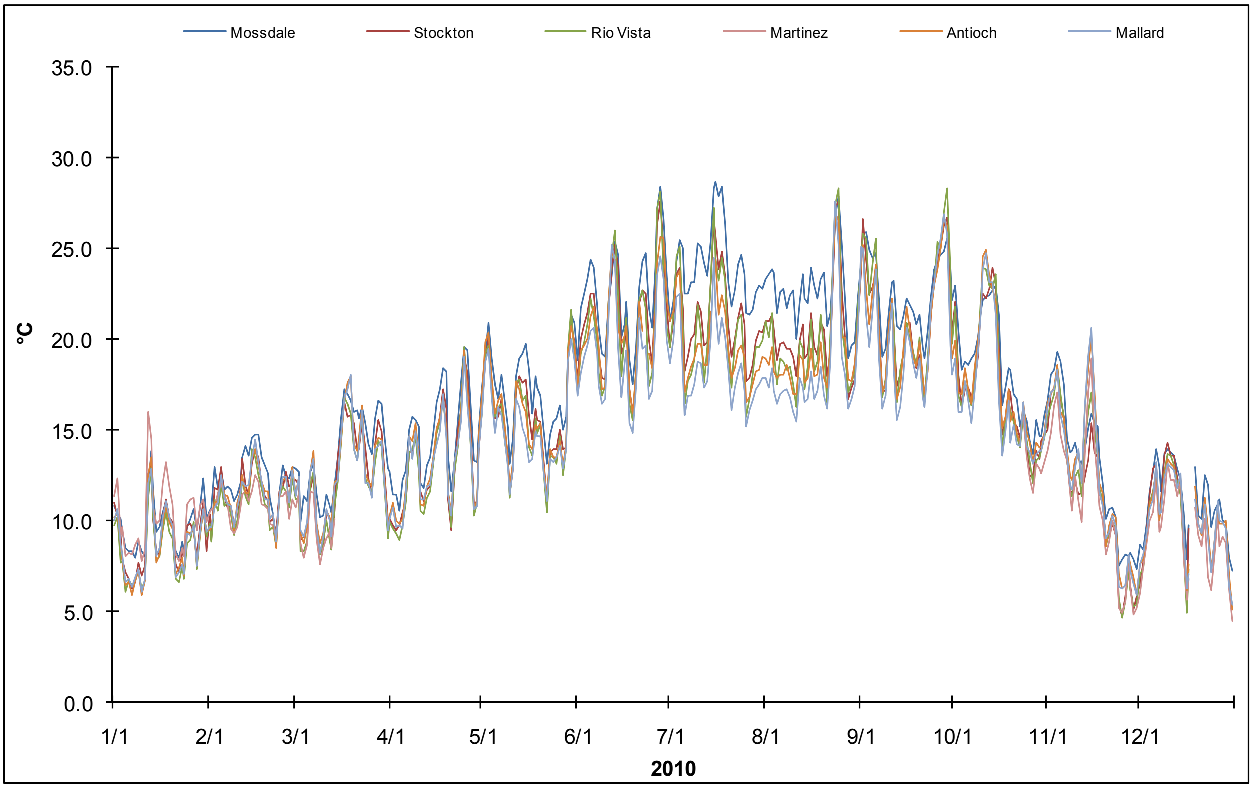


Figure 8-8a Average daily chlorophyll *a* fluorescence at 9 stations, 2010

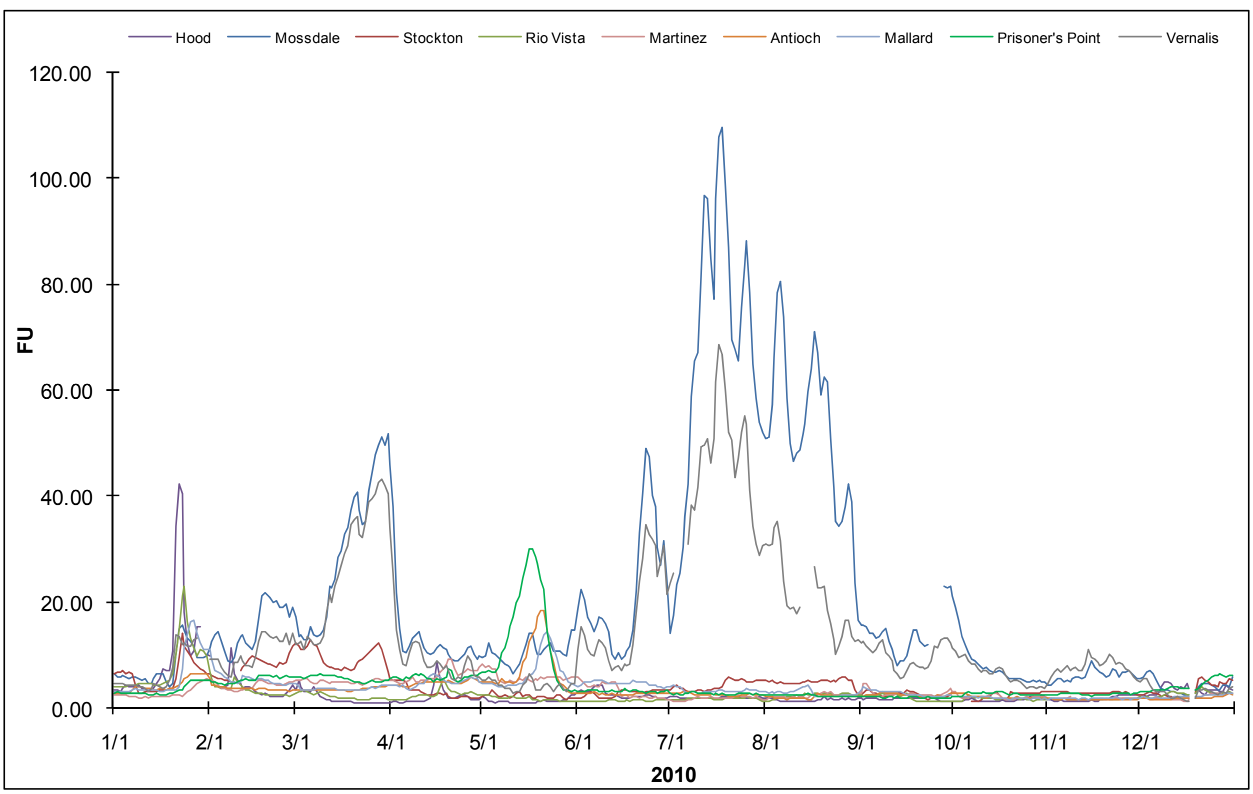


Figure 8-8b Average daily chlorophyll *a* fluorescence at 2 Sacramento River stations, 2010

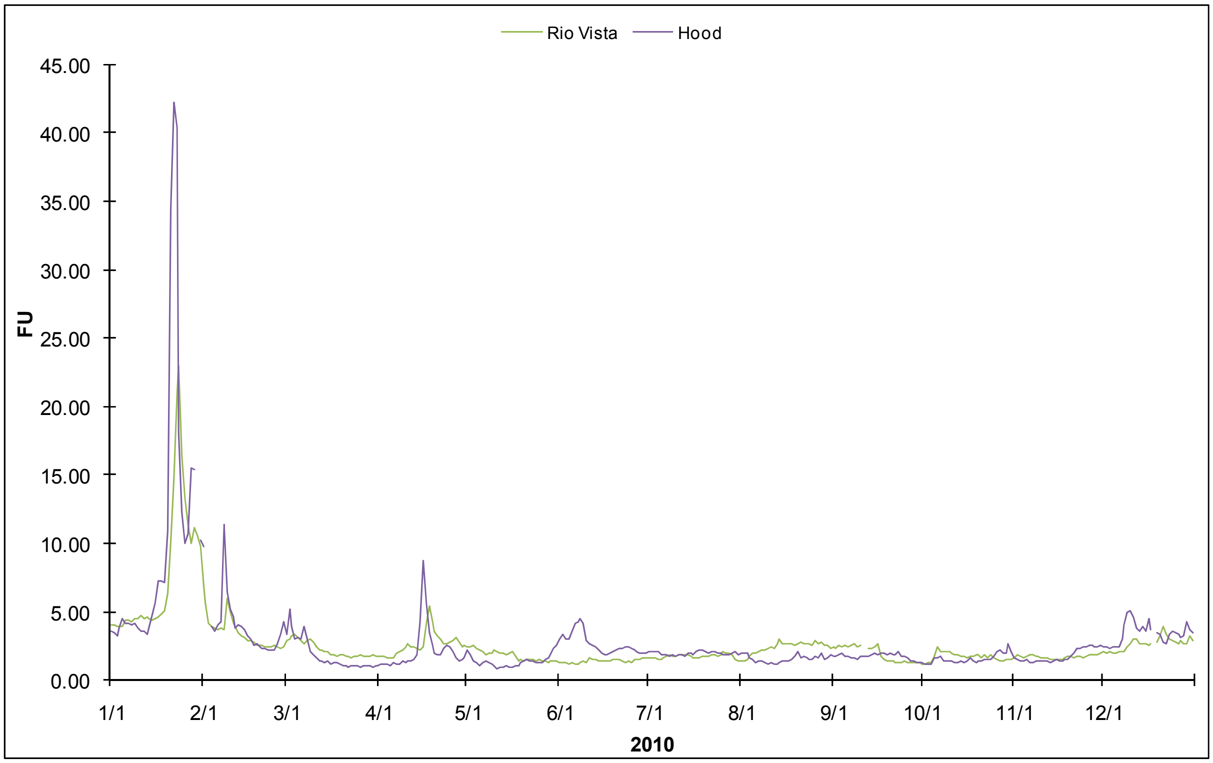


Figure 8-8c Average daily chlorophyll *a* fluorescence at 4 San Joaquin River stations, 2010

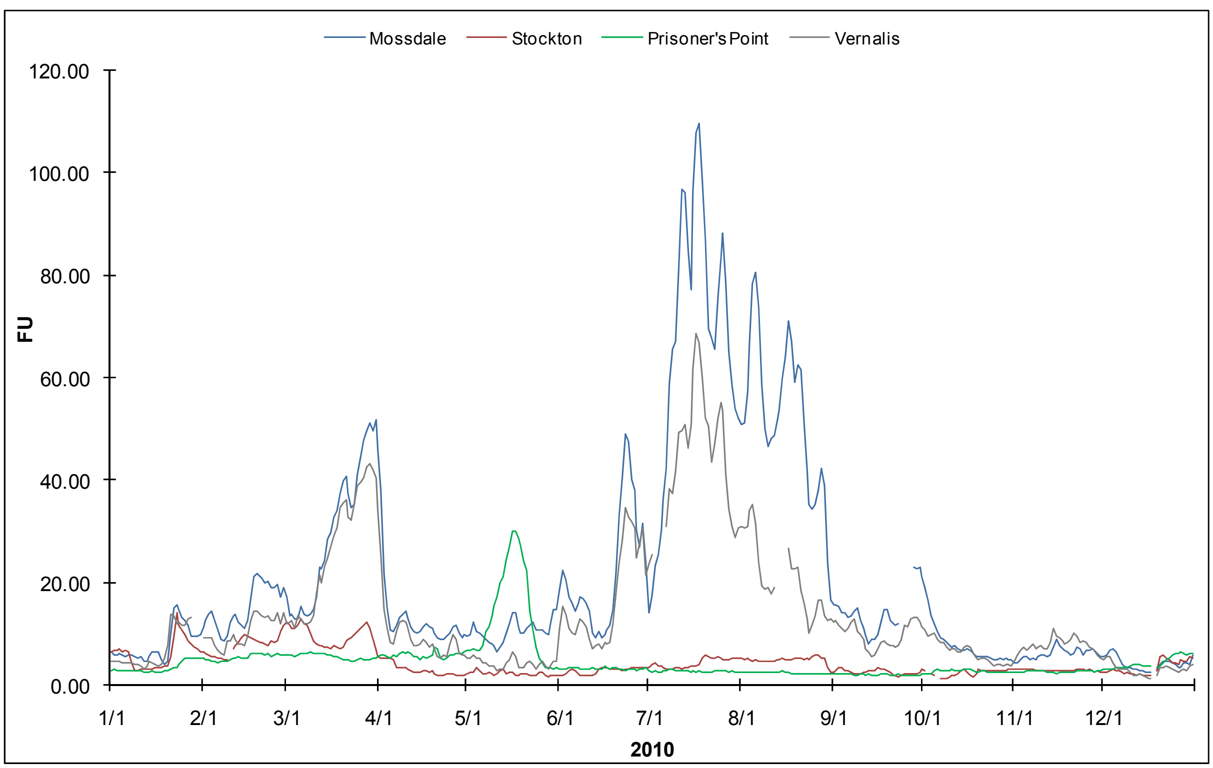


Figure 8-8d Average daily chlorophyll *a* fluorescence at 3 tidally influenced stations, 2010

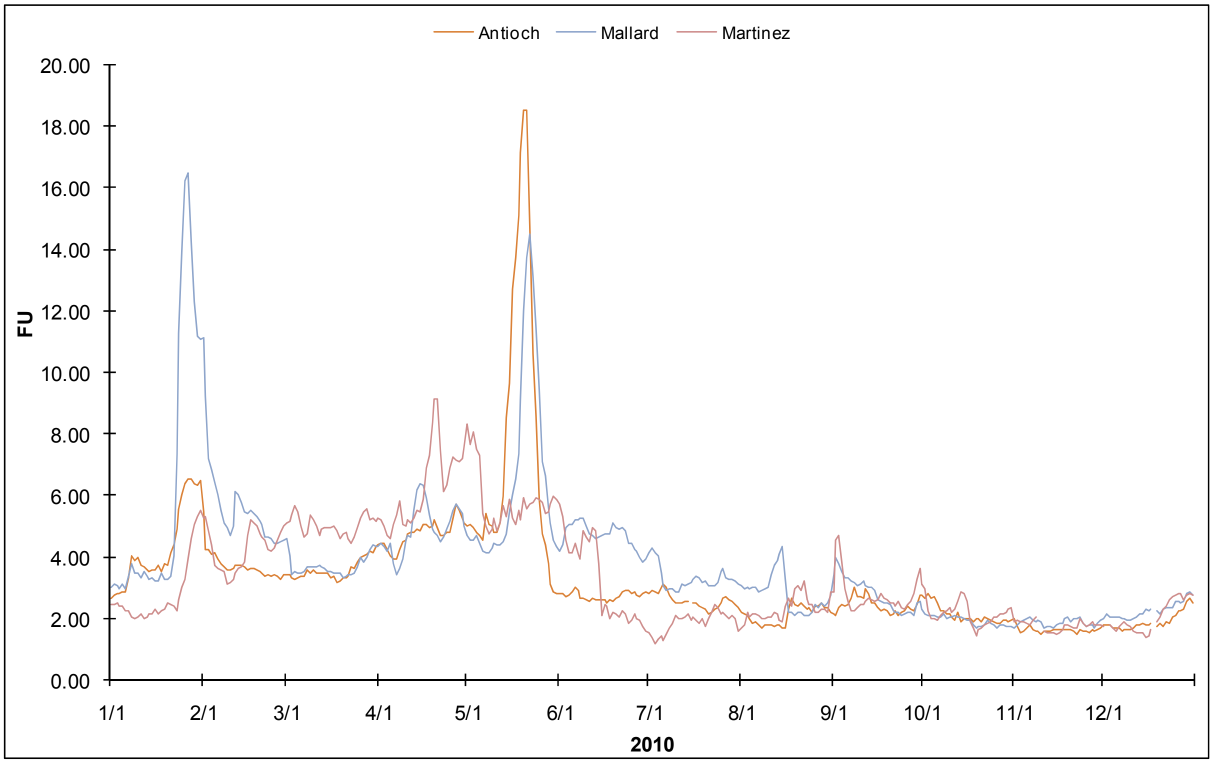


Figure 8-9a Average daily turbidity at 9 stations, 2010

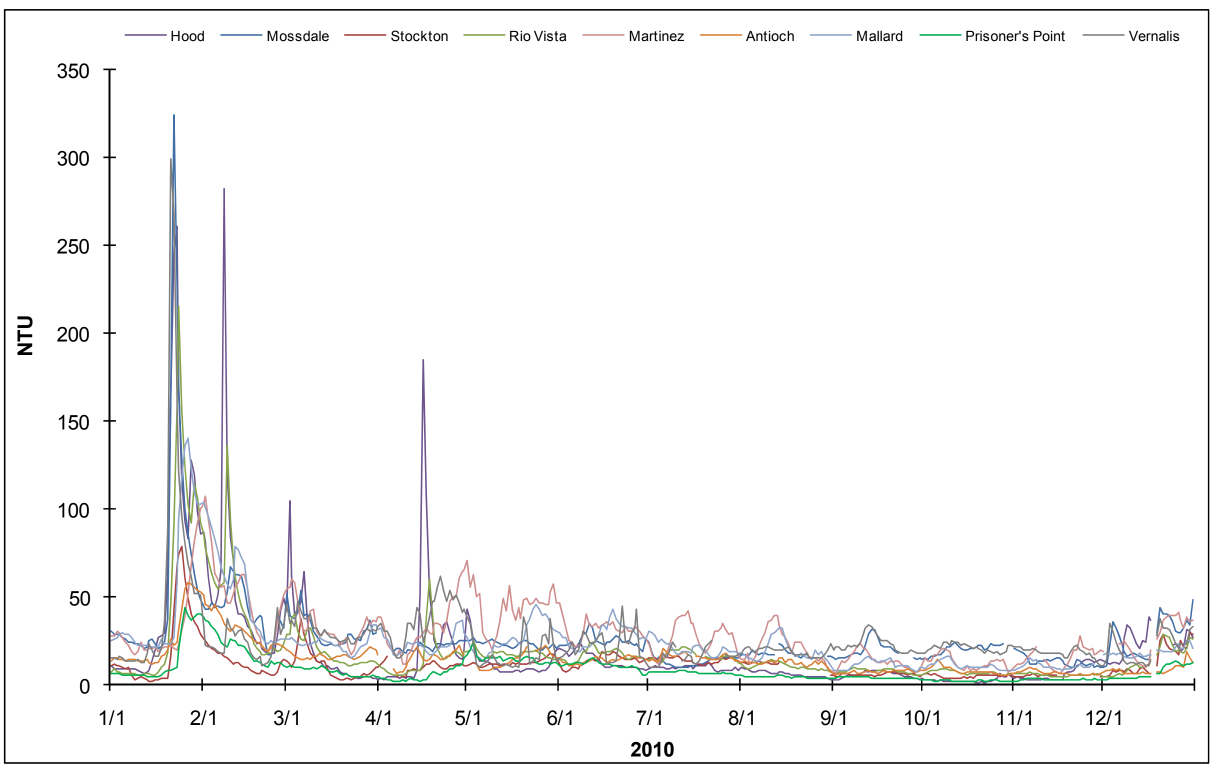


Figure 8-9b Average daily turbidity at 2 Sacramento River stations, 2010

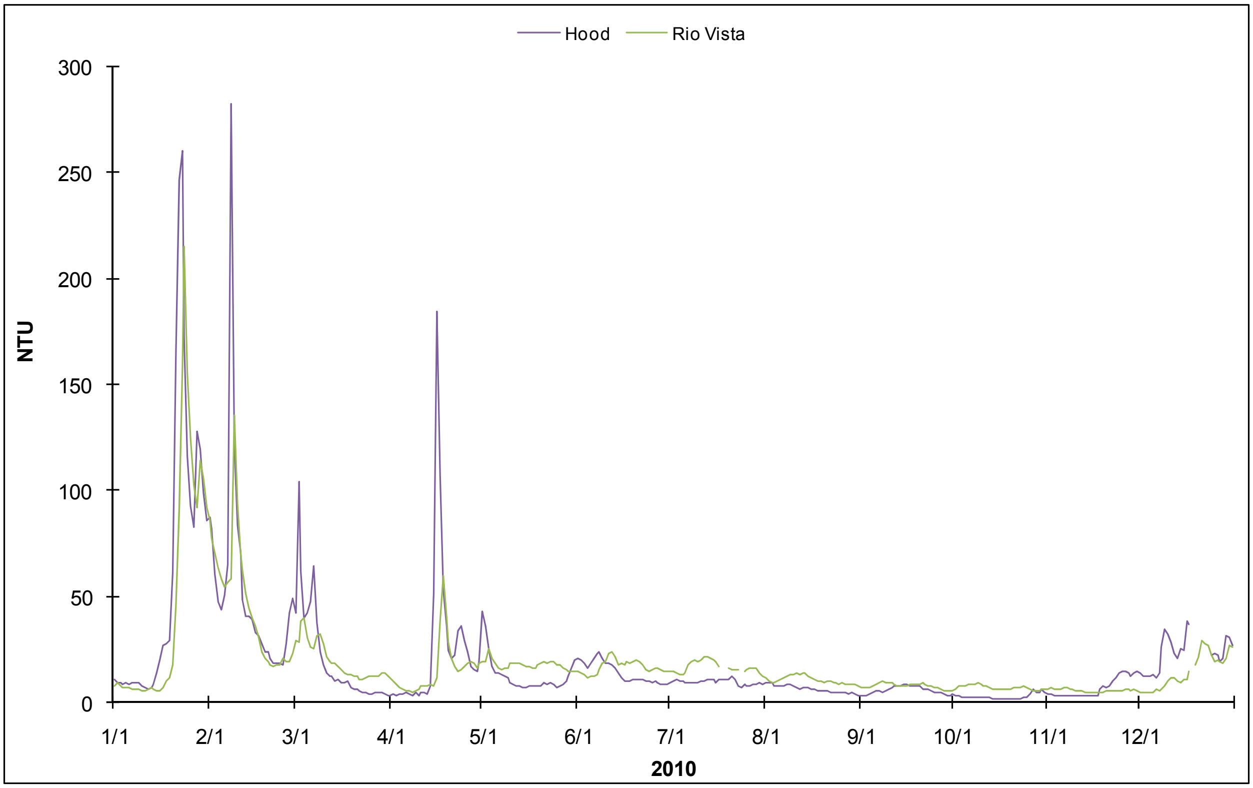


Figure 8-9c Average daily turbidity at 4 San Joaquin River stations, 2010

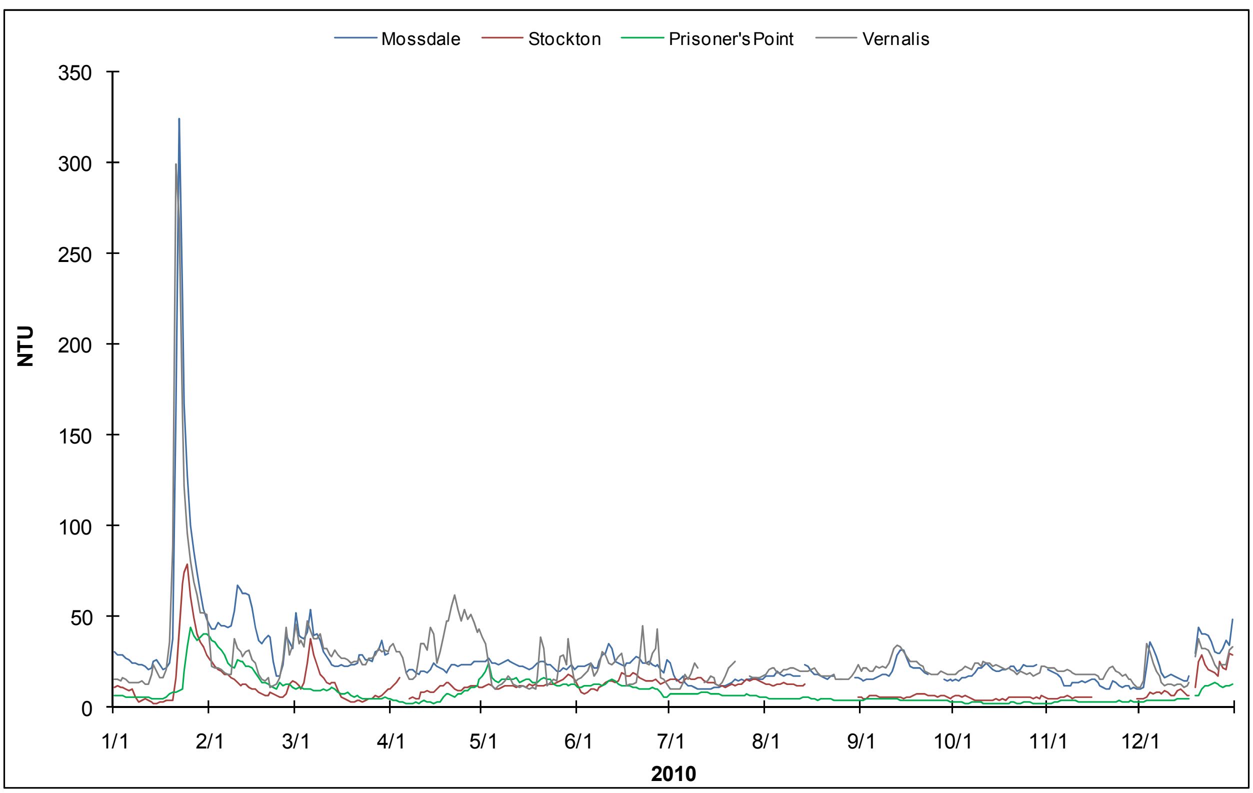


Figure 8-9d Average daily turbidity at 3 tidally influenced stations, 2010

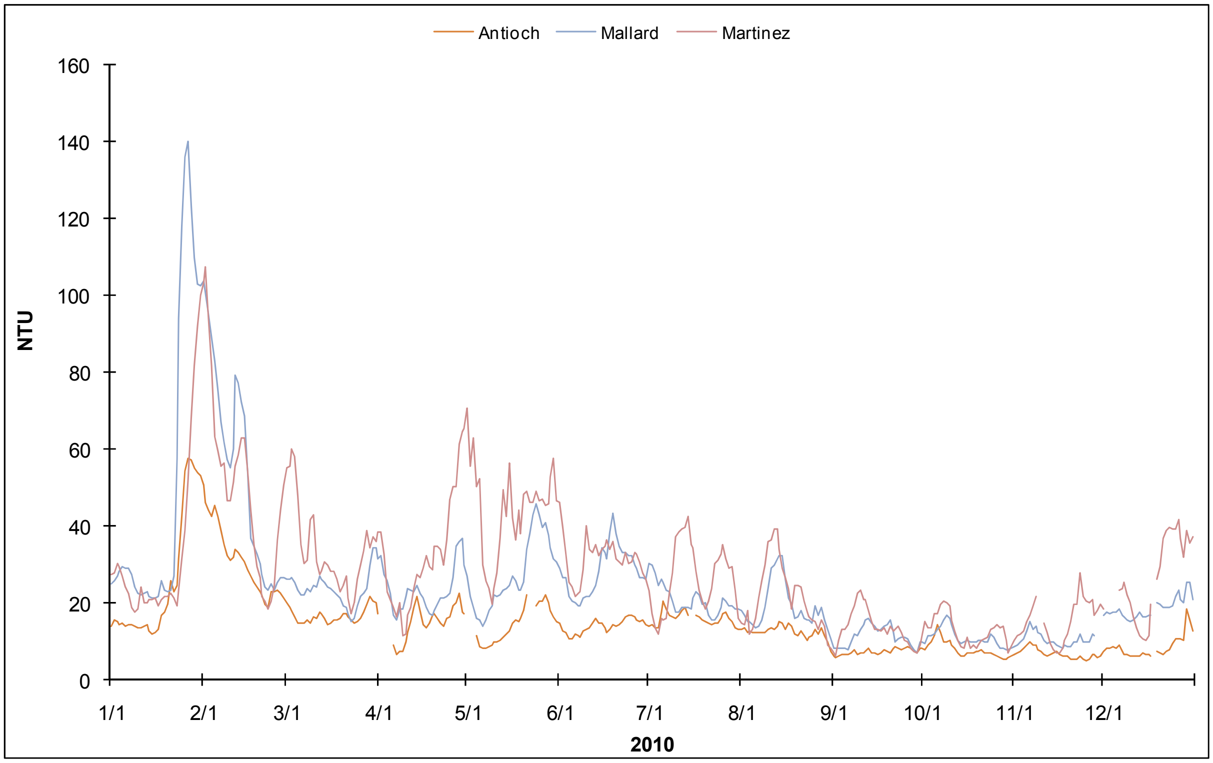
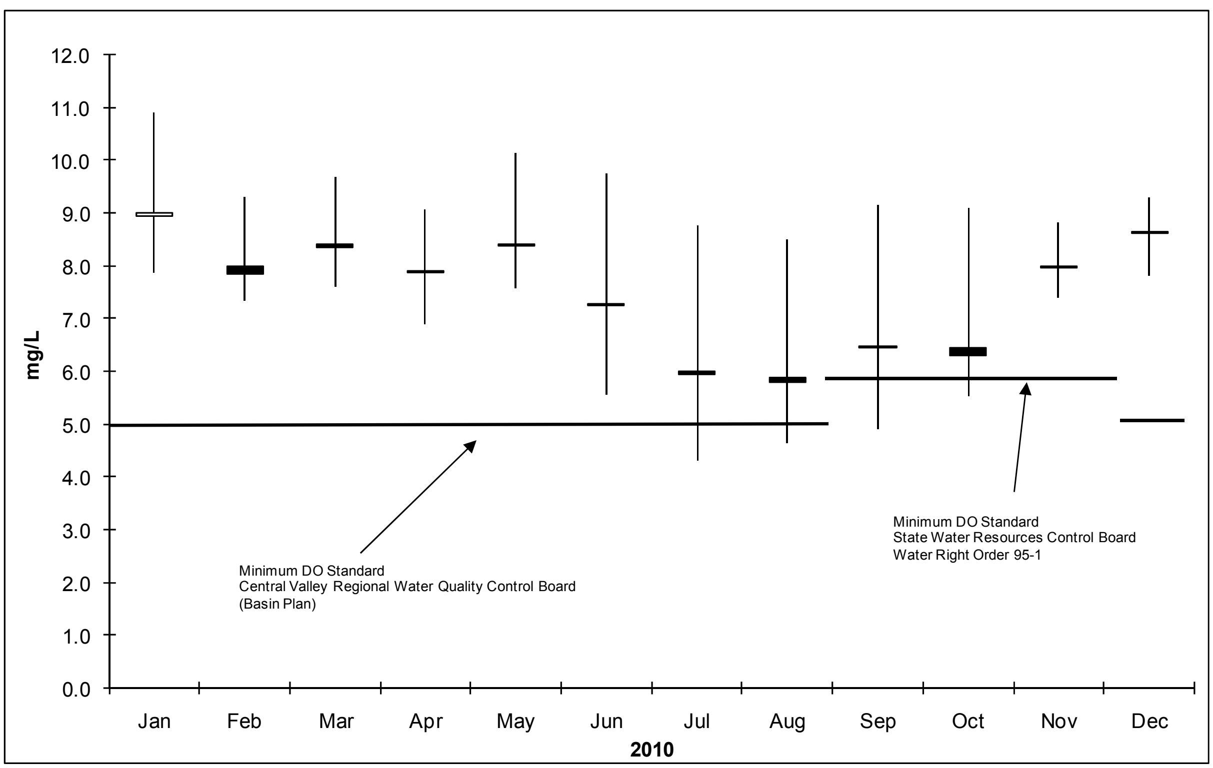


Figure 8-10 Range of monthly DO at Stockton, 2010



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

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	unitless	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 Sakata at bsakata@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.