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 2011

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

December 2012

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Executive Summary 2011

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 2011. 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 common to all phytoplankton, and is thus used as a measure of phytoplankton biomass. Samples for chlorophyll *a* and phytoplankton were taken from 15 of the 24 monitoring sites in the estuary. Chlorophyll *a* concentrations for 2011 showed seasonal patterns and were generally below 10 µg/L and ranged between 0.35 µg/L and 18.20 µg/L throughout the estuary. Of the 156 samples taken in 2011, 98.1% (153 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 2011 fell into 12 categories: centric diatoms, pennate diatoms, green algae, cryptomonad flagellates, cyanobacteria, haptophyte flagellates, dinoflagellates, euglenoid flagellates, ciliates, chrysophytes, little green algal balls, and kathablepharid flagellates. Cyanobacteria, centric diatoms, pennate diatoms, cryptomonad flagellates, and haptophyte flagellates constituted 99.4% of the organisms collected in the twelve identified groups.

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 then *Neomysis kadiakensis/japonica*. *Pseudodiaptomus forbesi* was the most common calanoid copepod followed by *Acartiella sinensis*. *Acartia* spp. was third most abundant. The 3 most common cyclopoid copepods continued to be the introduced *Limnoithona tetraspina* and *Oithona davisae*, followed by the native *Acanthocyclops vernalis.* The 3 most abundant cladocerans were *Bosmina* spp., *Diaphanosoma* spp., and *Daphnia* spp. *Synchaeta* spp. was the most common rotifer, followed by *Keratella* spp., and *Polyarthra* 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

2011 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida, and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda, and Mollusca constituted 98% of the organisms collected during the study period. Ten species in these phyla represent 81% 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 2011. 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 15 to November 23 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 6.3 to 9.8 mg/L at the surface and 6.5 to 9.4 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	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VAMP	Vernalis Adaptive Management Plan
VSS	volatile suspended solids
WR 2000-02	Water Right Decision 2000-2002

Metric Conversion Table

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

Chapter 1 Introduction

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Chapter 1. Introduction

The SWRCB establishes water quality objectives and monitoring plans to protect the variety of beneficial uses of the water within the upper San Francisco estuary (estuary). The SWRCB ensures that these objectives are met, in part, by inclusion of water quality monitoring requirements into water rights decisions issued to DWR and USBR as conditions for operating the SWP and CVP, respectively. These requirements include minimum outflows, limits to water diversion by the SWP and CVP, and maximum allowable salinity levels. In addition, DWR and USBR are required to conduct a comprehensive monitoring program to determine compliance with the water quality objectives and report the findings to the SWRCB. Water quality objectives were issued in December 1999 by D-1641 (SWRCB 1999) and revised by directive 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, *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2011*, summarizes the findings of the EMP for calendar year 2011. Separate chapters are devoted to the water quality, benthic, phytoplankton, zooplankton, and special study components of the EMP. Within each chapter, the major patterns and trends demonstrated by the water quality and biological data within and between years are described in the text and displayed in summary plots and tables. This report is submitted to the SWRCB to fulfill the reporting requirements of D-1641.

References

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

Chapter 2 Hydrologic Conditions Contents

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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 two 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 2011, covered by this report, comprises the period October 1, 2010 to September 30, 2011.

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 2011b). 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.

[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 the export of water to or import of water from other basins measured in MAF (Dayflow 2011). Figure 2-1 shows the monthly average Delta outflow and Figure 2-2 shows 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 it reaches 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 2011 was classified as wet for the San Joaquin Valley[7] and wet 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 include 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 also includes the previous 14 years for reference. Maximum Delta outflow indices were 431,460 ac-ft/day (217,525 cfs) on March 26, 2011 and minimum outflow indices were 4862 ac-ft/day (2452 cfs) on October 11, 2010 (Kate Le, pers. comm.). The figures in this summary may not match what was published in DWR *Bulletin 120* due to changes in averages, course selection, and reported preliminary data (CDEC 2011a).

Water year 2011 began with a very wet three-month period from October to December. In the northern Sierra this period ranked in the 10th wettest of the historic record (CDEC 2011a). On January 1st, 2011, statewide seasonal precipitation was nearly twice the average. Precipitation for the month of January was extremely dry and was recorded in the lowest 10 percent of the historical record (CDEC 2011a). Precipitation from a series of cold storms in March increased the mountain snowpack by more than half. The snowpack was more than 200 percent of normal for the year. The snowpack remained on the mountains, which assured a near normal water supply. On January 1, 2011, the snowpack in all regions of the state was close to or greater than 1983, one of the wettest years on record (CDEC 2011a). Flow rates through June 28th for all the forecasted rivers were greater than 160 percent of average. There were not any deficiencies imposed on the Central Valley Project (SWRCB 1999) in 2011.

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Chapter 2. Appendix

Figure 2-1 Net Delta Outflow Indices, water year 2011

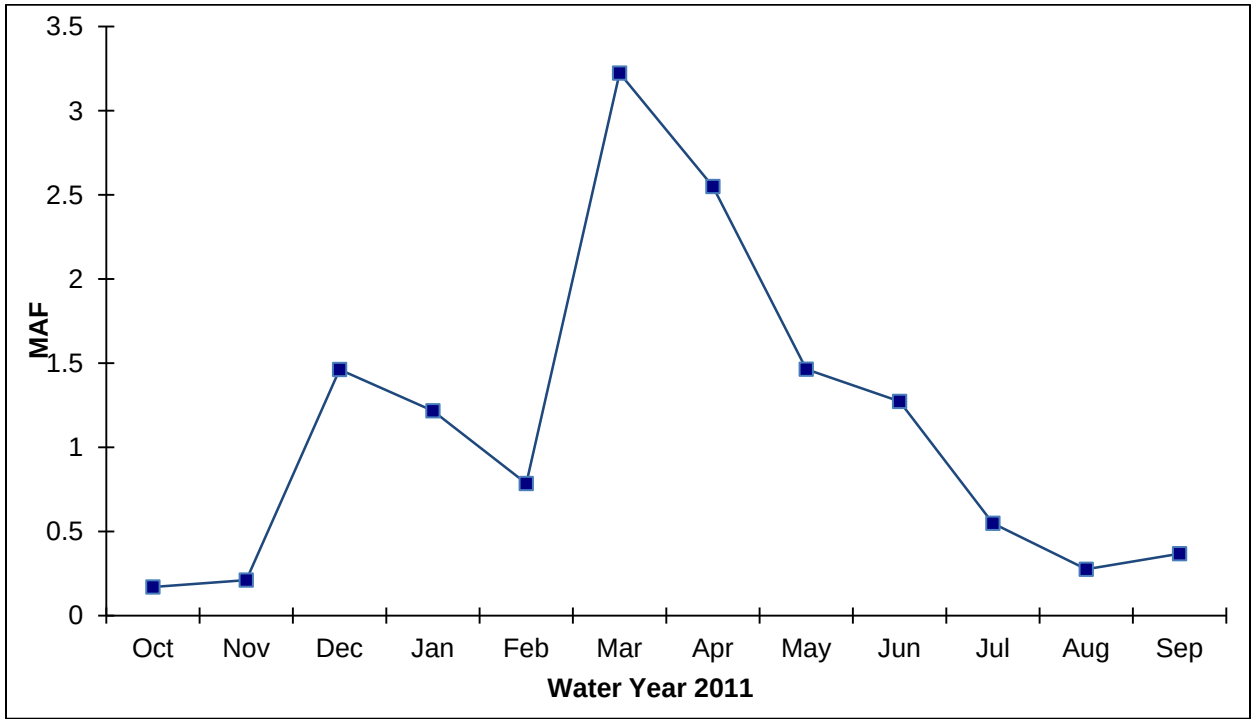

Figure 2-2 Unimpaired runoff for the Sacramento and San Joaquin rivers, water years 1997-2011

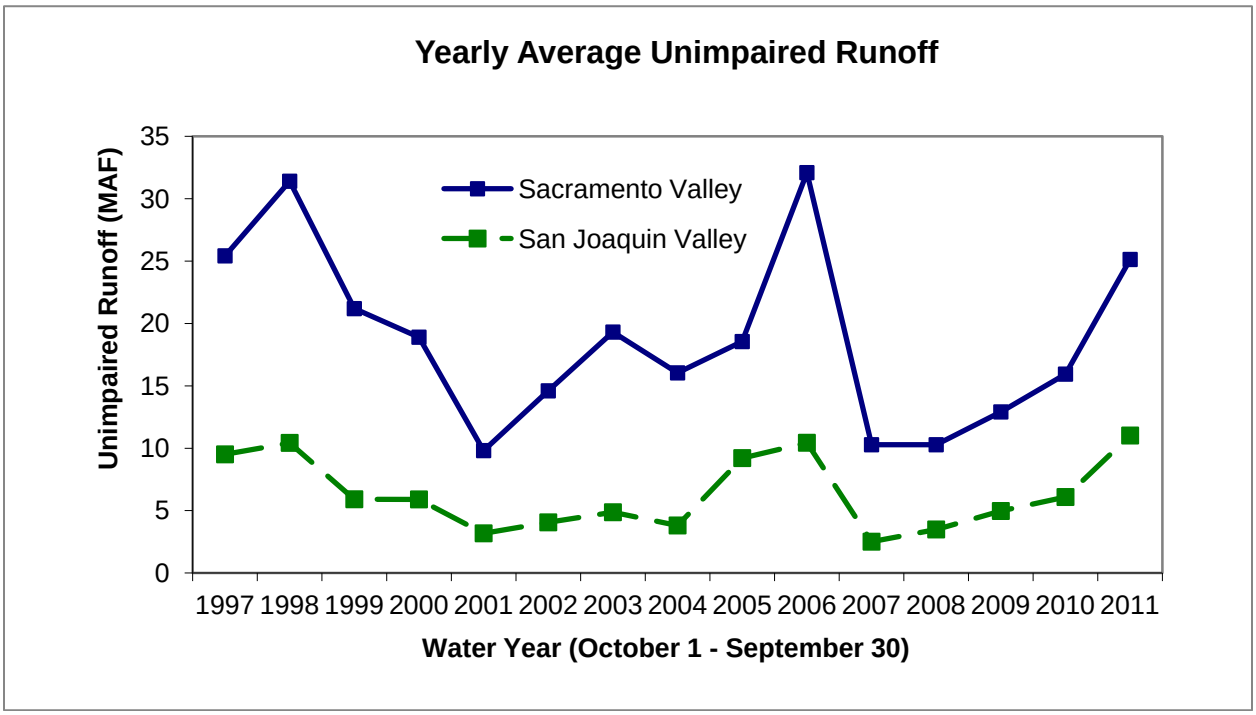

Figure 2-3 Sacramento River Hydrologic Region 40-30-30 Indices, water years 1997–2011

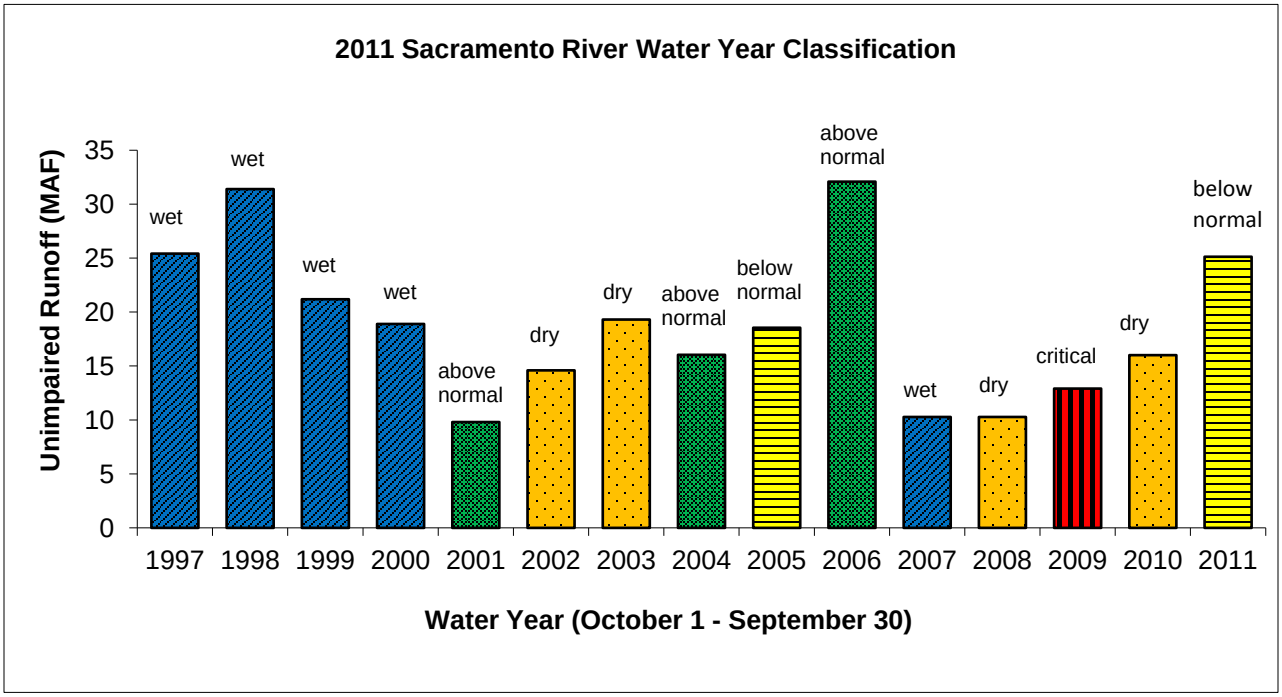

Figure 2-4 San Joaquin River Hydrologic Region 60-20-20 Indices, water years 1997–2011

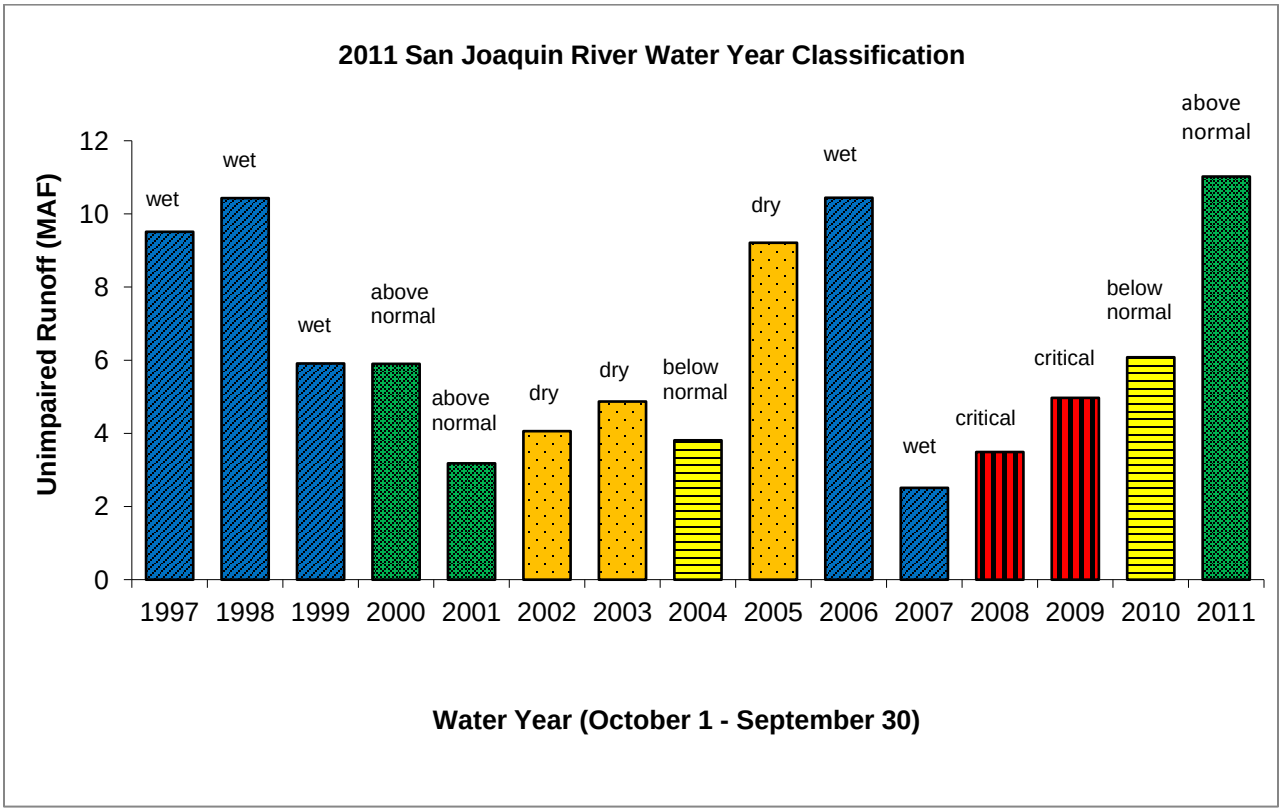

Table 2-1 Summary of statewide major hydrologic characteristics on May 1, water years 1997–2011

Water year	Precipitation October 1st to date	Runoff October 1st to date	May 1st Reservoir Storage	May 1st Snow Water Content
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	60	80	60
2010	110	75	95	140
2011	135	130	110	185

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 1997–2011

	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)
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
2011	12.63	11.52	25.13	2011	3.68	6.91	11.02

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

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Chapter 3. Water Quality Monitoring

Introduction

Water quality monitoring in 2011 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 eleven representative sites as described in the *1996 Water Quality Report* (Lehman et al. 2001), and stations C3A and C10A. Sampling site C3A replaced station C3 in 2004 and C10A replaced station C10 in 2005. Discrete samples were collected 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 Pacific Standard Time. A qualitative statement of weather conditions (e.g. wind conditions and cloud cover) was recorded for each cruise. Samples were analyzed in terms of fifteen physical and chemical parameters, shown in Table 3-1.

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

Parameters Measured

Except as noted, all discrete water quality samples were obtained with shipboard sampling equipment using the U.S. Bureau of Reclamation (USBR) research vessel *Endeavor* or the Department of Water Resources (DWR) research vessel *San Carlos*. Supplemental discrete samples were taken with mobile laboratory equipment at sites inaccessible to the research vessels in the north and south Delta (C3A and C10A). Secchi disk depth is not measured at site C10A due to restrictions of the sample site that require sampling equipment to be deployed from 50 ft above the water's surface.

Water Temperature

Water temperature was measured in °C with a YSI thermistor. Temperatures were measured from water collected by a through-hull pump at a depth of one meter for all sites except C3A and C10A. Temperatures for sites C3A and C10Awere measured from water collected at the continuous monitoring stations through float-mounted pumps that draw water at one meter in depth.

A water temperature minimum of 7.9 °C was recorded in January 2011 at station MD10A in the east Delta (Figures 3-2 and 3-3). This minimum temperature represents a decrease of 1.2 °C from the previously recorded minima in 2010 (Riordan et al. 2011).

Temperature minima at most sites during 2011 occurred during the month of January; site D41A was an exception with a temperature minimum in December. The timing of these sites' temperature minima is similar to the 2010 study period, where all temperature minima occurred during January (Riordan et al. 2011).

A water temperature maximum of 27.6 °C was recorded in July at station MD10A in the east Delta. This maximum is a 0.9 °C increase from the temperature maximum reported for 2010 (Riordan et al. 2011). Recorded temperatures exhibited strong seasonal variability due to cooling during the winter and warming during the summer.

Dissolved Oxygen

The amount of dissolved oxygen (DO) present in water samples is measured using the modified Winkler iodometric method as described in *Standard Methods* (APHA 1992). A sample aliquot is collected at a depth of one meter from a through-hull pump located on the research vessels, or from a float-mounted pump at a continuous monitoring station (sites C3A and C10A). The samples are collected in 300 mL glass-stoppered bottles and immediately analyzed.

During 2011, DO concentrations ranged from 5.3 mg/L at site MD10A in July to 10.9 mg/L at site C3A in January and site MD10A in February (Figures 3-4 and 3-5). Seasonal trends were evident in most regions, with a decrease in DO concentrations during the summer and a rise in levels during the winter. Reduced summer DO levels coincided with warmer water temperatures. This suggests 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

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

SC varied greatly between sites monitored, ranging from 88 µS/cm at site C3A in May to 44,029 µS/cm at site D41 in December (Figures 3-6 and 3-7). This range of SC was similar to the range of 127 - 44,994 µS/cm reported for 2010 (Riordan et al. 2011).

SC generally increases from east to west and is well correlated to inflows and tidal action. Maximum values occurred at most sites in the winter when flows through the Delta were lower and marine intrusion was more pronounced.

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

Secchi Disk Depth

Water transparency is measured to the nearest cm using a 20 cm diameter Secchi disk attached to a 2.5 m rod marked in centimeters. Secchi disk transparency is recorded as the average depth in which visual determination of the disk is lost as it is lowered into the water column, and the depth of its visual perception as it is raised. All measurements are made from the shaded side of the vessel.

A minimum Secchi depth of 16 cm was recorded at D41A (San Pablo Bay) in June and D7 (Suisun Bay) in August (Figures 3-8 and 3-9). A maximum Secchi depth of 344 cm was recorded at sampling site D28A (central Delta) in October. Secchi values during 2010 ranged from 20 to 312 cm (Riordan et al. 2011).

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

Turbidity

Turbidity is a measure of the optical properties of water and substances contained in 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 is determined from samples collected from a through-hull pump at a depth of one meter. The samples are 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). Due to their inaccessibility by vessel, turbidity is measured at continuous monitoring station sites C3A and C10A from samples collected via float-mounted pump using a Hach 2100P turbidimeter.

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 0.8 NTU at site MD10A (east Delta) in December to 58.4 NTU at site C10A (south Delta) in January. This range of turbidity was very similar to the 0.6 to 60.3 NTU range reported for 2010 (Riordan et al. 2011). 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. Other sites showed no consistent seasonal pattern.

Orthophosphate

Orthophosphate is soluble, inorganic phosphate, which is the phosphorus compound most immediately available for assimilation by phytoplankton. Orthophosphate concentrations are measured by first collecting sample aliquots from a one meter depth into new, rinsed polyethylene bottles. The water samples are then passed through a pre-washed membrane filter with 0.45 µm pore size. The filtrate is immediately frozen and later transported to Bryte Laboratory[9] for analysis according to 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 recorded value was 0.02 mg/L at stations C10A in February, C3A in January, February, April, May, and June, D28A in February, D4 in April and May, and D6 in April. The 2010 study period showed the lowest value (0.03 mg/L) of orthophosphate occurring at sites MD10A, C3A, D4, and D26 during multiple months (Riordan et al. 2011).

The highest value of orthophosphate was 0.15 mg/L at site P8 in November. During 2010, the highest orthophosphate concentration was 0.19 mg/L at site MD10A in March and site P8 in February (Riordan et al. 2011).

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.

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

Total phosphorus concentrations are measured by first collecting sample aliquots from a depth of one meter into new, rinsed polyethylene bottles. The water samples are then passed through a pre-washed membrane filter with 0.45 µm pore size. The filtrate is immediately frozen and later transported to Bryte Laboratory for analysis according to 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 0.03 mg/L was recorded at site D26 in November. This value is slightly lower than the minimum value of 0.04 mg/L recorded during 2010 at site C3A in August, site D26 in August and October, and site MD10A in September and November. (Riordan et al. 2011). A maximum value of 0.19 mg/L was recorded at site D41A in February and June, and site P8 in November. This value is lower than the maximum value of 0.31 mg/L recorded during 2010 at site C10A in March (Riordan et al. 2011).

Site D41A had the highest average total phosphorus concentrations during 2011. 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 are measured by first collecting sample aliquots from a depth of one meter into new, rinsed polyethylene bottles. The water samples are then passed through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate is immediately frozen and later transported to Bryte Laboratory for analysis according to 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 many sites: C3A in February; D19 in May, July, and September through November; D26 in June and September through November; D28A in July, August, October, and November; D4 in May and October; D41 in September; D7 in May and June; D8 in May and July; and MD10A in November, to 0.7 mg/L at site C10A in January, C3A in November, and MD10A in January (Figures 3-16 and 3-17). During 2010, Kjeldahl nitrogen levels peaked at site P8 with a high of 1.3 mg/L (Riordan et al. 2011).

Kjeldahl nitrogen concentrations were generally highest at sites C10A, D41A, and D6. Many sites showed a pattern of highs in the winter and spring with lower values occurring during the summer or fall.

Dissolved Inorganic Nitrogen

Dissolved inorganic nitrogen (DIN) is a measure of NH_3, NO_3, and NO_2, which are the nitrogen forms immediately available for assimilation by phytoplankton. DIN is measured by first pumping water samples from a depth of one meter into new, rinsed polyethylene bottles. The water samples are then passed through a pre-washed membrane filter with 0.45 µm pore size. The filtrate is immediately frozen and later transported to Bryte Laboratory for NH_3 analysis 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 0.05 mg/L at site MD10A in September to a maximum of 2.31 mg/L at site P8 in November. (Figures 3-18 and 3-9). This range is smaller than the range observed during 2010, which recorded a minimum value of 0.03 mg/L at site MD10A in August and a maximum of 3.43 mg/L at station P8 in January (Riordan et al. 2011). 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 functionally defined as nitrogen 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 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).

Dissolved Organic Nitrogen (DON) is measured by first pumping water samples from a one meter depth into new, rinsed polyethylene bottles. The water samples are then passed through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate is 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 recorded DON concentration was 0.1 mg/L at most stations, excluding MD10A, during multiple months. A maximum concentration of 0.6 mg/L was recorded at stations C10A and MD10A in January (Figures 3-20 and 3-21). Peak DON during 2010 was higher, reaching 1.0 mg/L at station P8 in March (Riordan et al. 2011).

Total Dissolved Solids

Total dissolved solids (TDS) is 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 is measured by first pumping water samples from a one meter depth into new, rinsed polyethylene bottles. The samples are then filtered through a pre-washed membrane filter with a 0.45 µm pore size. The filtrate is 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 52 mg/L at site C3A in May to 27,900 mg/L at site D41 in December (Figures 3-22 and 3-23). The values were similar during 2010, which had a range of 78 mg/L to 28,980 mg/L (Riordan et al. 2011). 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 retained on a filter after the sample is filtered. Suspended solids include a wide variety of material such as silt, living or decaying organic matter, and anthropogenic matter. High amounts of suspended solids block light penetration into the water column and increase heat absorption.

Total suspended solids (TSS) may increase in surface waters due to increases in flow rate as higher velocities increase 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 are taken from aliquots collected from a depth of one meter, 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 1.0 mg/L at sites D19 in April, D28A in August and November and MD10A in December to 144 mg/L at site D41A in June (Figures 3-24 and 3-25). During the 2010 study period the highest TSS value (149 mg/L) was also recorded at site D41A in August and the lowest TSS value was below the minimum reporting limit at sites D28A and MD10A in December (Riordan et al. 2011).

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

Volatile Suspended Solids

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

VSS levels fell below minimum reporting levels (<1 mg/L) at stations D19, D26, D28A, D4, D8, MD10A, and P8 during multiple months, and reached a high of 23.0 mg/L at site D41A in February, June, and July (Figures 3-26 and 3-27). These results were lower than those observed in 2010, which had a maximum value of 31.0 mg/L at site D41A in August (Riordan et al., 2011). Most sites showed a high degree of variability, with no apparent seasonal trends.

Silica

Water samples for silica analysis are taken from aliquots collected from a depth of one meter into new, rinsed polyethylene bottles. The water samples are 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 are analyzed for silica according to USEPA (1983) Method 200.7. The minimum reporting level for silica in these analyses is 0.1 mg/L.

Silica concentrations ranged from a low of 3.6 mg/L at site D41A in December to a high of 163 mg/L at site D41 in November (Figures 3-28 and 3-29). Values during 2010 exhibited a smaller range, from 2.4 mg/L at site MD10A in May to 21.6 mg/L at site C3A in January (Riordan et al. 2011).

Chloride

Water samples for chloride analysis are taken from aliquots collected from a depth of one meter into new, rinsed polyethylene bottles. The water samples are 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 are analyzed for chloride according to USEPA (1983) Method 300.0.

Chloride concentrations in the estuary varied over a wide range from 3 mg/L at site C3A in April and May to 15,900 mg/L at site D41 in December (Figures 3-30 and 3-31). These results are very similar to those observed during 2010, which recorded a low of 5 mg/L at site C3A in June, July, and August and a high of 16,200 mg/L at site D41 in January and September (Riordan et al. 2011). 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 reported values 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. 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 within 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). Washington DC.

Riordan, D., Brown, T., Dempsey, M., Elkins, R., Fuller, H., Hennessy, A., Noble, B., and Yu, E. 2011. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 2010.* Sacramento, CA: Department of Water Resources.

Lehman, P., Hayes, S., Marsh, G., Messer, C., Ralston, C., Gehrts, K., and 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

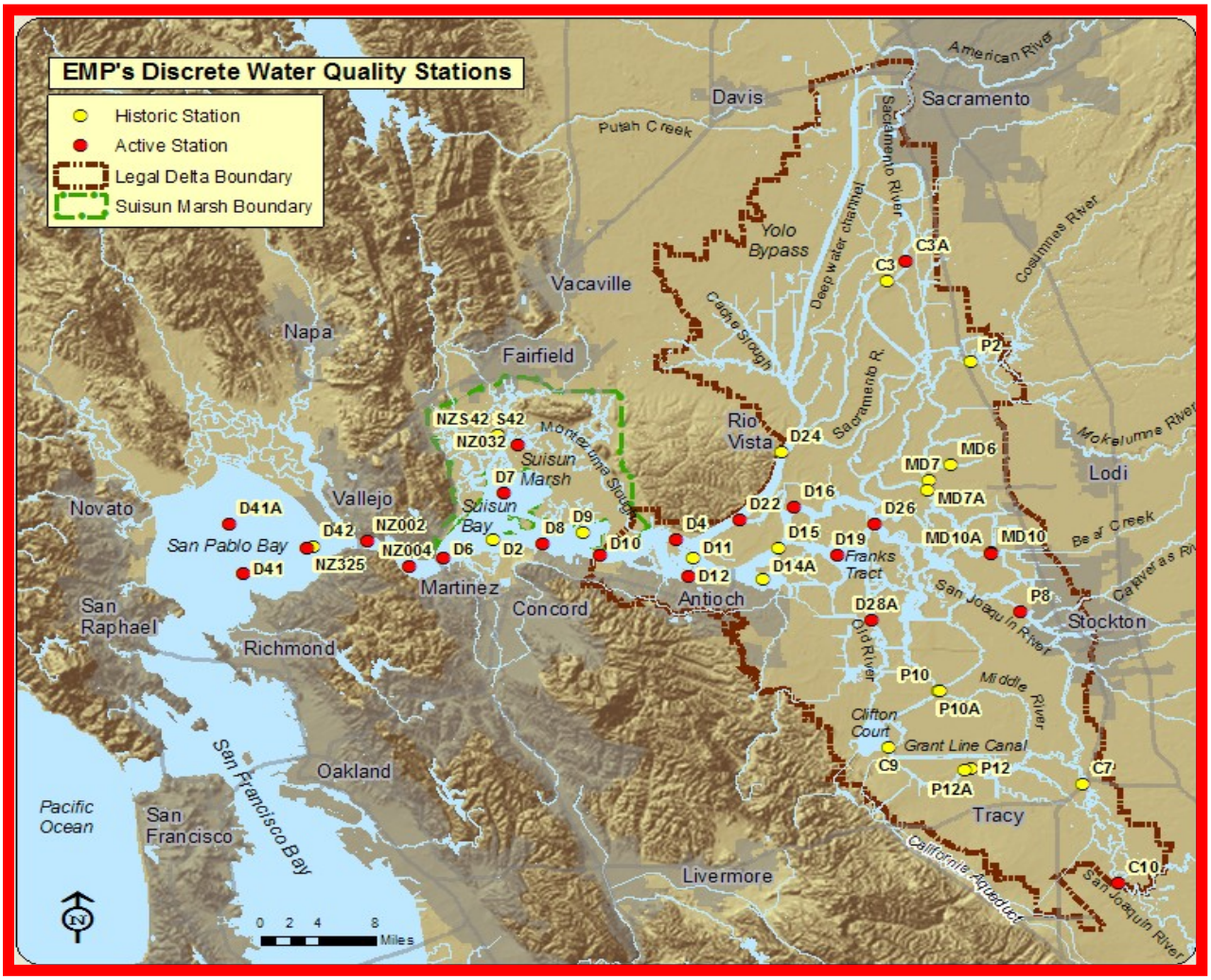

Figure 3-2 Water temperature comparisons, 2011

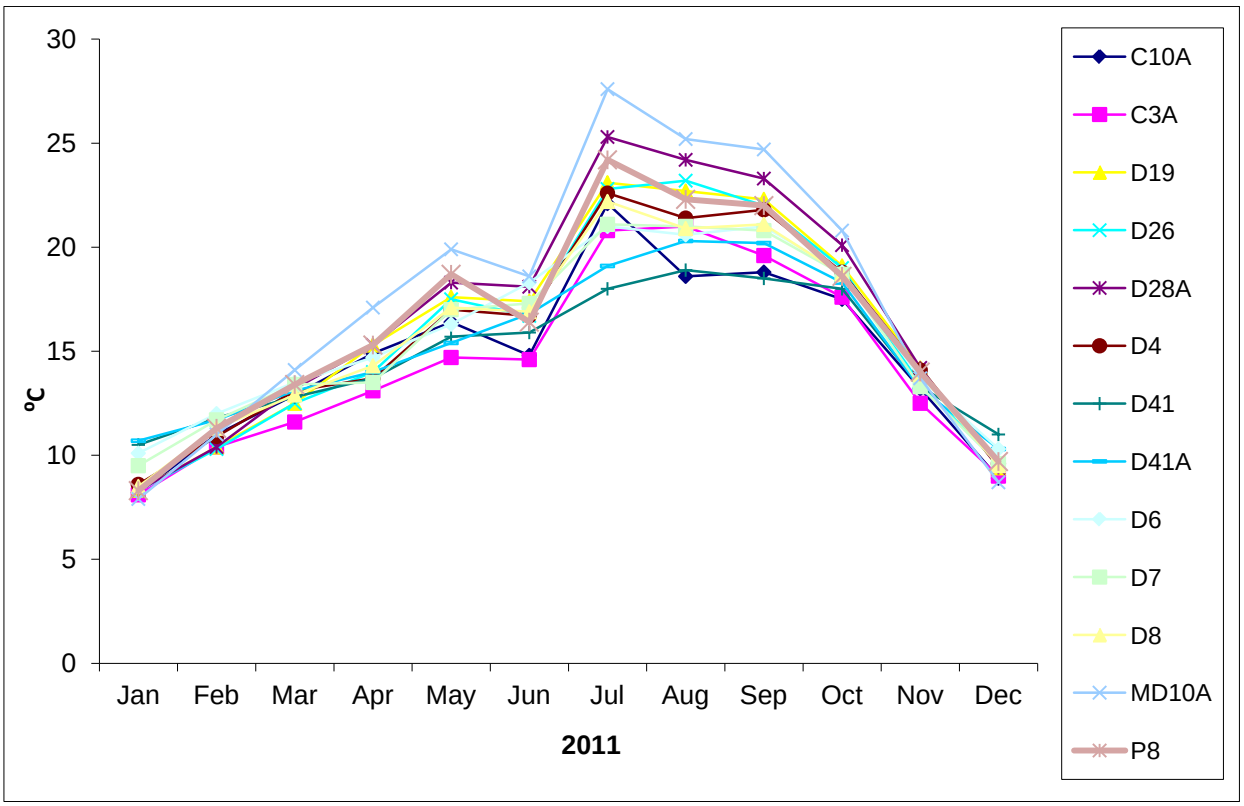

Figure 3-3 Water temperature by station, 2011

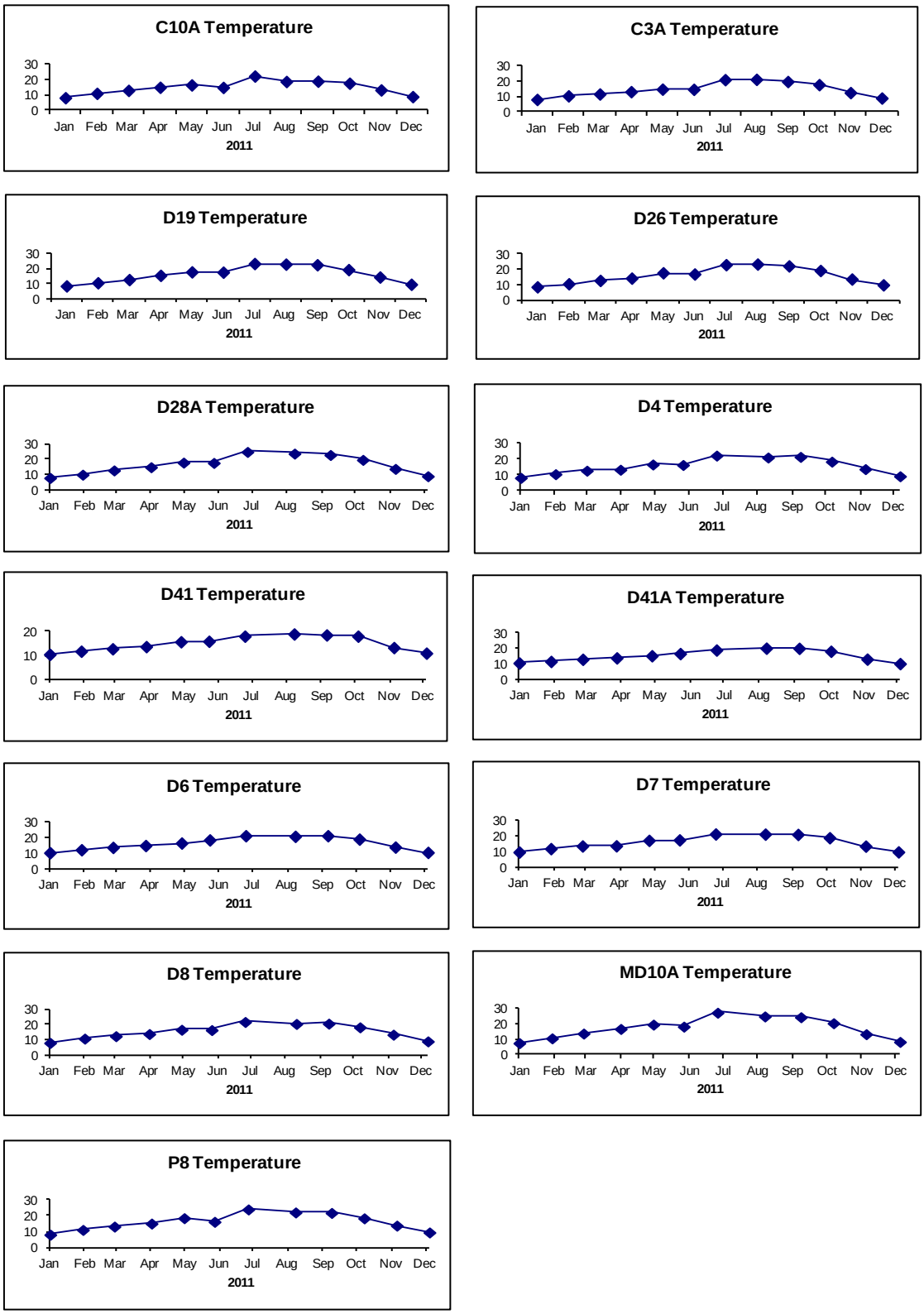

Figure 3-4 DO comparisons, 2011

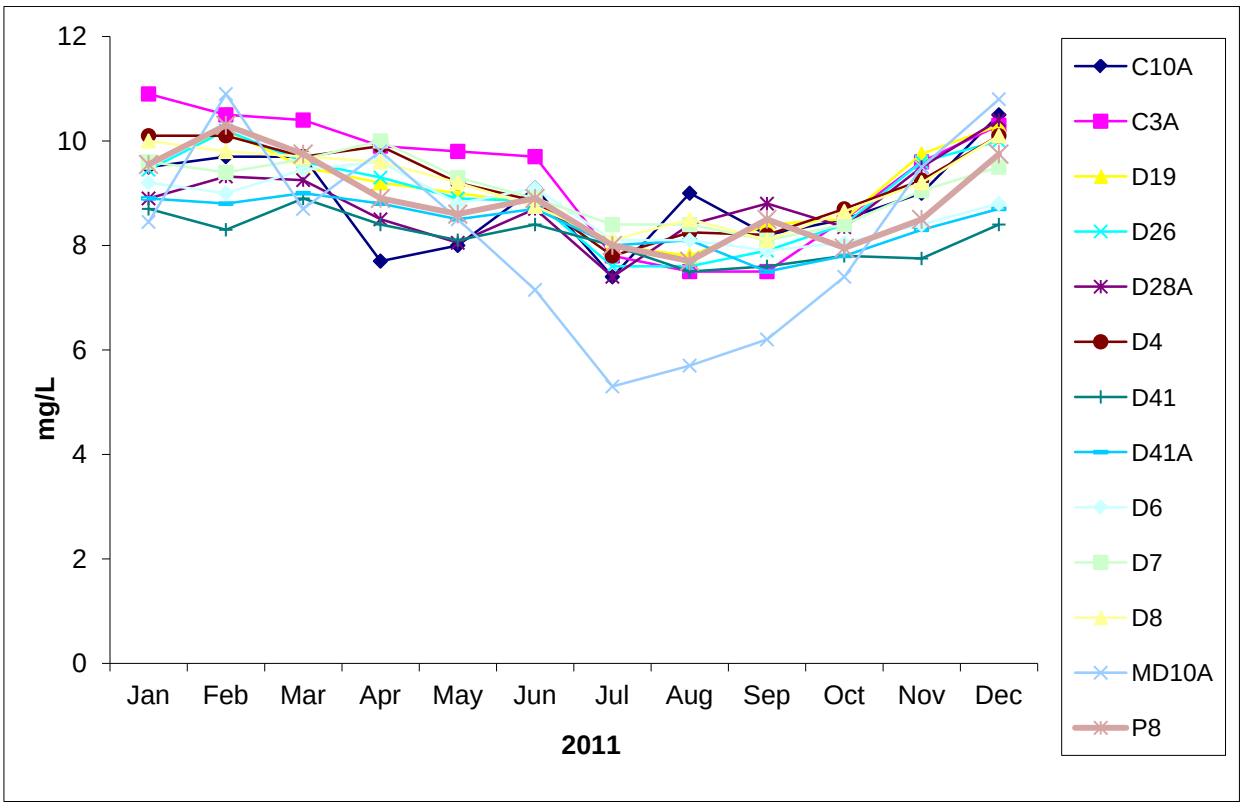

Figure 3-5 DO by station, 2011

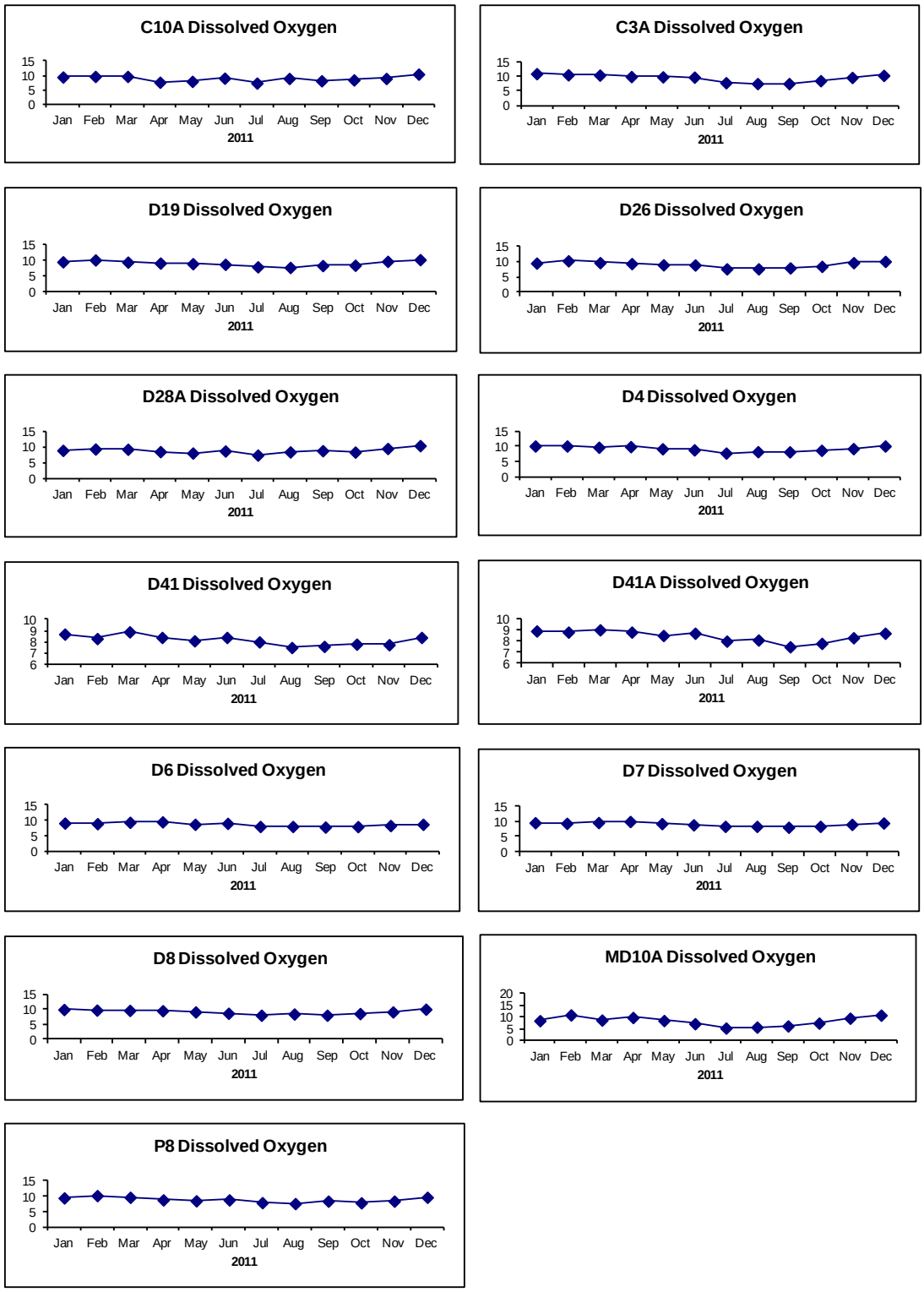

Figure 3-6 SC comparisons, 2011

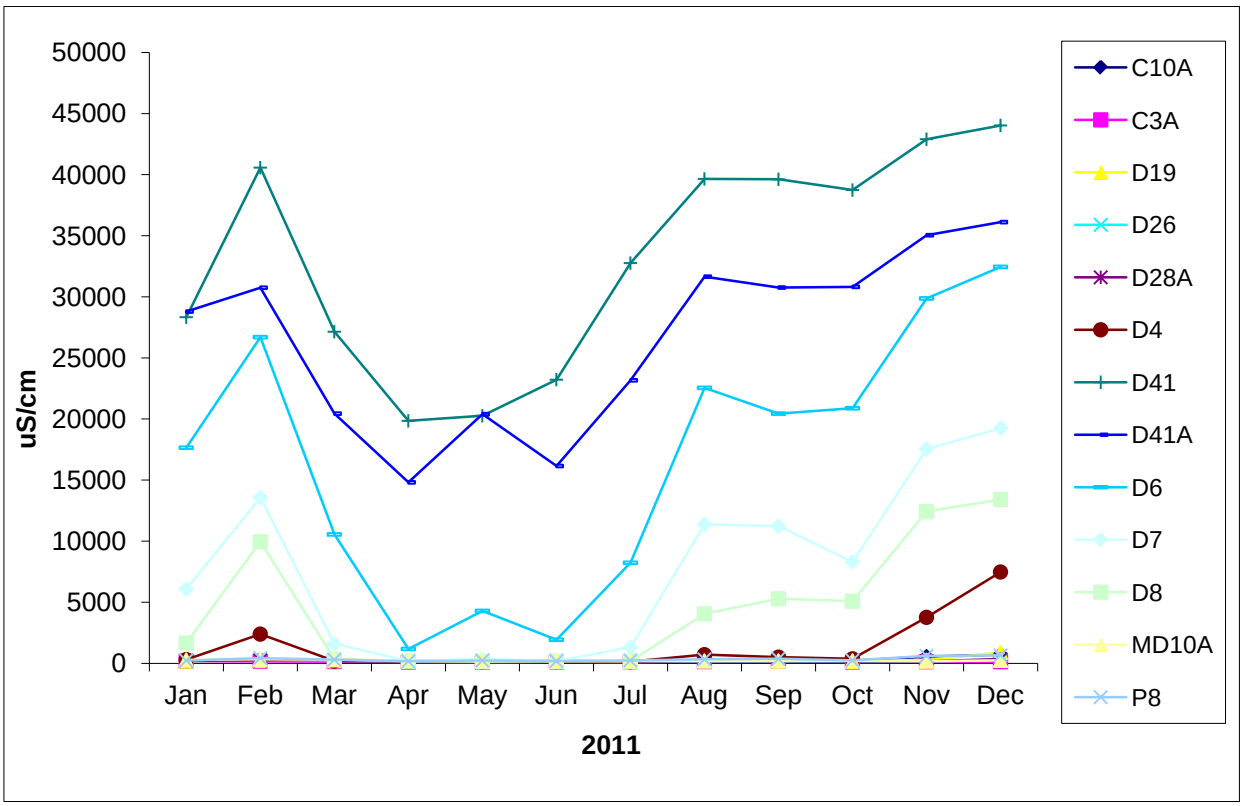

Figure 3-7 SC by station, 2011

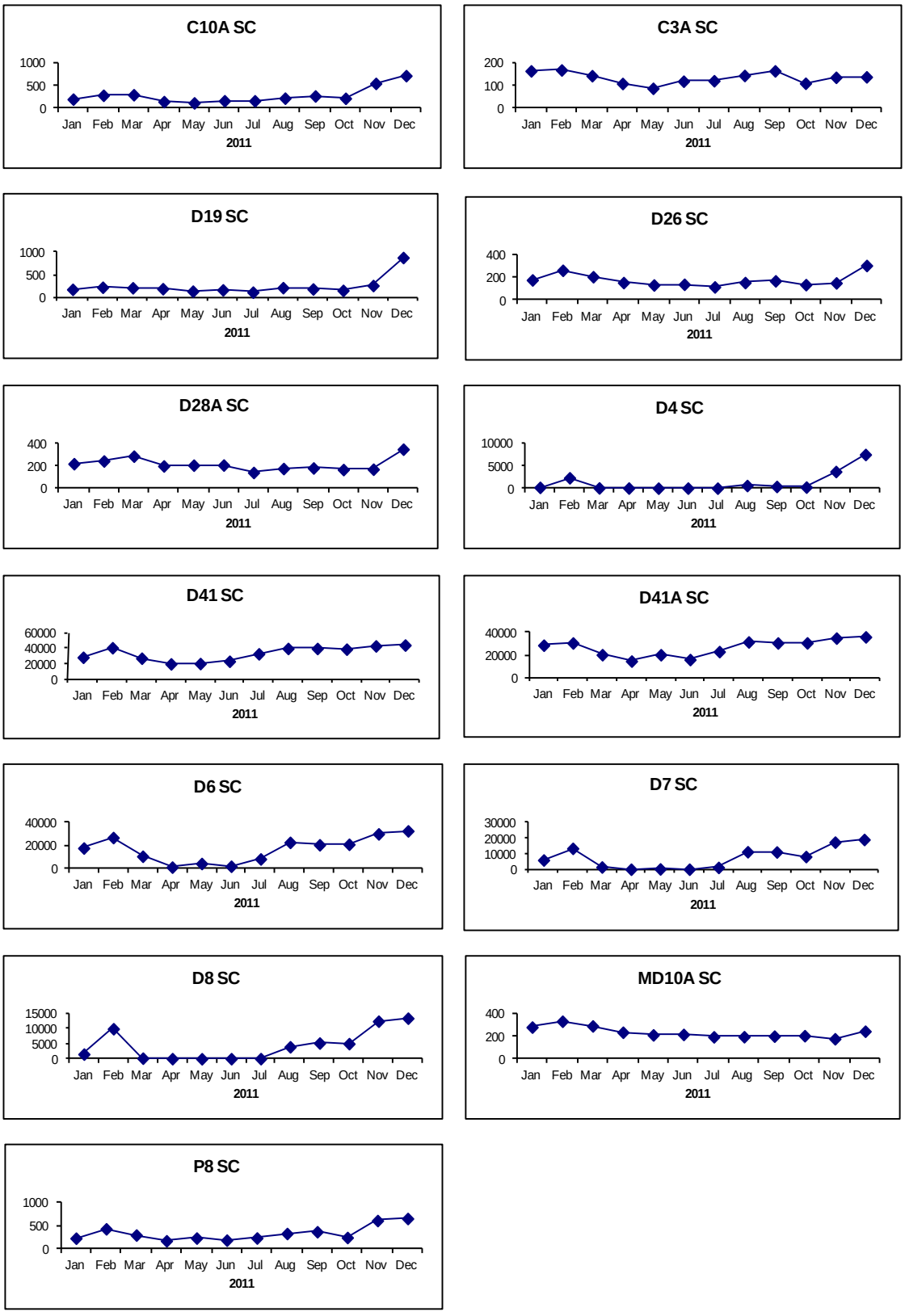

Figure 3-8 Secchi disk depth comparisons, 2011

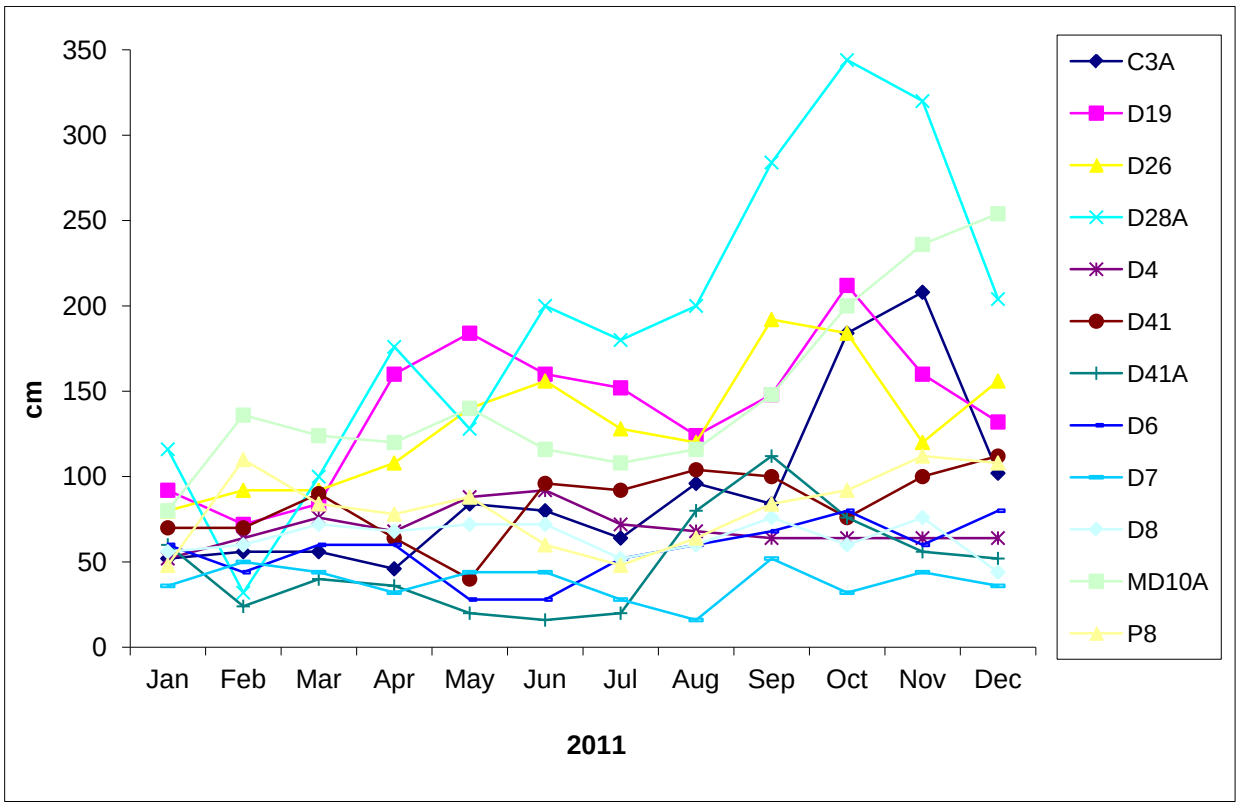

Figure 3-9 Secchi disk by station, 2011

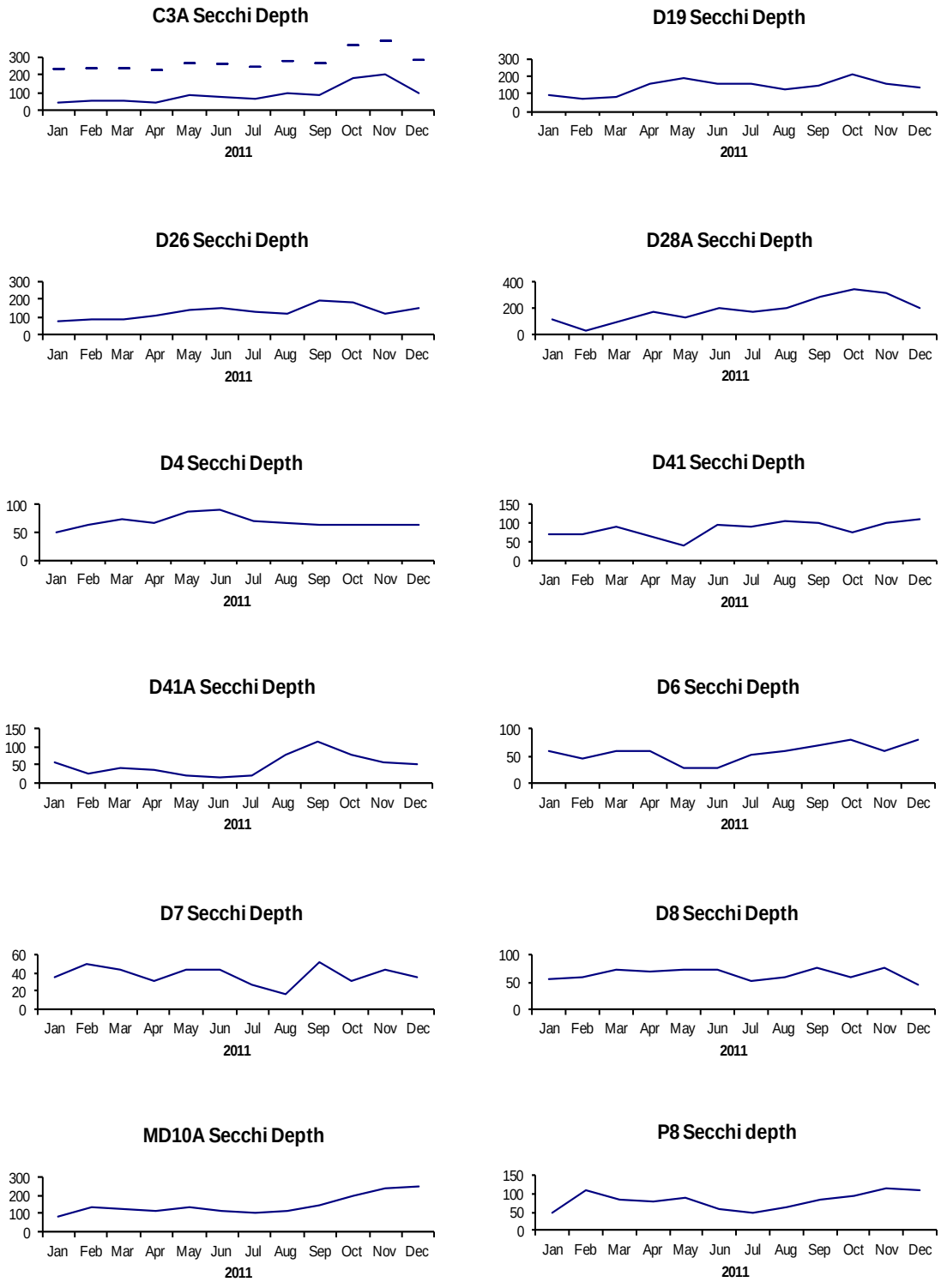

Figure 3-10 Turbidity comparisons, 2011

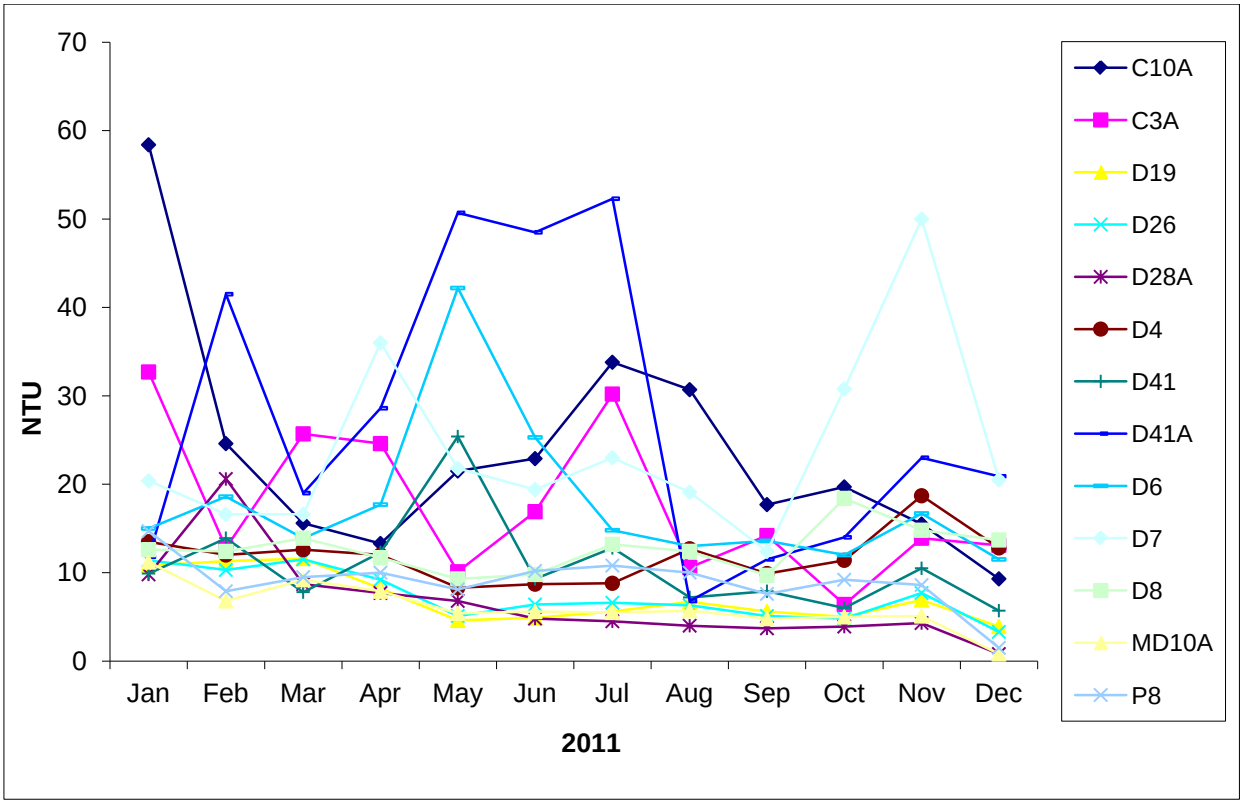

Figure 3-11 Turbidity by station, 2011

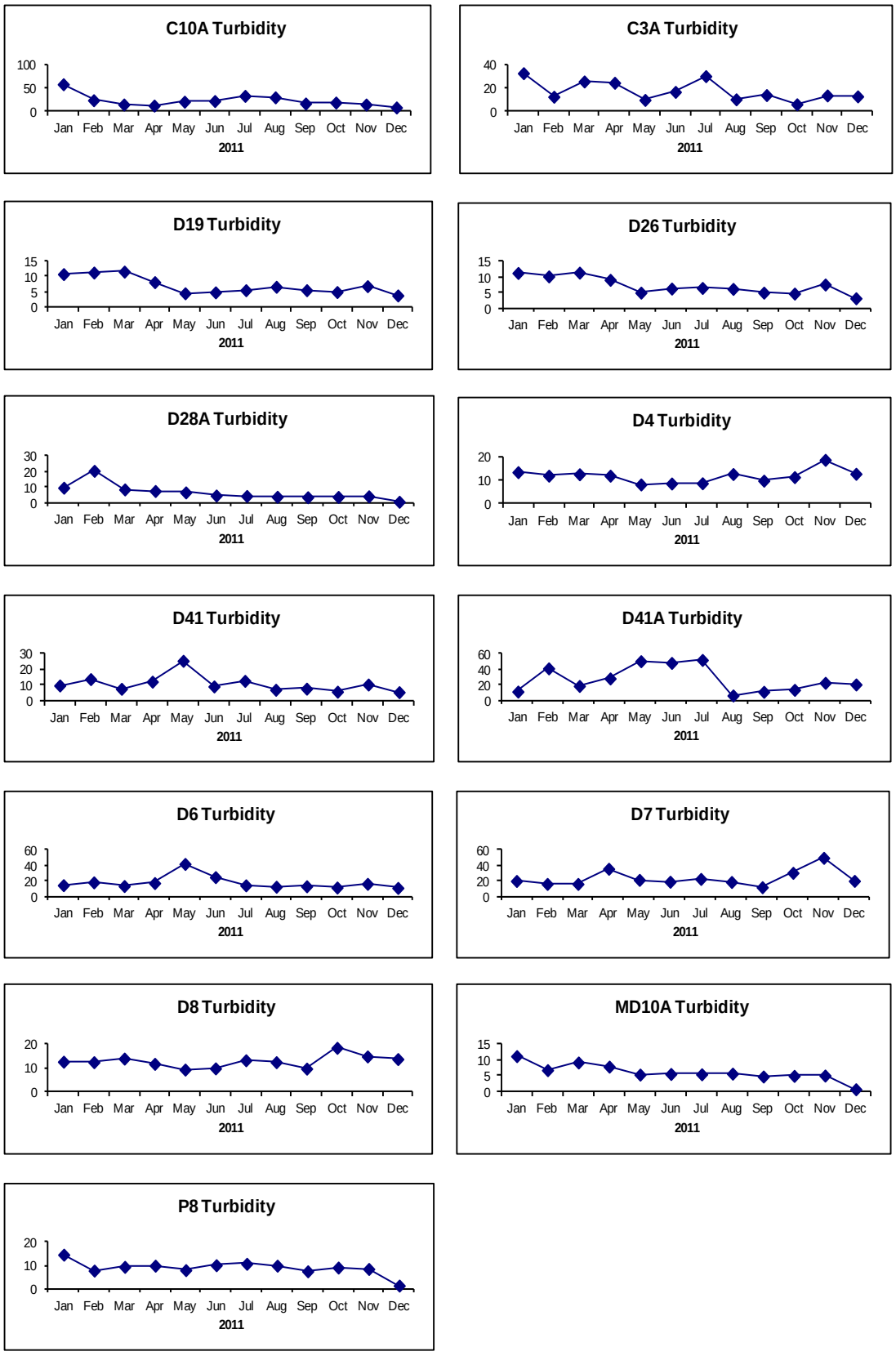

Figure 3-12 Orthophosphate comparisons, 2011

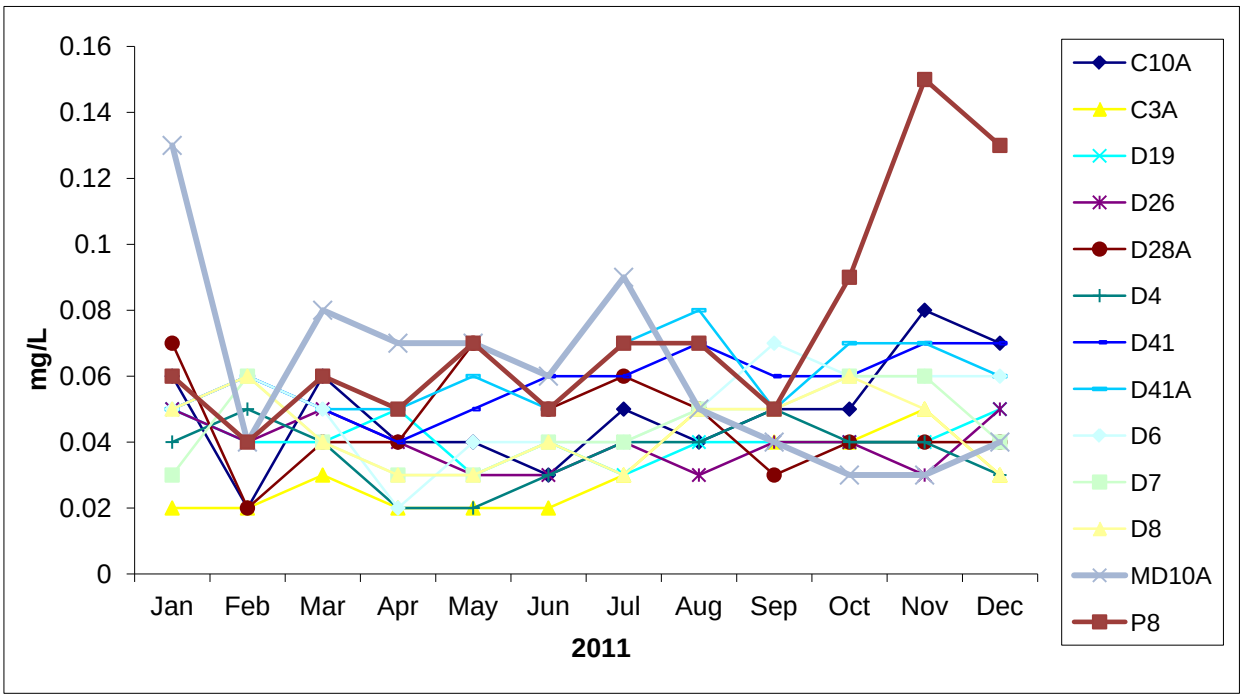

Figure 3-13 Orthophosphate by station, 2011

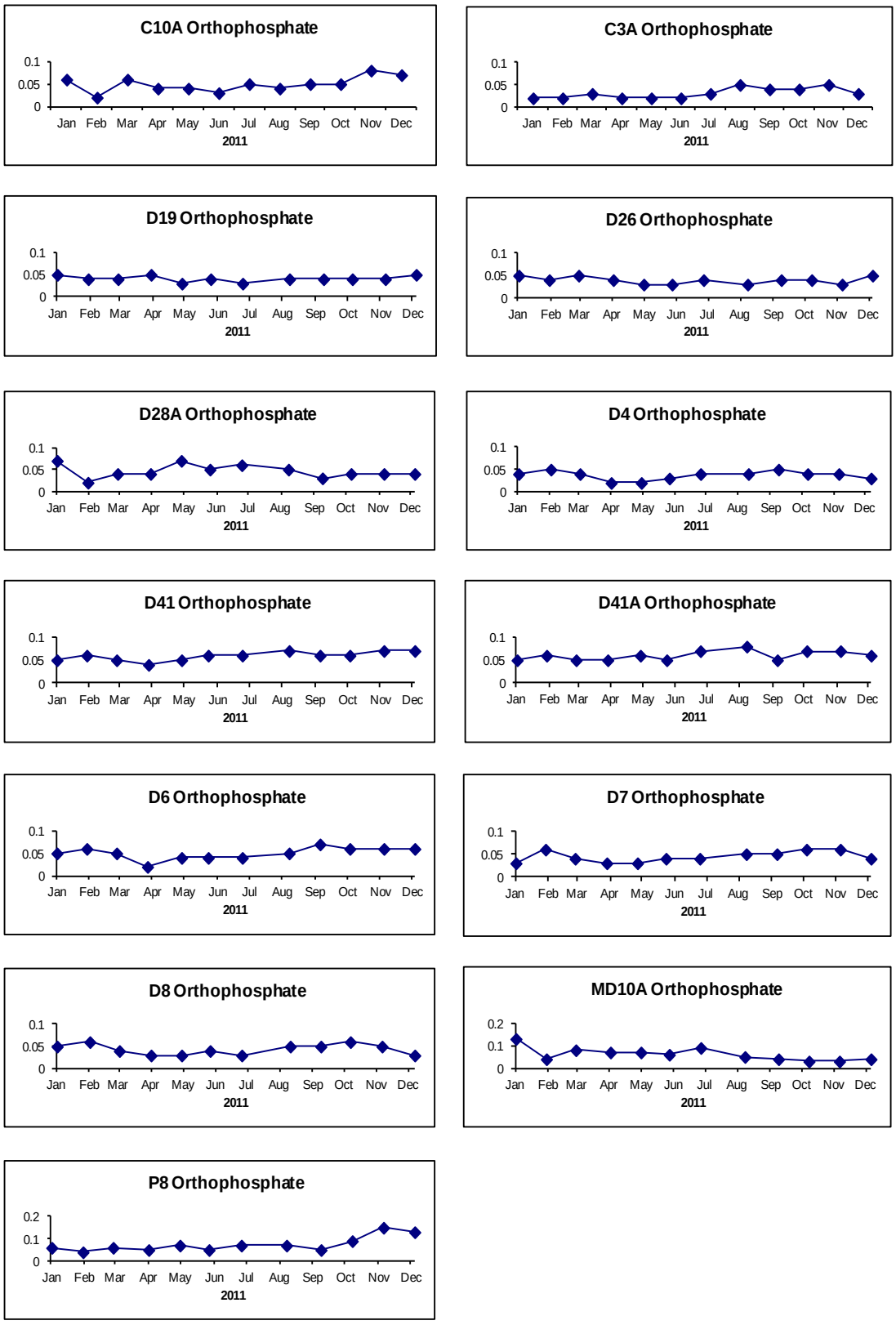

Figure 3-14 Total phosphorus comparisons, 2011

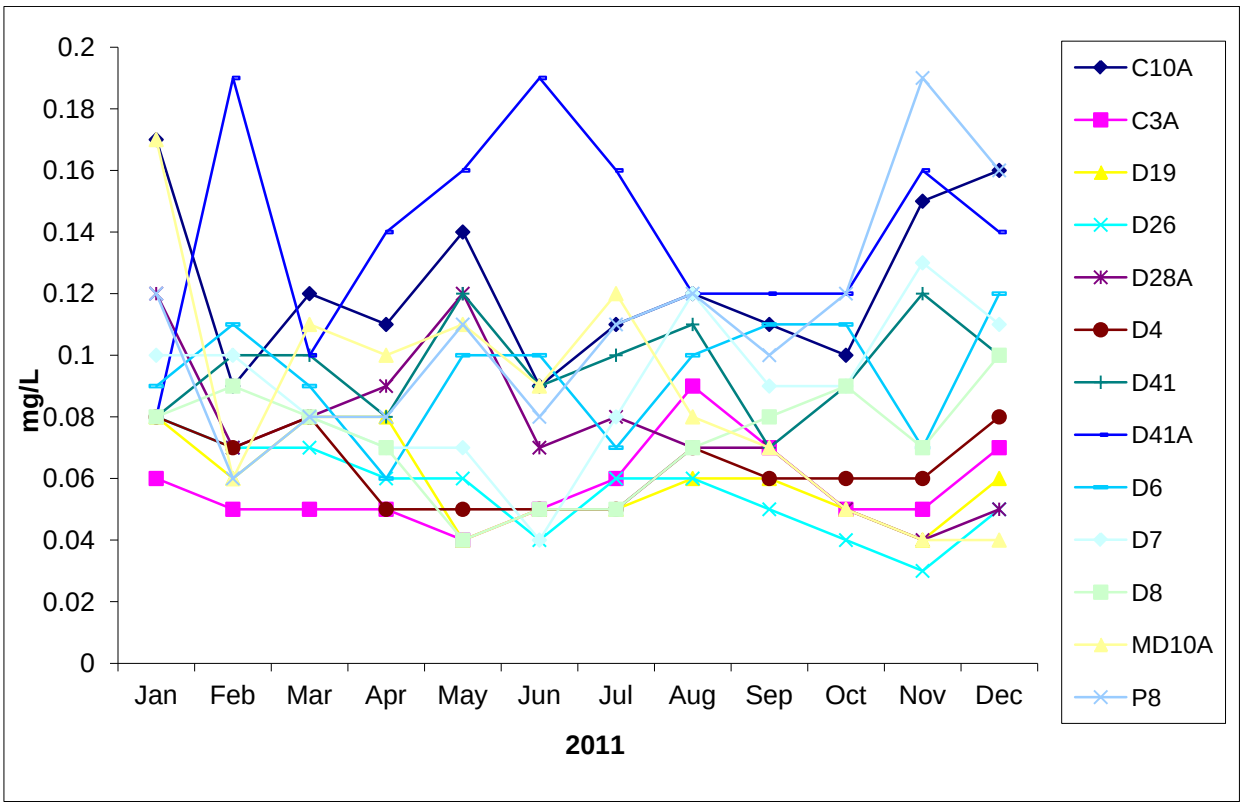

Figure 3-15 Total phosphorus by station, 2011

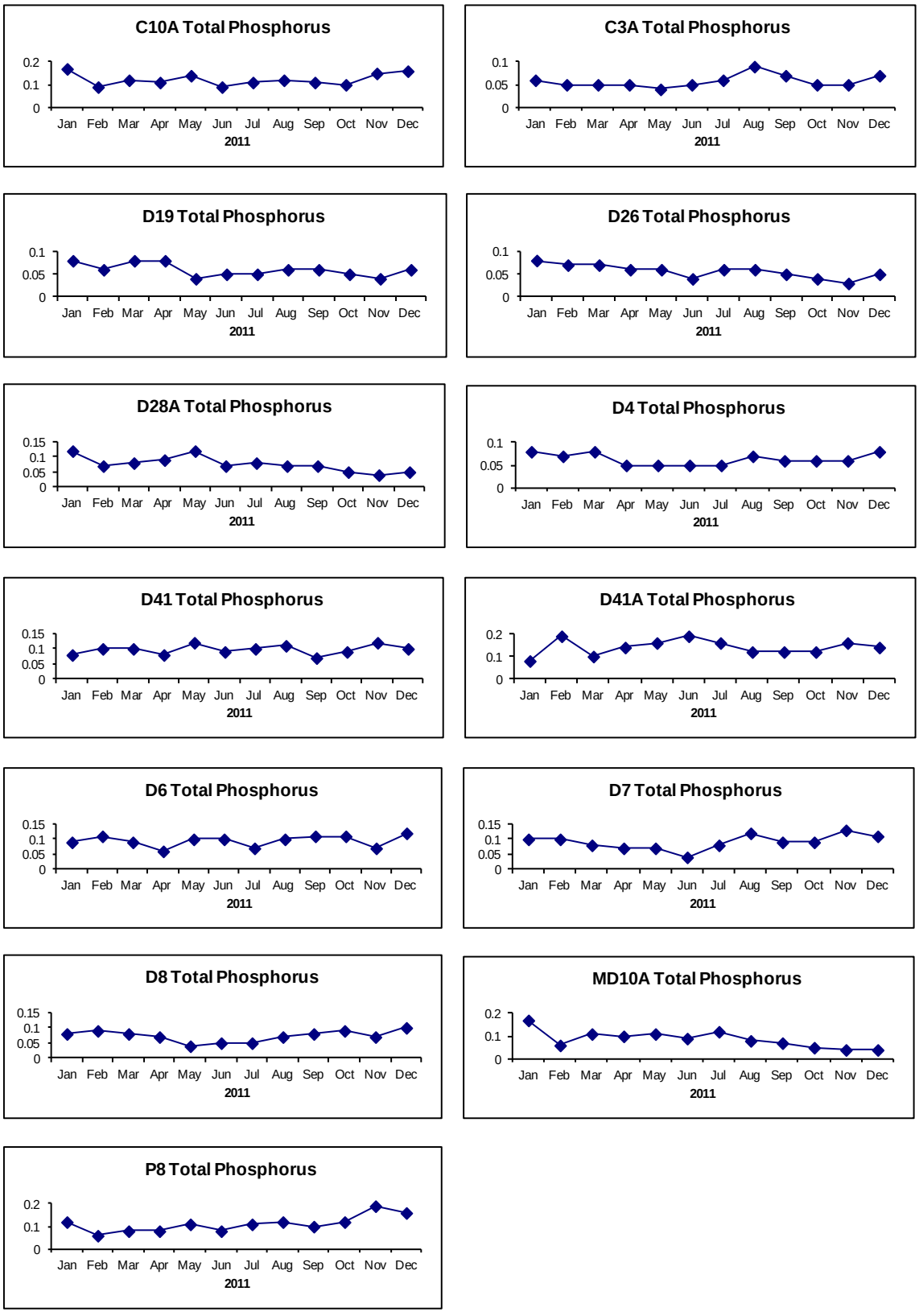

Figure 3-16 Kjeldahl nitrogen comparisons, 2011

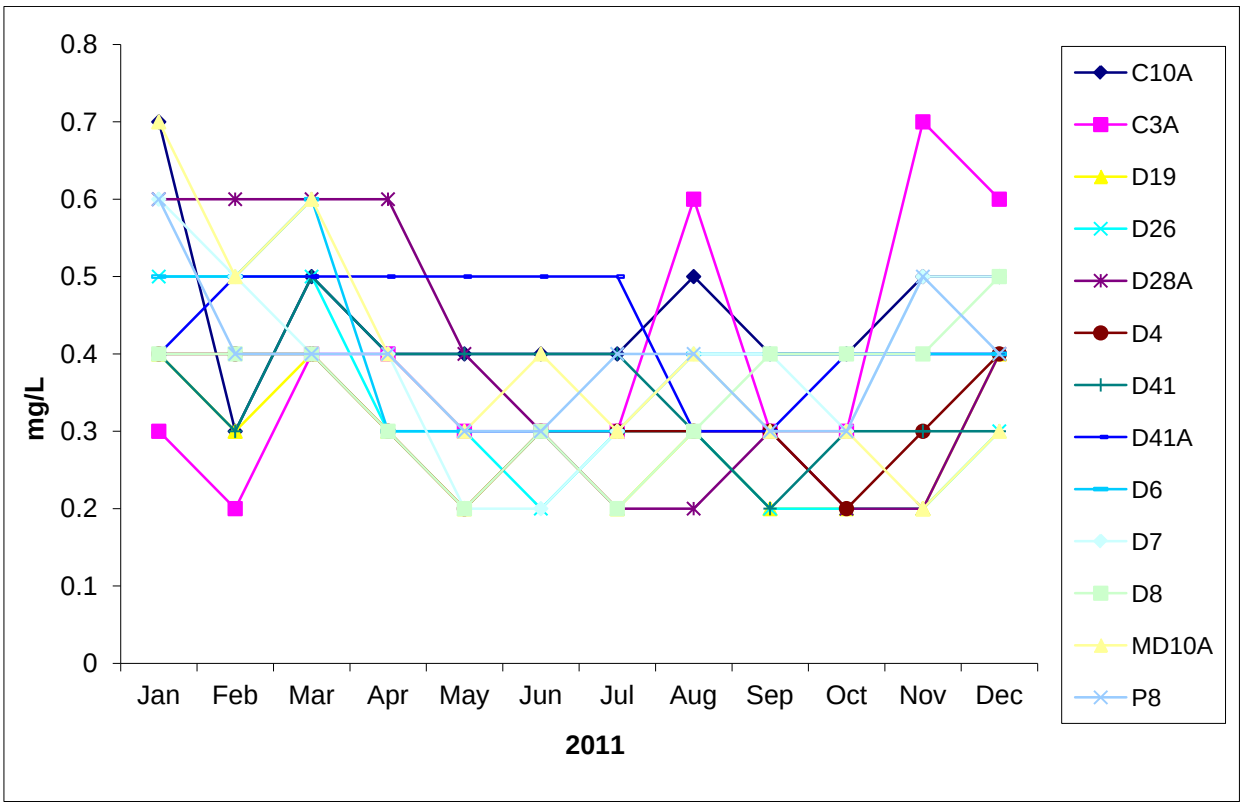

Figure 3-17 Kjeldahl nitrogen by station, 2011

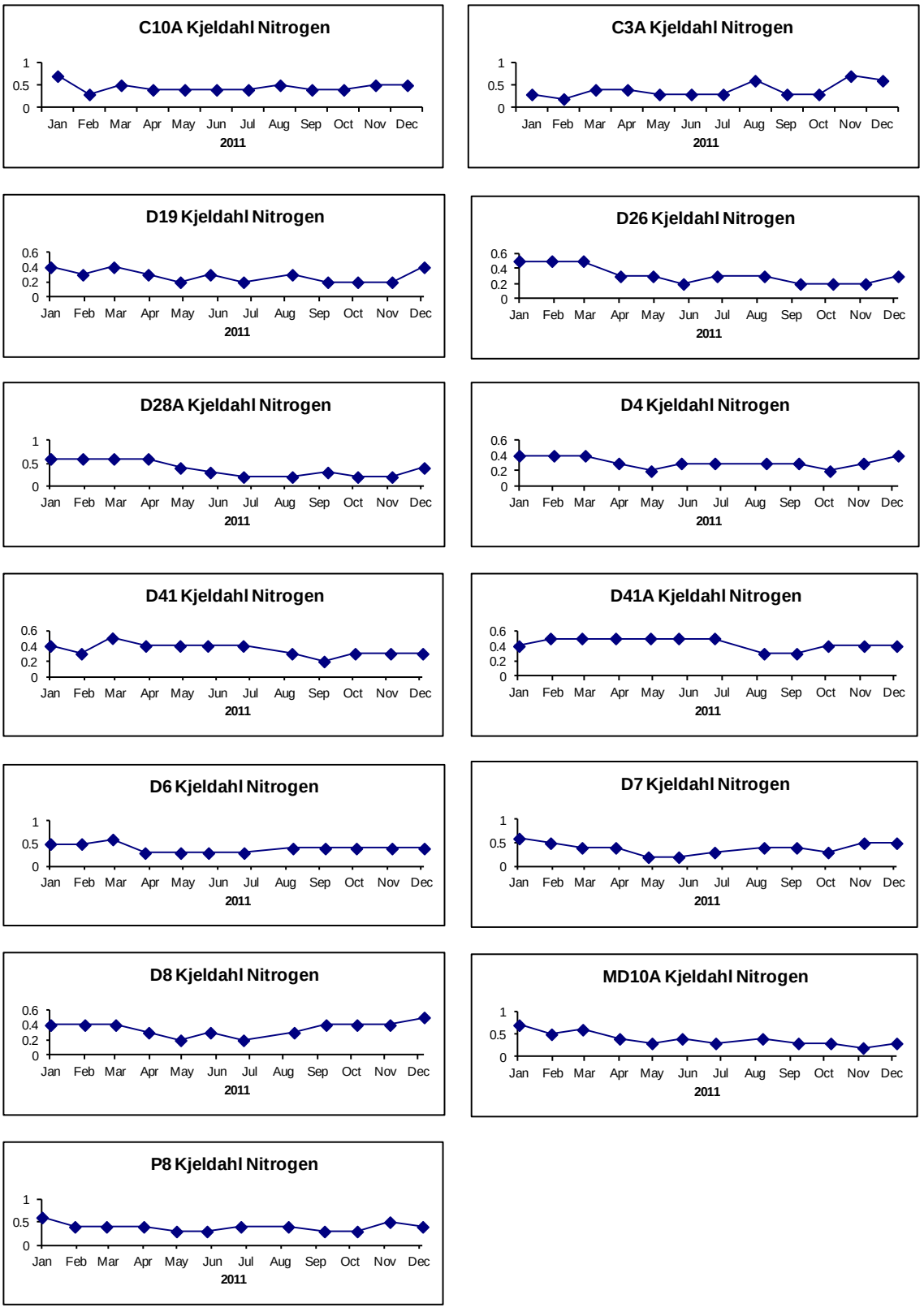

Figure 3-18 DIN comparisons, 2011

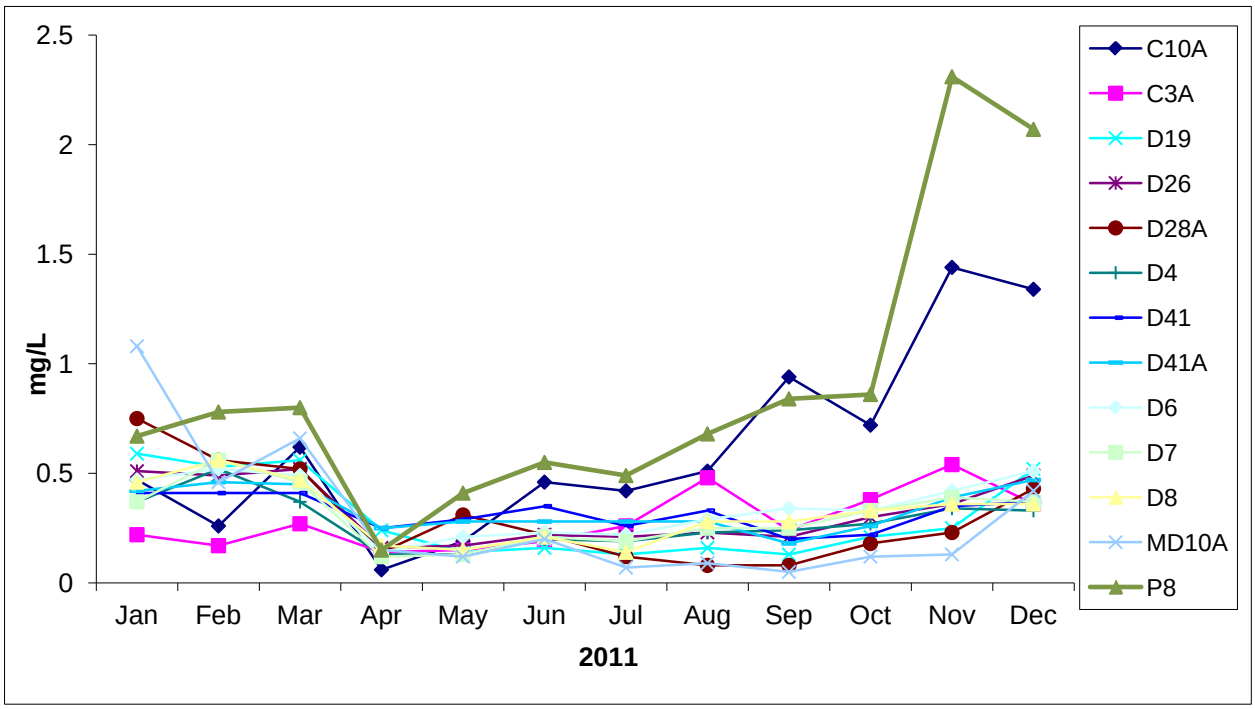

Figure 3-19 DIN by station, 2011

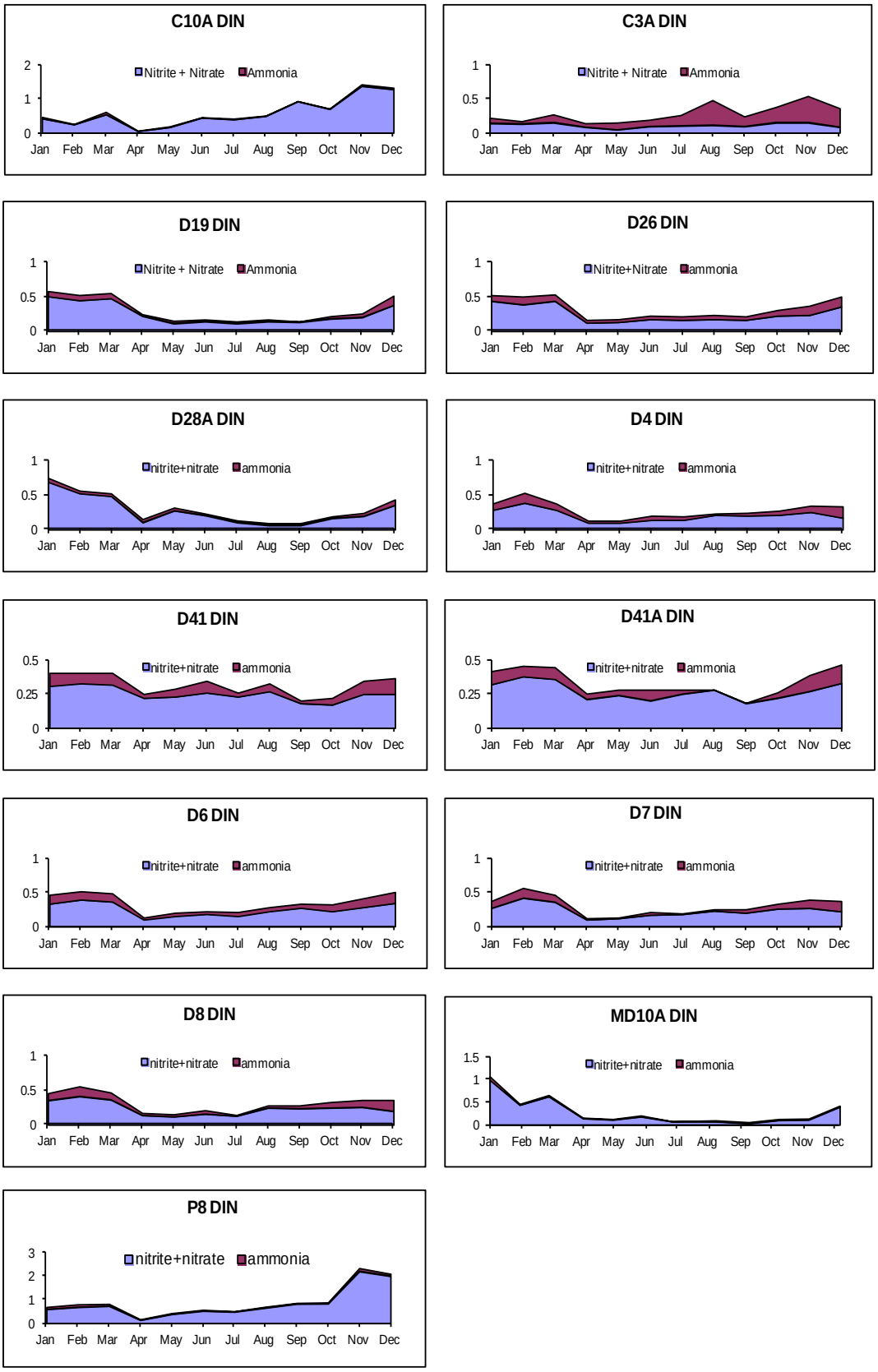

Figure 3-20 DON comparisons, 2011

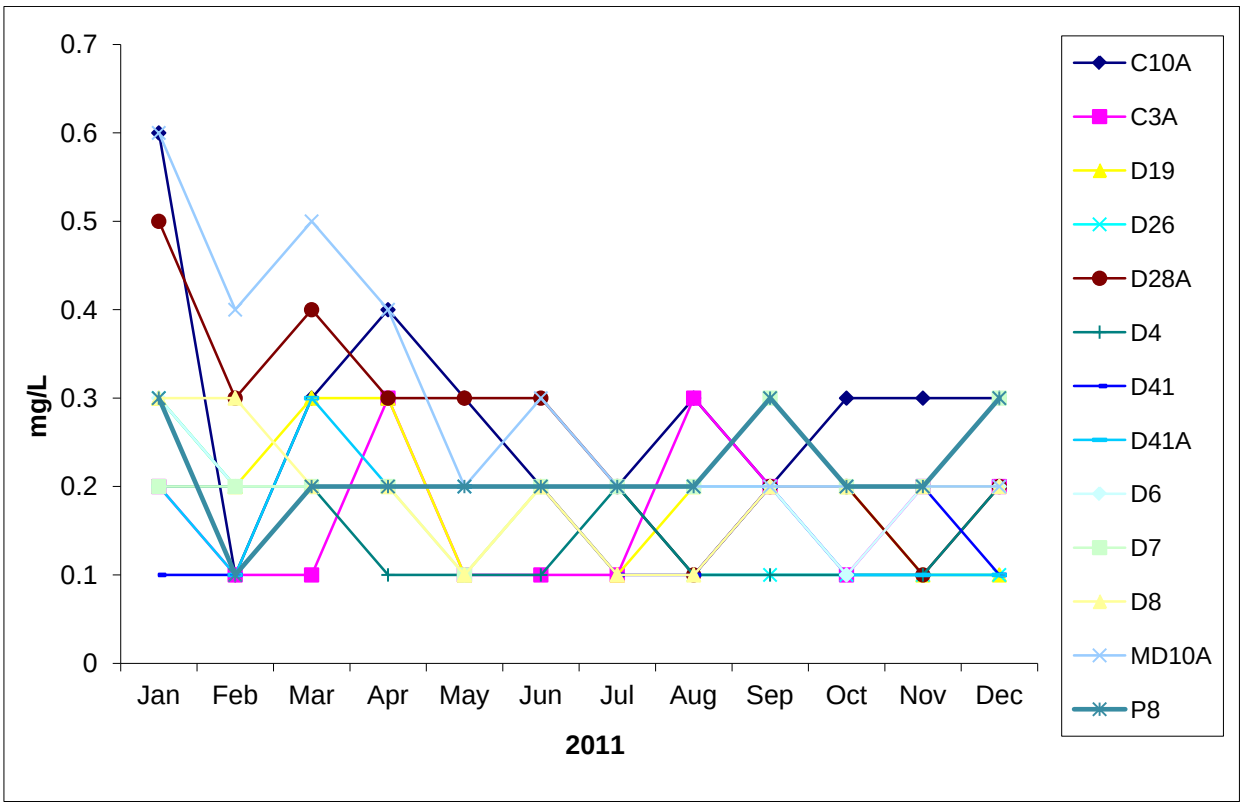

Figure 3-21 DON by station, 2011

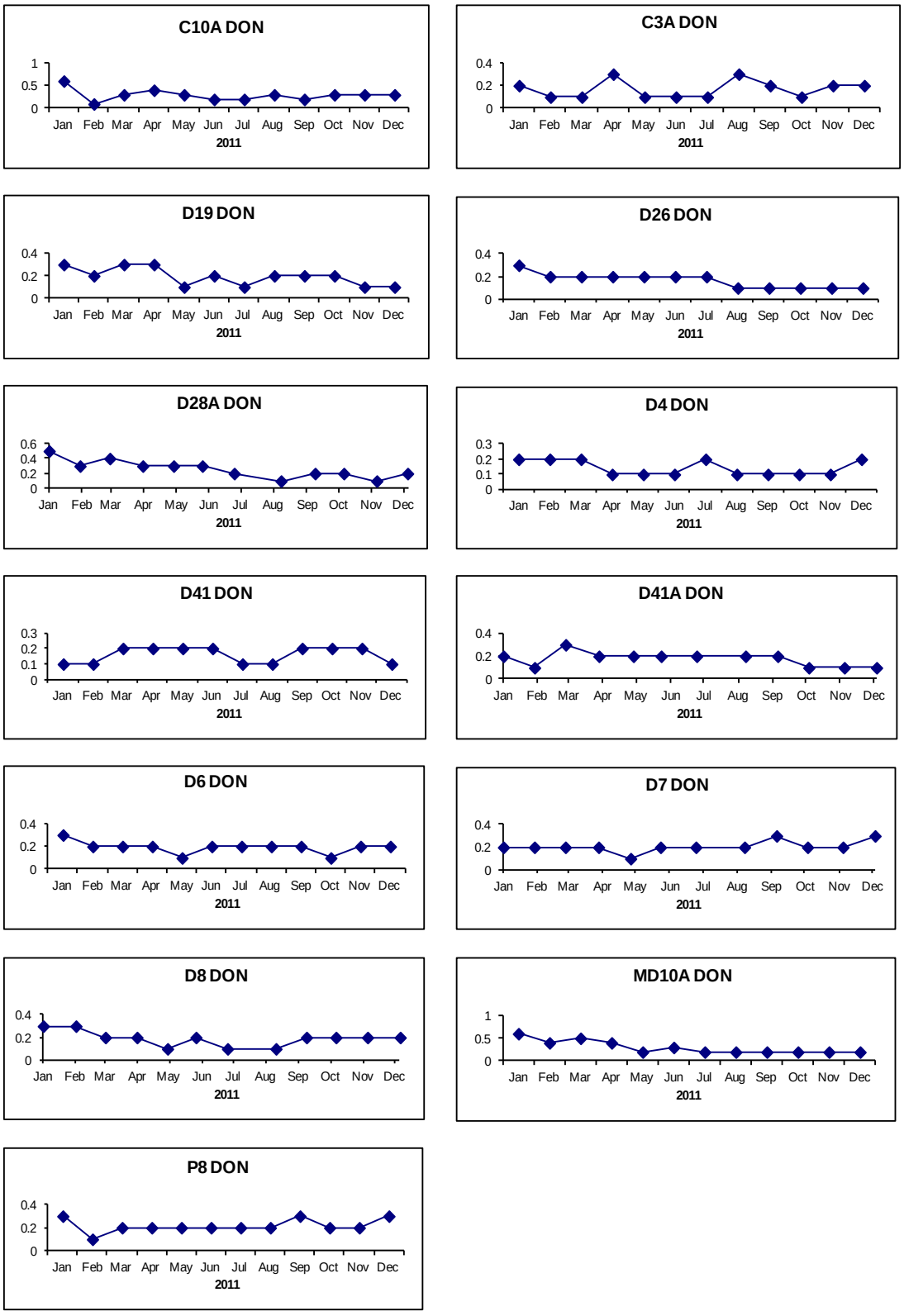

Figure 3-22 TDS comparisons, 2011

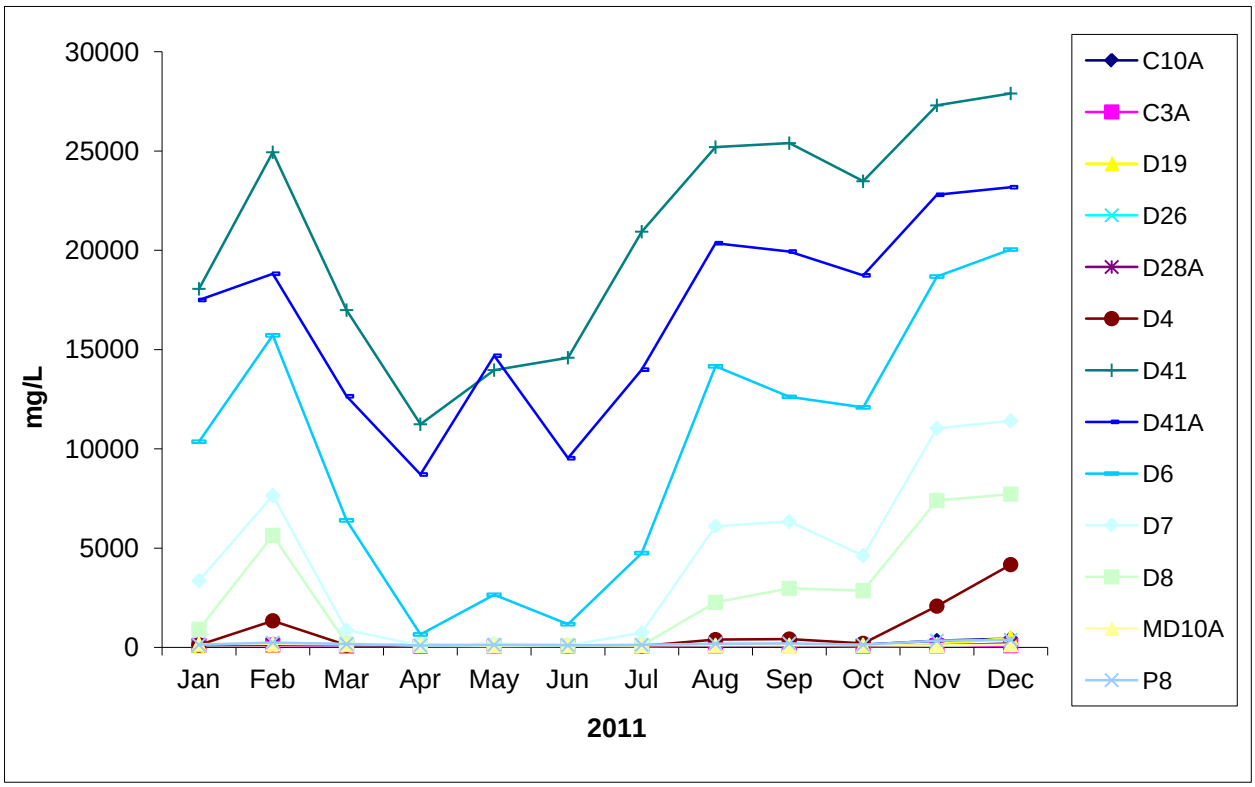

Figure 3-23 TDS by station, 2011

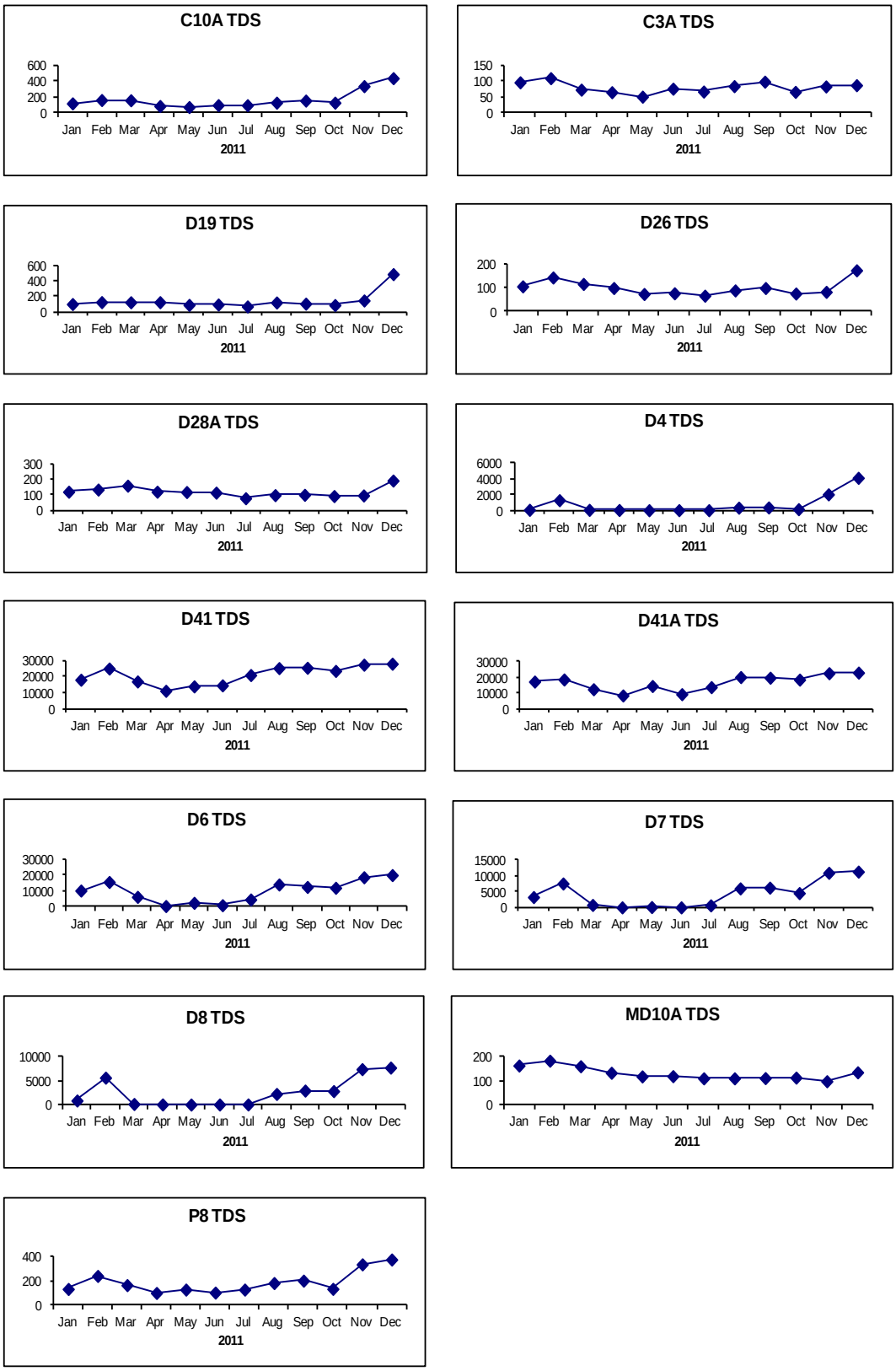

Figure 3-24 TSS comparisons, 2011

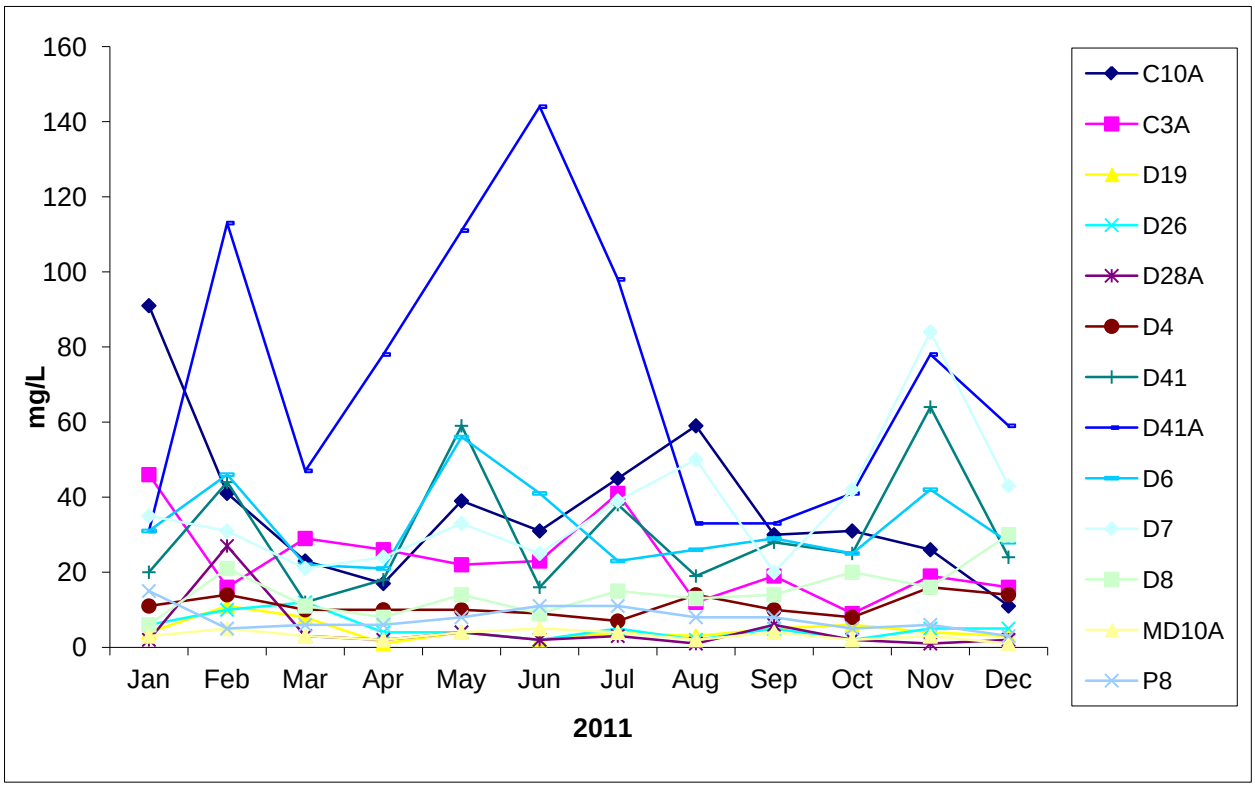

Figure 3-25 TSS by station, 2011

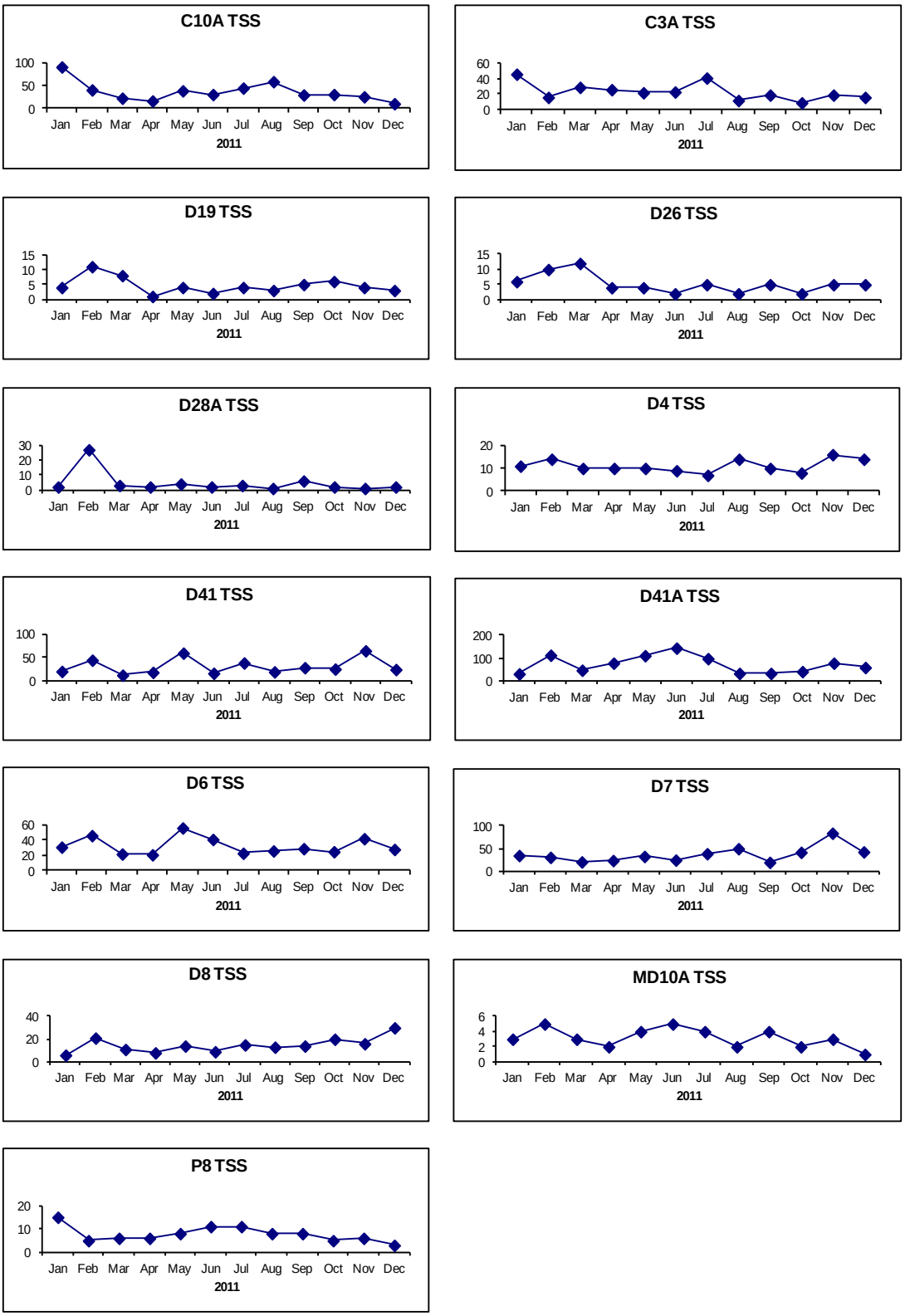

Figure 3-26 VSS comparisons, 2011

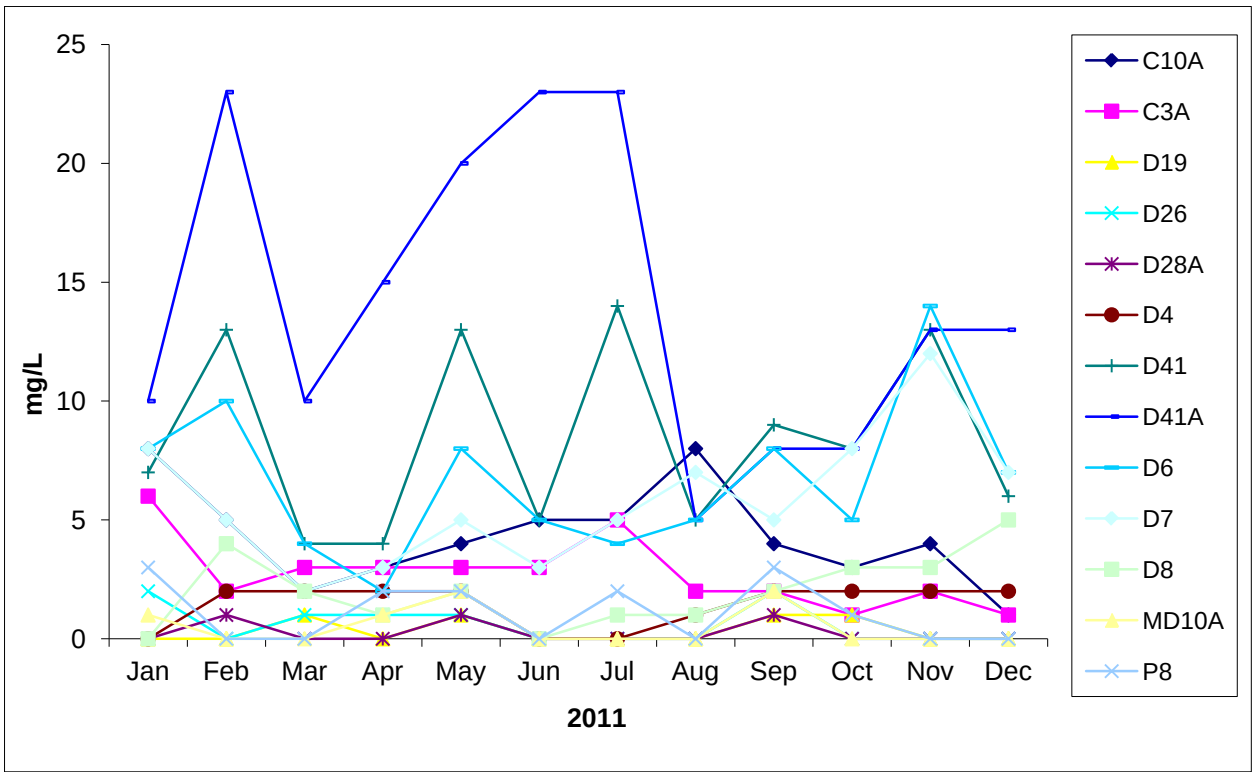

Figure 3-27 VSS by station, 2011

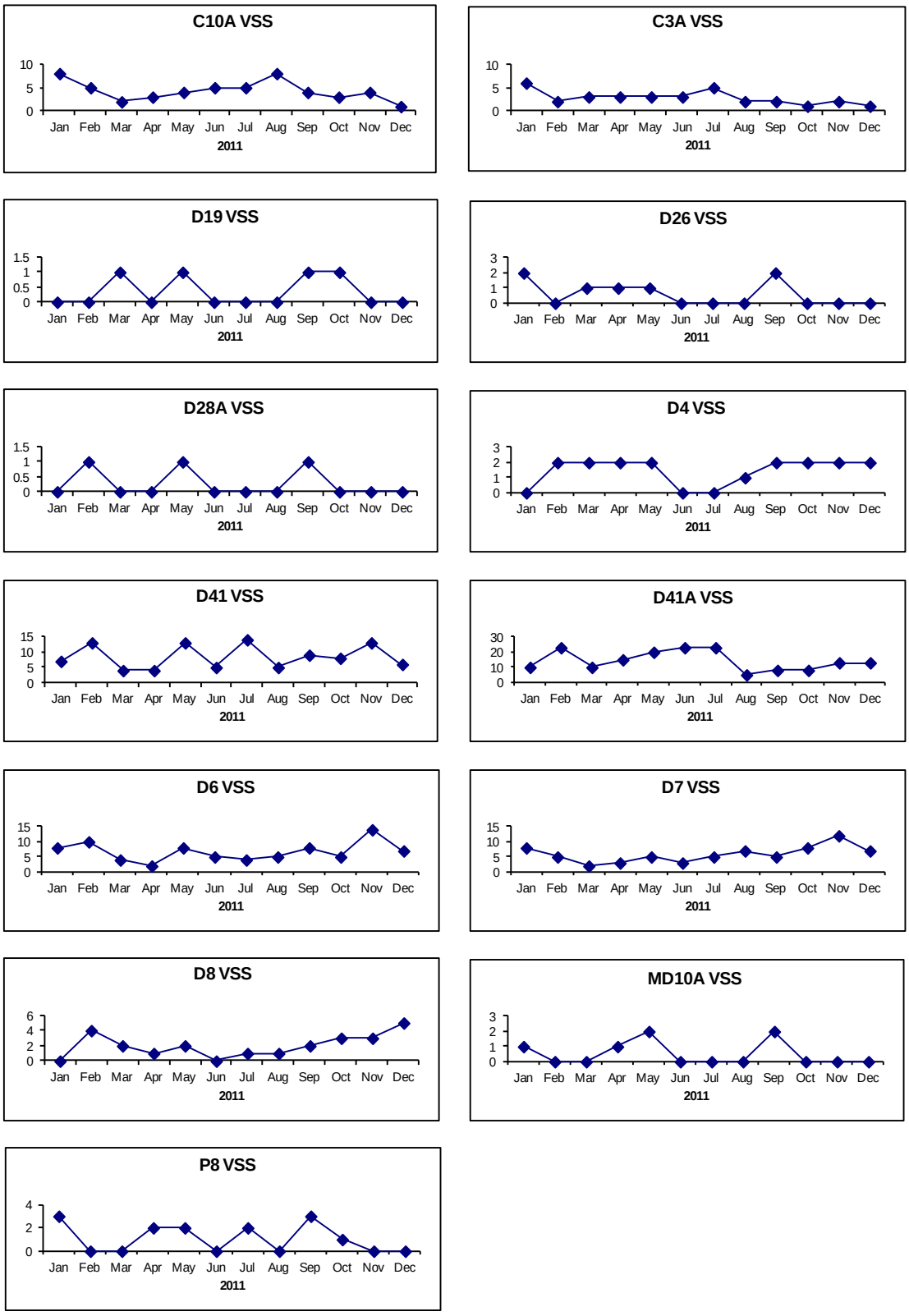

Figure 3-28 Silica comparisons, 2011

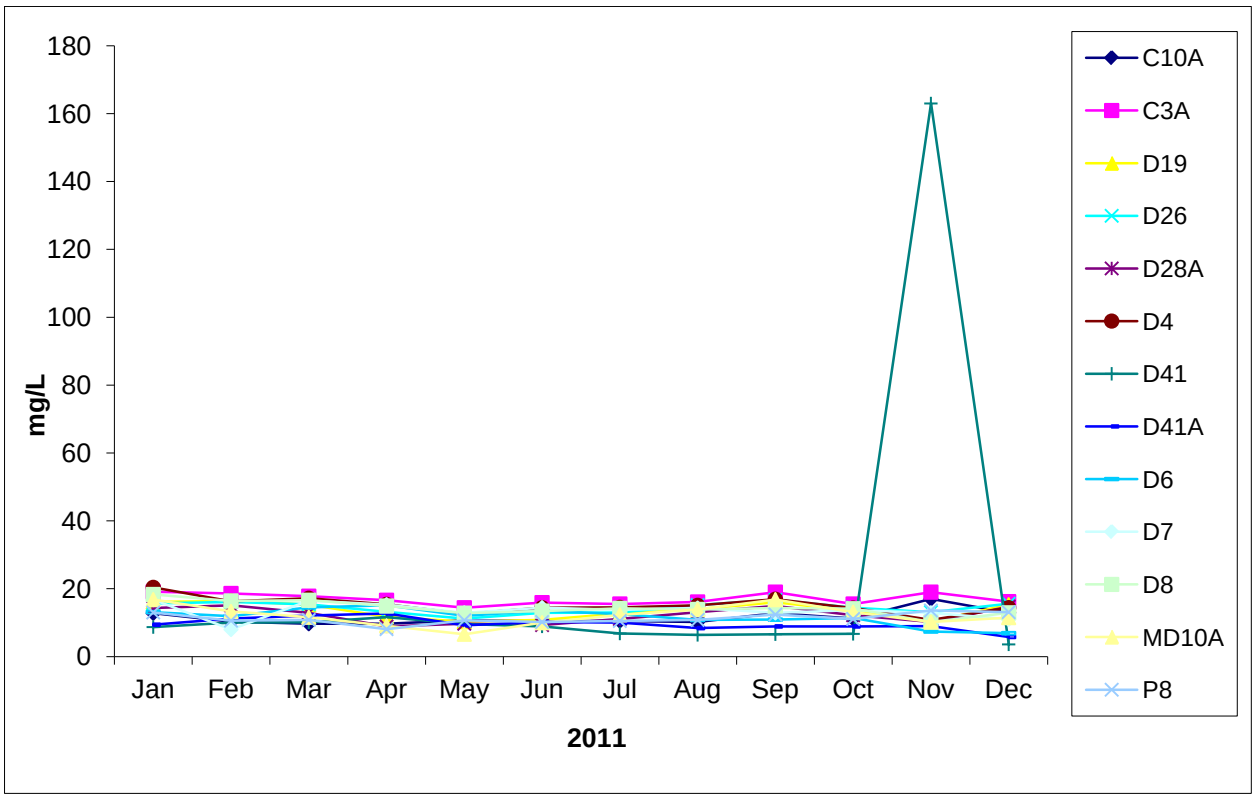

Figure 3-29 Silica by station, 2011

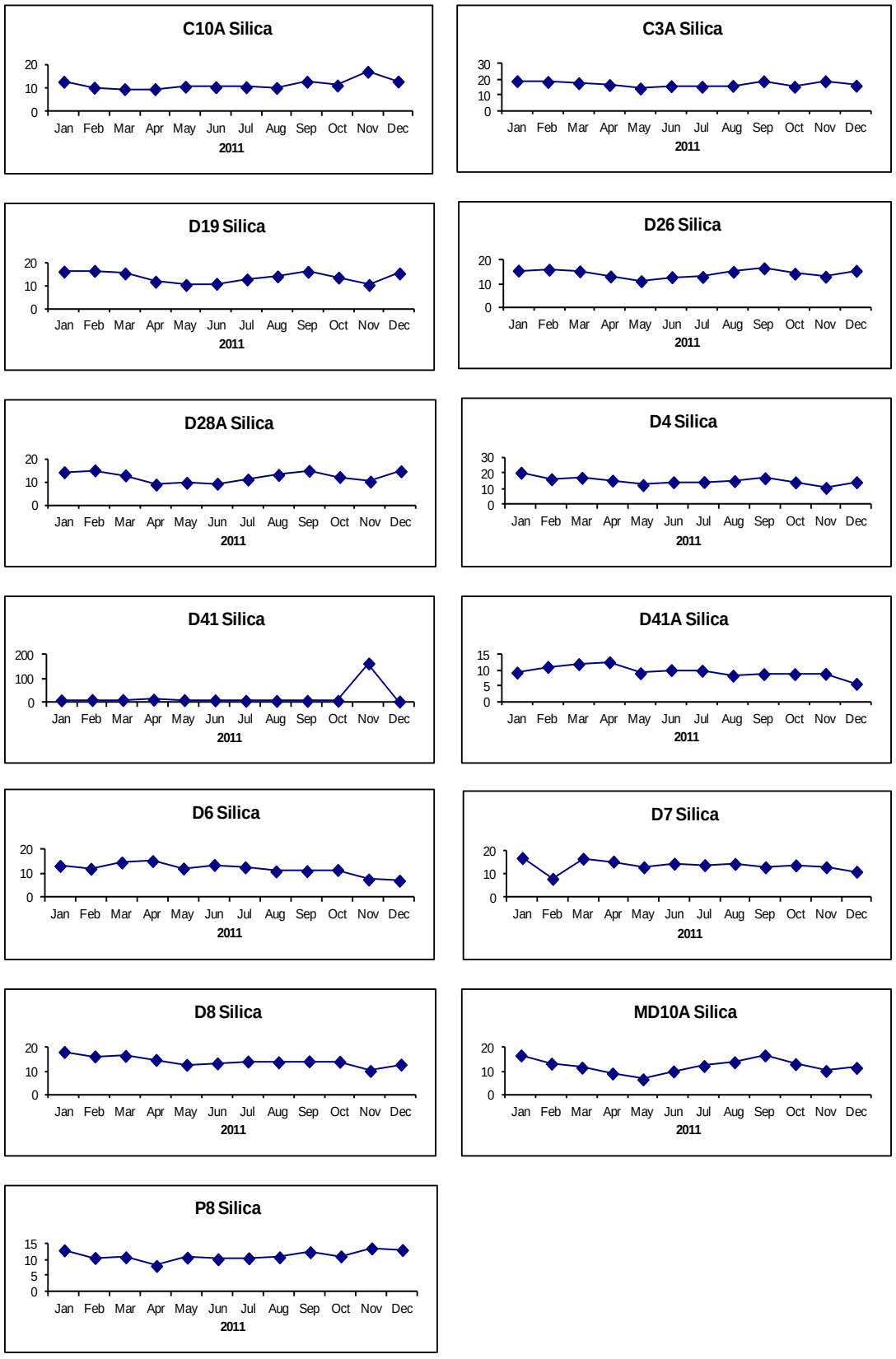

Figure 3-30 Chloride comparisons, 2011

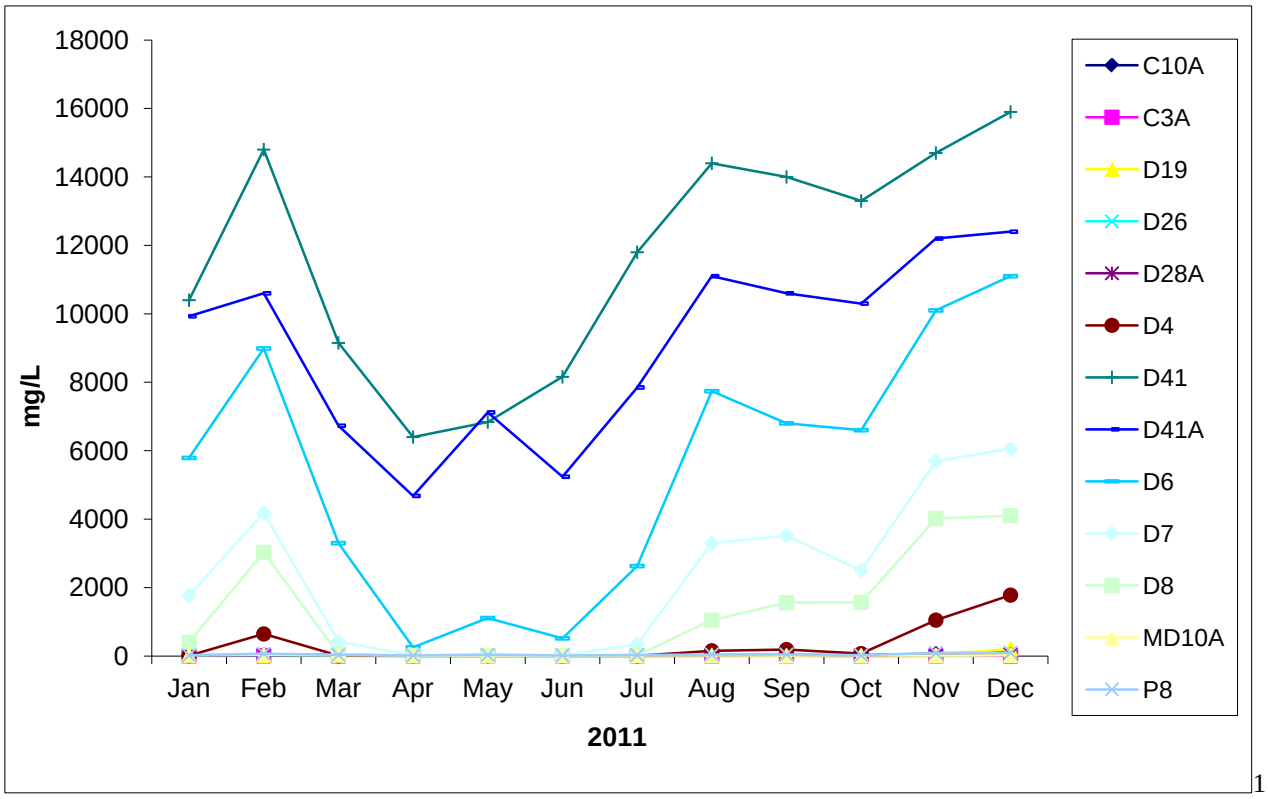

Figure 3-31 Chloride by station, 2011

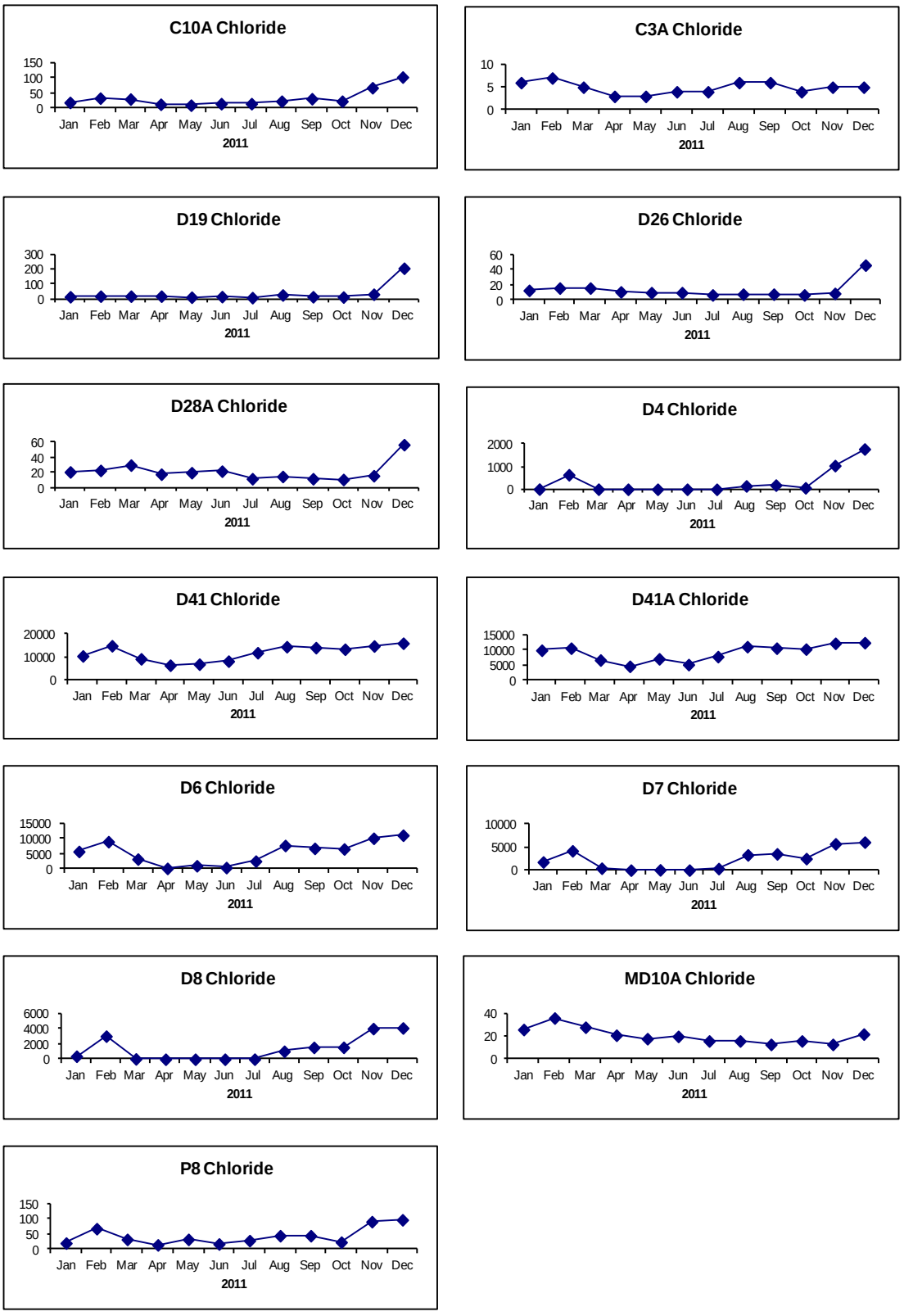

Table 3-1 Water quality parameters measured

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

Table 3-2 Water quality sampling sites and regions

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

Chapter 4 Phytoplankton and Chlorophyll *a*

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Chapter 4. Phytoplankton and Chlorophyll *a*

Introduction

The Department of Water Resources (DWR) and the U.S. 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 eastern San Pablo Bay to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats from narrow, freshwater channels in the Delta to broad, estuarine bays. This chapter describes the results of these monitoring efforts for the 2011 calendar year.

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; 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 common to all phytoplankton and 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 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, *Potamocorbula amurensis* (Alpine and Cloern 1992; Huber 2010). Well-established benthic populations of *P. amurensis* in Suisun and San Pablo bays are thought to have contrib-

uted 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 thirteen monitoring sites throughout the upper estuary (Figure 4-1). Samples were collected using a submersible pump from one meter below the water's surface. The samples were stored in 50-milliliter glass bottles with Lugol's solution 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.[10] 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 ten most common genera were determined by summing the number of organisms per milliliter across all stations and months for each genus.

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

Chlorophyll *a*

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

Results

Phytoplankton Identification

Cyanobacteria, centric diatoms, pennate diatoms, cryptomonads, and haptophytes constituted 99.4% of the organisms collected of the twelve groups identified. (Figure 4-2. Other Taxa is the sum of the last seven groups, as they are too rare to appear individually on the graph).

All organisms collected in 2011 fell into these twelve categories:

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

Table 4-1 lists the genera found in each group in the upper estuary. The ten most common genera collected in 2011 were:

- *Anabaena* (cyanobacterium; class Cyanophyceae)
- *Aphanizomenon* (cyanobacterium; class Cyanophyceae)
- *Cyclotella* (centric diatom; class Coscinodiscophyceae)
- *Fragilaria* (pennate diatom; class Fragilariophyceae)
- *Chroomonas* (cryptomonad flagellate; class Cryptophyceae)
- *Aulacoseira* (centric diatom; class Coscinodiscophyceae)
- *Cocconeis* (pennate diatom; class Bacillariophyceae)
- *Cryptomonas* (cryptomonad flagellate; class Cryptophyceae)

- *Pseudanabaena* (cyanobacterium; class Cyanophyceae)
- *Melosira* (centric diatom; class Coscinodiscophyceae)

A list of all phytoplankton genera identified, their shape codes, and the total number counted can be found in the Phytoplankton Dictionary available online at: http://www.water.ca.gov/bdma/meta/phytoplankton.cfm.

Pigment Concentrations

Some, but not all, stations showed seasonal patterns in chlorophyll *a* concentration. Most maxima occurred in spring and summer while minima occurred in fall or winter. (Table 4-2 and Figures 4-3a through 4-15a; note the different scales for each graph, and secondary Y-axis on some graphs).

Monthly chlorophyll *a* concentrations throughout much of the estuary were relatively low. Of the 156 samples taken in 2011, 98.1% (153 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 three samples with chlorophyll *a* concentrations above 10 µg/L, all were from two stations in the south Delta during summer (P8 in July and C10A in July and August). The mean chlorophyll *a* concentration for all samples in 2011 was 3.22 µg/L; the median value was 2.26 µg/L. The maximum chlorophyll *a* concentration in 2011 was 18.20 µg/L, recorded in July in the south Delta (P8). Chlorophyll *a* maxima were recorded in spring and summer for most stations; exceptions were MD10A (east Delta), which had its maximum value in winter, and D26 (lower San Joaquin River), D41 (San Pablo Bay), D19 and D28A (central Delta), where maxima occurred in fall. The minimum chlorophyll *a* concentration was 0.35 µg/L, recorded in January in the central Delta (D28A). All chlorophyll *a* minima were recorded 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 4-3a through 4-15a). The mean pheophytin *a* concentration for all samples in 2011 was 1.30 µg/L, and the median value was 0.99 µg/L. The maximum pheophytin *a* concentration was 7.24 µg/L, recorded at C10A (south Delta) in August. Pheophytin *a* maxima were recorded in spring and summer at most stations. Exceptions were MD10A (east Delta) and D28A (central Delta) which had maxima in winter, as well as D19 (central Delta) and D4 (lower Sacramento River) where maxima occurred in fall. The minimum pheophytin *a* concentration was 0.16 µg/L, recorded at D7 (Suisun Bay) in December. Pheophytin *a* minima were recorded in fall and winter at all stations except D41 (San Pablo Bay) where the minimum occurred in August.

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*, pheophytin *a* analysis and phytoplankton composition at each station. For the phytoplankton composition graphs, very rare taxa have been categorized 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.water.ca.gov/bdma/meta/.

Site C3A: North Delta

There was a slight seasonal pattern in chlorophyll *a* with higher values in spring and summer. The highest concentration was recorded in April (6.15 µg/L), and the lowest was recorded in October (1.30 µg/L) (Figure 4-3a; Table 4-2). The mean and median were similar (2.70 µg/L and 2.32 µg/L, respectively).

Pheophytin *a* did not show a seasonal pattern; values were low (less than 3 µg/L) and stable throughout the year (Figure 4-3a). The maximum (2.19 µg/L) was recorded in March, and the minimum (0.90 µg/L) was recorded in October (Table 4-2). Like chlorophyll *a*, the mean and median were similar (1.53 µg/L and 1.38 µg/L, respectively).

Pennate diatoms dominated most of the year with extremely large blooms in January and November (Figure 4-3b; Other Taxa are green algae, chrysophytes, euglenoids, little green algal balls, and dinoflagellates).

Site C10A: South Delta

The maximum chlorophyll *a* concentration for this station was recorded in August (17.70 µg/L); the minimum was in January (2.38 µg/L) (Figure 4-4a; Table 4-2). The peak in chlorophyll *a* in August skewed the mean (6.84 µg/L) higher than the median (5.56 µg/L). Chlorophyll *a* still showed a slight seasonal pattern despite this peak (Figure 4-4a).

The largest pheophytin *a* value for the year was recorded at this station in August (7.24 µg/L) (Figure 4-4a; Table 4-2). The minimum occurred in December (1.73 µg/L). The August peak skewed the mean (3.12 µg/L) higher than the median (2.52µg/L) (Table 4-2). Pheophytin *a* showed some seasonality (Figure 4-4a).

Pennate diatoms were common throughout the year with peaks in January and December. The December peak was dwarfed by extremely high numbers of cyanobacteria and centric diatoms (Figure 4-4b; note the secondary Y-axis for cyanobacteria and centric diatoms. Other Taxa are green algae, euglenoids, chrysophytes, 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 for this station (and the year) was recorded in July (18.20 µg/L), and the minimum in December (0.44 µg/L) (Table 4-2). The mean (5.20 µg/L) was higher than the median (4.72 µg/L).

Pheophytin *a* showed a slight seasonal pattern (Figure 4-5a). The mean and median were similar (1.57 and 1.49 µg/L, respectively) (Table 4-2). The maximum was 3.52µg/L in July, and the minimum was 0.44 µg/L in December.

Peaks of centric diatoms occurred in March and July; the July peak was accompanied by a peak of cyanobacteria (Figure 4-5b; Other Taxa are euglenoids, little green algal balls, and chrysophytes). Small peaks of cryptomonads occurred in the fall months.

Site MD10A: East Delta

Chlorophyll *a* did not show a significant seasonal pattern; peaks occurred throughout the year (Figure 4-6a). The maximum (9.29 µg/L) occurred in February (Table 4-2), and the minimum was recorded in January (0.63 µg/L). The mean (3.98 µg/L) was slightly higher than the median (3.60 µg/L).

Pheophytin *a* levels were similar to chlorophyll *a*, with no clear seasonal pattern (Figure 4-6a). The maximum of 3.04 µg/L occurred in February (Table 4-2). The minimum was recorded in January (0.36 µg/L). The mean and median were similar (1.37 µg/L and 1.11 µg/L, respectively).

A large bloom of centric diatoms occurred in February, followed by smaller peaks the rest of the year (Figure 4-6b; Other Taxa are green algae, chrysophytes, dinoflagellates, little green algal balls, and euglenoids). A bloom of cryptomonads occurred in December.

Site D26: Lower San Joaquin River

Chlorophyll *a* values did not show a seasonal pattern; the highest peaks were in fall (Figure 4-7a). The maximum was 4.12 µg/L in November, and the minimum was 0.64 µg/L in January (Table 4-2). The mean and median were similar (1.64 µg/L and 1.33 µg/L, respectively).

Pheophytin *a* values were extremely low (less than 2 µg/L) all year (Figure 4-7a). The maximum was 1.22 µg/L in April, and the minimum was 0.26 µg/L in January (Table 4-2). The mean and median were nearly identical (0.68 µg/L and 0.64 µg/L, respectively).

There was an extremely large bloom of cyanobacteria in September, followed by a bloom of centric diatoms in November (Figure 4-7b; note the secondary Y-axis for cyanobacteria. Other Taxa are little green algal balls, euglenoids, and dinoflagellates).

Site D19: Central Delta

Chlorophyll *a* concentrations did not show a strong seasonal pattern (Figure 4-8a). The maximum of 5.08 µg/L occurred in September; the minimum was 0.56 µg/L in January (Table 4-2). The peak in September skewed the mean higher than the median (2.00 and 1.72, respectively).

Pheophytin *a* concentrations also did not show a seasonal pattern, with all values below 2 µg/L (Figure 4-8a). The maximum was recorded in November (1.86 µg/L), and the minimum was recorded in January (0.30 µg/L) (Table 4-2). The mean and median were very close (1.01 µg/L and 0.97 µg/L, respectively).

An extremely large bloom of cyanobacteria occurred in May, accompanied by a smaller bloom of cryptomonads (Figure 4-8b; note the secondary Y-axis for cyanobacteria. Other Taxa are green algae, little green algal balls, and euglenoids). A small bloom of pennate and centric diatoms occurred in November, followed by a cryptomonad bloom in December.

Site D28A: Central Delta

Chlorophyll *a* did not show a seasonal pattern; the peak in September was the maximum for this station (4.24 µg/L) (Figure 4-9; Table 4-2). Values were below 4 µg/L the rest of the year. The minimum of 0.35 µg/L was recorded in January and was the lowest recorded value for the year. The mean (1.68µg/L) was slightly higher than the median (1.48 µg/L).

Pheophytin *a* values were low all year with most values below 2 µg/L (Figure 4-9a). The maximum of 4.82 µg/L was recorded in February, and skewed the mean (1.18 µg/L) higher than the median (0.87 µg/L) (Table 4-2). The minimum of 0.42 µg/L was recorded in January.

A very large bloom of cyanobacteria in September was followed by a bloom of cryptomonads and pennate diatoms in December (Figure 4-9b; note the secondary Y-axis for cyanobacteria. Other Taxa are centric diatoms, little green algal balls, and euglenoids).

Site D4: Lower Sacramento River

Chlorophyll *a* showed a slight seasonal pattern with peaks in spring and summer and declines in winter (Figure 4-10a). The maximum was 5.16 µg/L in August; the minimum was 0.59 µg/L in December (Table 4-2). The mean was lower than the median (2.79 µg/L and 3.18 µg/L, respectively).

Pheophytin *a* did not show a seasonal pattern; values were low (less than 3 µg/L) all year (Figure 4-10a). The maximum (2.13 µg/L) was recorded in November; the minimum (0.43 µg/L) was recorded in January (Table 4-2). The mean was 0.98 µg/L; the median 0.85 µg/L.

A very large cyanobacterial bloom occurred in September (Figure 4-10b; note the secondary Y-axis for cyanobacteria. Other Taxa are cryptomonads, green algae, euglenoids, ciliates, chrysophytes, little green algal balls, and dinoflagellates). Pennate and centric diatoms were present throughout the year with a peak in pennate diatoms in January and a peak in centric diatoms in November.

Site D6: Suisun Bay

Chlorophyll *a* showed a seasonal pattern. The maximum was 5.87 µg/L in June; the minimum was 0.95 µg/L in January (Table 4-2). The mean (2.83 µg/L) was slightly higher than the median (2.51 µg/L).

Pheophytin *a* also showed a slight seasonal pattern; the maximum was recorded in May (2.50 µg/L) and the minimum was recorded in October (0.49 µg/L) (Figure 4-11a; Table 4-2). The mean was higher than the median (1.02 µg/L and 0.80 µg/L, respectively).

There were peaks of pennate and centric diatoms in January and April, followed by smaller peaks of centric diatoms and a dinoflagellate peak in September (Figure 4-11b; Other Taxa are little green balls and green algae). Despite these peaks, phytoplankton densities were extremely low (less than 150 organisms per mL) throughout the year.

Site D7: Suisun Bay

Chlorophyll *a* showed a strong seasonal pattern with higher values in spring and summer. The maximum was 9.29 µg/L in May, and the minimum was 0.50 µg/L in January (Figure 4-12a; Table 4-2). The high values in spring and summer skewed the mean (3.25 µg/L) much higher than the median (1.58 µg/L).

Pheophytin *a* did not show a seasonal pattern; values were low (less than 3 µg/L) all year (Figure 4-12a; Table 4-2). The maximum was 2.37 µg/L in May; the minimum (0.16 µg/L) was recorded in December and was the lowest value for the year (Table 4-2). The mean and median were similar (1.29 µg/L and 1.35 µg/L, respectively).

There was a peak of pennate diatoms, centric diatoms, and cryptomonads in April (Figure 4-12b; Other Taxa are ciliates, euglenoids, green algae, little green algal balls, and dinoflagellates). Phytoplankton densities were low (less than 200 organisms per mL) most of the year.

Site D8: Suisun Bay

Chlorophyll *a* showed a strong seasonal pattern; the maximum of 5.06 µg/L was recorded in April, and the minimum was 0.56 µg/L in January (Figure 4-13a; Table 4-2). The mean (2.28 µg/L) was similar to the median (2.17 µg/L).

Pheophytin *a* showed a slight seasonal pattern, though overall values were low (less than 2 µg/L) (Figure 4-13a). The maximum (1.52 µg/L) was recorded in July; the minimum (0.28 µg/L) was recorded in January (Table 4-2). The mean and median were similar (0.82 µg/L and 0.71 µg/L, respectively).

Peaks of pennate diatoms, centric diatoms, and cryptomonads occurred in spring, followed by a very large bloom of cyanobacteria in September (Figure 4-13b; note the secondary Y-axis for cyanobacteria. Other Taxa are ciliates, green algae, little green algal balls, kathablepharids, euglenoids, and chrysophytes). The September bloom also included dinoflagellates, pennate diatoms, and cryptophytes.

Site D41: San Pablo Bay

Chlorophyll *a* showed a slight seasonal pattern; there were peaks in spring and summer, and one fall peak which was the maximum (8.01 µg/L) (Figure 4-14a; Table 4-2). The minimum of 1.60 µg/L was recorded in December. The mean (3.71 µg/L) was slightly higher than the median (3.39 µg/L) (Table 4-2).

Pheophytin *a* also showed a slight seasonal pattern; the maximum of 1.87 µg/L occurred in May and the minimum of 0.28 µg/L was recorded in August (Figure 4-14a; Table 4-2). The mean and median were very close (0.78 µg/L and 0.70 µg/L, respectively).

Various taxa had peaks throughout the year, but the largest blooms were haptophytes and cryptophytes in October (Figure 4-14b; Other Taxa are pennate diatoms, ciliates, euglenoids, little green algal balls, kathablepharids, cyanobacteria, chrysophytes, and green algae). Phytoplankton densities were fairly low (less than 500 organisms per mL) the rest of the year.

Site D41A: San Pablo Bay

Chlorophyll *a* showed a strong seasonal pattern with several peaks in spring and summer (Figure 4-15a; Table 4-2). The maximum of 5.37 µg/L occurred in April and the minimum of 1.07 µg/L was recorded in December (Table 4-2). The mean (2.96 µg/L) was slightly higher than the median (2.25 µg/L).

Pheophytin *a* also showed a strong seasonal pattern; the maximum of 3.79 µg/L was recorded in June (Figure 4-15a; Table 4-2). The minimum of 0.38 µg/L was recorded in January (Figure 4-15a, Table 4-2). The mean was slightly higher than the median (1.55 µg/L and 1.14 µg/L, respectively).

A peak of pennate and centric diatoms occurred in January; another peak of centric diatoms occurred in November (Figure 4-15b; Other Taxa are kathablepharids, little green algal balls, euglenoids, haptophytes, and cyanobacteria). Phytoplankton numbers overall were low for the year (less than 250 organisms per mL).

Summary

Phytoplankton and chlorophyll *a* samples were collected monthly at thirteen sites in 2011. Chlorophyll *a* samples were also analyzed for pheophytin *a*, the primary degradation product of chlorophyll *a*. All phytoplankton identified fell into the following twelve categories: cyanobacteria, centric diatoms, pennate diatoms, cryptomonad flagellates, haptophyte flagellates, green algae, dinoflagellates, euglenoid flagellates, chrysophtye flagellates, ciliates, little green algal balls, and kathablepharids. The ten most common genera were *Anabaena, Aphanizomenon, Cyclotella, Fragilaria, Chroomonas, Aulacoseira, Cocconeis, Cryptomonas, Pseudanabaena,* and *Melosira.*

Chlorophyll *a* concentrations showed a seasonal pattern at some, but not all, stations; values ranged from 0.35 µg/L to 18.20 µg/L. Pheophytin *a* concentrations mainly did not show a seasonal pattern, with some exceptions; values ranged from 0.16 µg/L to 7.24 µg/L. Despite sporadic peaks at some stations, chlorophyll *a* concentrations overall were relatively low when compared with historical data.

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Chapter 4. Appendix

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

Figure 4-2 Percent of phytoplankton composition by group, 2011

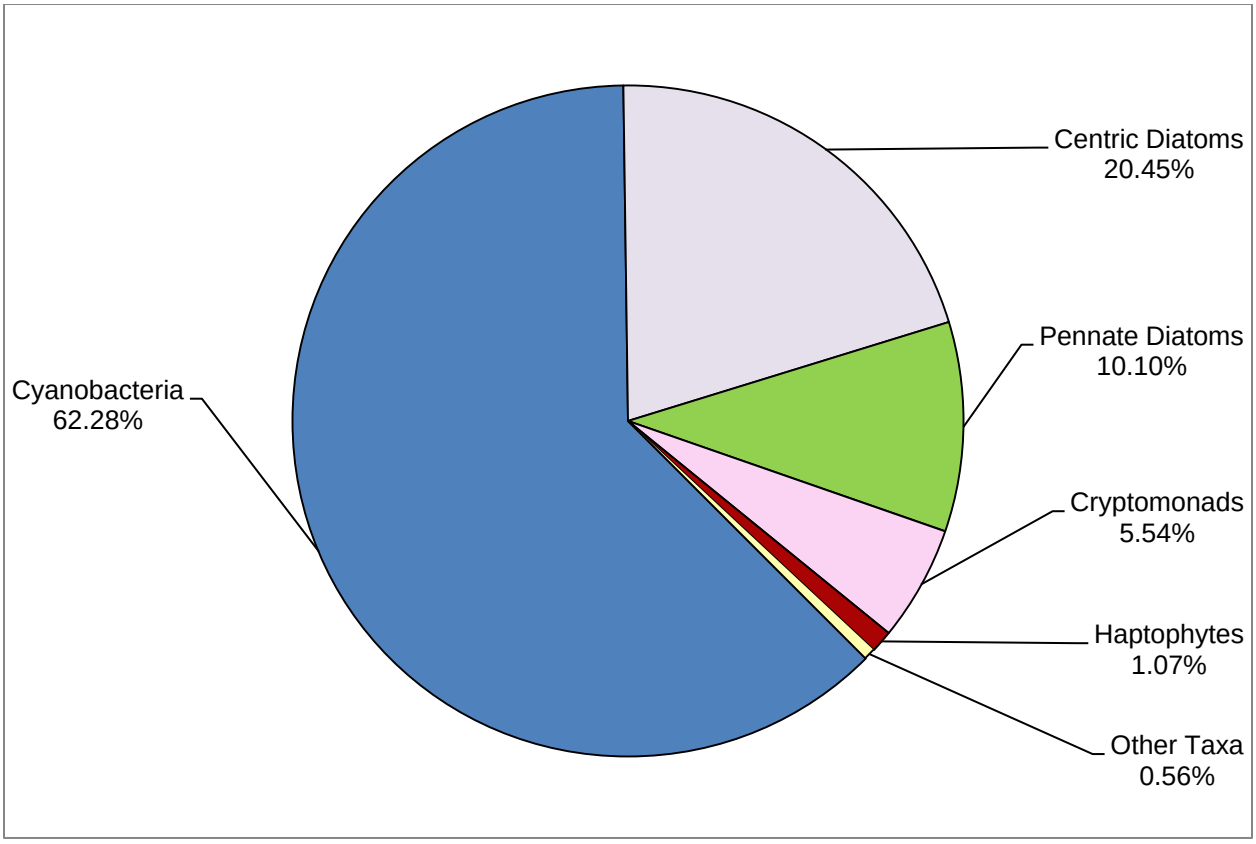

Figure 4-3a Pigment concentrations at C3A, 2011

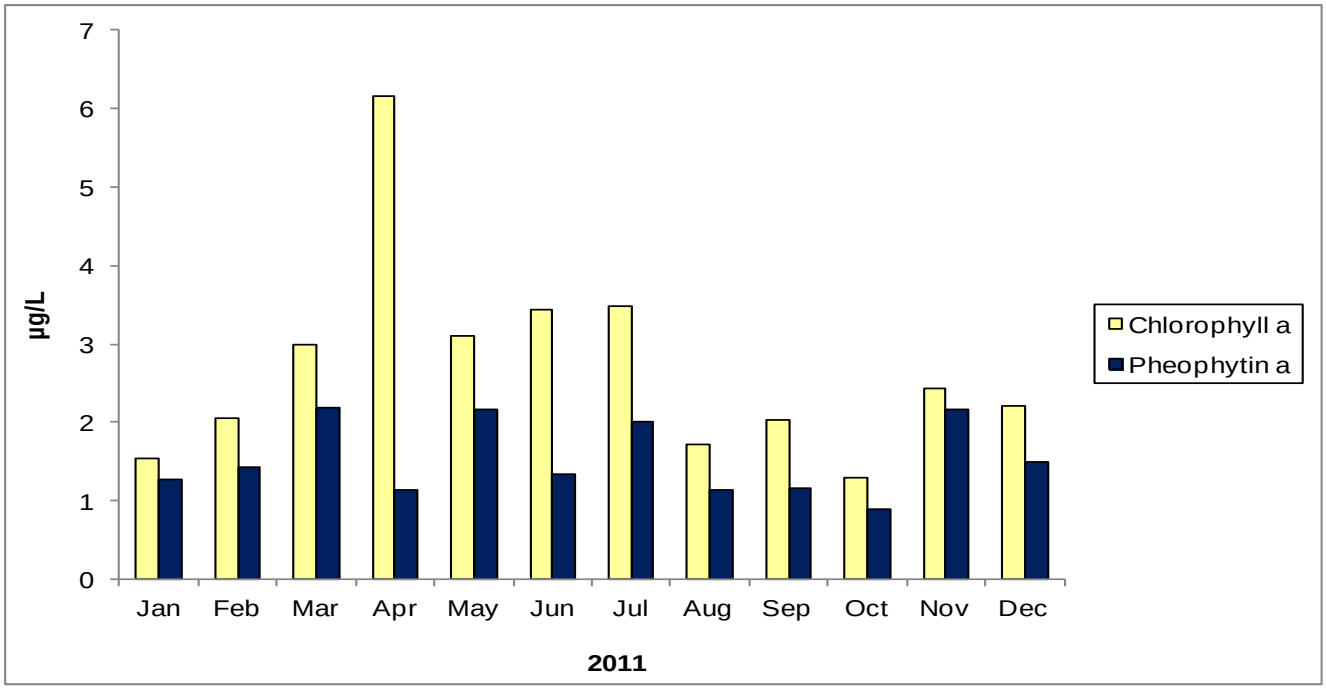

Figure 4-3b Phytoplankton composition at C3A, 2011

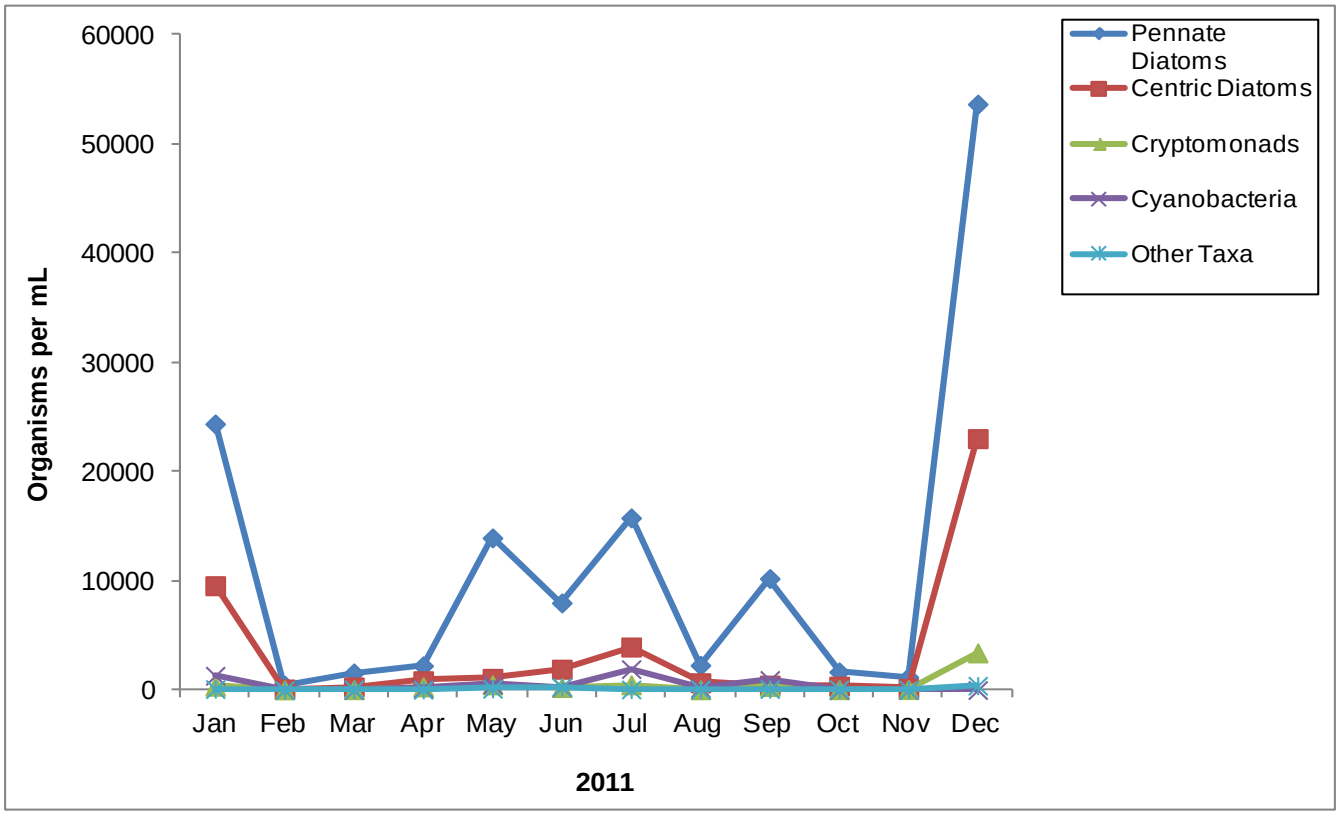

Figure 4-4a Pigment concentrations at C10A, 2011

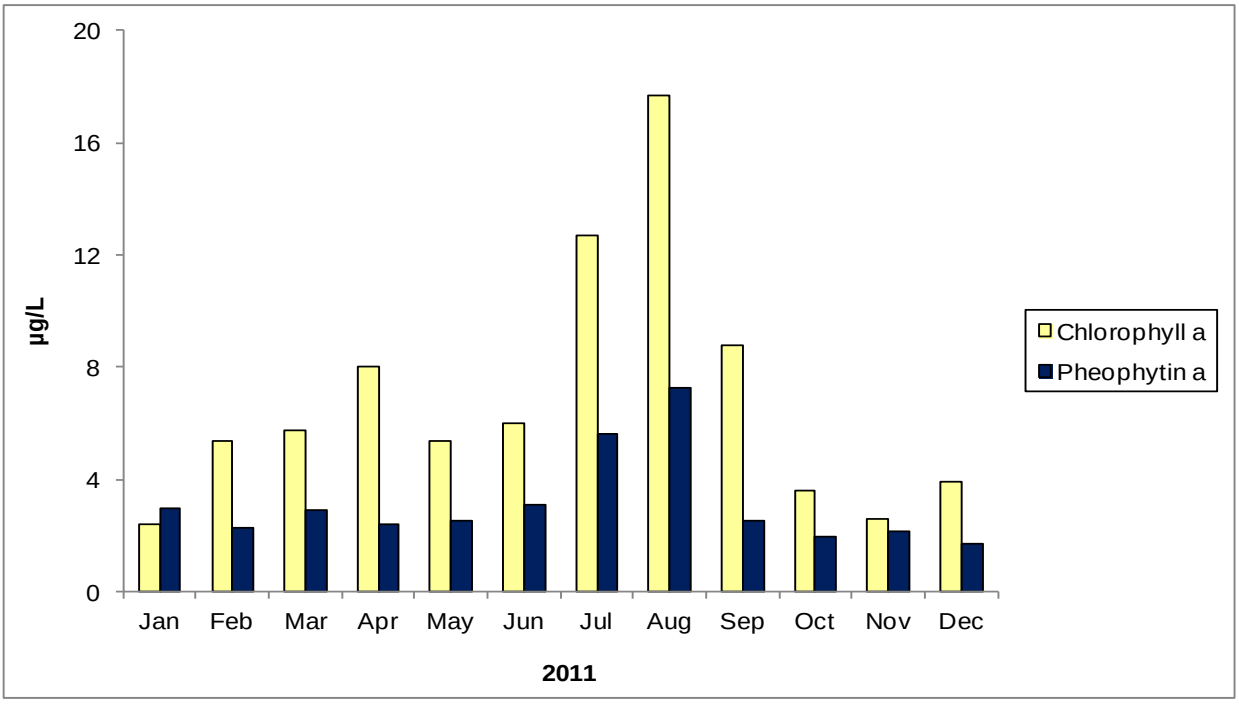

Figure 4-4b Phytoplankton composition at C10A, 2011

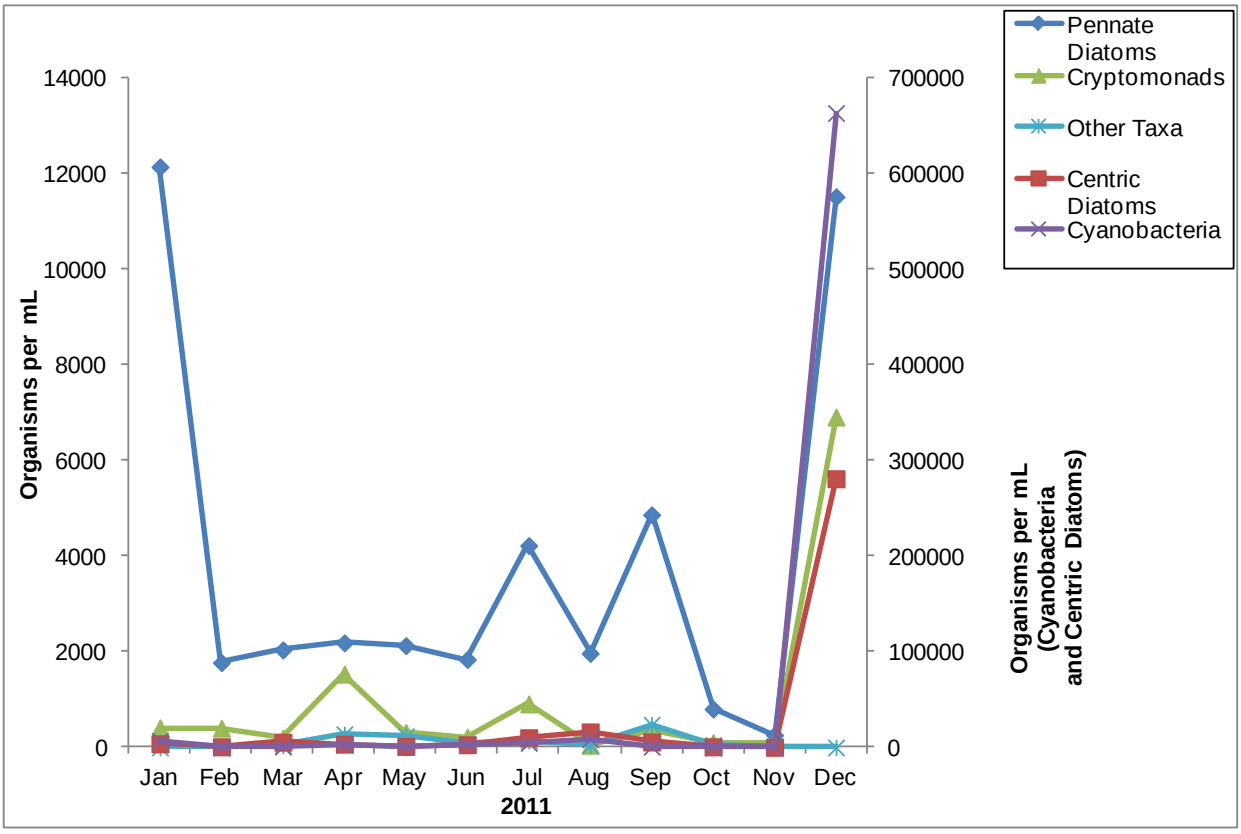

Figure 4-5a Pigment concentrations at P8, 2011

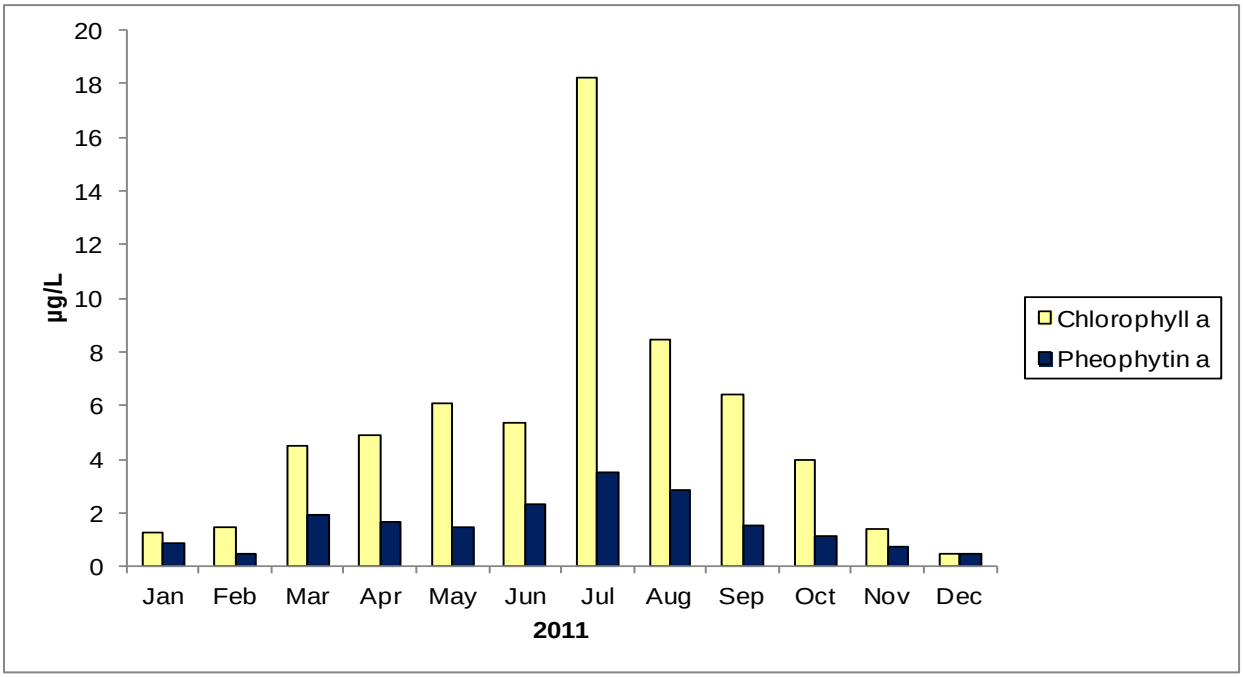

Figure 4-5b Phytoplankton composition at P8, 2011

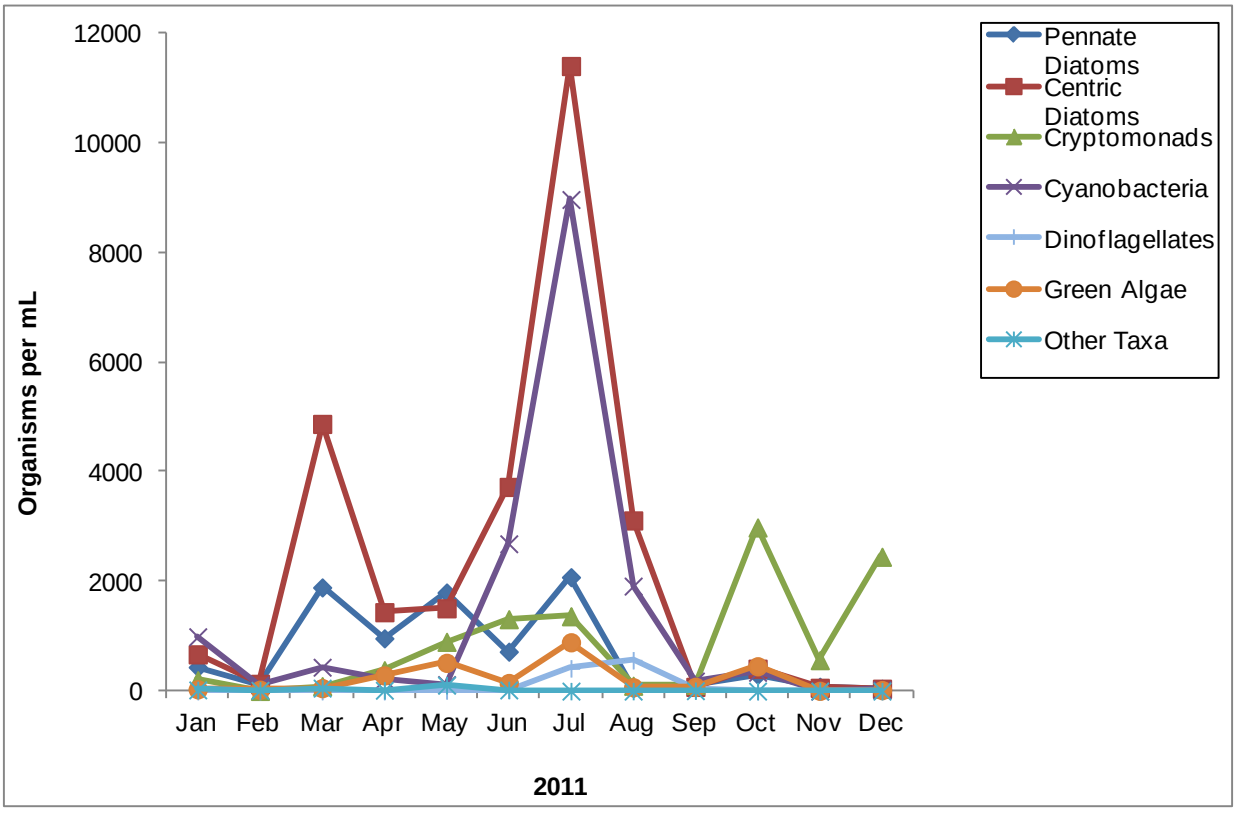

Figure 4-6a Pigment concentrations at MD10A, 2011

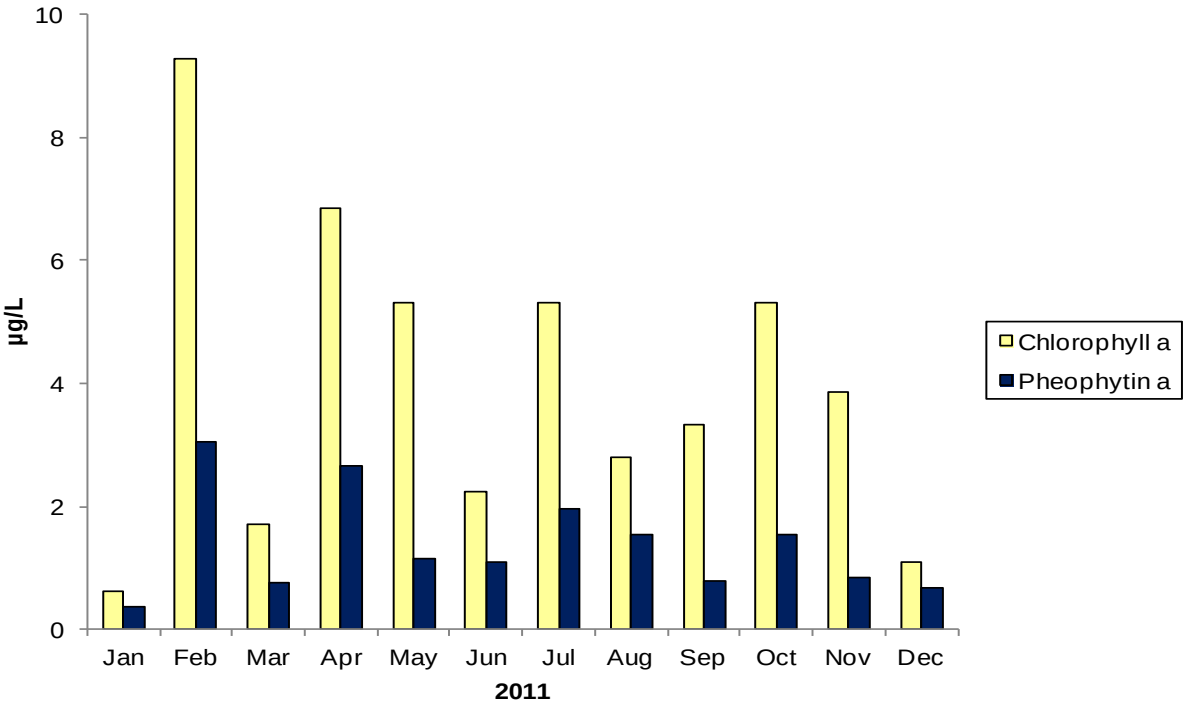

Figure 4-6b Phytoplankton composition at MD10A, 2011

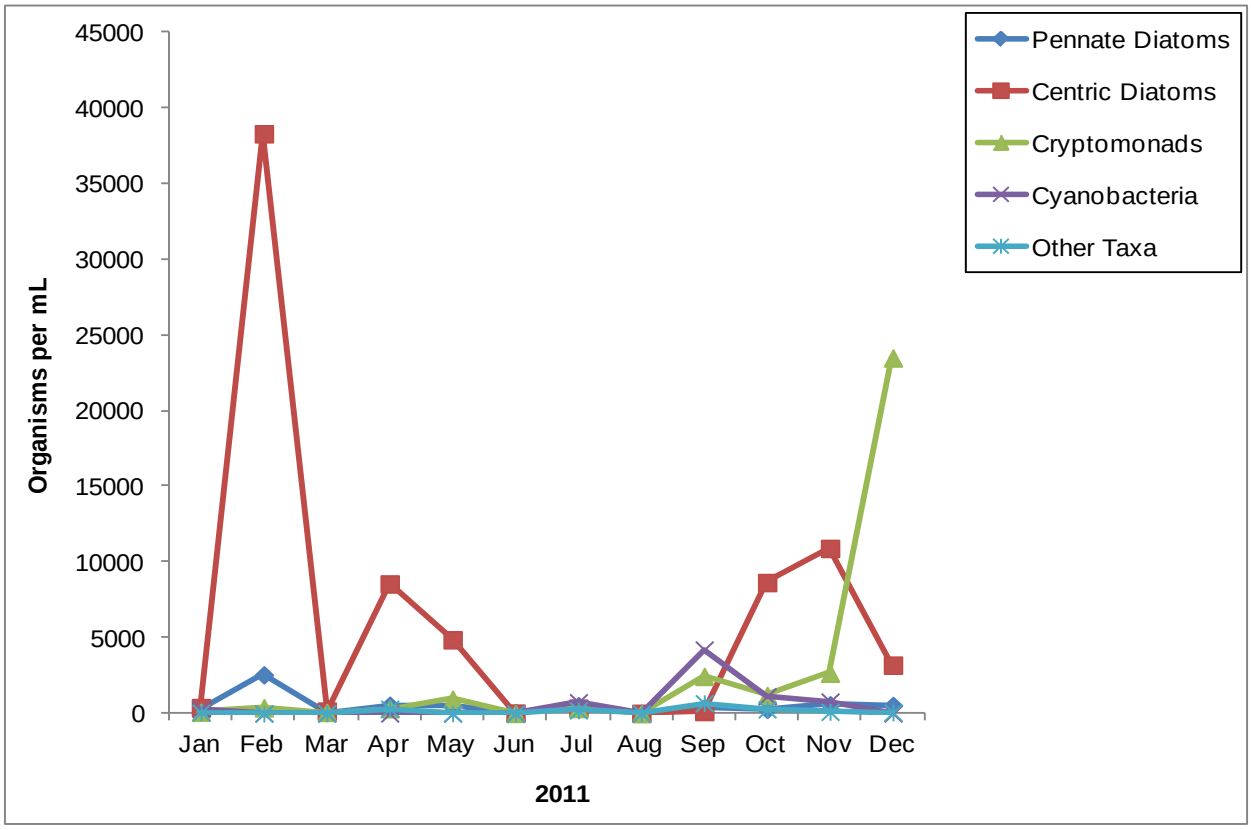

Figure 4-7a Pigment concentrations at D26, 2011

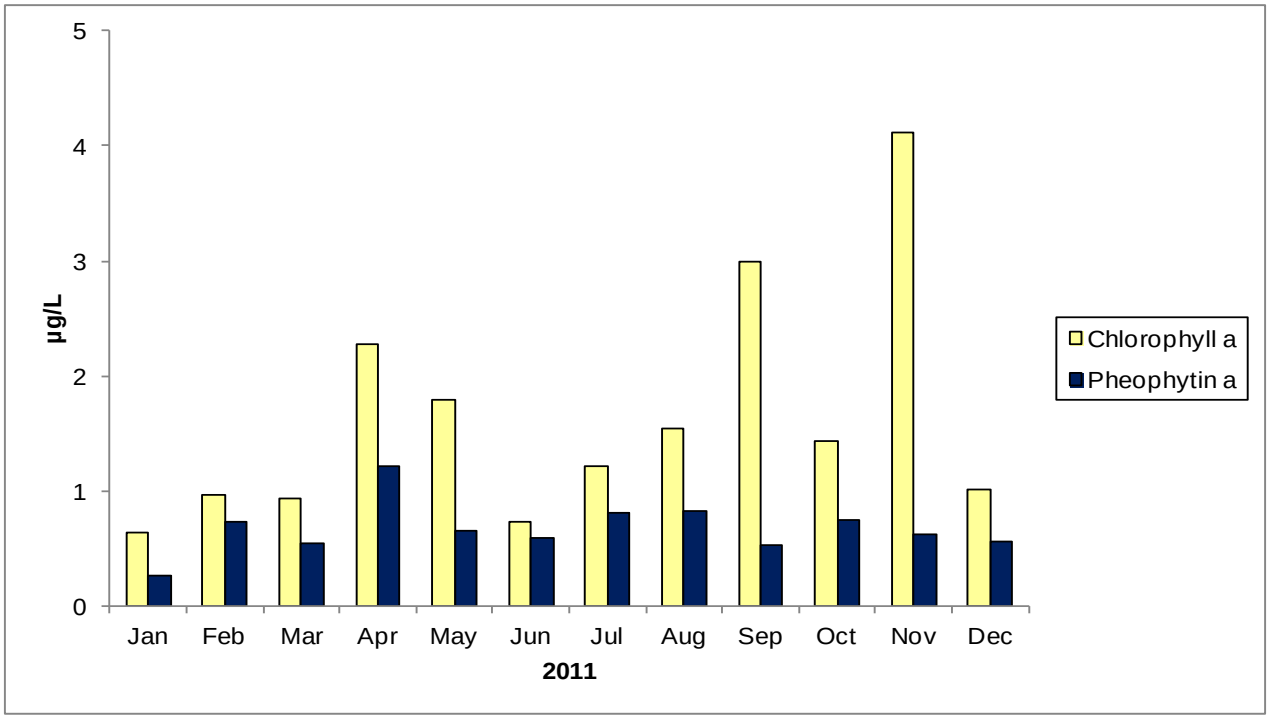

Figure 4-7b Phytoplankton composition at D26, 2011

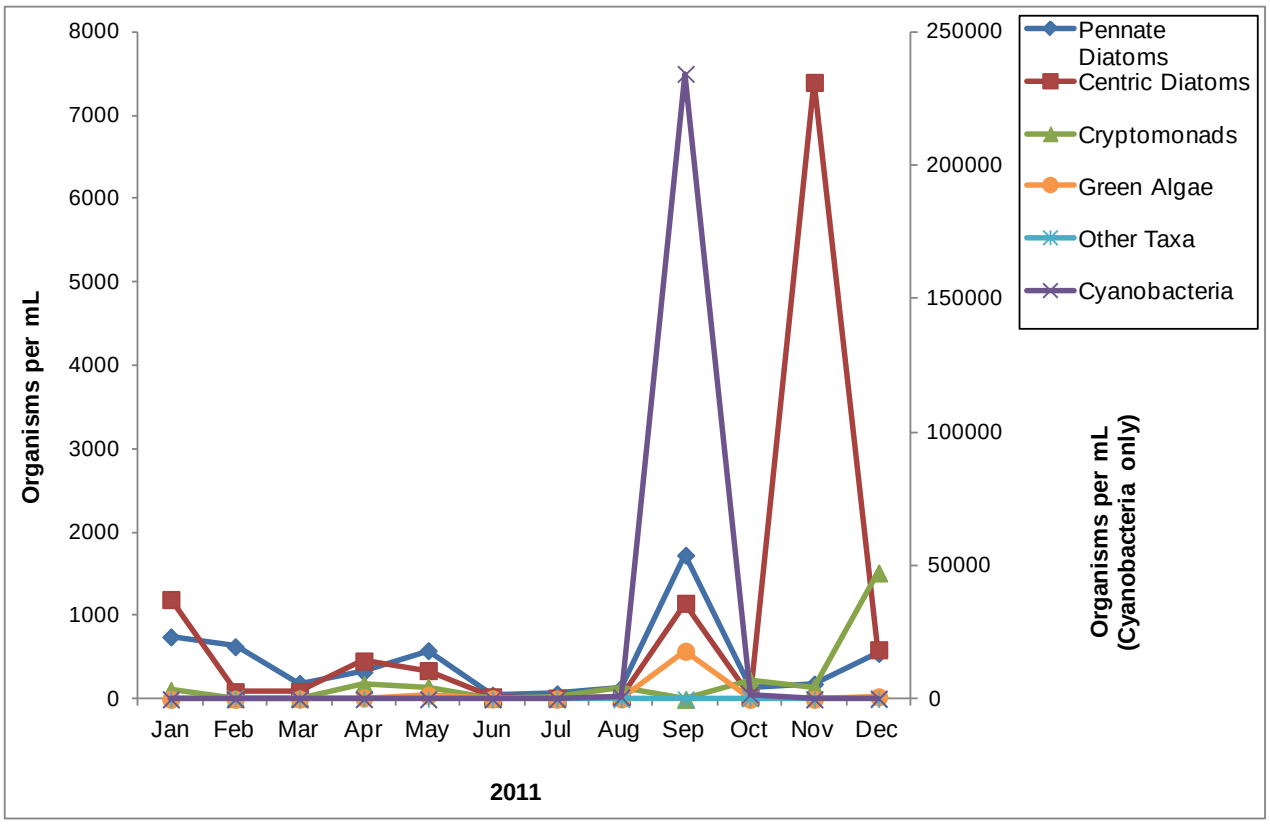

Figure 4-8a Pigment concentrations at D19, 2011

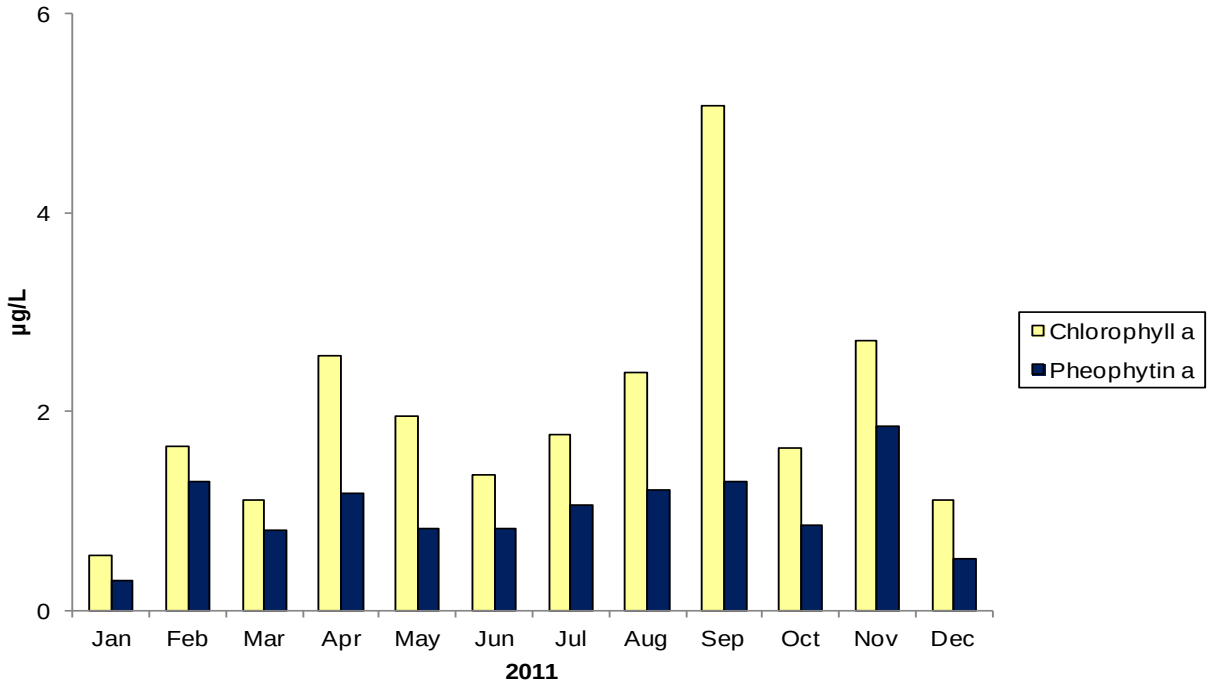

Figure 4-8b Phytoplankton composition at D19, 2011

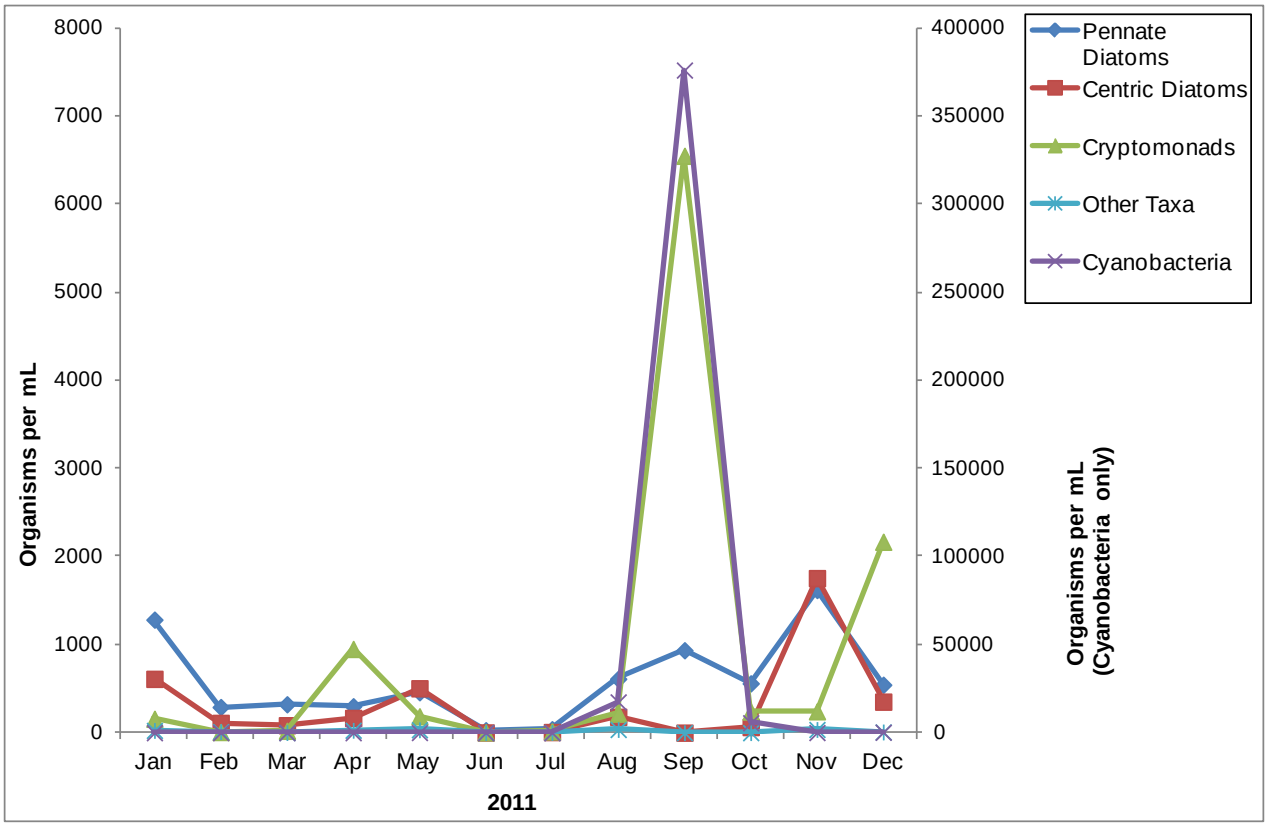

Figure 4-9a Pigment concentrations at D28A, 2011

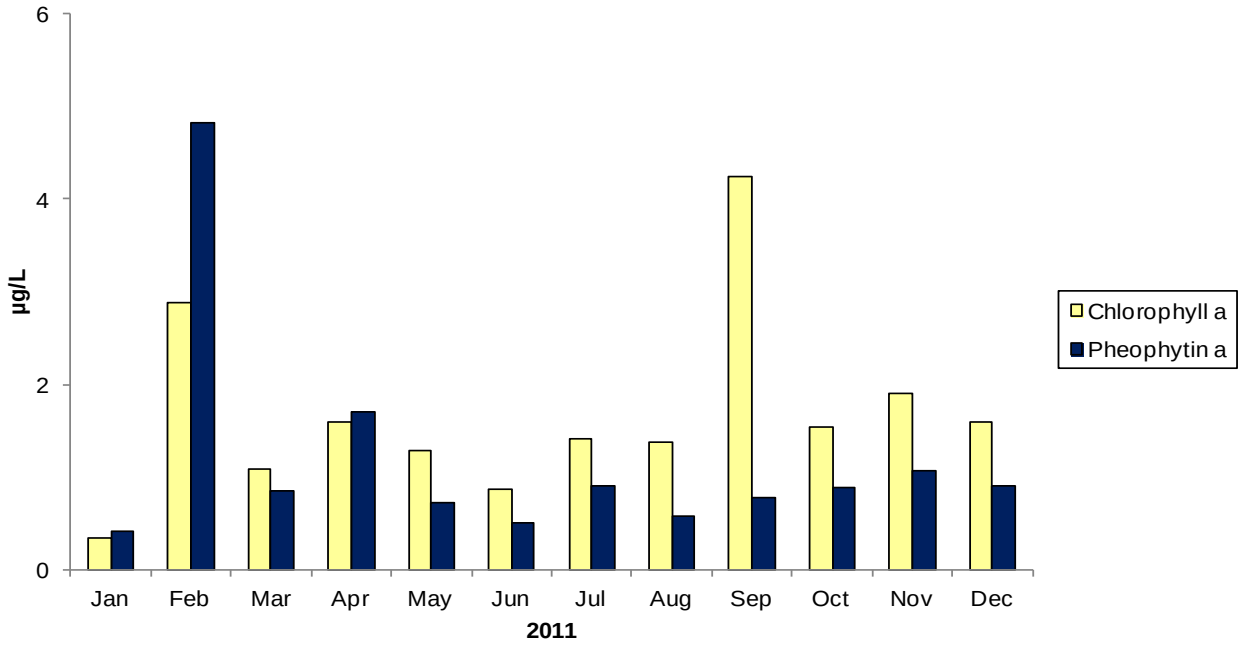

Figure 4-9b Phytoplankton composition at D28A, 2011

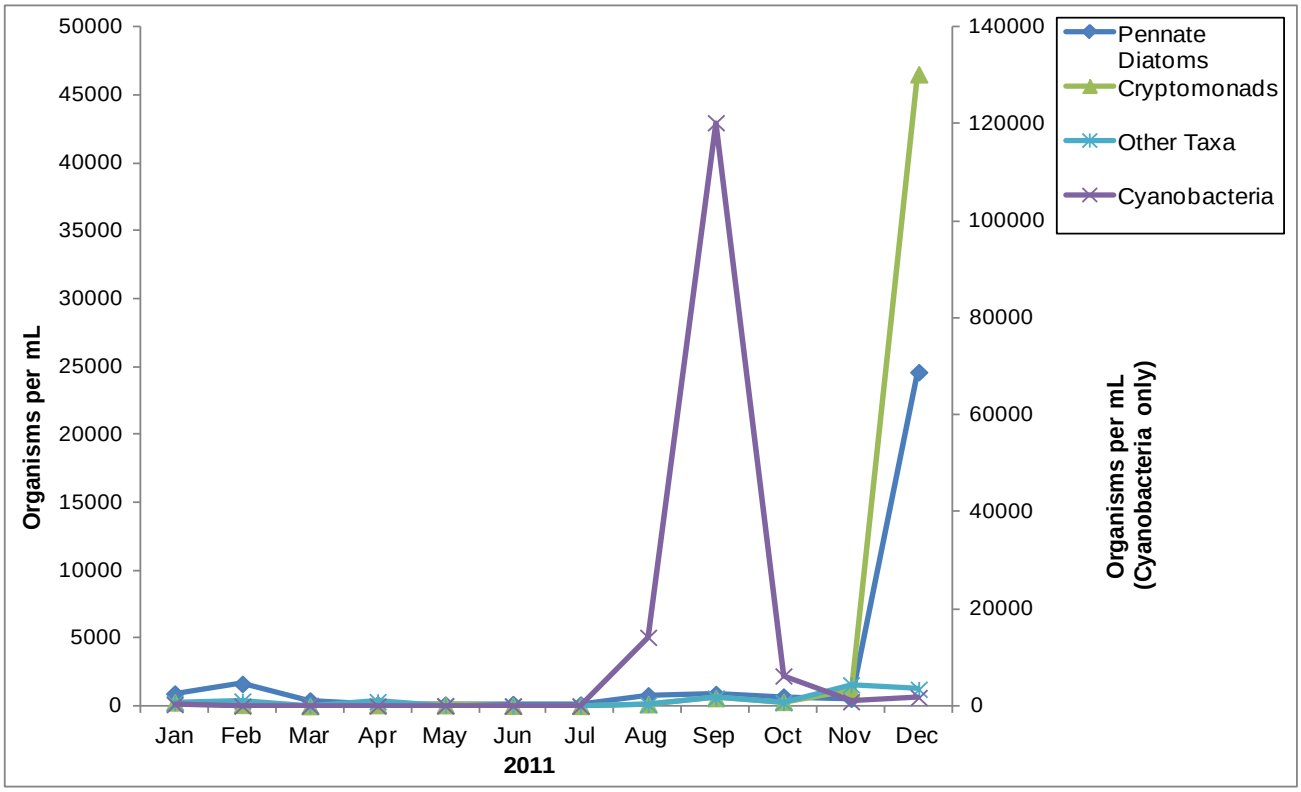

Figure 4-10a Pigment concentrations at D4, 2011

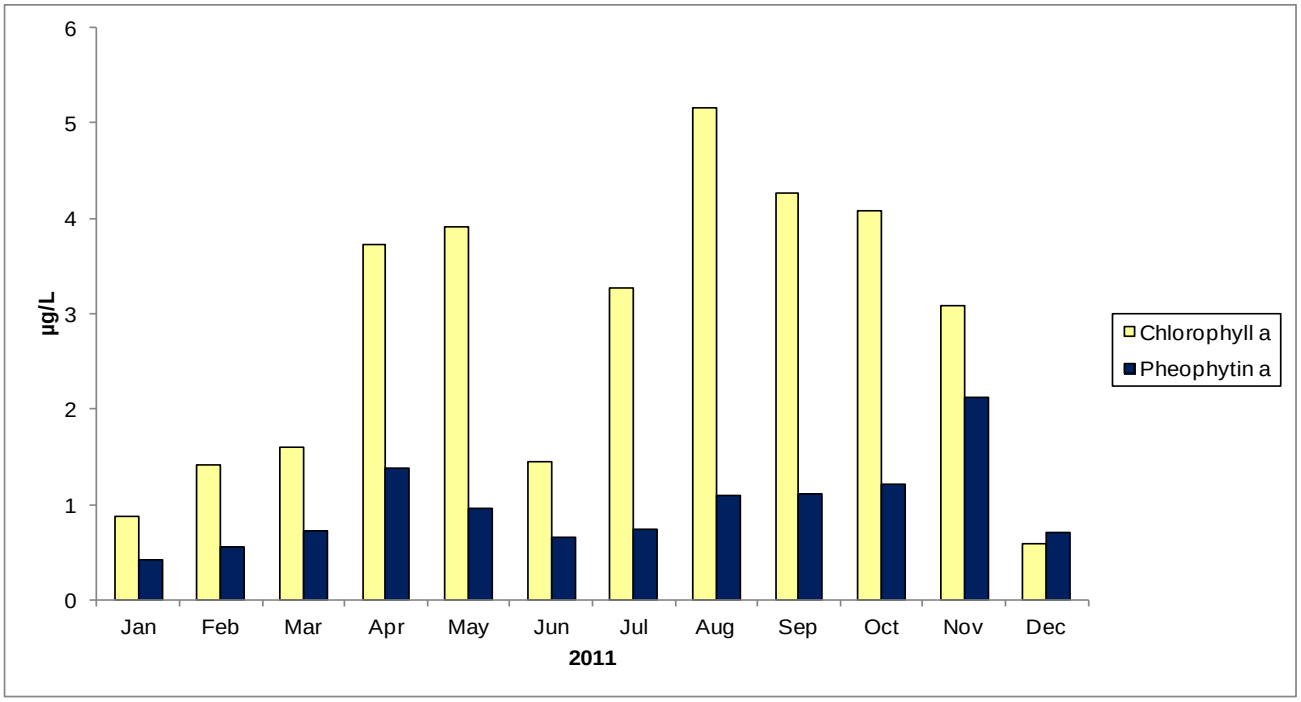

Figure 4-10b Phytoplankton composition at D4, 2011

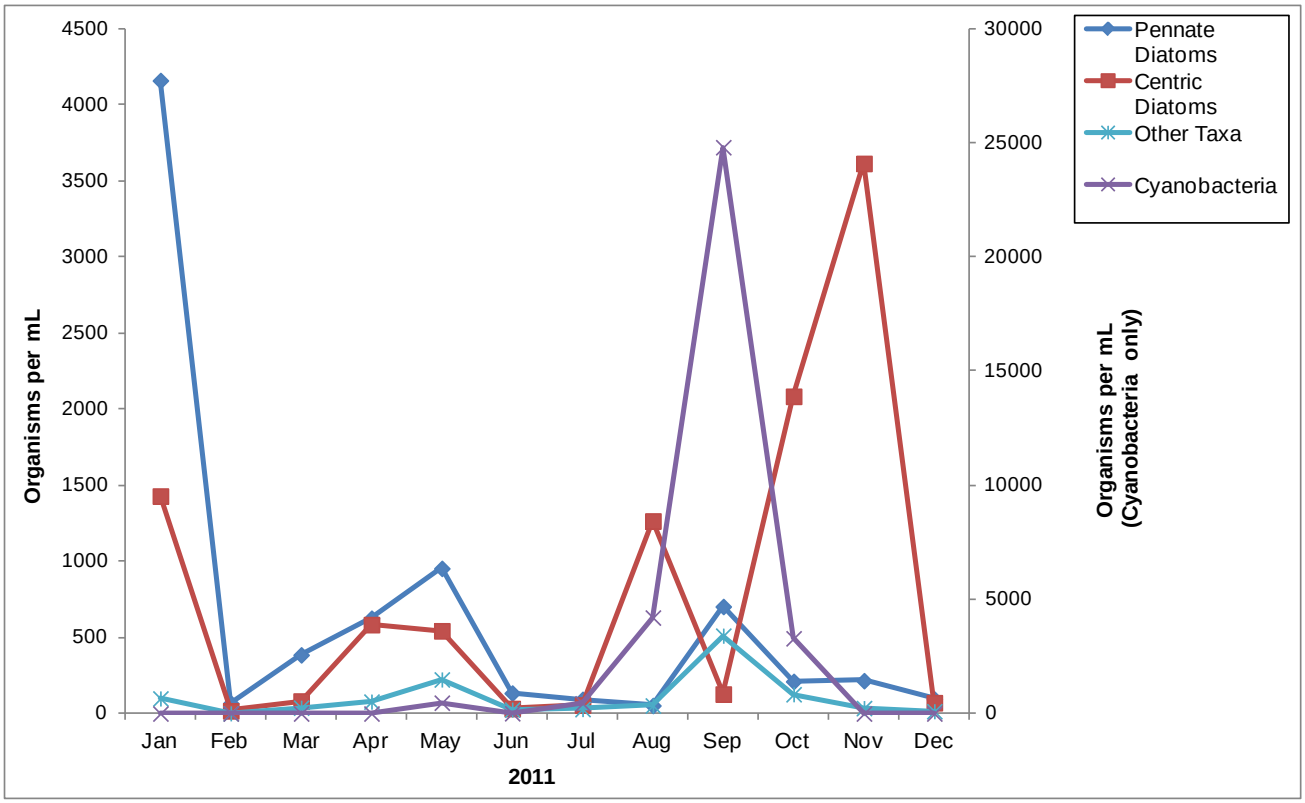

Figure 4-11a Pigment concentrations at D6, 2011

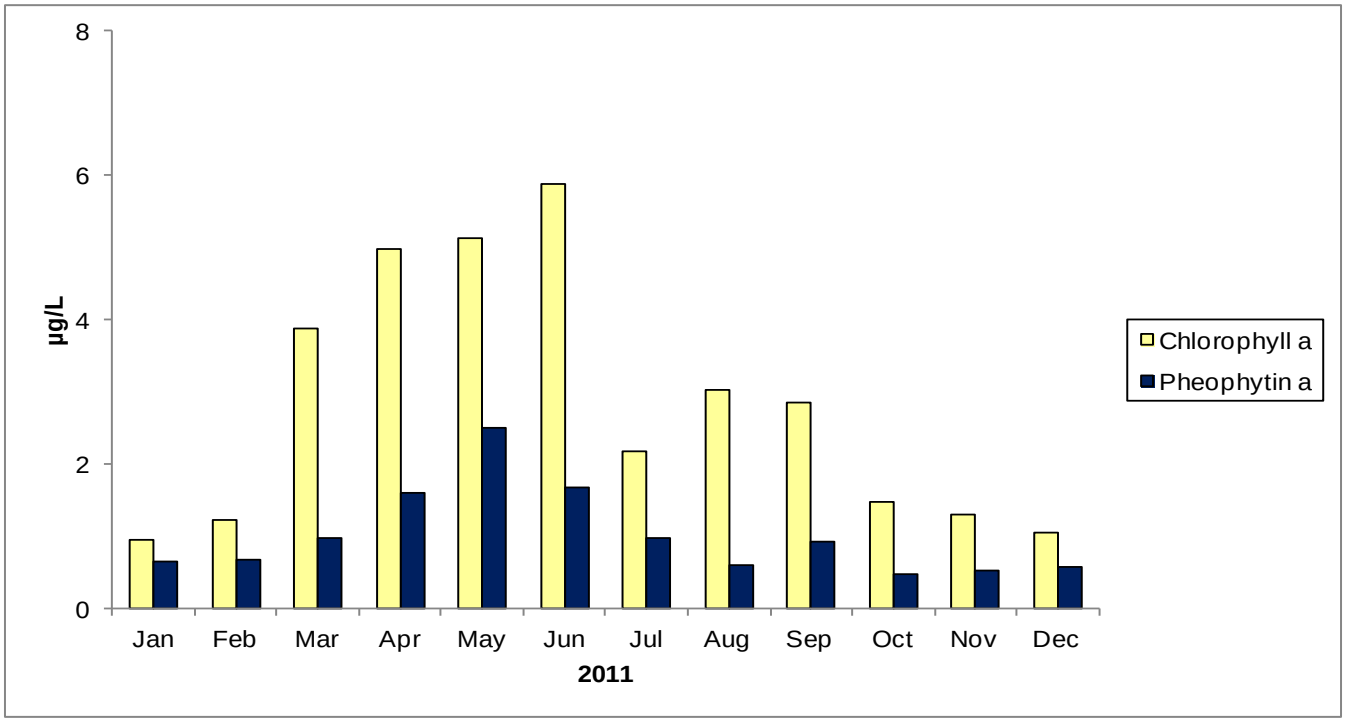

Figure 4-11b Phytoplankton composition at D6, 2011

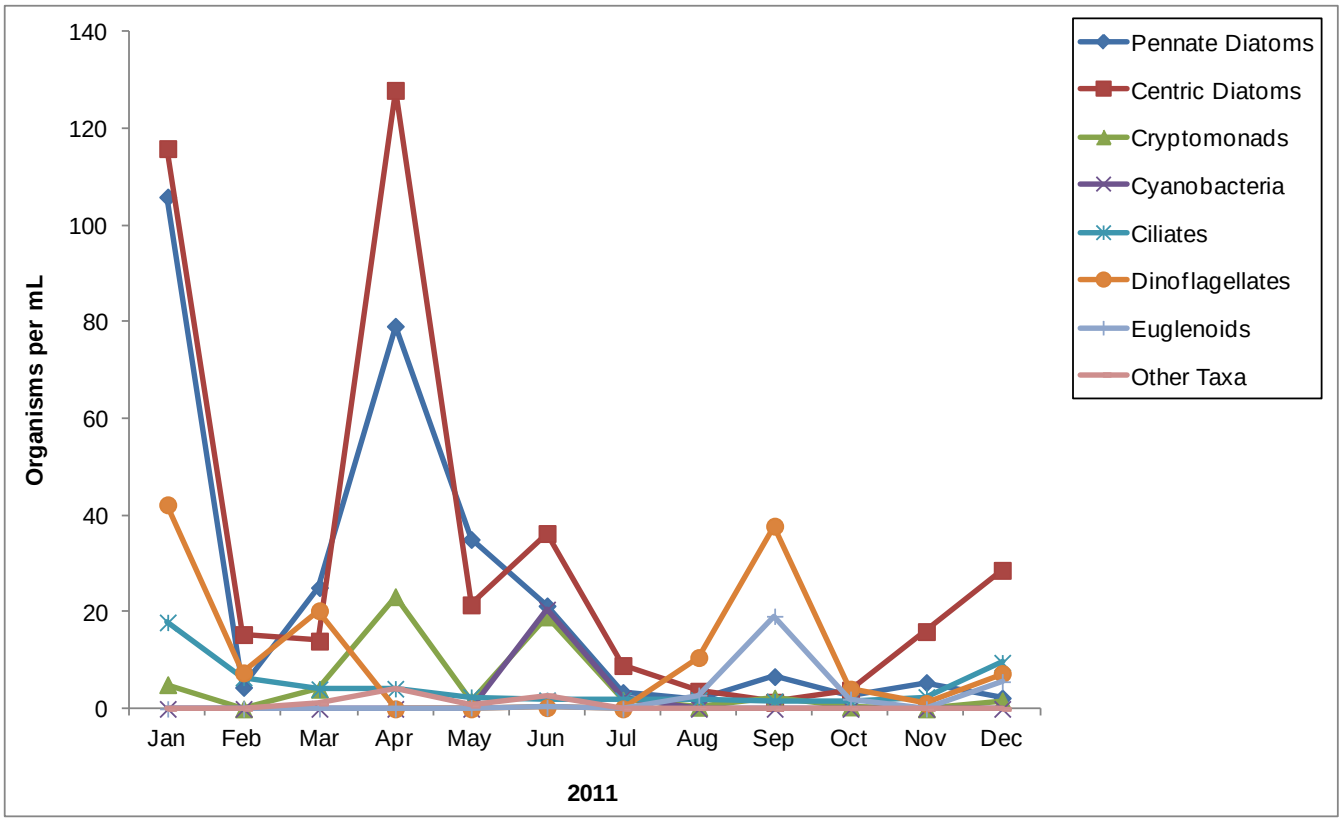

Figure 4-12a Pigment concentrations at D7, 2011

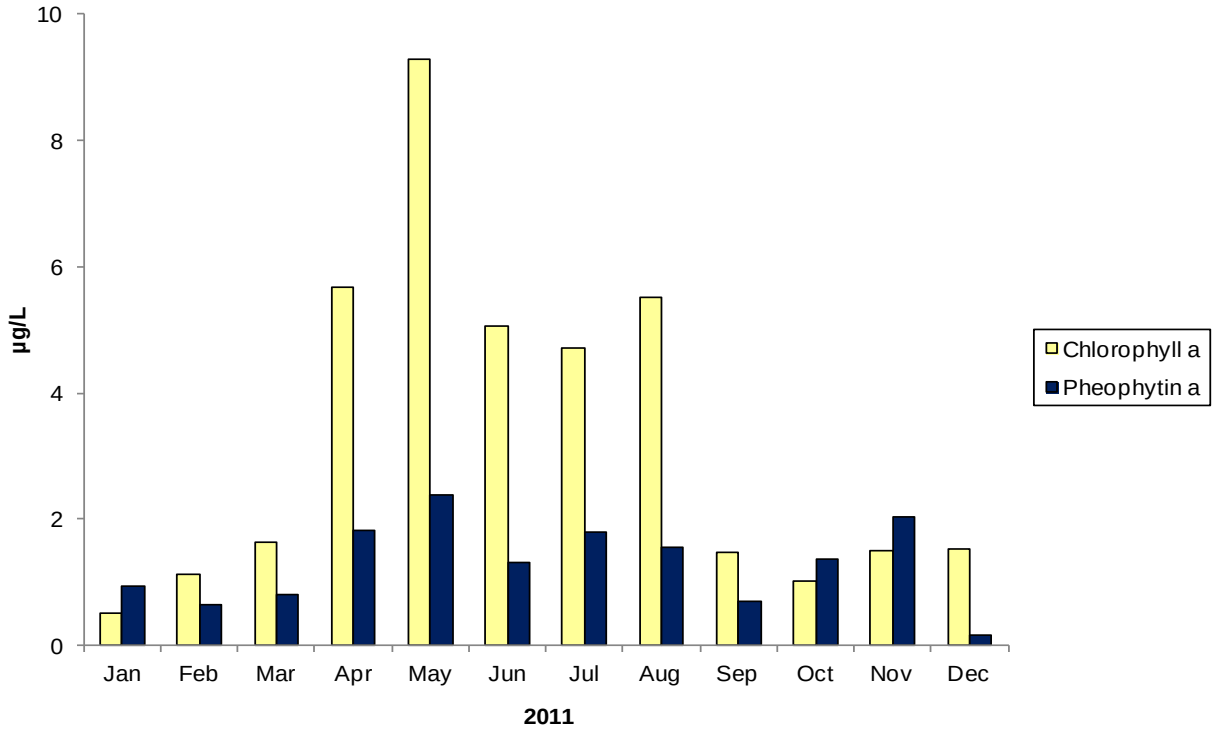

Figure 4-12b Phytoplankton composition at D7, 2011

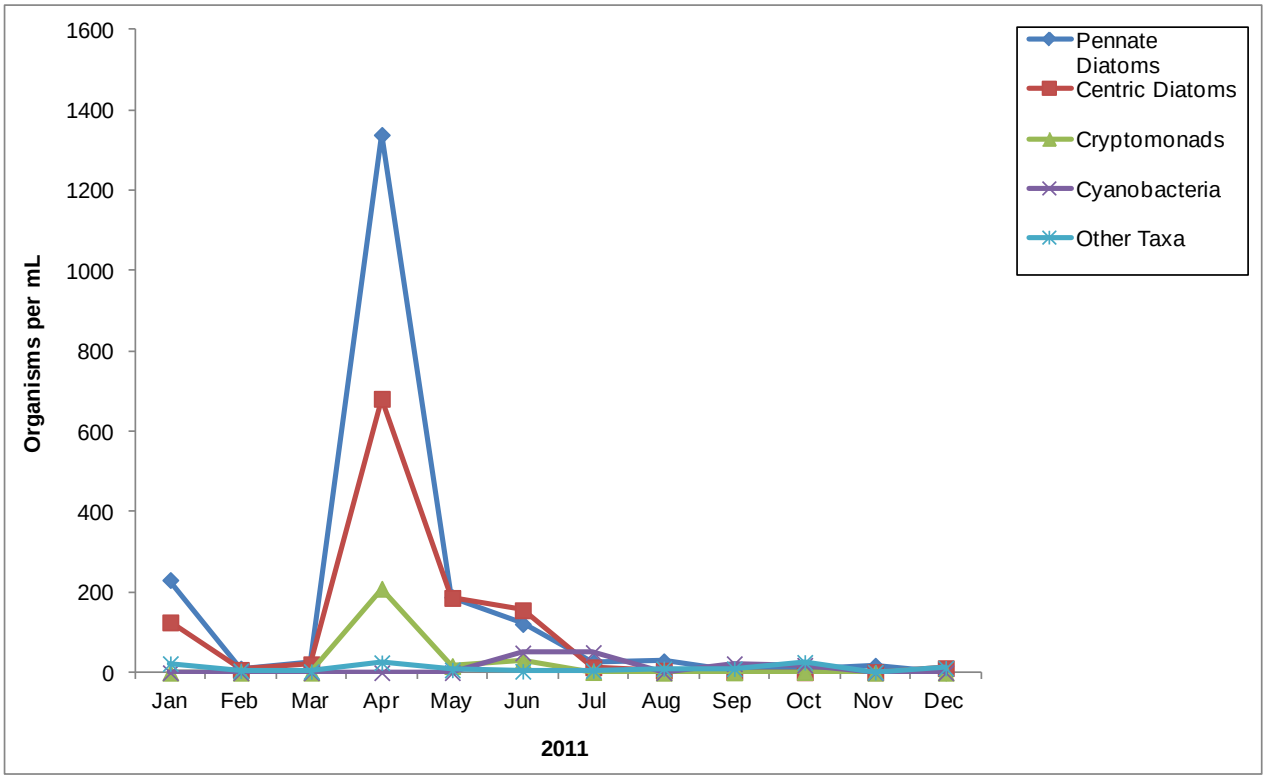

Figure 4-13a Pigment concentrations at D8, 2011

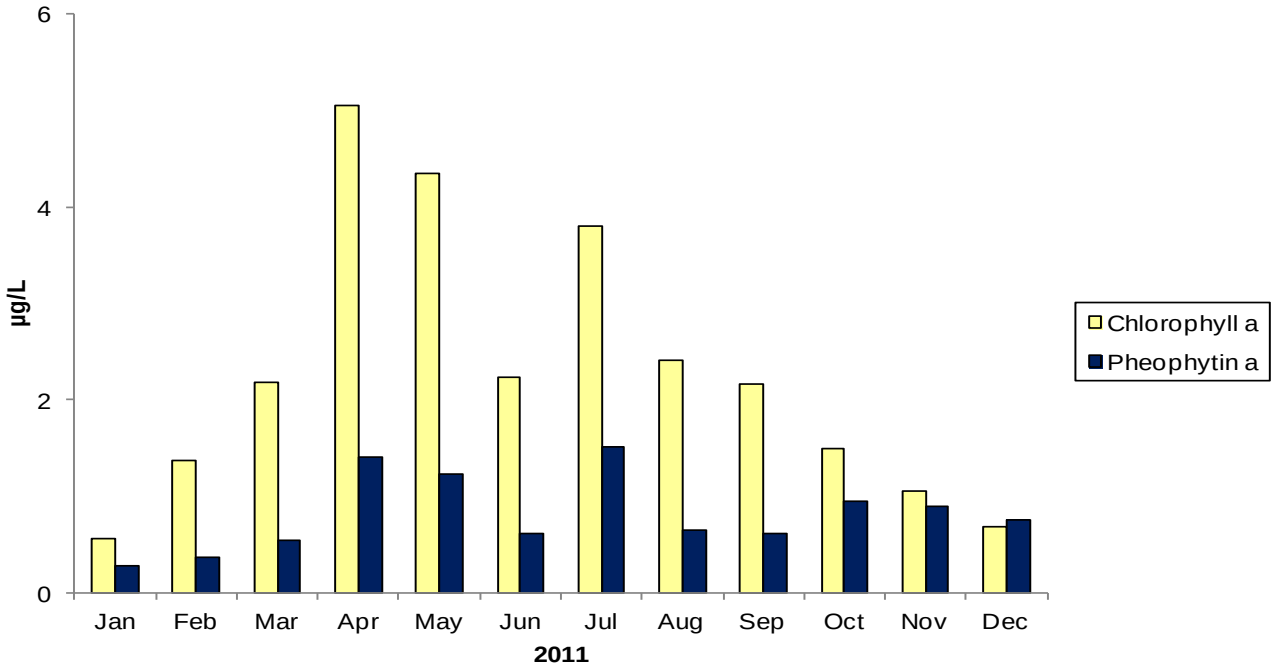

Figure 4-13b Phytoplankton composition at D8, 2011

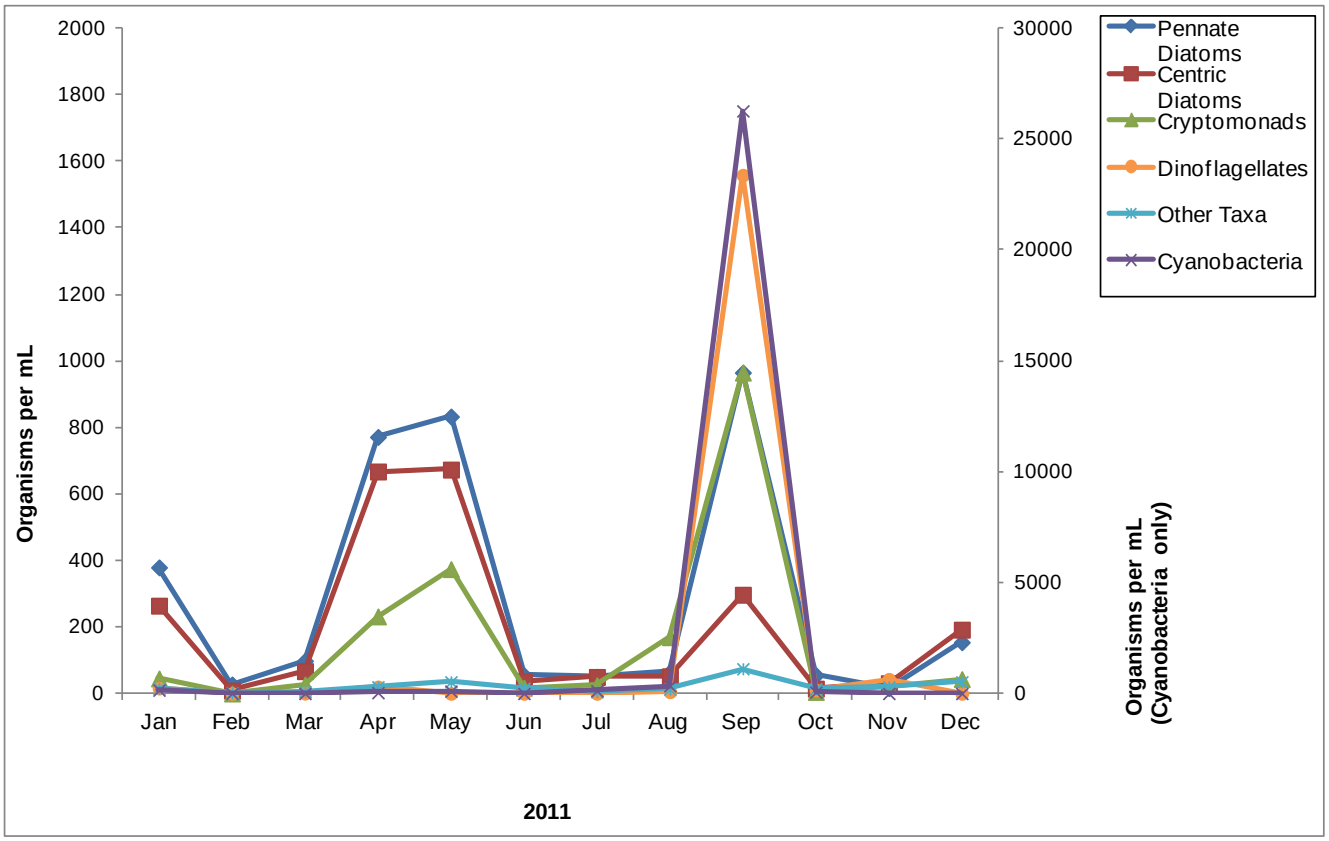

Figure 4-14a Pigment concentrations at D41, 2011

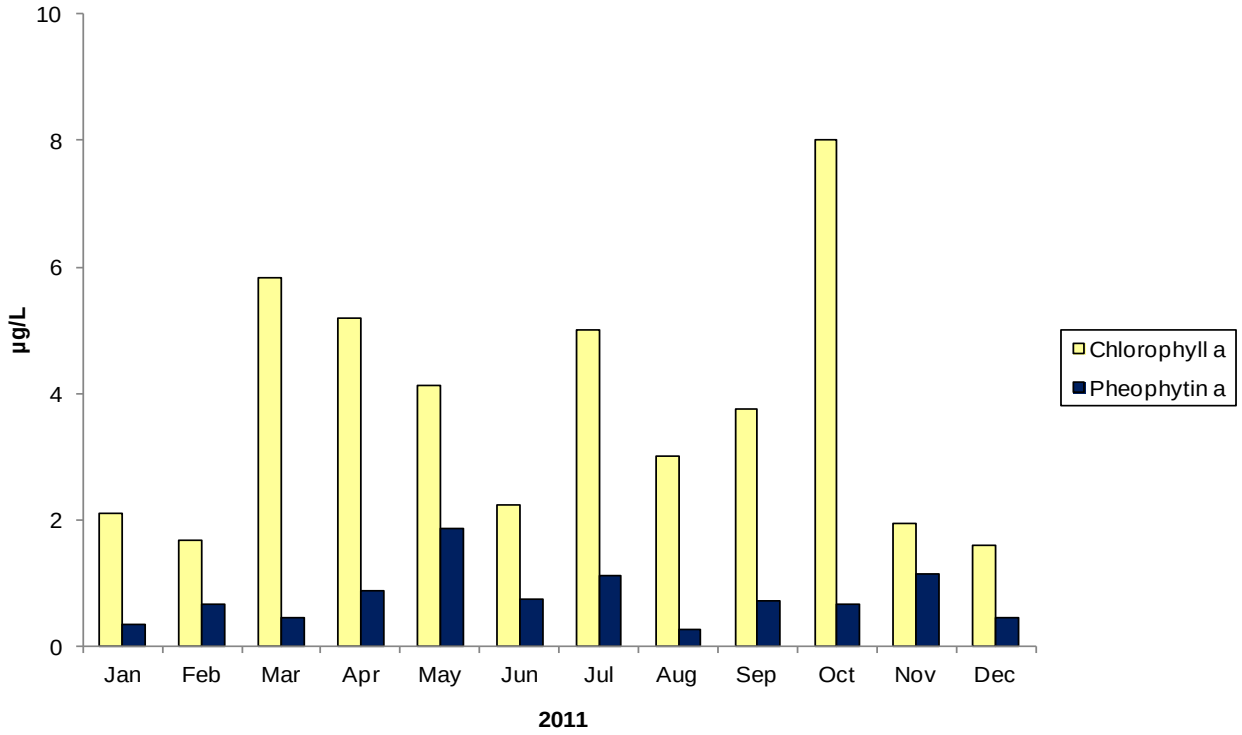

Figure 4-14b Phytoplankton composition at D41, 2011

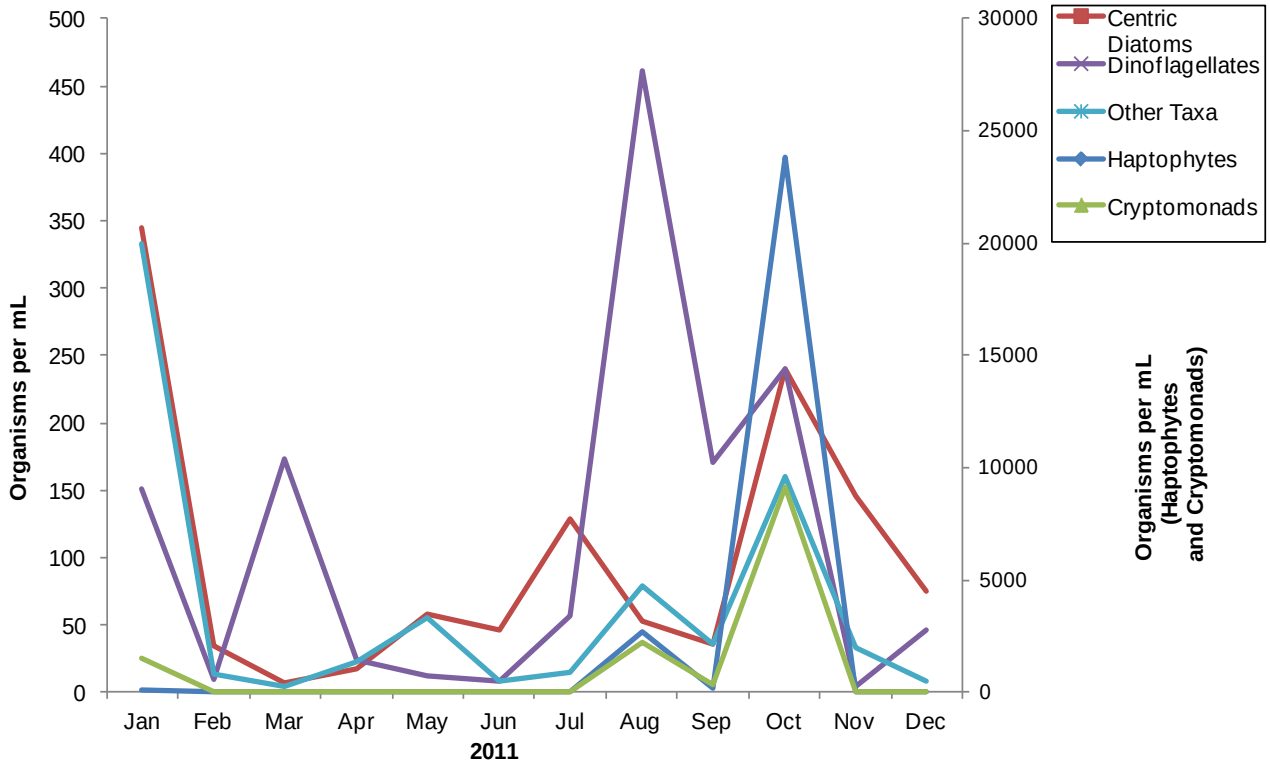

Figure 4-15a Pigment concentrations at D41A, 2011

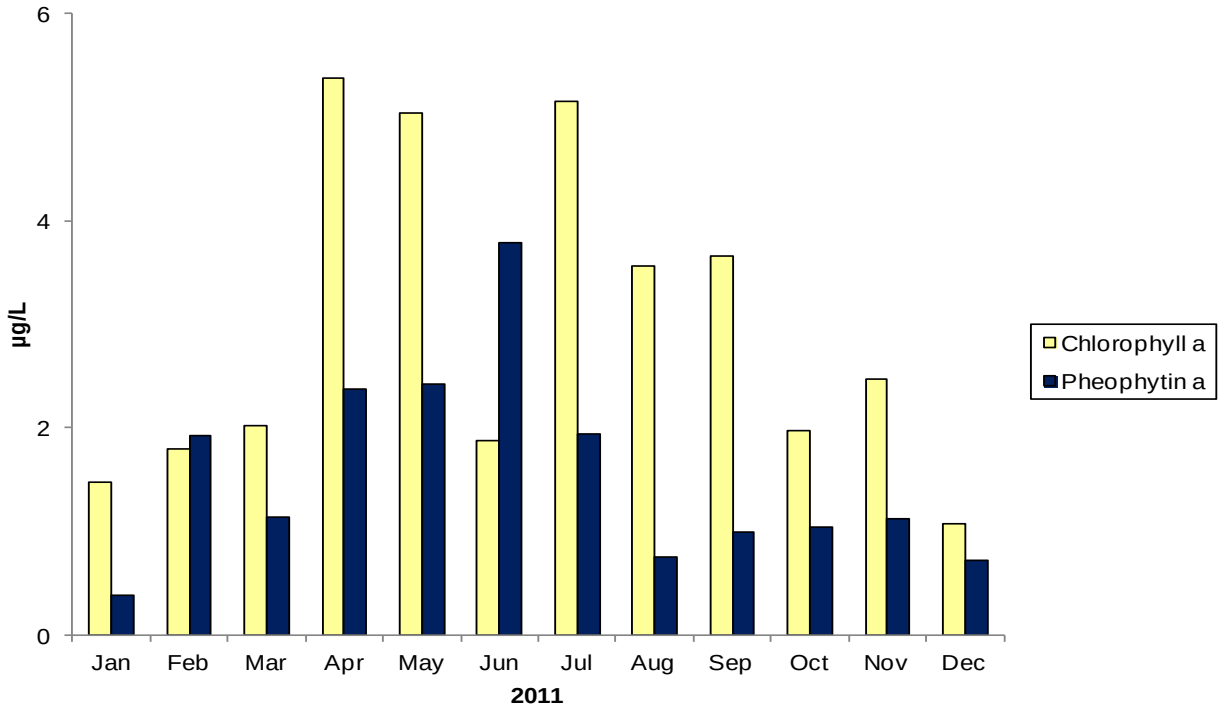

Figure 4-15b Phytoplankton composition at D41A, 2011

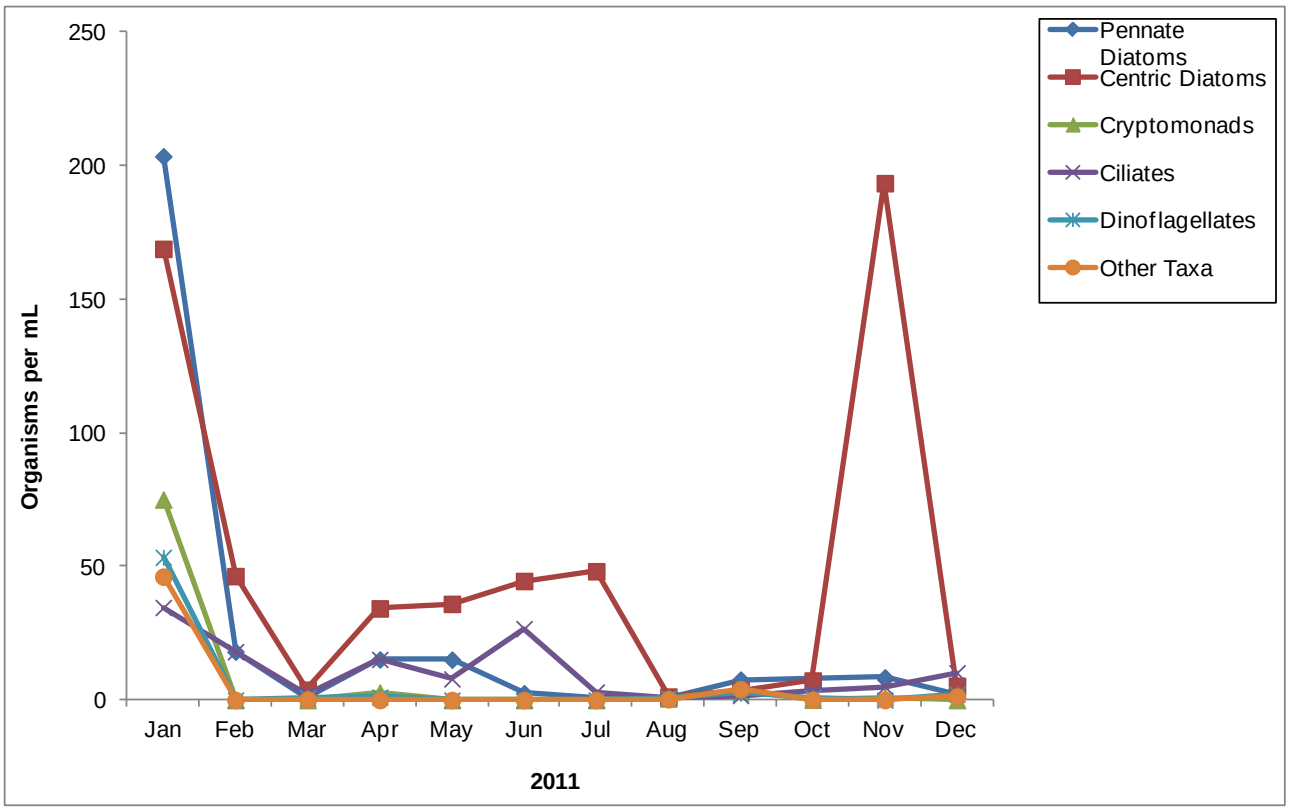

Table 4-1 Phytoplankton genera by group, 2011

Pennate Diatoms	Centric Diatoms	Green Algae	Dinoflagellates
Achnanthes	Actinoptychus	Actinastrum	Akashiwo
Amphora	Aulacoseira	Ankyra	Alexandrium
Asterionella	Biddulphia	Carteria	Ceratium
Bacillaria	Coscinodiscus	Chlamydomonas	Crypthecodinium
Cocconeis	Cyclotella	Chlorococcum	Dinophysis
Cymatopleura	Hydrosera	Closterium	Gonyaulax
Cymbella	Melosira	Coelastrum	Gymnodinium
Diatoma	Odontella	Cosmarium	Katodinium
Diploneis	Paralia	Crucigenia	Mesoporos
Entomoneis	Rhizosolenia	Crucigeniella	Oxyphysis
Epithemia	Skeletonema	Elakatothrix	Peridinium
Eunotia	Stephanodiscus	Gonium	Prorocentrum
Fragilaria	Terpsinoe	Monoraphidium	Protoperidinium
Gomphoneis	Thalassiosira	Oedogonium	Scrippsiella
Gomphonema	Unknown centric diatom	Oocystis	Unknown dinoflagellates
Gyrosigma	**Cryptomonads**	Pediastrum	Warnowia
Navicula	Chroomonas	Scenedesmus	Woloszynskia
Nitzschia	Cryptomonas	Sphaerocystis	**Cyanobacteria**
Pinnularia	Hemiselmis	Staurastrum	Anabaena
Rhoicosphenia	Komma	Teilingia	Aphanizomenon
Rhopalodia	Rhodomonas	Tetraedron	Chroococcus
Staurosira	Teleaulax	Tetrastrum	Gomphosphaeria
Stenopterobia	**Euglenoids**	**Haptophytes**	Leptolyngbya
Surirella	Euglena	Chrysochromulina	Lyngbya
Synedra	Eutreptiella	Phaeocystis	Oscillatoria
Chrysophytes	Lepocinclis	**Ciliates**	Phormidium
Chromulina	Phacus	Mesodinium	Pseudanabaena
Chrysocapsella	Strombomonas	Salpingella	Synechococcus
Chrysococcus	Trachelomonas	**Kathablepharids**	
Dinobryon	**Unknown**	Leucocryptos	
Pseudokephyrion	Little green algal balls		

Table 4-2 Chlorophyll *a* and pheophytin *a* concentrations, 2011

Chlorophyll *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	6.15	1.30	2.32	2.70	1.31
C10A	17.70	2.38	5.56	6.84	4.48
P8	18.20	0.44	4.72	5.20	4.77
MD10A	9.29	0.63	3.60	3.98	2.54
D26	4.12	0.64	1.33	1.64	1.04
D19	5.08	0.56	1.72	2.00	1.16
D28A	4.24	0.35	1.48	1.68	1.01
D4	5.16	0.59	3.18	2.79	1.52
D6	5.87	0.95	2.51	2.83	1.76
D7	9.29	0.50	1.58	3.25	2.72
D8	5.06	0.56	2.17	2.28	1.44
D41	8.01	1.60	3.39	3.71	2.00
D41A	5.37	1.07	2.25	2.96	1.54

Pheophytin *a* (µg/L)

Station	Maximum	Minimum	Median	Mean	Standard Deviation
C3A	2.19	0.90	1.38	1.53	0.47
C10A	7.24	1.73	2.52	3.12	1.63
P8	3.52	0.44	1.49	1.57	0.95
MD10A	3.04	0.36	1.11	1.37	0.83
D26	1.22	0.26	0.64	0.68	0.23
D19	1.86	0.30	0.97	1.01	0.41
D28A	4.82	0.42	0.87	1.18	1.19
D4	2.13	0.43	0.85	0.98	0.46
D6	2.50	0.49	0.80	1.02	0.61
D7	2.37	0.16	1.35	1.29	0.66
D8	1.52	0.28	0.71	0.82	0.39
D41	1.87	0.28	0.70	0.78	0.44
D41A	3.79	0.38	1.14	1.55	0.97

Chapter 5. Zooplankton

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Chapter 5. Zooplankton

Introduction

Zooplankton are important food organisms for larval and juvenile salmon, striped bass, 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 upper 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 include monitoring copepods, cladocerans, and rotifers. Other mysid species were consistently identified and enumerated as of 1998 while newly introduced copepods 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.

Three types of equipment were deployed at each station: 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.

A towing frame at each station 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 and after forward momentum had ceased, the pump was lowered to the bottom and turned on. Then it was raised slowly to the surface, following a retrieval schedule based on depth that ensured the entire water column was sampled evenly. Pumped water was discharged into a 35 µm plankton net suspended in a large plastic garbage can filled with water to minimize 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 (usually to genus or species level) and enumeration.

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

Abundance is reported here only for the equipment that collects the taxon most efficiently: 1) the mysid net for all mysids, 2) the CB net for all calanoid copepods, the cyclopoid copepod *Acanthocyclops vernalis*, and all cladocerans, 3) the pump for all rotifers, and 4) both the CB and pump for the cyclopoid copepods *Limnoithona tetraspina* and *Oithona davisae*. Abundance for the latter two species is presented for both equipment 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 equipment 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 2011 CPUE for all stations sampled. Monthly abundance trends are presented for the top three to five ranked mysids, calanoid copepods, cyclopoid copepods, cladocerans, and rotifers.

Results

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*) is an introduced mysid that was first collected in the upper estuary in 1993 and has been the most abundant mysid in the upper estuary since 1995. In 2011, *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 19% of entrapment zone abundance. Upstream abundance was much lower at only 3% of entrapment zone abundance. Seasonal patterns were similar among zones, with abundance peaks in summer and early fall (Figure 5-2). Entrapment zone abundance rose steadily starting in April and peaked in June, after which abundance declined steadily in fall with slight increases in September and December. Although entrapment zone abundance declined steadily after June, *H. longirostris* remained relatively abundant in the entrapment zone through fall. Abundance had also declined upstream and downstream of the entrapment zone in fall.

Alienacanthomysis macropsis is a native brackish water mysid that was the second most abundant mysid in 2011 for the third year in a row, although numbers were very low (Table 5-2). *A. macropsis* abundance decreased from 2010 to 2011, although this apparent decrease may be due in part to lower salinity in 2011 that resulted in *A. macropsis* to be distributed further downstream than the sampling area. *A. macropsis* was not collected upstream of the entrapment zone in 2011 (Figure 5-3). In the entrapment zone, *A. macropsis* was only collected in January, February, November, and December in 2011 and in very low numbers. Downstream of the entrapment zone, *A. macropsis* was collected during every month of 2011. *A. macropsis* abundance peaked in January in Carquinez Strait, where densities were $12m^{-3}$; and again in March in San Pablo Bay, where densities were $9m^{-3}$. After the January and March peaks, 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 DWR staff can 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 2011, for the third year in a row (Table 5-2). Upstream of the entrapment zone *N. kadiakensis/japonica* was caught March through August, at very few stations and in very low numbers, indicating that if *N. japonica* is present in the estuary, abundance was very low in 2011 (Figure 5-4). Abundance was highest in the entrapment zone with a peak in May. Downstream abundance was slightly lower than in the entrapment zone and was highest April through August.

Neomysis mercedis was the fourth most abundant mysid again in 2011 for the second year in a row, 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 2011, *N. mercedis* abundance was highest upstream of the entrapment zone, with the highest densities May through July (Figure 5-5). In the entrapment zone, abundance was lower at only 52% of upstream abundance. In 2011, abundance peaked in the entrapment zone in July in Suisun Bay, but abundance was very low in all zones in every month. Downstream of the entrapment zone, *N. mercedis* was only caught during January, February, and May, 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 2011, *A. aspera* was the fifth most abundant mysid for the second year in a row (Table 5-2). *A. aspera* was only found downstream of the entrapment zone in 2011, as is typical for this brackish water species. Although *A. aspera* was only found in low numbers, small peaks occurred in May in San Pablo Bay and September in Carquinez Strait (Figure 5-6).

Calanoid Copepods

The introduced *Pseudodiaptomus forbesi* was the most abundant calanoid copepod in 2011 for the second year in a row (Table 5-3). *P. forbesi* was most abundant upstream of the entrapment zone with the highest abundances in July in the eastern delta and Suisun Marsh (Figure 5-7). Entrapment zone abundance was lower at only 67% of upstream abundance. Downstream abundance was much lower at only 6% of upstream abundance. Seasonal patterns were similar among the zones with the highest abundances occurring June through September in the

entrapment zone and downstream whereas upstream abundance was highest June through October.

The introduced *Acartiella sinensis* was the second most abundant calanoid copepod in 2011 (Table 5-3), moving up from fourth most abundant in 2010. *A. sinensis* abundance was highest in the entrapment zone from August through October (Figure 5-8) with peaks in August in Suisun Bay and in September in the lower Sacramento River. Downstream abundance was 36% of entrapment zone abundance, and was also highest late summer and fall in Suisun Bay. Upstream of the entrapment zone, abundance was much lower at only 5% of entrapment zone abundance. January through June abundance upstream of the entrapment zone was low, but increased in summer and fall, with a peak in August in the lower Sacramento River.

The genus *Acartia* consists of three native brackish water species, which fell to the third most abundant calanoid copepod taxon in 2011 from the second most abundant in 2010 (Table 5-3). *Acartia* spp. was the most common calanoid copepod collected downstream of the entrapment zone. In 2011, *Acartia* spp. was collected in very low numbers upstream of the entrapment zone in January and May (Figure 5-9). Within the entrapment zone, it was collected in January, February, and July, in very low numbers. Downstream abundance was highest January through April in San Pablo Bay, and lowest in September.

Sinocalanus doerrii fell to the fourth most abundant calanoid copepod in 2011 from the third in 2010 (Table 5-3). *S. doerrii* was most common upstream of the entrapment zone, where abundance peaked in May and June in Suisun Marsh and Suisun Bay (Figure 5-10). Entrapment zone abundance was 30% of upstream abundance with a similar seasonal trend. In 2011, upstream and within the entrapment zone, abundance increased through spring, peaked late spring through summer, then decreased in late summer and early fall before increasing again. Downstream abundance was much lower at only 2% of upstream abundance. Downstream abundance increased through spring and was highest in May, before declining again.

Eurytemora affinis was the fifth most abundant calanoid copepod in 2011 (Table 5-3), and has been since 2008. *E. affinis* was most common in the entrapment zone in 2011, where abundance was highest April through June and declined sharply thereafter, before increasing again in October (Figure 5-11). In 2011, abundance peaked in May in Suisun Marsh. Upstream abundance was 35% of entrapment zone abundance, and was higher in spring and fall, but declined in summer. Downstream abundance was lower at only 16% of entrapment zone abundance, and was highest in April before declining in summer and fall. 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 2011, with the highest abundance in the entrapment zone and downstream (Table 5-4). Abundance was highest most of the year in the pump samples (Figure 5-12). Pump abundance was highest in the entrapment zone in 2011; followed closely by downstream abundance, which was 97% of entrapment zone abundance. Upstream pump abundance was much lower at only 3% of entrapment zone abundance, with peaks in July and August, and again in October. Within the entrapment zone, abundance was highest July through October, while downstream abundance

was highest May through October. Pump abundance peaked in September and October in Suisun Bay and Suisun Marsh. CB abundance was also highest in the entrapment zone in 2011; followed by downstream abundance, which was 60% of entrapment zone abundance. Upstream CB abundance was much lower, and was only 3% of entrapment zone abundance. In the entrapment zone, CB abundance was highest May through July and again in November. CB abundance peaked in May in Carquinez Strait, and again in November in the lower Sacramento River. Downstream of the entrapment zone, pump abundance was relatively stable, with the exception of peaks in May and July. Upstream CB abundance was lower throughout the year with peaks in May, July, October and November.

Another introduced species, *Oithona davisae*, was the second most abundant cyclopoid copepod in the CB samples in 2011, and for the fourth year in a row was the second most abundant cyclopoid copepod in the pump samples (Table 5-4). *O. davisae* was most common downstream of the entrapment zone in both the CB and pump samples during late summer and fall (Figure 5-13). Both CB and pump abundance peaked in October in San Pablo Bay. Within and upstream of the entrapment zone, pump abundance was zero most of the year, except January in the entrapment zone and October upstream of the entrapment zone. Upstream of the entrapment zone, CB abundance was zero most of the year with small peaks in July and September. In the entrapment zone, CB abundance was highly variable with a peak in January.

The native *Acanthocyclops vernalis* was the third most common cyclopoid copepod in the CB net in 2011, for the sixth year in a row, and was most abundant in and upstream of the entrapment zone (Table 5-4). Upstream abundance was only 54% of entrapment zone abundance, and downstream abundance was only 37% of entrapment zone abundance. Upstream of the entrapment zone, *A. vernalis* abundance increased through spring and early summer, besides a small dip in May, but declined in fall (Figure 5-14). Entrapment zone abundance was highest in February, then declined throughout spring and summer and fell to zero in September, before peaking again in October. Downstream abundance peaked in April, then declined in summer before increasing again in fall. In 2011, *A. vernalis* abundance was highest in Suisun Marsh in June.

Cladocerans

The cladocerans most commonly collected by this study are freshwater, and therefore are mainly found upstream of the entrapment zone. *Bosmina* was the most abundant cladoceran genera in 2011, switching rankings with *Diaphanosoma*, which was most abundant in 2010. *Daphnia* was the third most abundant cladoceran genera for the fourth year in a row.

The most abundant cladoceran in 2011 was *Bosmina* spp. (Table 5-5). It was most common upstream of the entrapment zone where abundance remained steady through spring and summer, except for a small dip in August, increased again in September and declined thereafter (Figure 5-15). Within and downstream of the entrapment zone, seasonality was similar with a peak in April that coincided with higher outflow. *Bosmina* abundance peaked in the eastern delta in 2011 during September and October in Disappointment Slough.

Diaphanosoma spp. was the second most abundant cladoceran in 2011 (Table 5-5). It was most common upstream of the entrapment zone where abundance increased through spring and summer, and peaked in September before declining in fall (Figure 5-16). Entrapment zone abundance was zero during most months of 2011, except in April, June, July, and September.

Downstream of the entrapment zone, *Diaphanosoma* was only present June through August, and in very low numbers. In 2011, abundance peaked during August and September in the eastern delta in Disappointment Slough.

Daphnia spp. was the third most abundant cladoceran in 2011 (Table 5-5). It was most common upstream of the entrapment zone, where it was most abundant April through July (Figure 5-17). After a small dip in March, upstream abundance remained steady through spring and early summer, before declining sharply in August. Abundance was lower most of the year in the entrapment zone, except for a peak in April. Downstream abundance was even lower, with a small peak in April. No *Daphnia* were found August through November in the entrapment zone, and none were found July through November downstream of the entrapment zone. In 2011, *Daphnia* abundance was highest in July in the eastern delta near Stockton.

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 remained the same in 2011, although their relative rankings changed for the first time since 2008.

Synchaeta spp., which includes the brackish water species *Synchaeta bicornis*, was the most common rotifer in 2011, as it has been since 2008 (Table 5-6). It was most abundant in the entrapment zone, where abundance steadily increased January through May, then dipped in June and July, before increasing again in August and September (Figure 5-18). Downstream of the entrapment zone, abundance was relatively high all year, but was slightly lower in January and February, and again in November and December. Upstream of the entrapment zone, abundance was relatively stable all year, with a peak in April and a dip in August. In 2011, *Synchaeta* abundance was highest during September in Montezuma Slough in Suisun Bay.

Keratella spp. was the second most abundant rotifer in 2011, switching places with *Polyarthra* spp. which had been the second most abundant since 2008 (Table 5-6). It was most abundant upstream of the entrapment zone, where abundance was relatively stable throughout the year with a small peak in April (Figure 5-19). Entrapment zone abundance, although lower also had a small peak in April, but fell to zero in August before increasing again in fall. Downstream abundance was much lower, also had a small peak in April, but fell to zero in July and September. In 2011, *Keratella* abundance was highest during April in Suisun Slough in Suisun Bay.

Polyarthra spp. was the third most abundant rotifer in 2011 (Table 5-6). It was most abundant upstream of the entrapment zone, where abundance was relatively stable most of the year and highest in September (Figure 5-20). In the entrapment zone, abundance was highest in April, and then declined through summer and fall before increasing again in December. Downstream of the entrapment zone, abundance peaked in April, but fell to zero in July, August, and December. In 2011, *Polyarthra* abundance was highest in the eastern delta in September.

Summary

In 2011, the most common zooplankton taxa were the same as previous years, although some of their relative rankings changed. Monthly abundance patterns in 2011 were slightly different than

in other recent years, presumably due to higher flows in 2011. While abundance of some taxa was higher in 2011 than 2010, others were lower. *H. longirostris, A. macropsis,* and *N. kadiakensis* were again the most abundant mysids in 2011, as they were in 2010. *H. longirostris, A. macropsis,* and *A. aspera* abundance decreased, while *N. kadiakensis* and *N. mercedis* abundance increased in 2011 from 2010. *P. forbesi* and *A. sinensis* abundance increased in 2011 from 2010, while *Acartia* spp. and *S. doerrii* decreased, causing *A. sinensis* to move up from fourth most abundant in 2010 to second most abundant in 2011. *E. affinis* remained the fifth most abundant calanoid copepod in 2011, as it was in 2010, and 2011 abundance was double the 2010 abundance. *L. tetraspina, O. davisae,* and *A. vernalis* were again the most abundant cyclopoid copepods in the CB samples and abundance of each increased in 2011 from 2010. *L. tetraspina* switched ranks with *O. davisae* in 2011, and became the most abundant cyclopoid copepod in the CB samples. 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 2011 from 2010. *Bosmina* spp., *Diaphanosoma* spp., and *Daphnia* spp. were again the most abundant cladocerans in 2011, although abundance of each decreased in 2011 from 2010. *Bosmina* spp. was the most abundant cladoceran in 2011, as it was in 2008 and 2009, switching ranks with *Diaphanosoma* spp., which was most abundant in 2010. *Synchaeta* spp., *Keratella* spp., and *Polyarthra* spp. remained the most abundant rotifers in 2011, and abundance of each increased in 2011 from 2010. *Synchaeta* spp. remained the most abundant, but *Keratella* spp. was second most abundant in 2011, switching ranks with *Polyarthra* spp., which was second most abundant in 2010.

Chapter 5. Appendix

Figure 5-1 Zooplankton monitoring stations

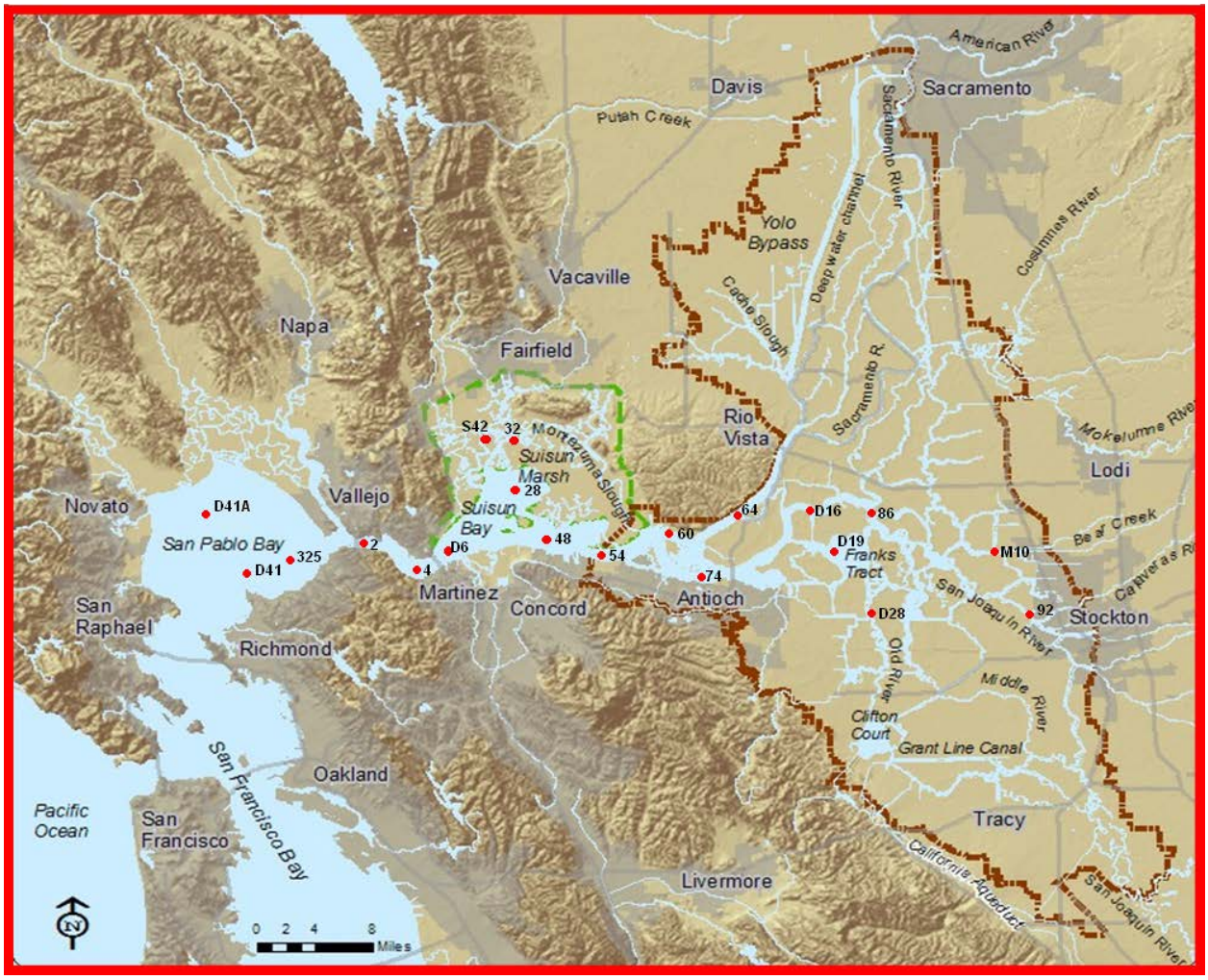

Figure 5-2 Monthly *Hyperacanthomysis longirostris* (*Acanthomysis bowmani*) abundance upstream, within, and downstream of the entrapment zone in 2011

Figure 5-3 Monthly *Alienacanthomysis macropsis* abundance upstream, within, and downstream of the entrapment zone in 2011

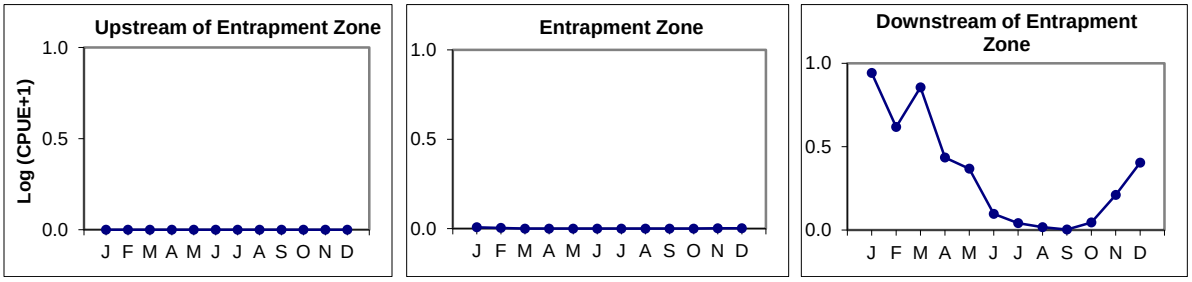

Figure 5-4 Monthly *Neomysis kadiakensis/japonica* abundance upstream, within, and downstream of the entrapment zone in 2011

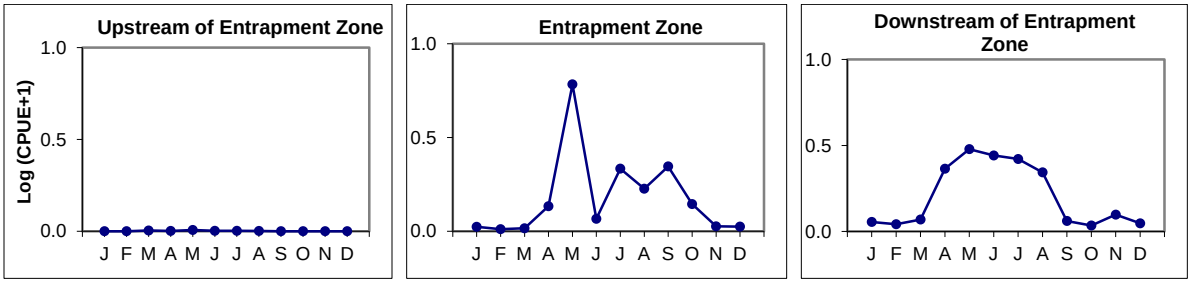

Figure 5-5 Monthly *Neomysis mercedis* abundance upstream, within, and downstream of the entrapment zone in 2011

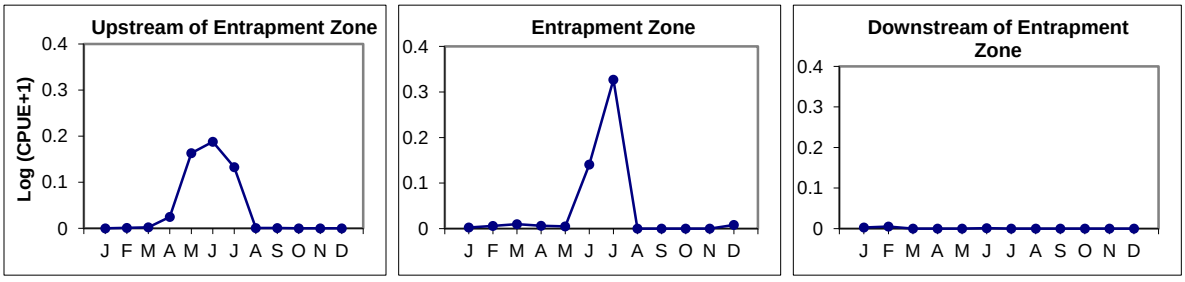

Figure 5-6 Monthly *Acanthomysis aspera* abundance upstream, within, and downstream of the entrapment zone in 2011

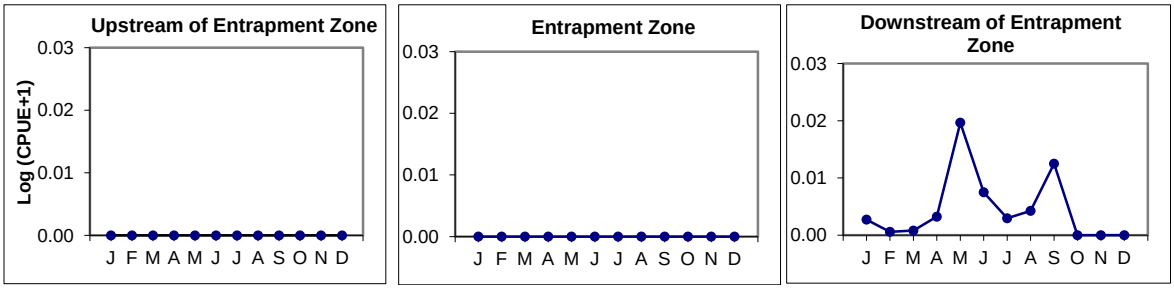

Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, within, and downstream of the entrapment zone in 2011

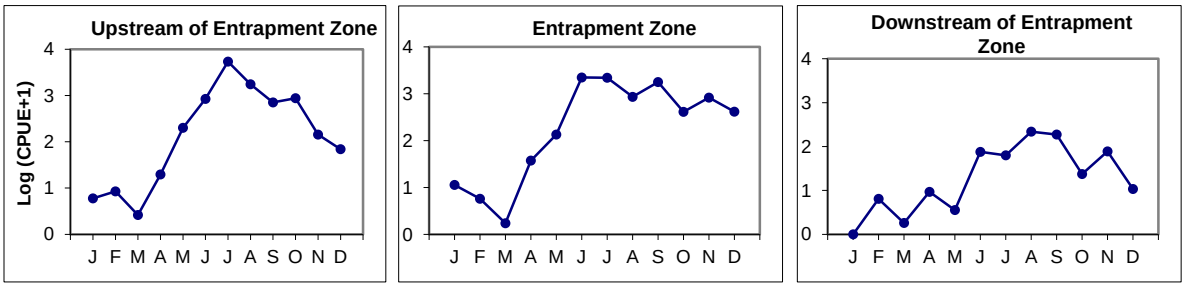

Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, within, and downstream of the entrapment zone in 2011

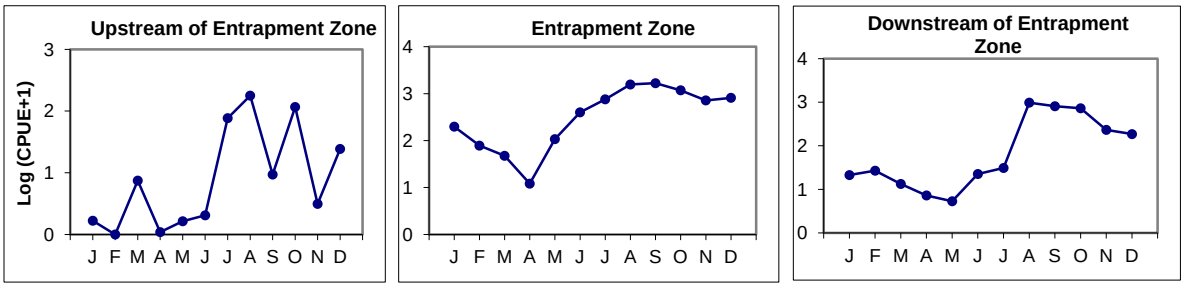

Figure 5-9 Monthly *Acartia* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

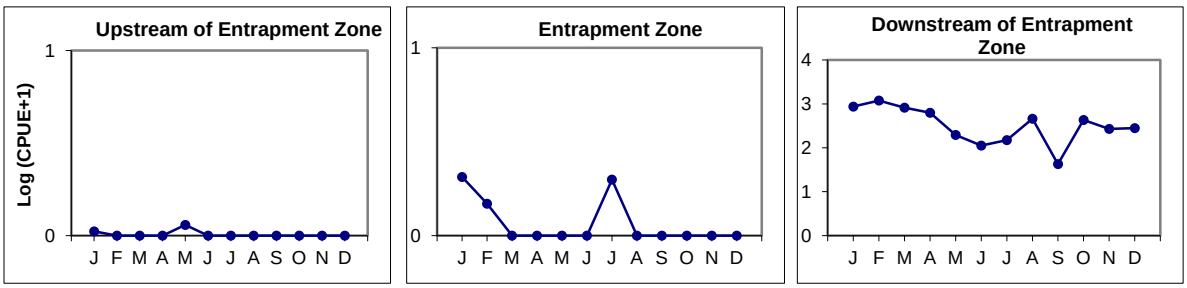

Figure 5-10 Monthly *Sinocalanus doerrii* abundance upstream, within, and downstream of the entrapment zone in 2011

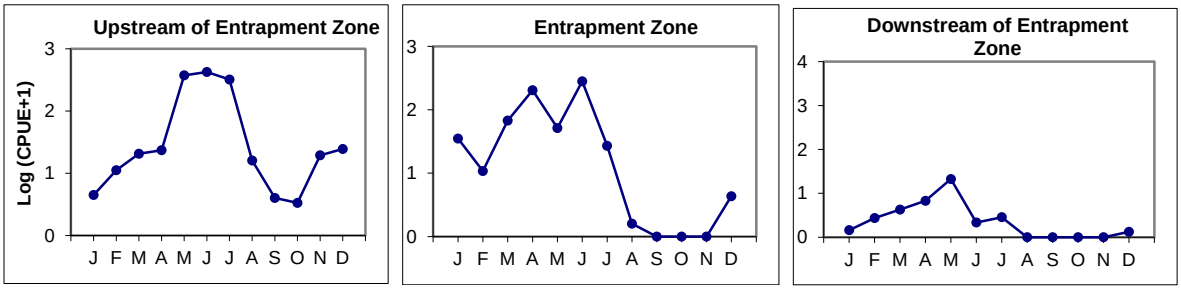

Figure 5-11 Monthly *Eurytemora affinis* abundance upstream, within, and downstream of the entrapment zone in 2011

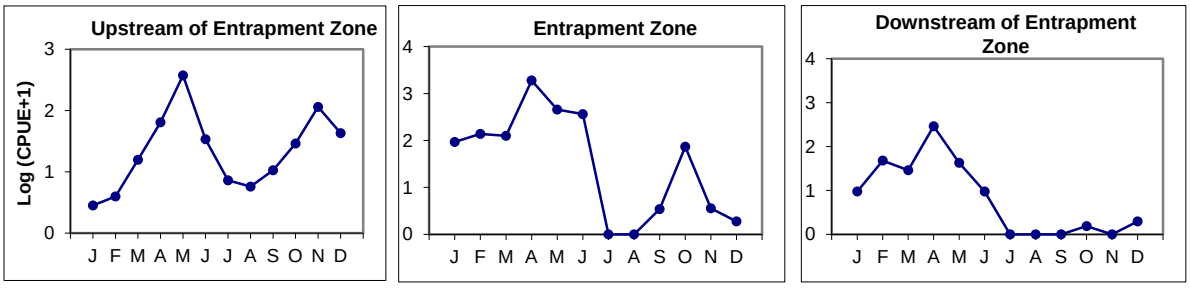

Figure 5-12 Monthly *Limnoithona tetraspina* abundance upstream, within, and downstream of the entrapment zone in 2011. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

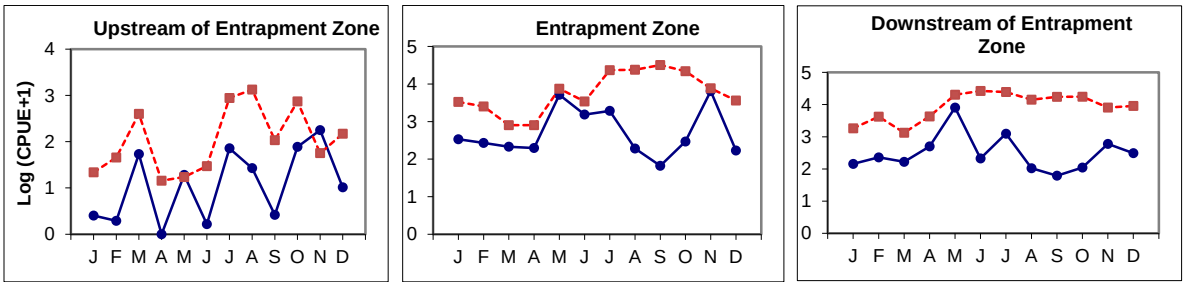

Figure 5-13 Monthly *Oithona davisae* abundance upstream, within, and downstream of the entrapment zone in 2011. Pump abundance is blue circles with solid line and CB abundance is red diamonds with dashed line

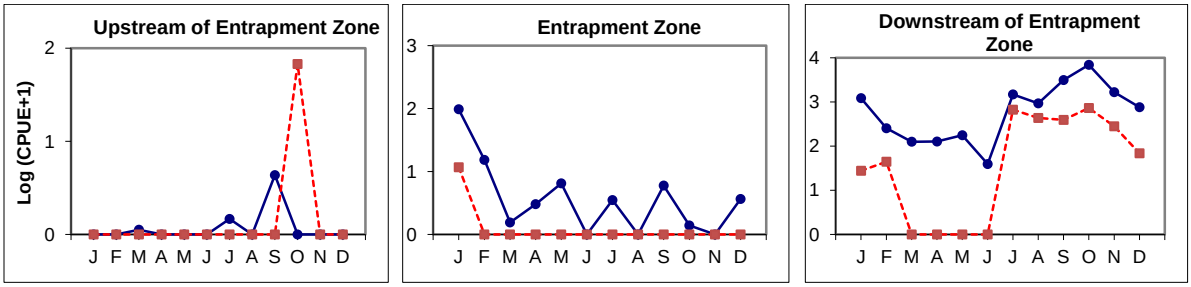

Figure 5-14 Monthly *Acanthocyclops vernalis* abundance upstream, within, and downstream of the entrapment zone in 2011

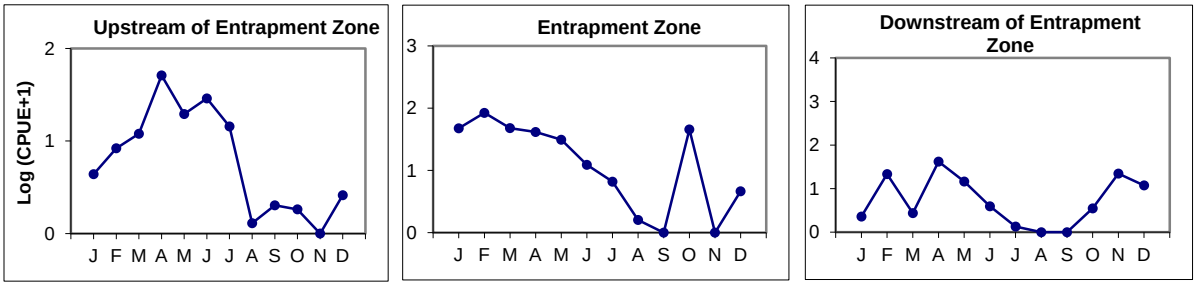

Figure 5-15 Monthly *Bosmina* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

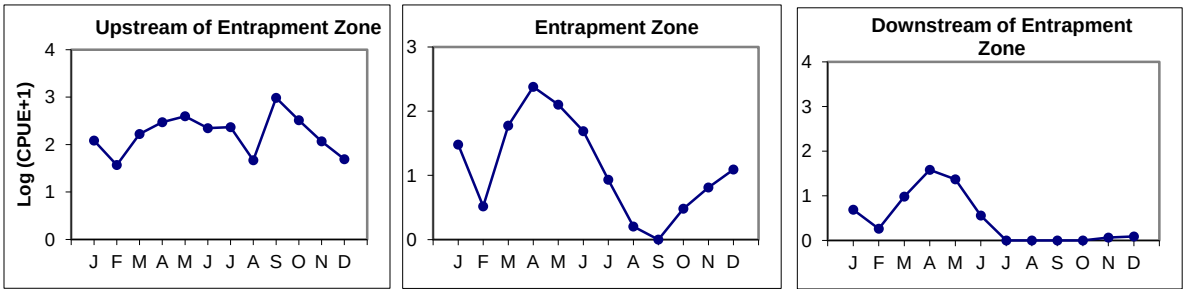

Figure 5-16 Monthly *Diaphanosoma* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

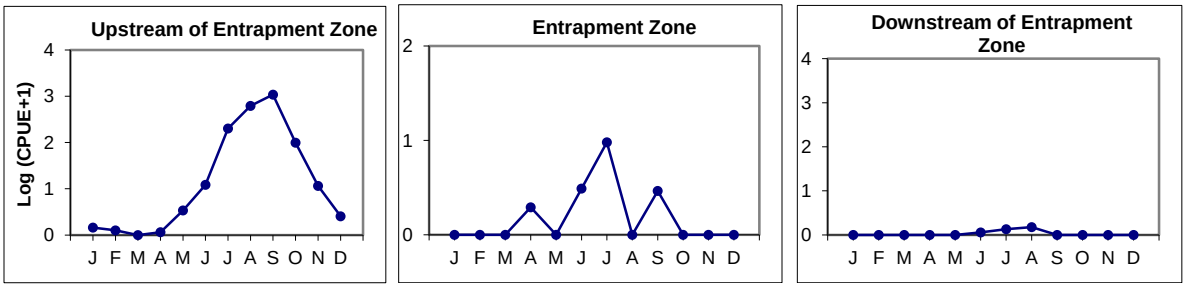

Figure 5-17 Monthly *Daphnia* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

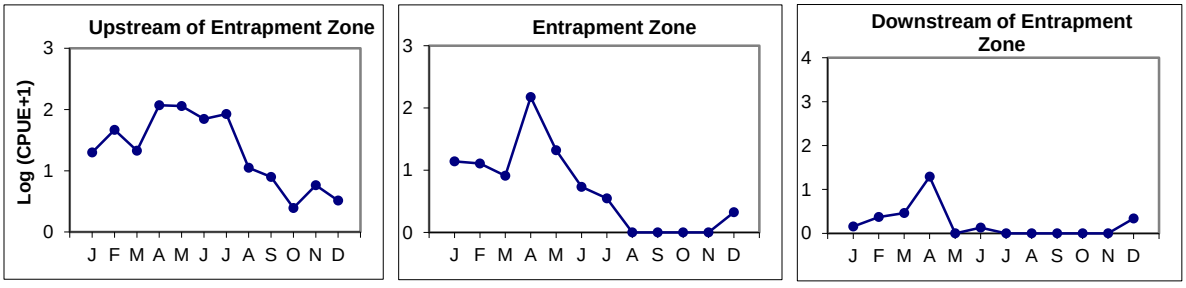

Figure 5-18 Monthly *Synchaeta* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

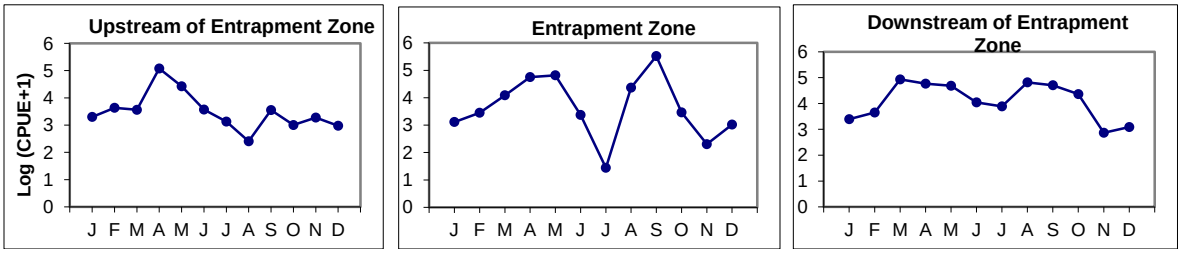

Figure 5-19 Monthly *Keratella* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

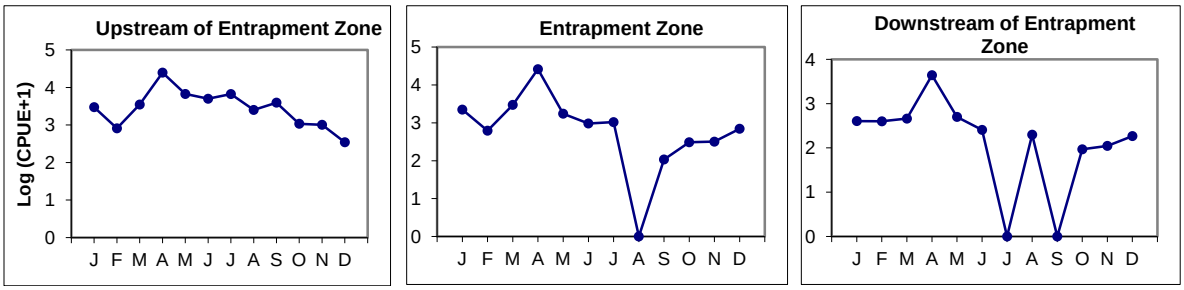

Figure 5-20 Monthly *Polyarthra* spp. abundance upstream, within, and downstream of the entrapment zone in 2011

Table 5-1 Number of stations sampled monthly in each zone in 2011

Survey Month	Upstream	Entrapment Zone	Downstream	All Zones
January	9	5	5	19
February	8	3	8	19
March	12	3	7	22
April	14	2	5	21
May	14	3	4	21
June	14	2	6	22
July	14	2	5	21
August	9	4	6	19
September	8	4	6	18
October	8	5	5	18
November	6	3	8	17
December	6	3	9	18
All Months	**122**	**39**	**74**	**235**

Table 5-2 Mysid abundance upstream, within, and downstream of the entrapment zone in 2011

Mysids	Upstream	Entrapment Zone	Downstream	All Zones
Hyperacanthomysis longirostris	0.26	7.72	1.50	1.898
Alienacanthomysis macropsis	0.00	0.00	1.93	0.605
Neomysis kadiakensis	0.00	0.74	0.64	0.326
Neomysis mercedis	0.16	0.08	0.00	0.098
Acanthomysis aspera	0.00	0.00	0.01	0.003

Table 5-3 Calanoid copepod abundance upstream, within, and downstream of the entrapment zone in 2011

Calanoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
Pseudodiaptomus forbesi	987.8	658.0	55.3	636.5
Acartiella sinensis	32.5	703.3	251.9	214.4
Acartia spp.	0.0	0.2	469.7	149.2
Sinocalanus doerrii	135.9	40.5	2.3	77.5
Eurytemora affinis	67.7	192.7	30.9	76.9

Table 5-4 Cyclopoid copepod abundance upstream, within, and downstream of the entrapment zone in 2011

Cyclopoid Copepods	Upstream	Entrapment Zone	Downstream	All Zones
CB net				
Limnoithona tetraspina	32.4	1241.0	745.4	461.1
Oithona davisae	0.3	14.9	1,313.3	419.7
Acanthocyclops vernalis	14.6	27.2	10.0	15.3
Pump				
Limnoithona tetraspina	315	12103	11696	5830
Oithona davisae	4	1	208	67

Table 5-5 Cladocerans abundance upstream, within, and downstream of the entrapment zone in 2011

Cladocerans	Upstream	Entrapment Zone	Downstream	All Zones
Bosmina spp.	248.7	34.7	5.1	135.6
Diaphanosoma spp.	141.5	0.8	0.1	73.0
Daphnia spp.	52.0	12.7	1.8	29.5

Table 5-6 Rotifers abundance upstream, within, and downstream of the entrapment zone in 2011

Rotifers	Upstream	Entrapment Zone	Downstream	All Zones
Synchaeta spp.	18,629	46,155	28,298	26,233
Keratella spp.	6,164	2,267	519	3,753
Polyarthra spp.	5,774	2,186	273	3,460

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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. 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, DWR implemented major programmatic revisions to form the current program. Since 1996, monitoring has 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 2011, field sampling was conducted monthly at 10 sites throughout the estuary. Figure 6-1 shows the location of each site and Table 6-1 summarizes latitude, longitude, salinity range, and substrate composition for each site. The research vessels *San Carlos*, *Endeavor*, and *Whaler*, all equipped with a hydraulic winch and Ponar dredge, were used to conduct this sampling. The Ponar dredge samples a bottom area of 0.053 m^2. Five grabs were done using the Ponar at each benthic monitoring site every month. Four of these grabs were used for organism enumeration and identification and one was used for sediment analysis. The contents of the dredge were washed over a Standard No. 30 stainless steel mesh screen (0.595 mm openings) to remove as much of the substrate as possible. All material remaining on the screen was preserved in approximately 20% buffered formaldehyde containing Rose Bengal dye and then 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[11], a private laboratory under contract with DWR, identified and enumerated organisms in the macrofaunal samples. A

[11] 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 in 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[12] for analysis.

Particle size analysis and dry weight measurements were performed for each sediment sample. Sediment was analyzed for particle size according to the American Society of Testing and Materials Protocol D422 (ASTM 2000a). Particles were sorted into the following categories: sand (>75 µm) and fine (<75 µm). The organic content of the sediment was determined using the American Society of Testing and Materials Protocol D2974, Method C (ASTM 2000b). For this method, the ash-free dry weight of the sample was used to determine the organic content of the sediment.

Results

Benthic Composition and Abundance

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 211 species collected in 2011, 10 represented 81% of all organisms collected. These species are listed below.

Numerically Dominant Species

Amphipods, phylum Arthropoda

Ampelisca abdita
Americorophium spinicorne
Americorophium stimpsoni
Corophium alienense
Gammarus daiberi

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

Asian Clams, phylum Mollusca

Potamocorbula (formerly *Corbula*) *amurensis* (Huber 2010)

Corbicula fluminea

Sabellid Polychaete, phylum Annelida

Manayunkia speciosa

Tubificid Worms, phylum Annelida

Limnodrilus hoffmeisteri

Varichaetadrilus angustipenis

Of the 10 dominant species, *P. amurensis, and A. abdita,* represent macrofauna that inhabit a typically higher saline environment and were found in San Pablo Bay, Suisun Bay, and Grizzly Bay. *C. alienense, A. spinicorne,* and *A. stimpsoni* tolerate a wider range of salinity. They were collected both in the higher saline western sites and the more brackish-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 2011 fell into 9 phyla:

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

Of the 9 phyla identified, Annelida, Arthropoda, and Mollusca constituted 98% 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. Very rare phyla (contributing a total of <100 individuals per m^2 over the year) were left off these charts.

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 2011 ranged from 40,690 org/m^2 in June at C9 to 3,097 org/m^2 in May at D16. Minimum abundances ranged from 8,458 org/m^2 in October at D4 to 152 org/m^2 in March at D16.

Site C9: South Delta

Maximum abundance in 2011 occurred in June with a total of 40,690 org/m^2 (Figure 6-3). *L. hoffmeisteri* (12,022 org/m^2) was the most abundant species. The minimum abundance in 2011 occurred in February with a total of 5,662 org/m^2. *V. angustipenis* (1,734 org/m^2) was the most abundant species.

Site P8: South Delta

The maximum abundance in 2011 occurred in August with a total of 18,835 org/m^2 (Figure 6-4). *A. stimpsoni* (6,436 org/m^2) was the most abundant species. The minimum abundance in 2011 occurred in December with a total of 3936 org/m^2. *A. stimpsoni* and *V. angustipenis* (both 789 org/m^2) were the most abundant species.

Site D28A: Central Delta

Maximum abundance in 2011 occurred in May with a total of 11,210 org/m^2 (Figure 6-5). The ostracod *Cyprideis* sp. *A* (1,292 org/m^2) was the most abundant species. The minimum abundance in 2011 occurred in March with a total of 3,631 org/m^2. *Cyprideis* sp. *A* (1,249 org/m^2) was the most abundant species.

Site D16: Lower San Joaquin River

Maximum abundance in 2011 occurred in May with a total of 3,097 org/m^2 (Figure 6-6). *C. fluminea* (561 org/m^2) was the most abundant species. The minimum abundance in 2011 occurred in March with a total of 152 org/m^2; there was no dominant species.

Site D24: Lower Sacramento River

Maximum abundance in 2011 occurred in October with a total of 3,206 org/m^2 (Figure 6-7). *C. fluminea* (2,161 org/m^2) was the dominant species. The minimum abundance in 2011 occurred in August with a total of 1,634 org/m^2. *C. fluminea* (1,049 org/m^2) was the dominant species.

Site D4: Lower Sacramento River

Maximum abundance in 2011 occurred in July with a total of 27,787 org/m^2 (Figure 6-8). *A. spinicorne* (7,828 org/m^2) was the most abundant species. The minimum abundance in 2011 occurred in October with a total of 8,458 org/m^2. *A. stimpsoni* (2,641 org/m^2) was the most abundant species.

Site D6: Suisun Bay

Maximum abundance in 2011 occurred in November with a total of 9,709 org/m^2 (Figure 6-9). *P. amurensis* (9,048 org/m^2) was the dominant species. The minimum abundance in 2011 occurred in August with a total of 1,672 org/m^2. *P. amurensis* (1,397org/m^2) was the dominant species.

Site D7: Suisun Bay

Maximum abundance in 2011 occurred in September with a total of 12,112 org/m^2 (Figure 6-10). *A. stimpsoni* (3,809 org/m^2) was the most abundant species. The minimum abundance in 2011

occurred in June with a total of 3,643 org/m^2. *C. alienense* (1,786 org/m^2) was the dominant species.

Site D41: San Pablo Bay

Maximum abundance in 2011 occurred in November with a total of 7,716 org/m^2 (Figure 6-11). *A. abdita* (5,743 org/m^2) was the dominant species. The minimum abundance in 2011 occurred in June with a total of 890 org/m^2. There were no dominant species.

Site D41A: San Pablo Bay

Maximum abundance in 2011 occurred in October with a total of 18,261 org/m^2 (Figure 6-12). *P. amurensis* (12,279 org/m^2) was the dominant species. The minimum abundance in 2011 occurred in February with a total of 2,609org/m^2. *A. abdita* (1,078 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 2011, organic content ranged from 0.3% at site D28A to 40.7% at site D4.

Site C9: South Delta

Sand with silt dominated the sediment content at C9 in most of 2011, except for April through August, which was mainly silty sand (Figure 6-13). The percentage of organic content ranged from 1.2% to 3.7%. Higher measurements of organic matter coincided with higher amounts of finer sediments.

Site P8: South Delta

Through 2011 the sediment at P8 was most often about four-fifths silt with sand, with large increases of sand in June through August as well as November and December (Figure 6-14). The organic matter ranged from 2.8% to 7.8%, with the higher organic values typically coinciding with finer sediments.

Site D28A: Central Delta

Sandy sediment was dominant during every month at site D28A for 2011, with slight increases in silt for January, June, and July (Figure 6-15). The organic matter ranged from 0.3% to 5.5%. Larger quantities of organic matter coincided with an increase in fine sediment.

Site D16: Lower San Joaquin River

Silt dominated the sediment type at site D16 for 2011 with the exception of February, March, May, and April, when sand greatly increased (Figure 6-16). The amount of organic matter at this site ranged from 0.5% to 5.7% with higher values coinciding with higher percentages of fine sediment.

Site D24: Lower Sacramento River

Sand dominated the sediment at site D24 during 2011 (Figure 6-17). The amount of organic matter ranged from 0.9% to 2.4%.

Site D4: Lower Sacramento River

Silt with sand dominated at site D4 during 2011, with the exception of a large increase of sand in August (Figure 6-18). The percent of organic matter at this site was exceptionally high during April and September compared with the rest of the year, and ranged from 4.8% to 40.7%.

Site D6: Suisun Bay

Silty clay dominated site D6 throughout 2011 (Figure 6-19). Organic matter at this site remained quite constant ranging from 2.5% to 6.9%.

Site D7: Suisun Bay

Silty clay dominated site D7 for all of 2011 (Figure 6-20). The organic matter at this site was stable throughout the year ranging from 3.0% to 7.3%.

Site D41: San Pablo Bay

Several months at site D41 in 2011 contained higher percentages of sandy sediment while January, March, and November contained a slightly higher percent of silty fines. However, May, June, July, and September were dominated by silty sand (Figure 6-21). The organic matter ranged from 1.1% to 5.8%, generally stable throughout the year.

Site D41A: San Pablo Bay

Fine clay and silt sediments dominated site D41A for all of 2011 (Figure 6-22). The percent organic matter at this site evenly ranged from 2.4% to 6.5%.

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 2011 fell into 9 phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, Phoronida, and Platyhelminthes. Of these 9 phyla, Annelida, Arthropoda, and Mollusca constituted 98% of the organisms collected during the study period. Ten species represent 81% of all organisms collected during this period. These species are: (1) The amphipods—*A. abdita, A. spinicorne, A. stimpsoni, C. alienense,* and *G. daiberi*; (2) The Sabellid polychaete—*M. speciosa;* (3) the Tubificid worms—*V. angustipenis and L. hoffmeisteri*; and (4) the Asian clams—*P. amurensis* and *C. fluminea*.

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 edition). Washington DC, 10.60-10.74.

[ASTM] American Society of Testing and Materials. 2000a. *Soil and Rock (I): D420 - D5779, 04.08*, Protocol D422.

[ASTM] American Society of Testing and Materials. 2000b. *Soil and Rock (I): D420 - D5779, 04.08*, Protocol D2974, Method C.

Huber, M. 2010. *Potamocorbula amurensis* (Schrenck 1861). In: Bouchet, P.; Gofas, S.; Rosenberg, G. 2010 World Marine Mollusca database. Accessed through: World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=search on 2012-05-03.

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

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

Chapter 6. Appendix

Figure 6-1 Location of macrobenthic monitoring stations

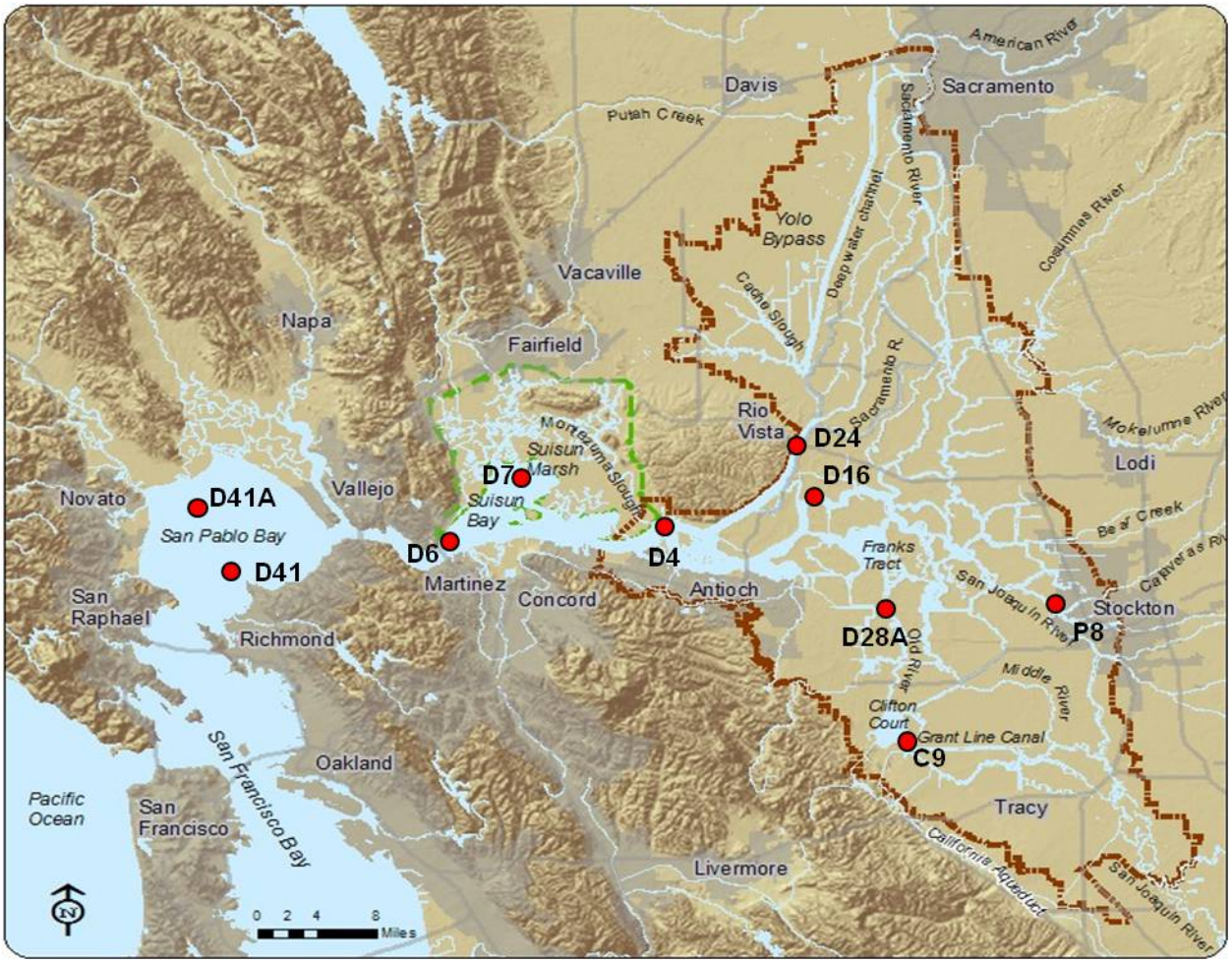


Figure 6-2 Total contribution by phyla for all stations, 2011

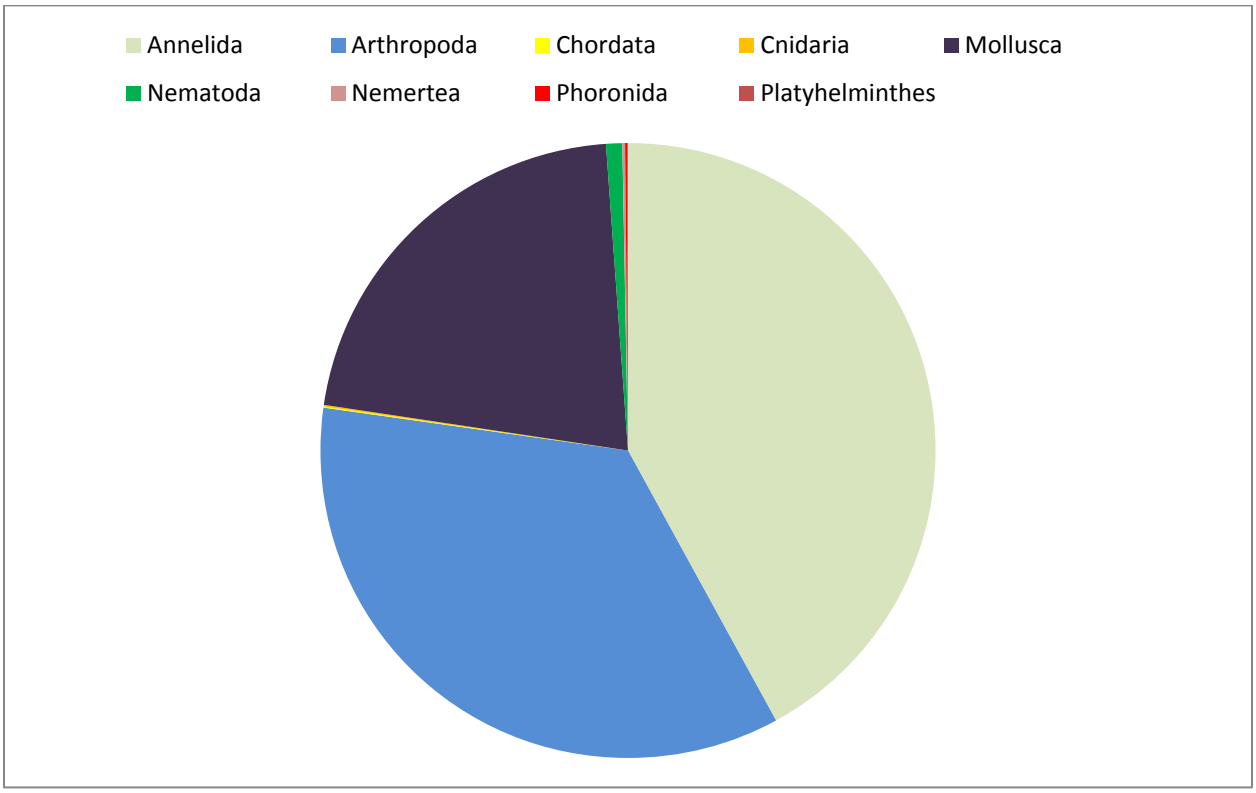


Figure 6-3 Total abundance at C9, 2011

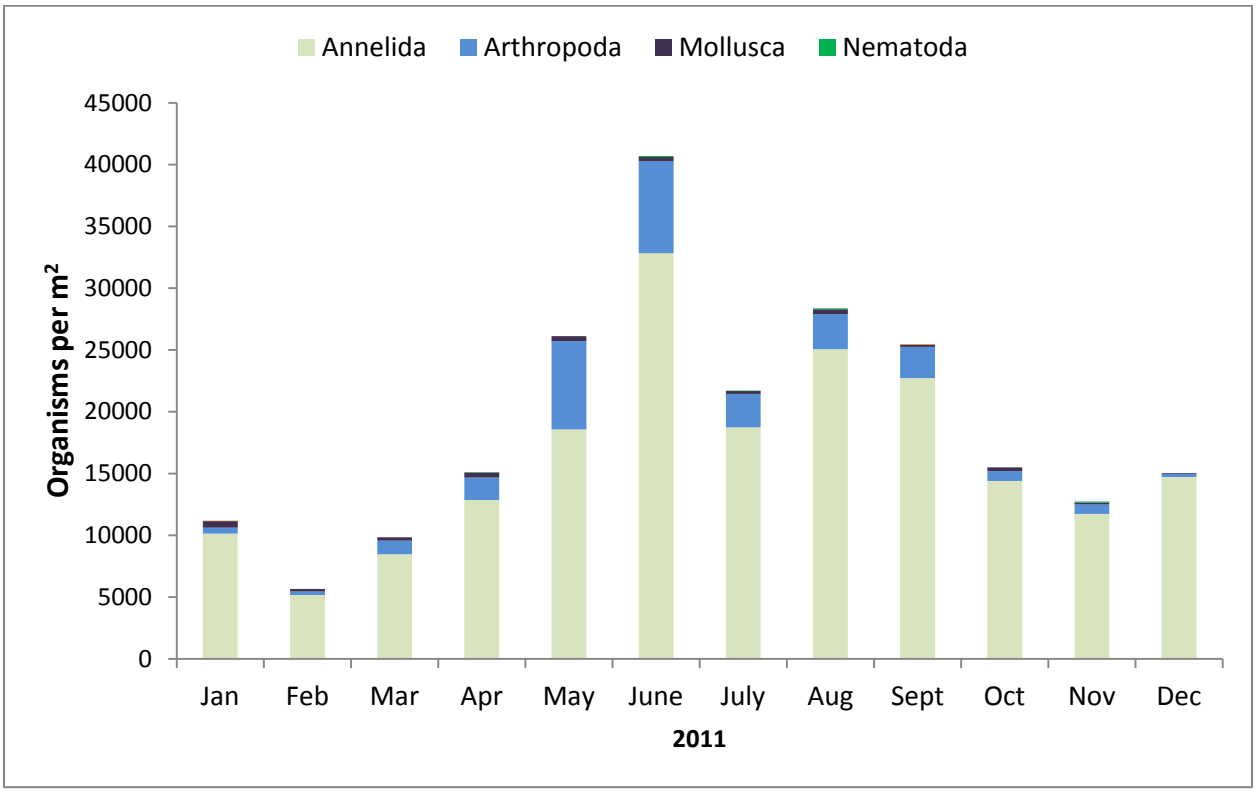


Figure 6-4 Total abundance at P8, 2011

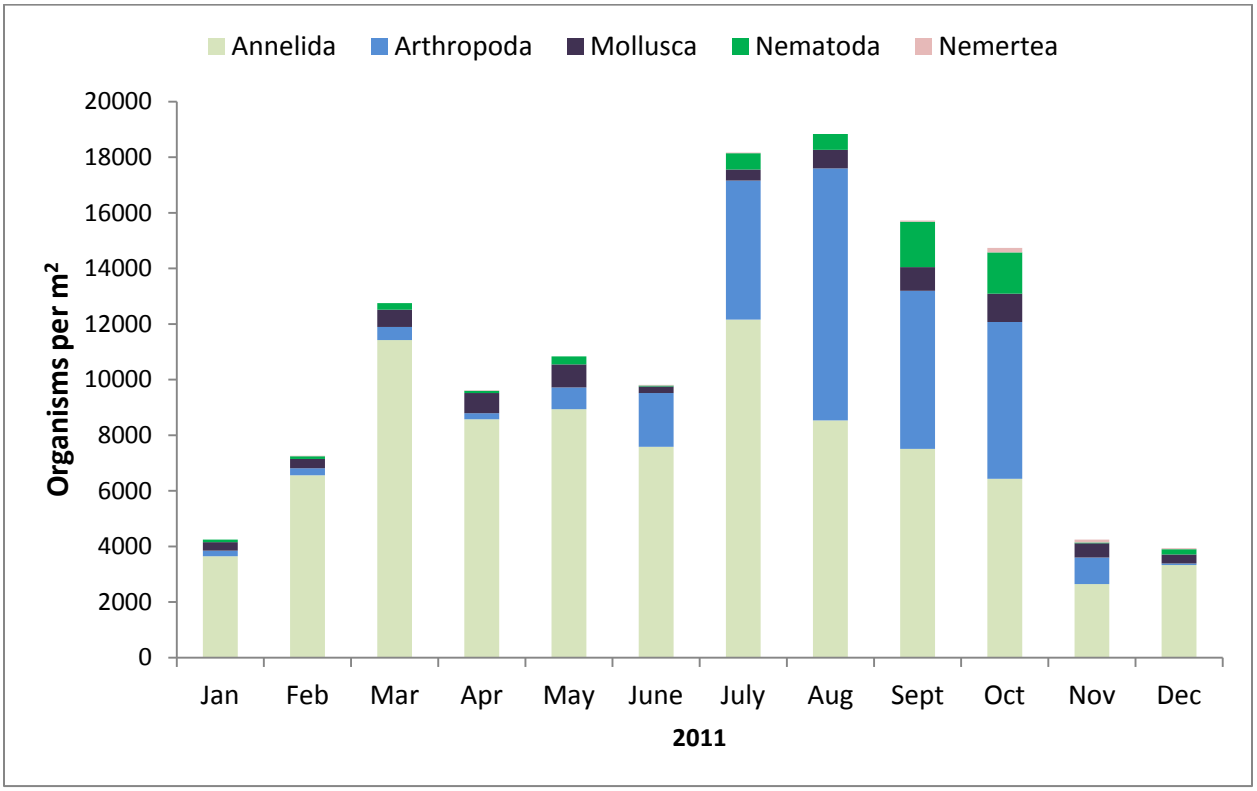


Figure 6-5 Total abundance at D28A, 2011

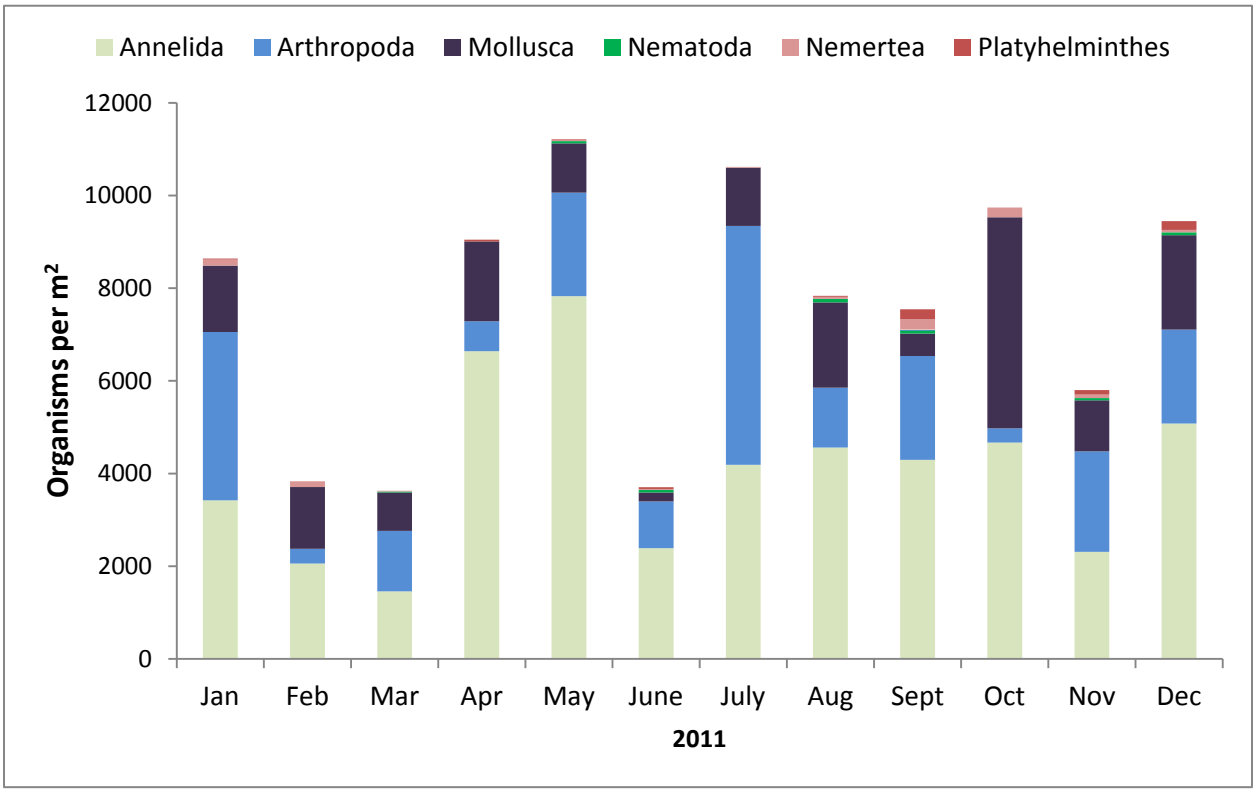


Figure 6-6 Total abundance at D16, 2011

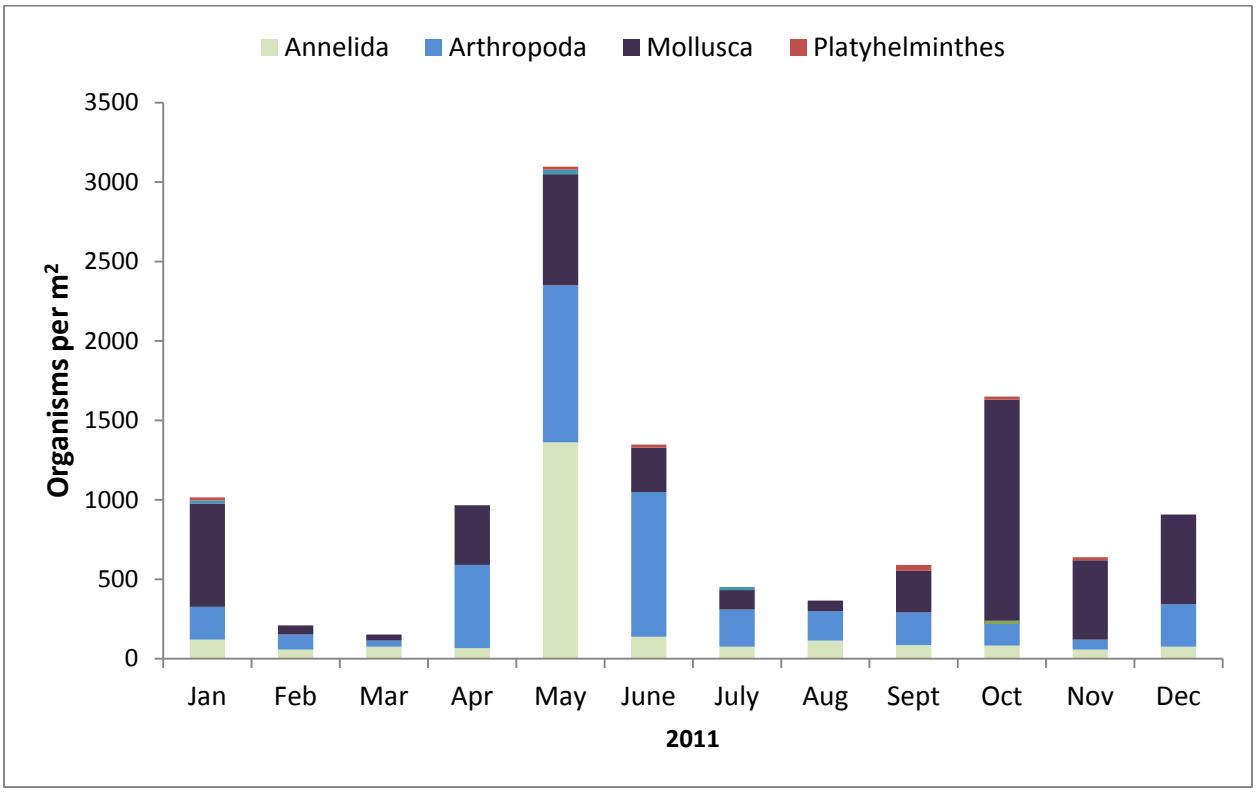


Figure 6-7 Total abundance at D24, 2011

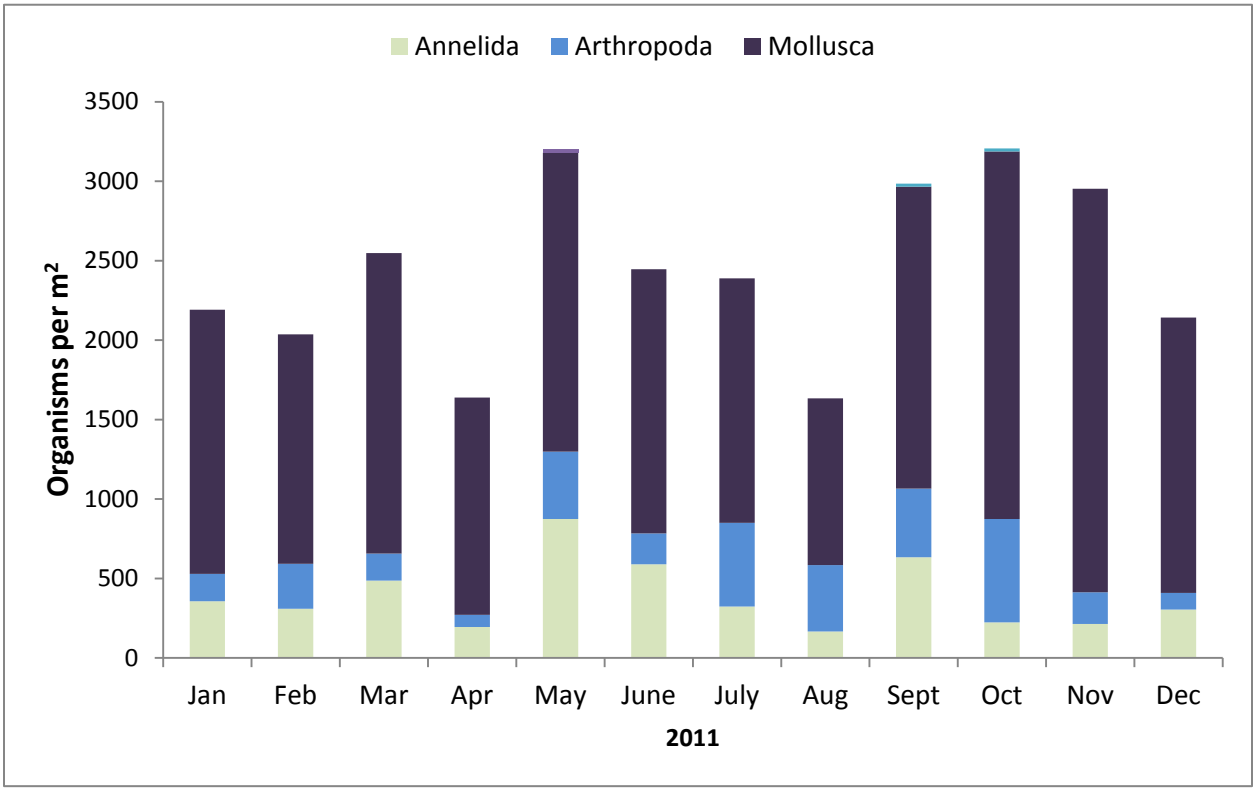


Figure 6-8 Total abundance at D4, 2011

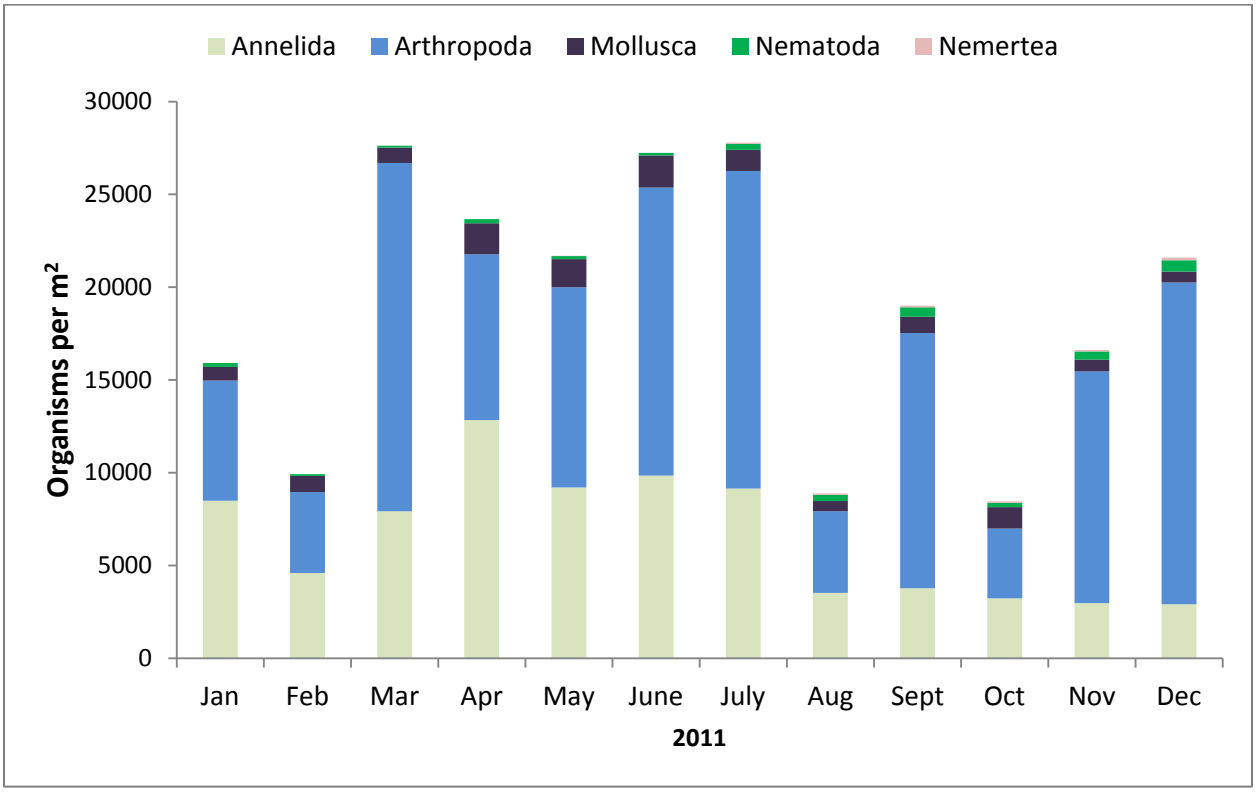


Figure 6-9 Total abundance at D6, 2011

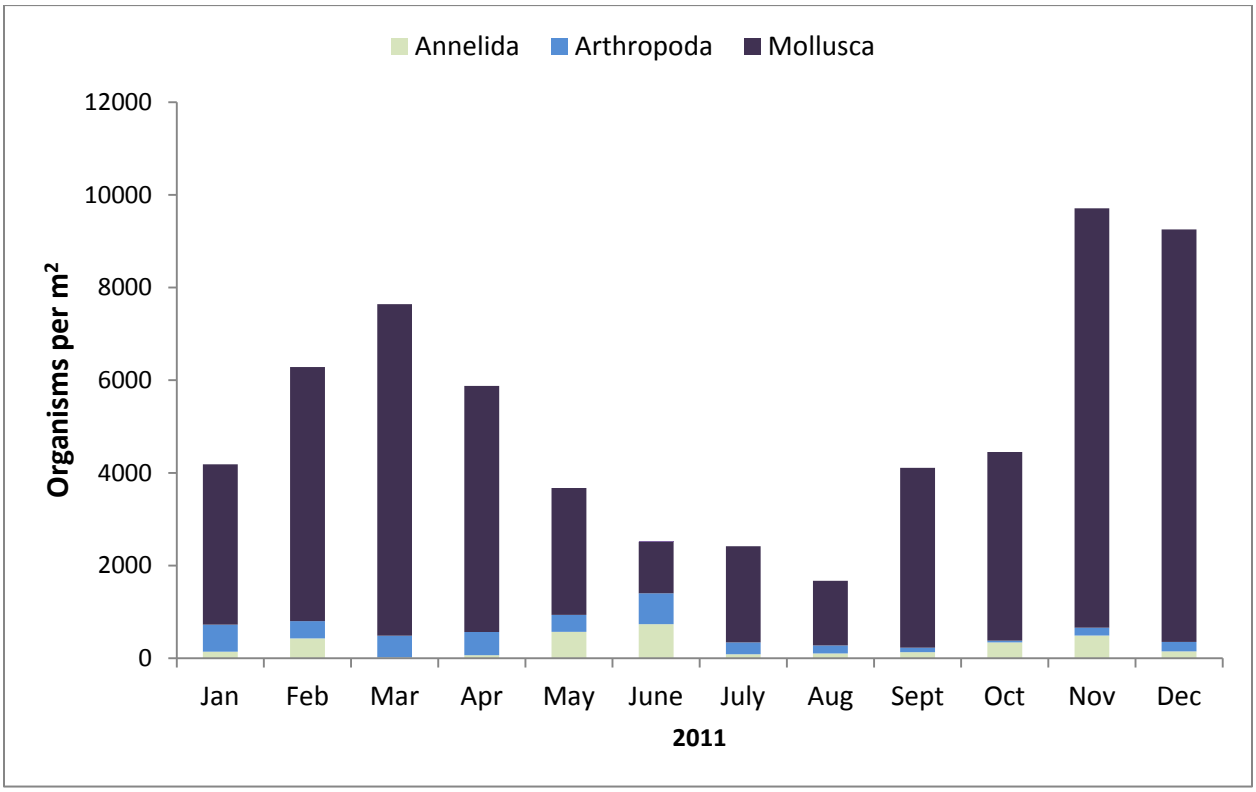


Figure 6-10 Total abundance at D7, 2011

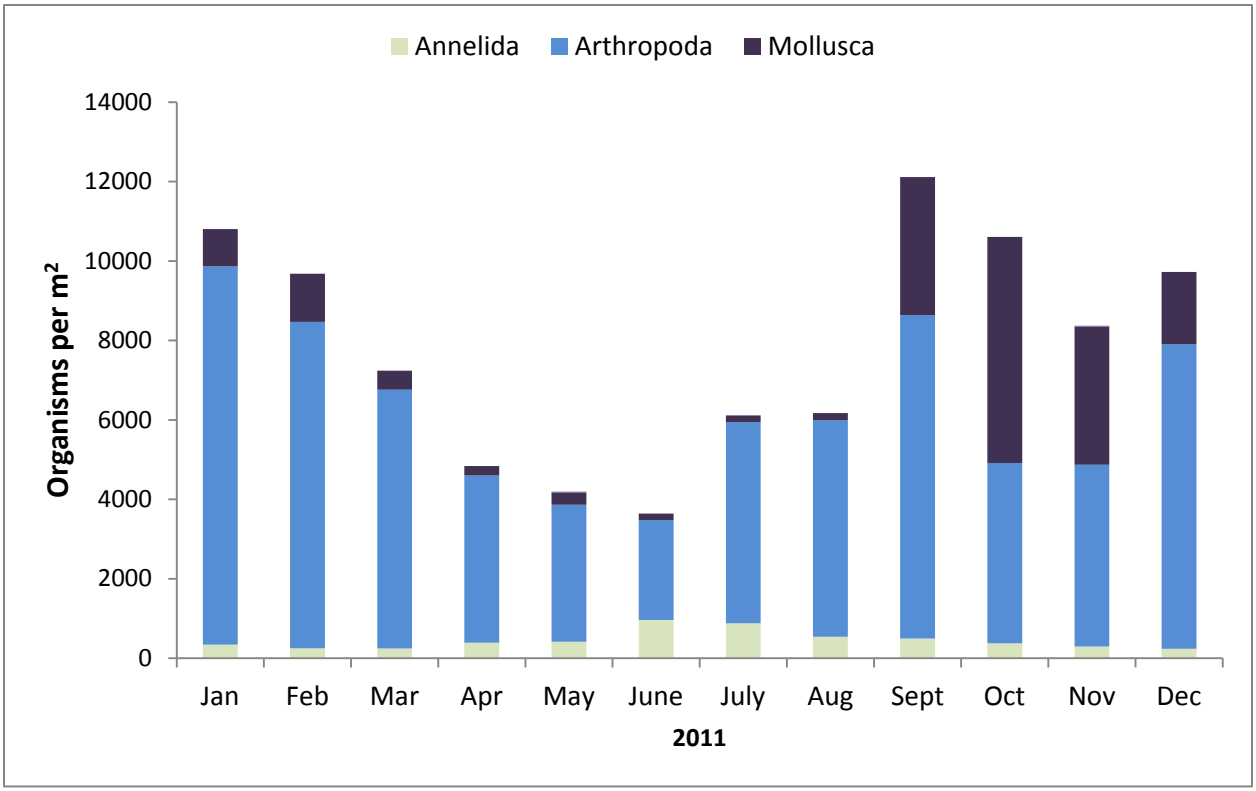


Figure 6-11 Total abundance at D41, 2011

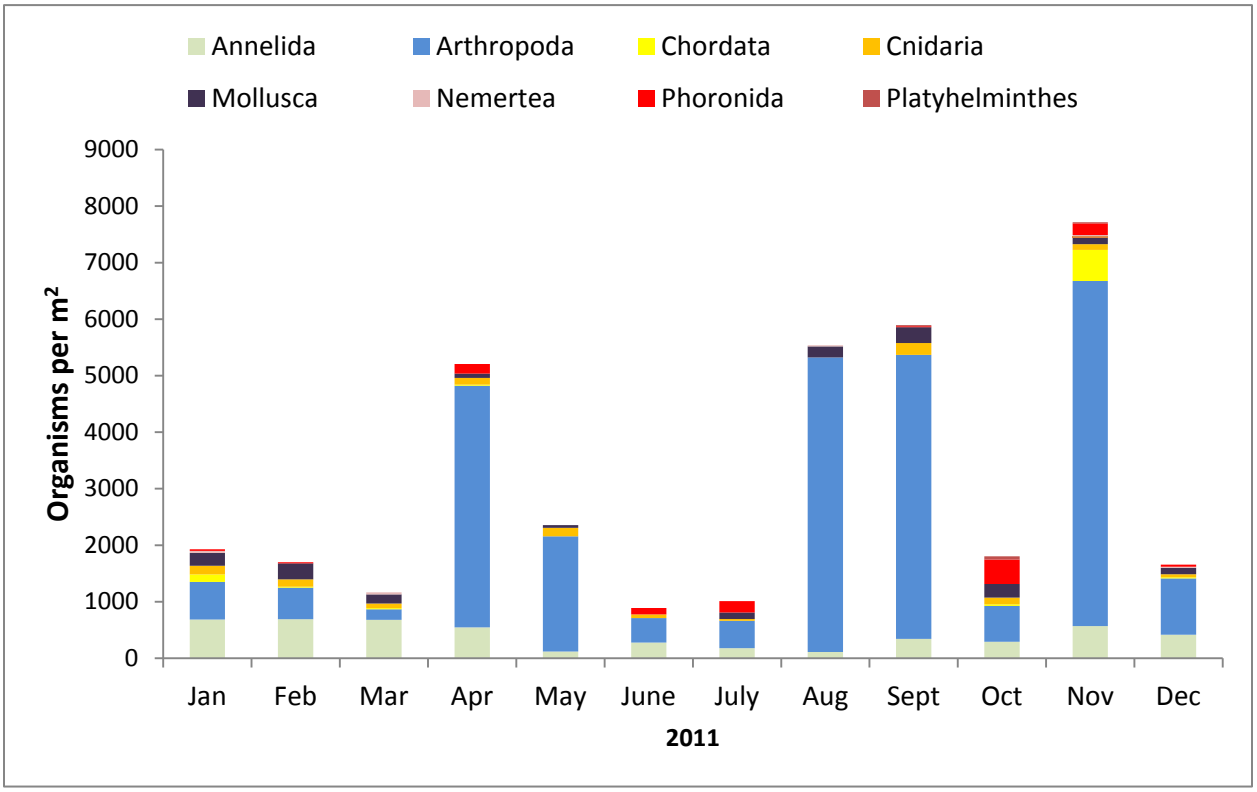


Figure 6-12 Total abundance at D41A, 2011

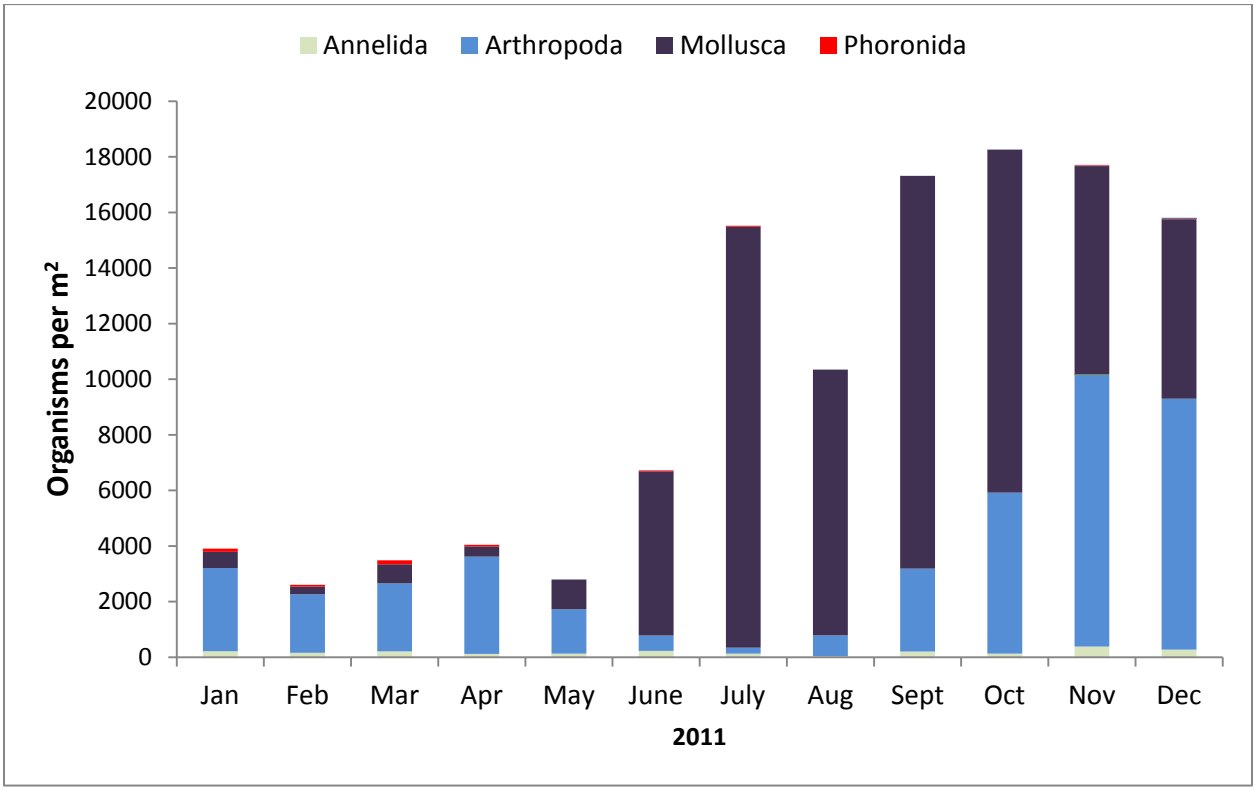
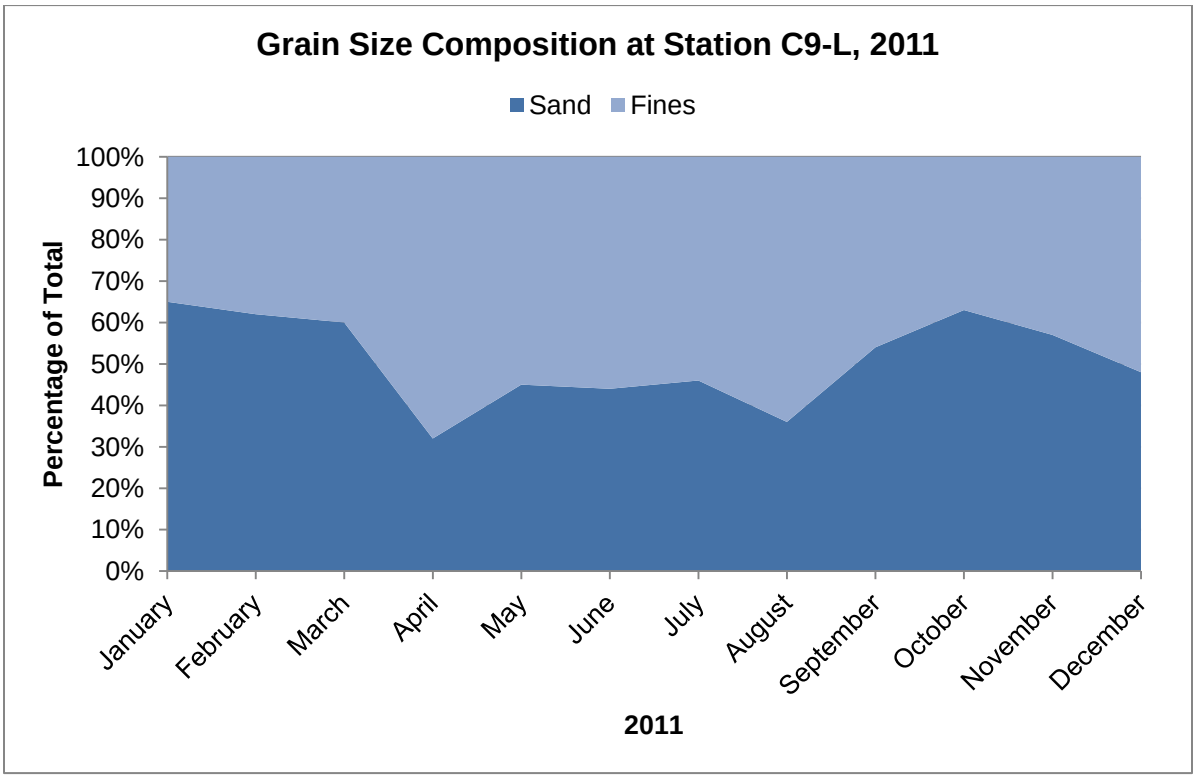


Figure 6-13 Sediment grain size and organic content at C9, 2011



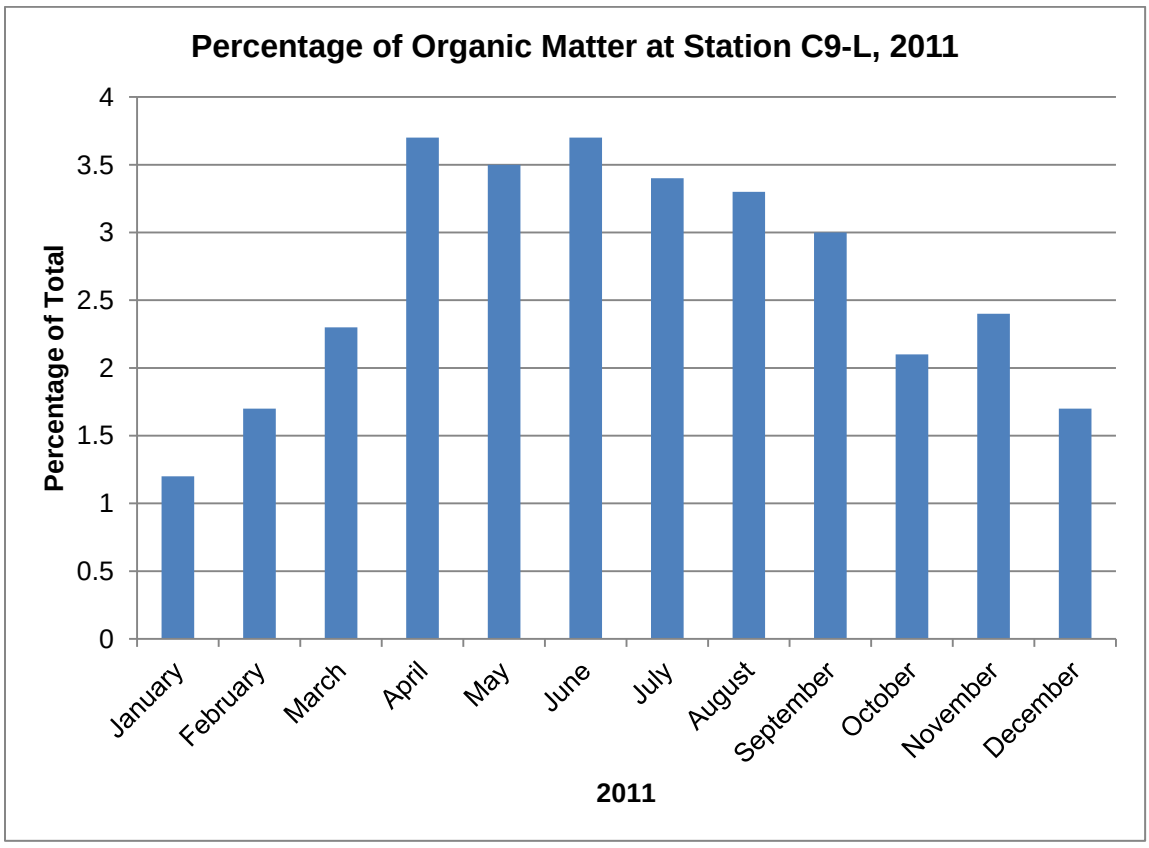
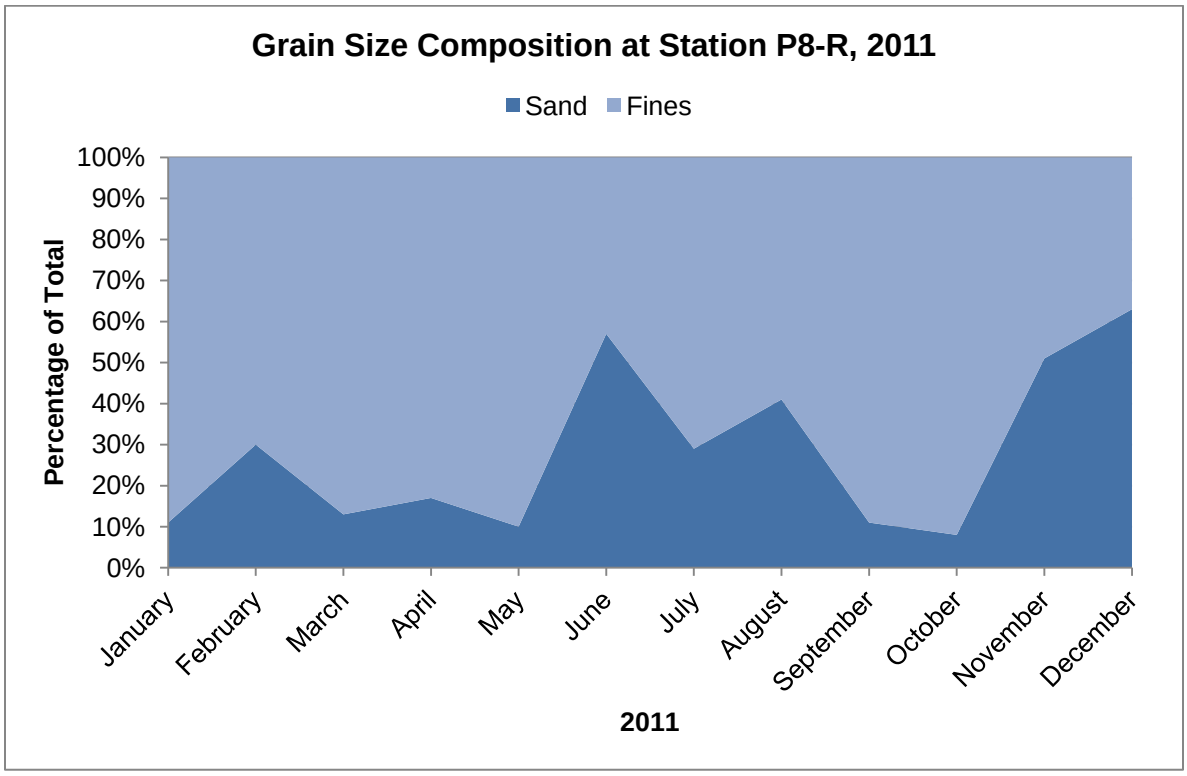


Figure 6-14 Sediment grain size and organic content at P8, 2011



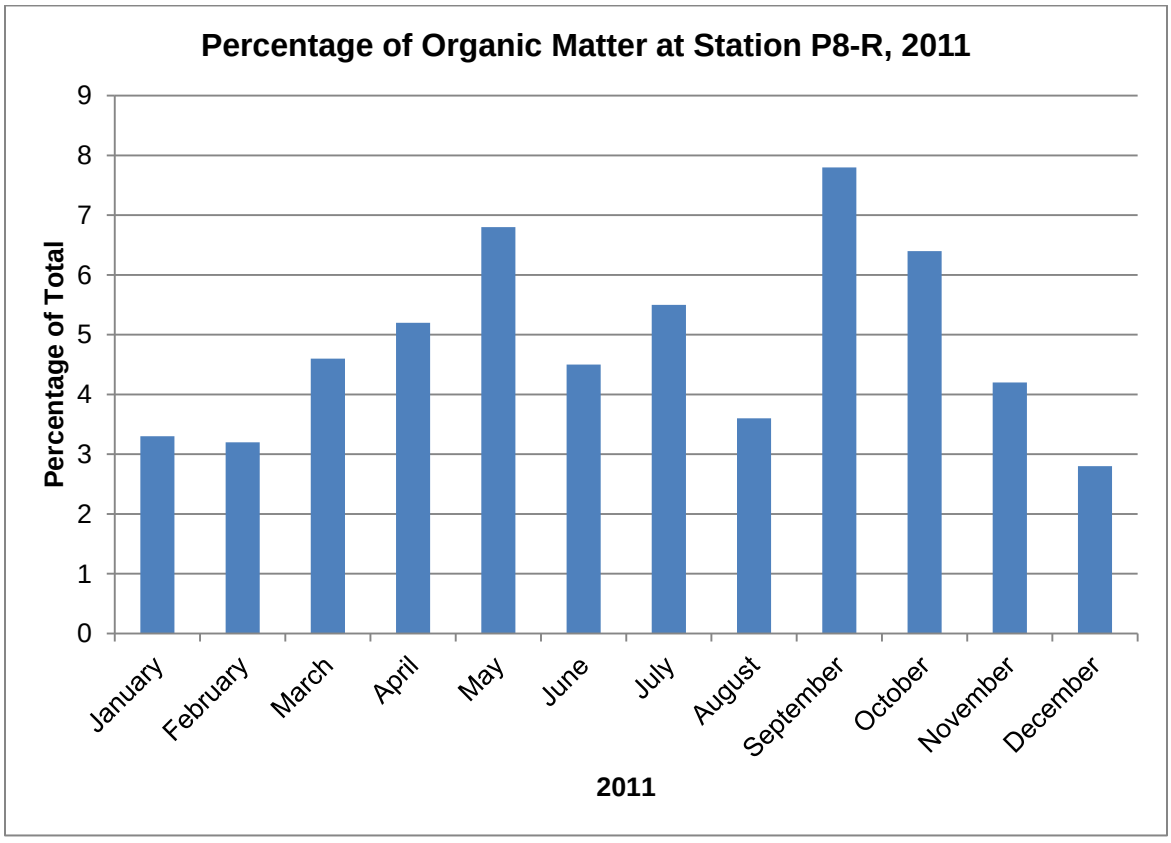
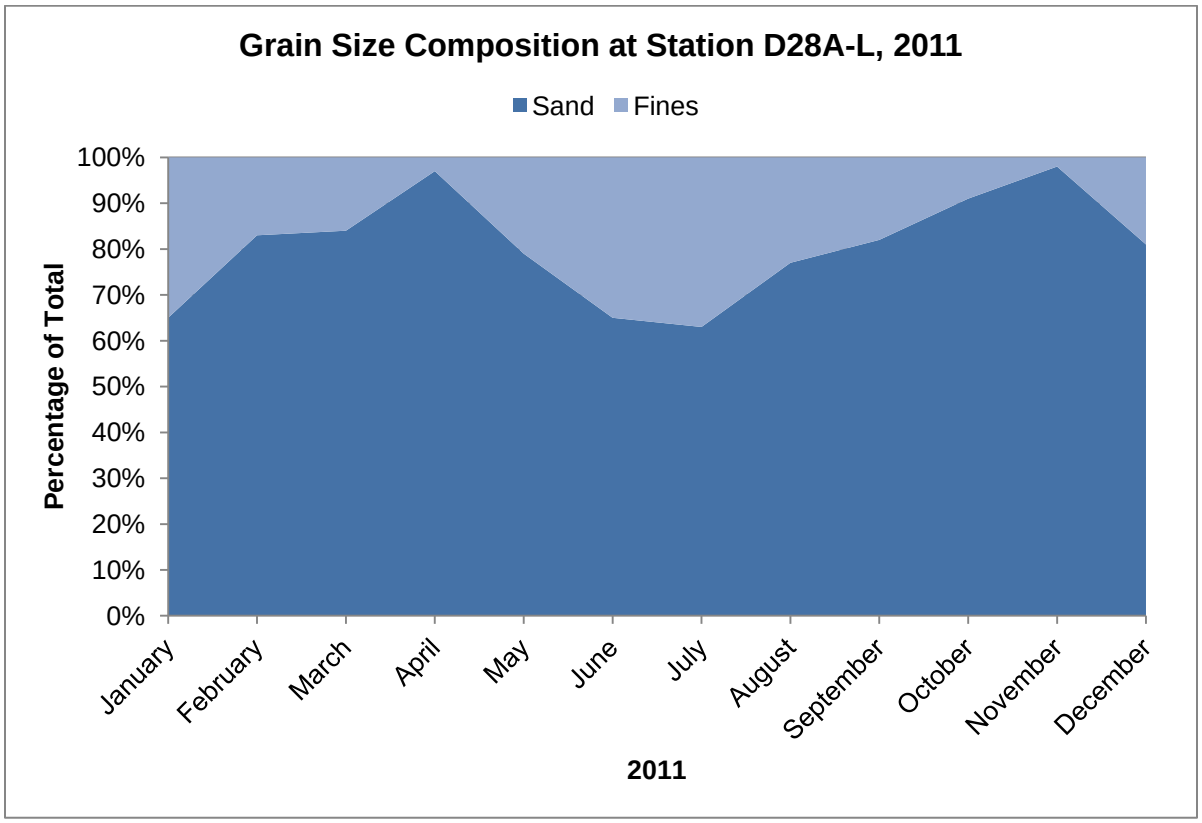


Figure 6-15 Sediment grain size and organic content at D28A, 2011



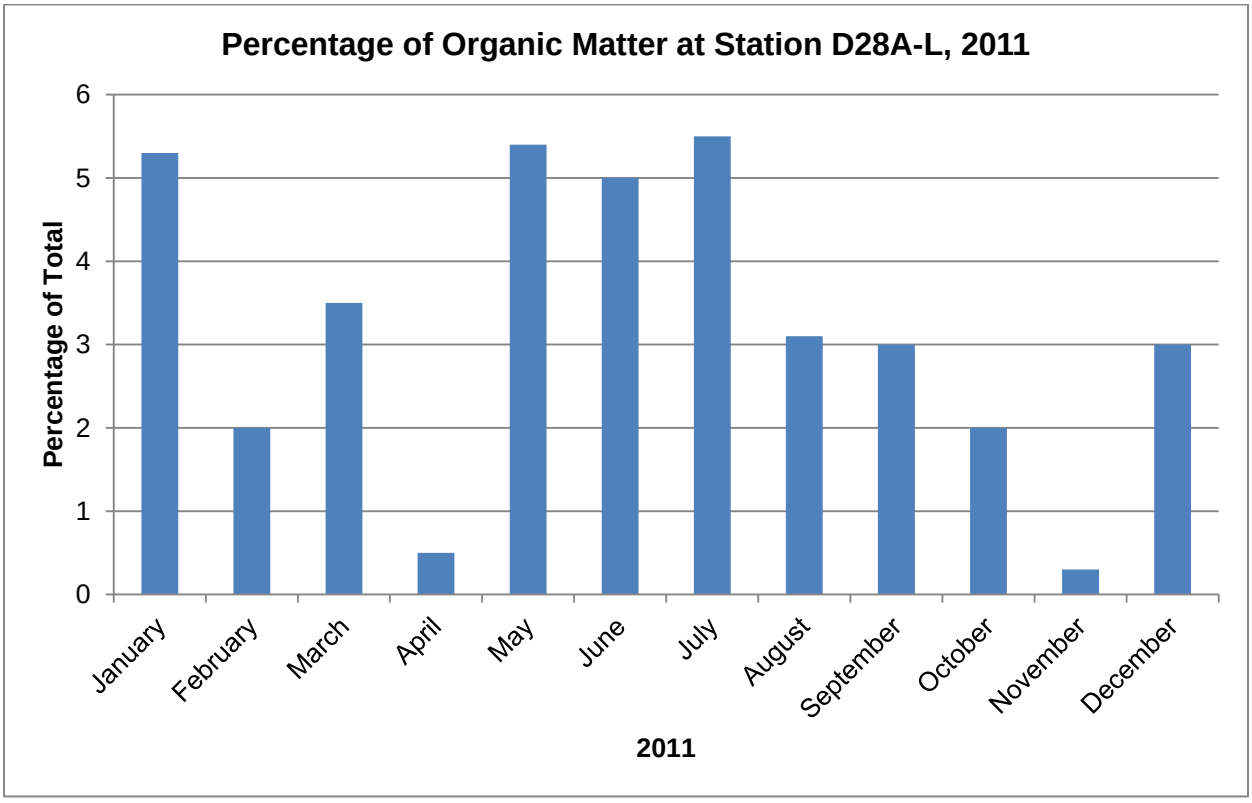
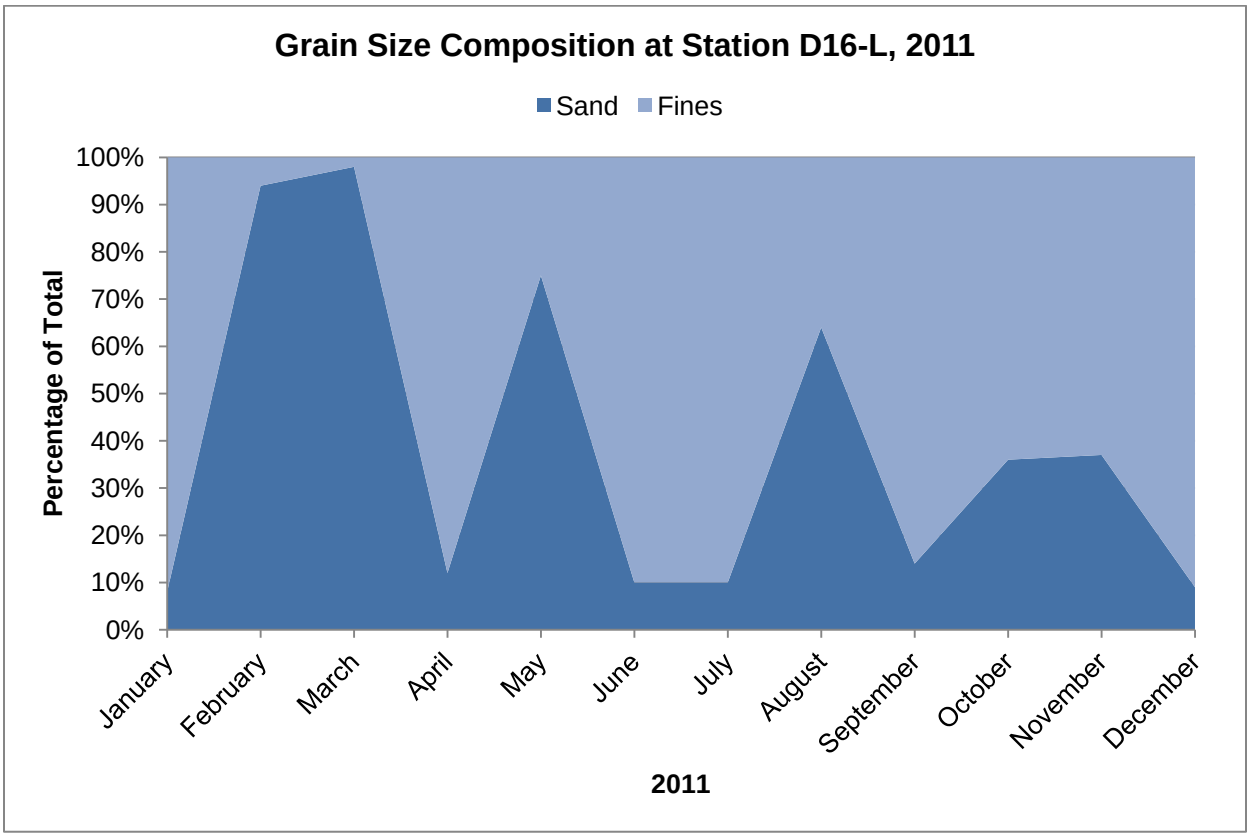


Figure 6-16 Sediment grain size and organic content at Station D16, 2011



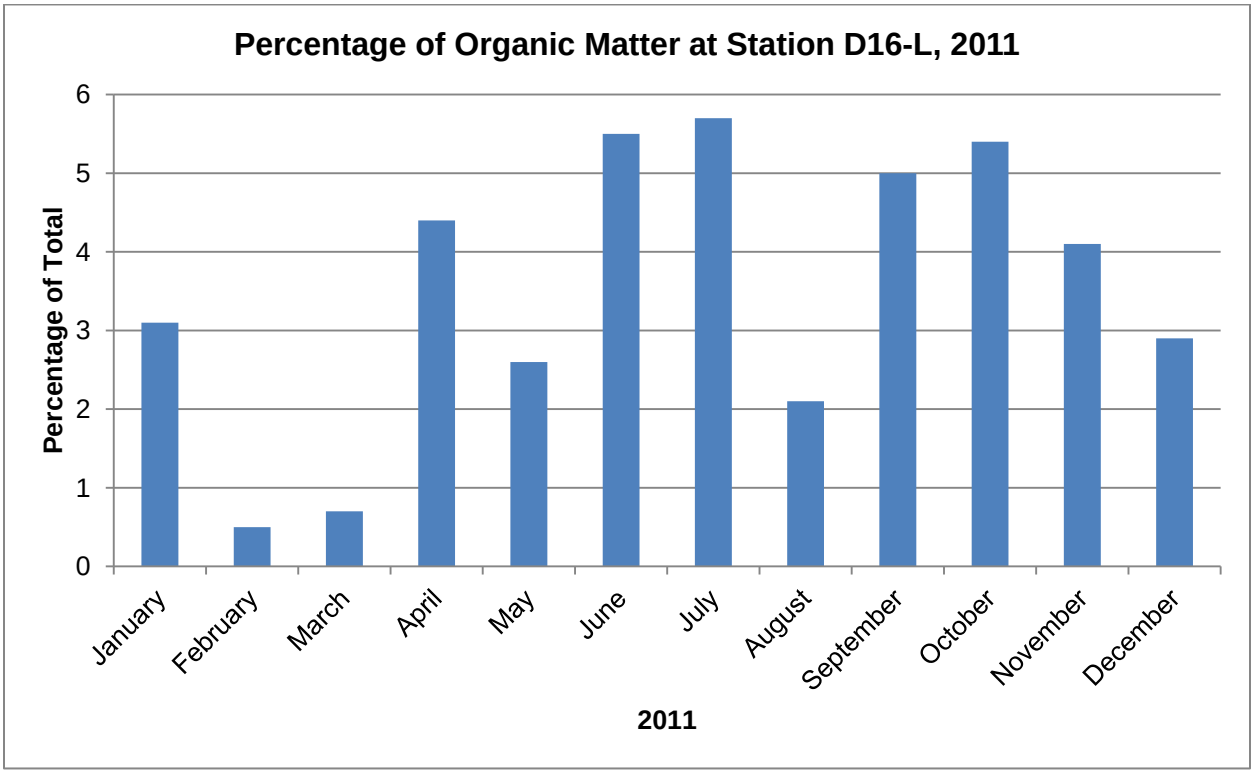
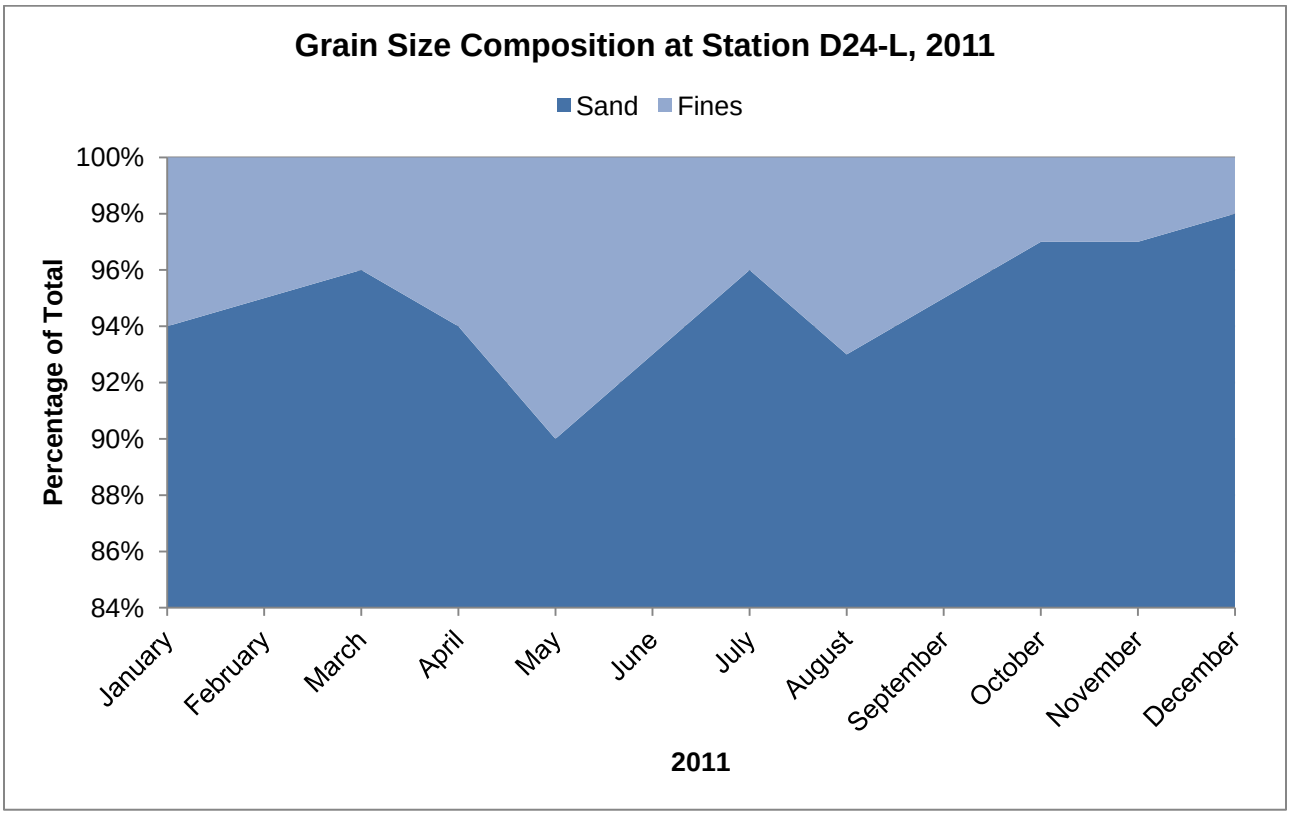


Figure 6-17 Sediment grain size and organic content at D24, 2011



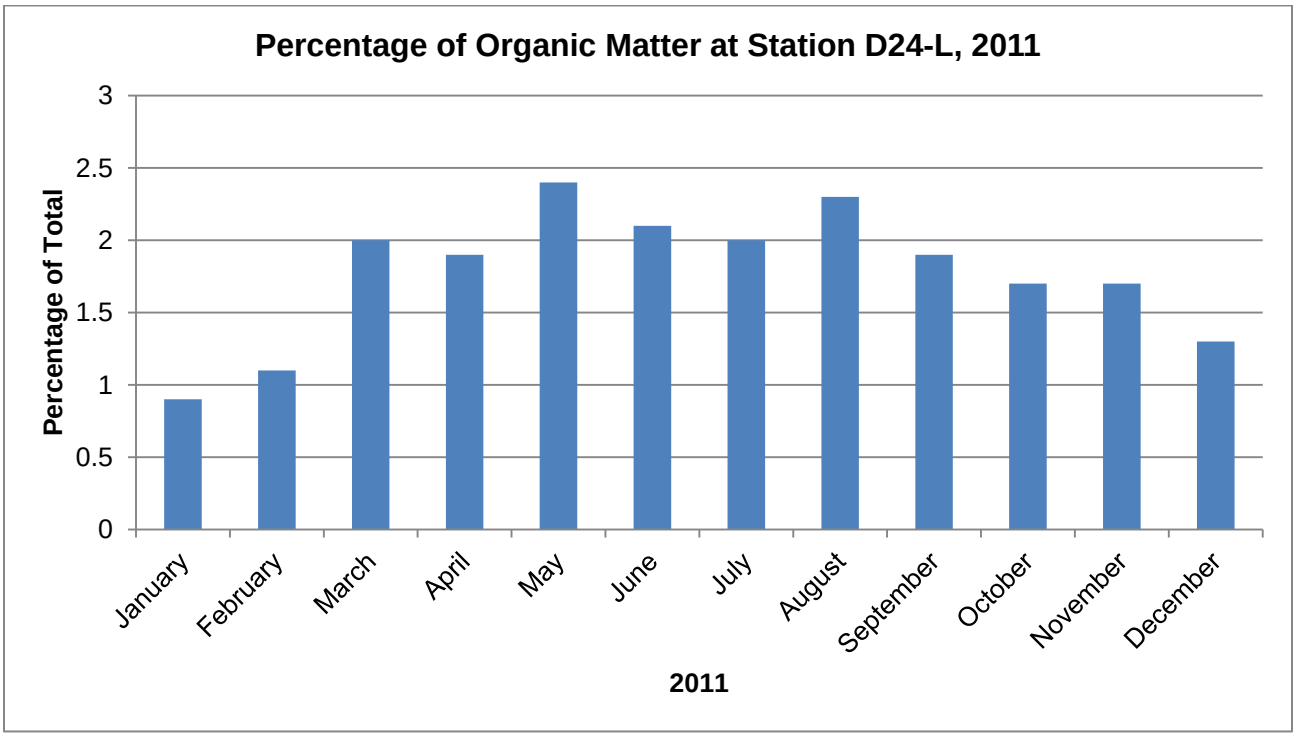
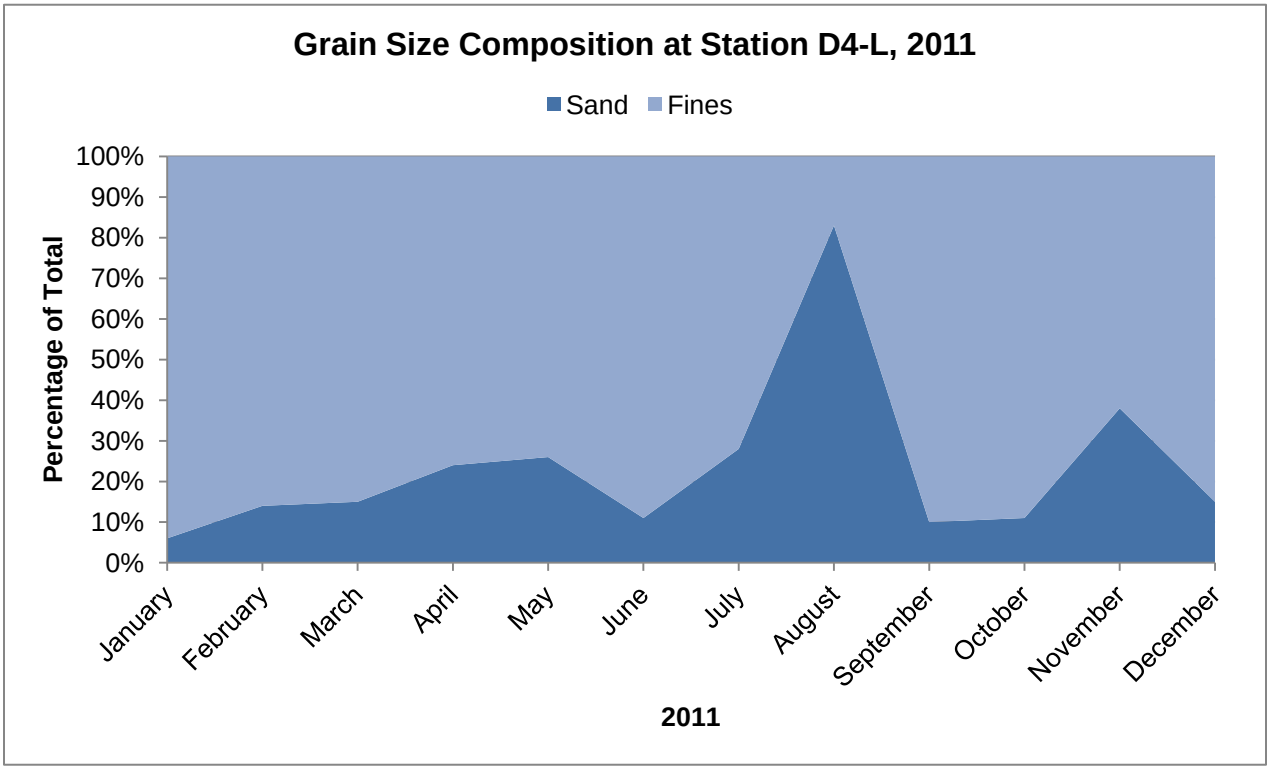


Figure 6-18 Sediment grain size and organic content at Station D4, 2011



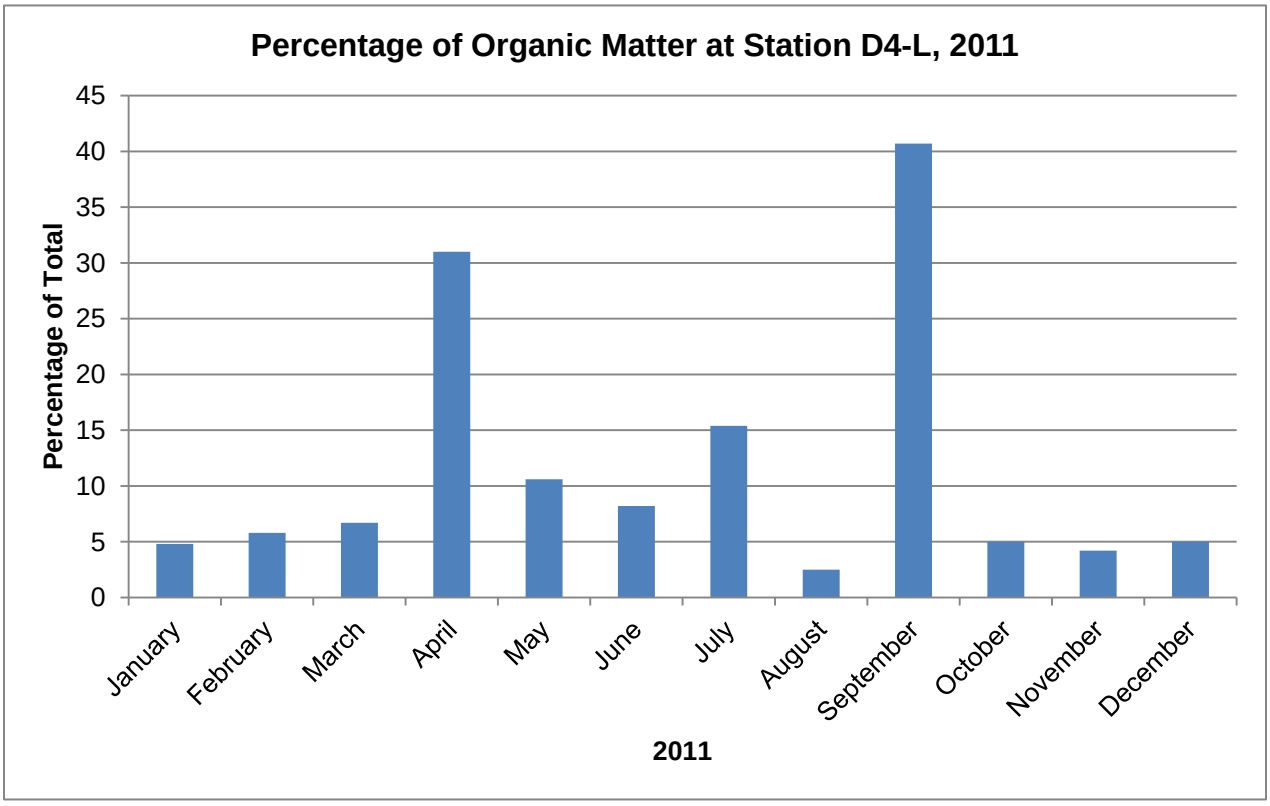
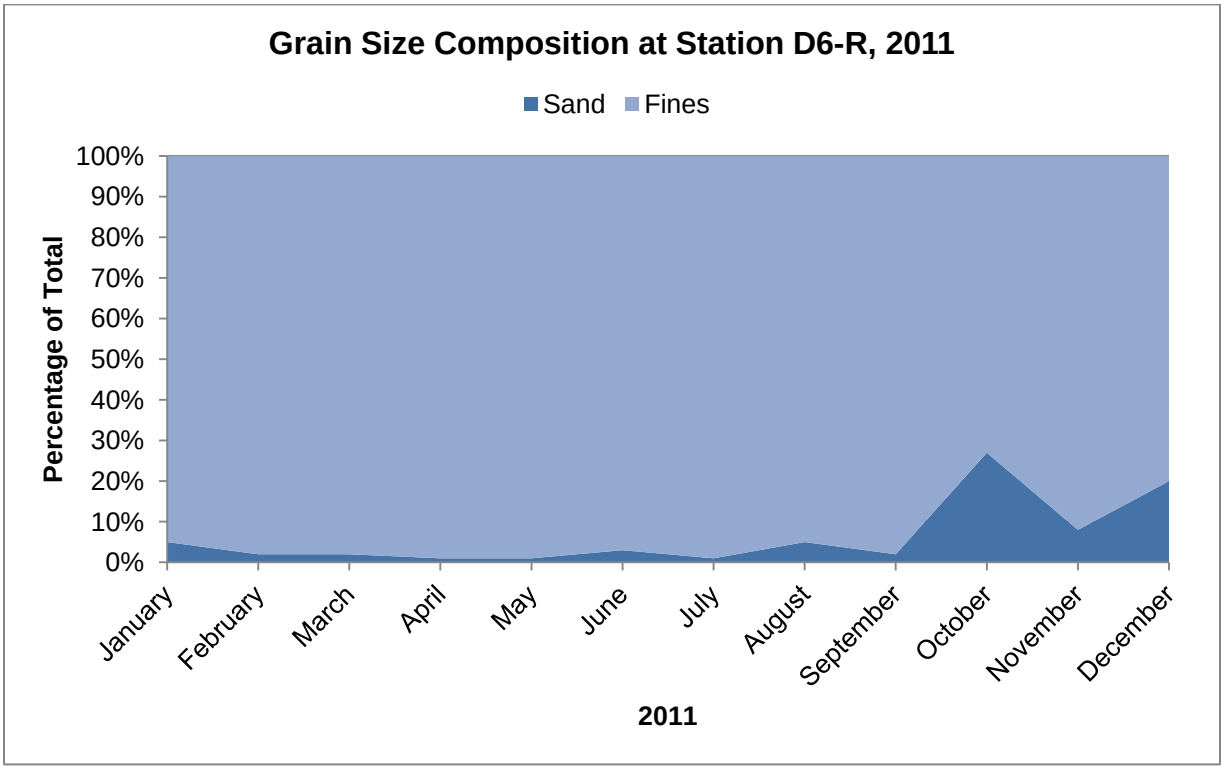


Figure 6-19 Sediment grain size and organic content at D6, 2011



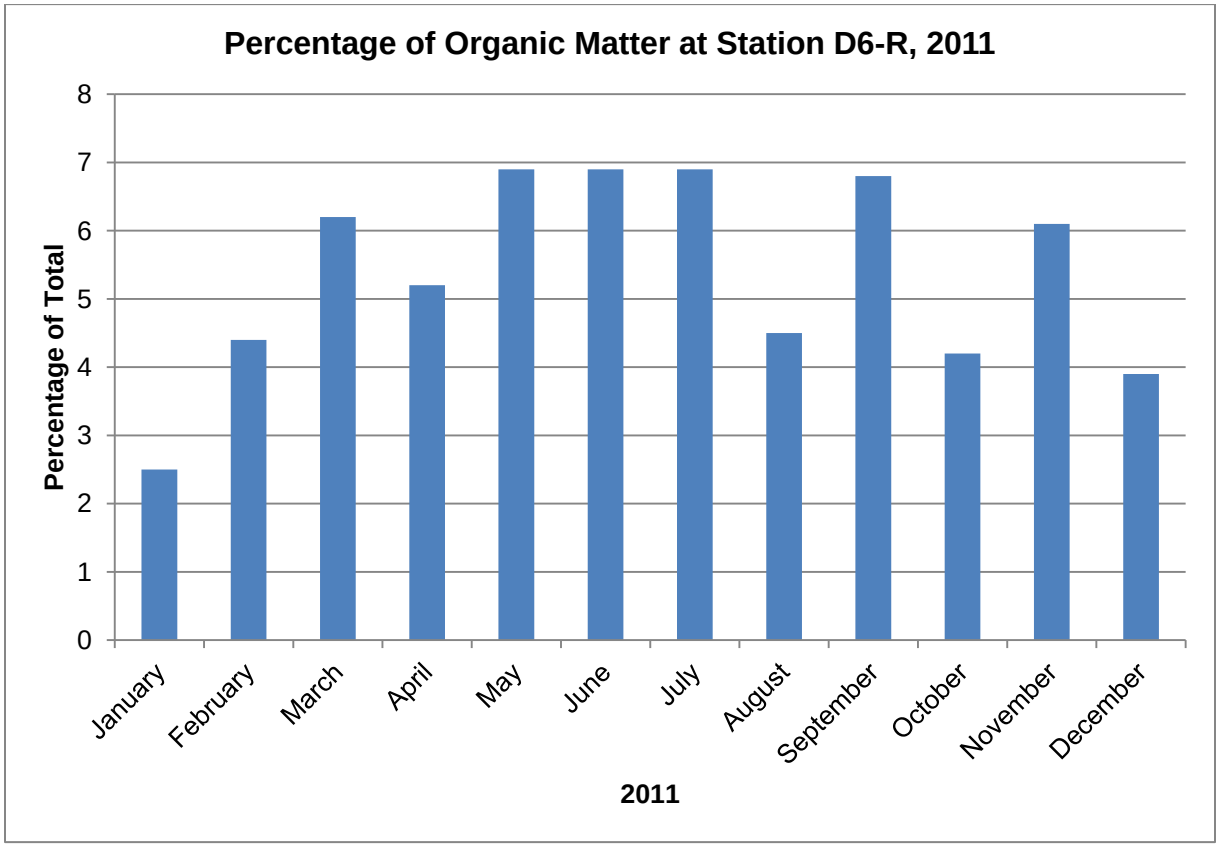
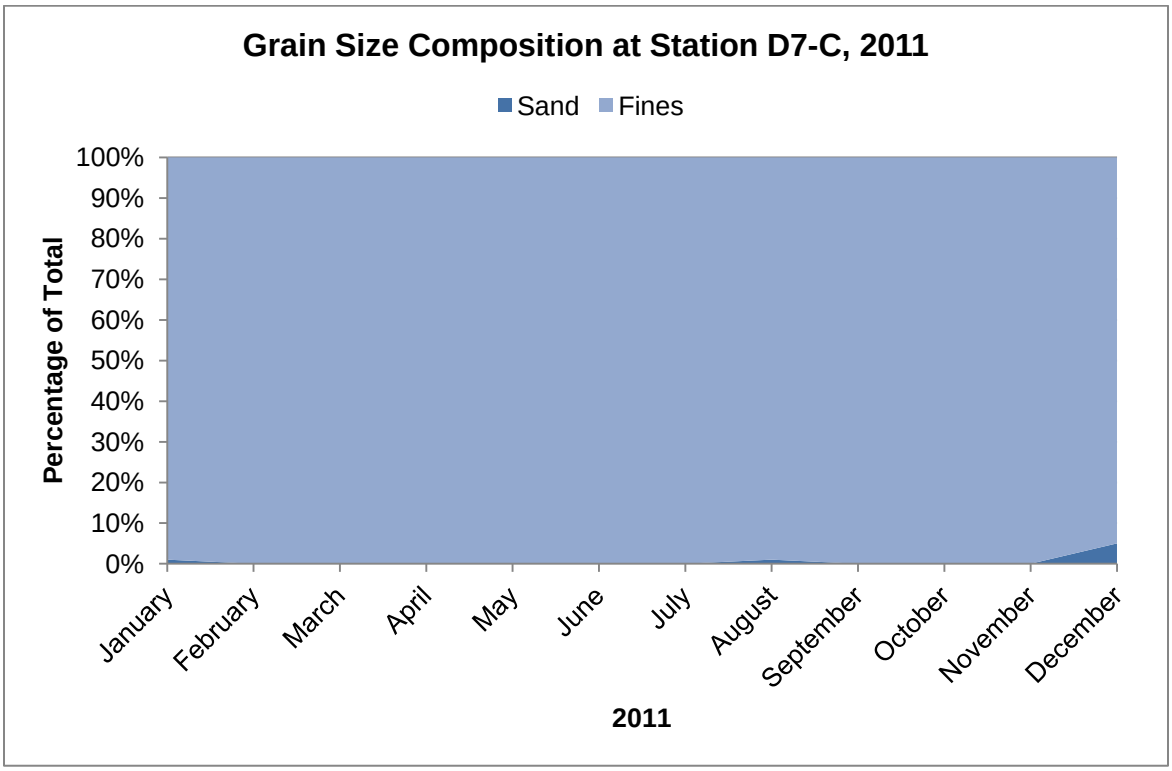


Figure 6-20 Sediment grain size and organic content at D7, 2011



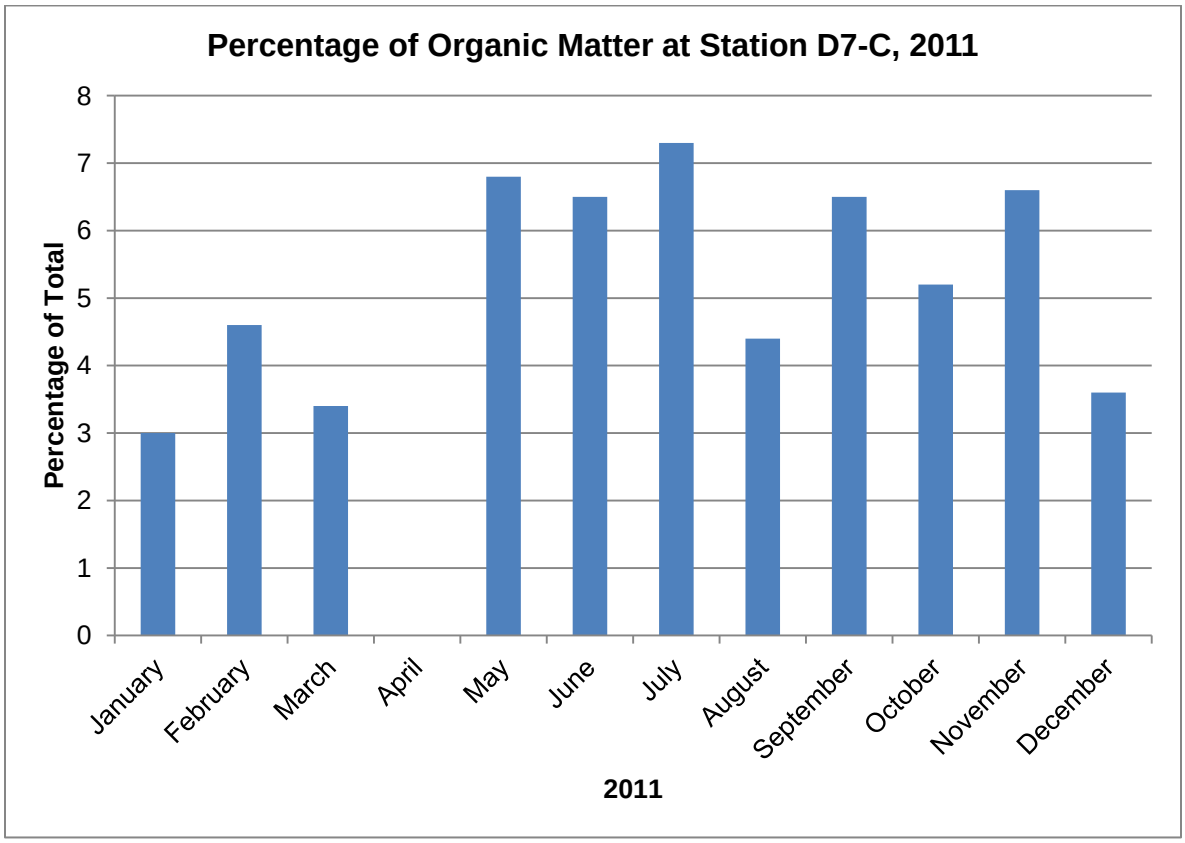
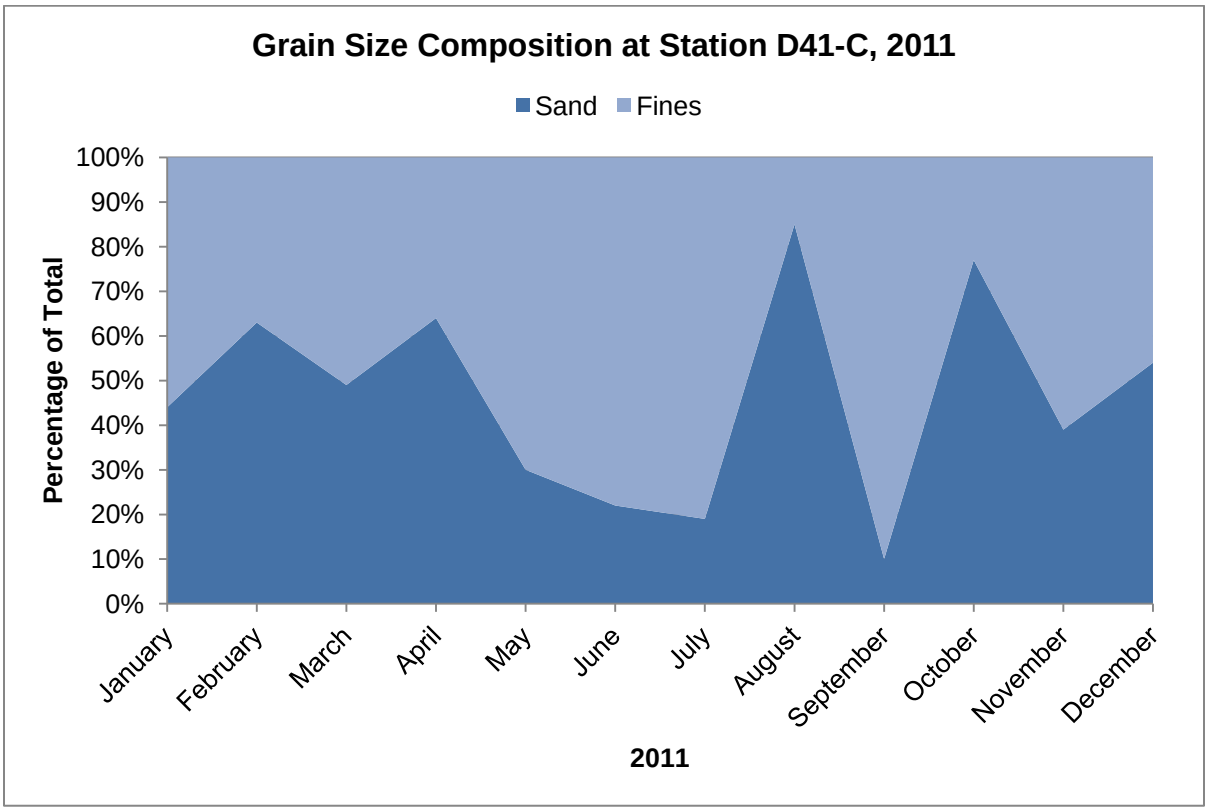


Figure 6-21 Sediment grain size and organic content at D41, 2011



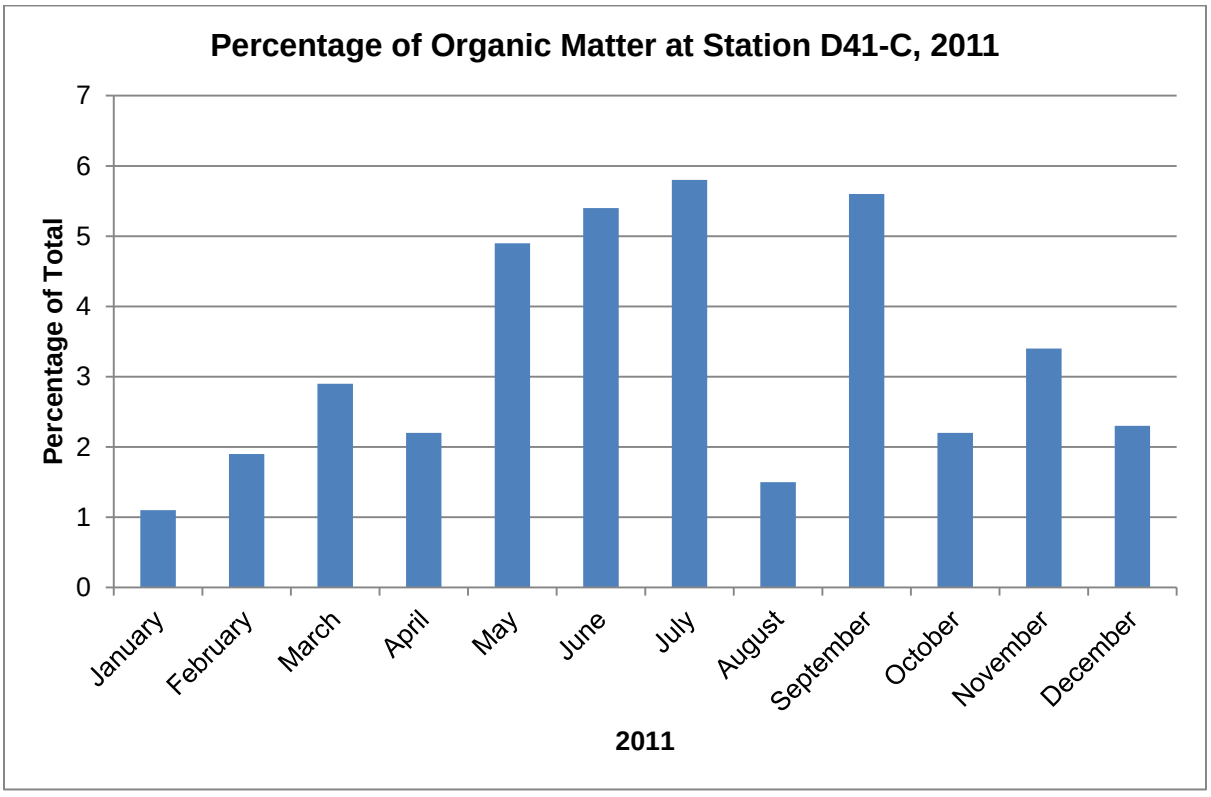
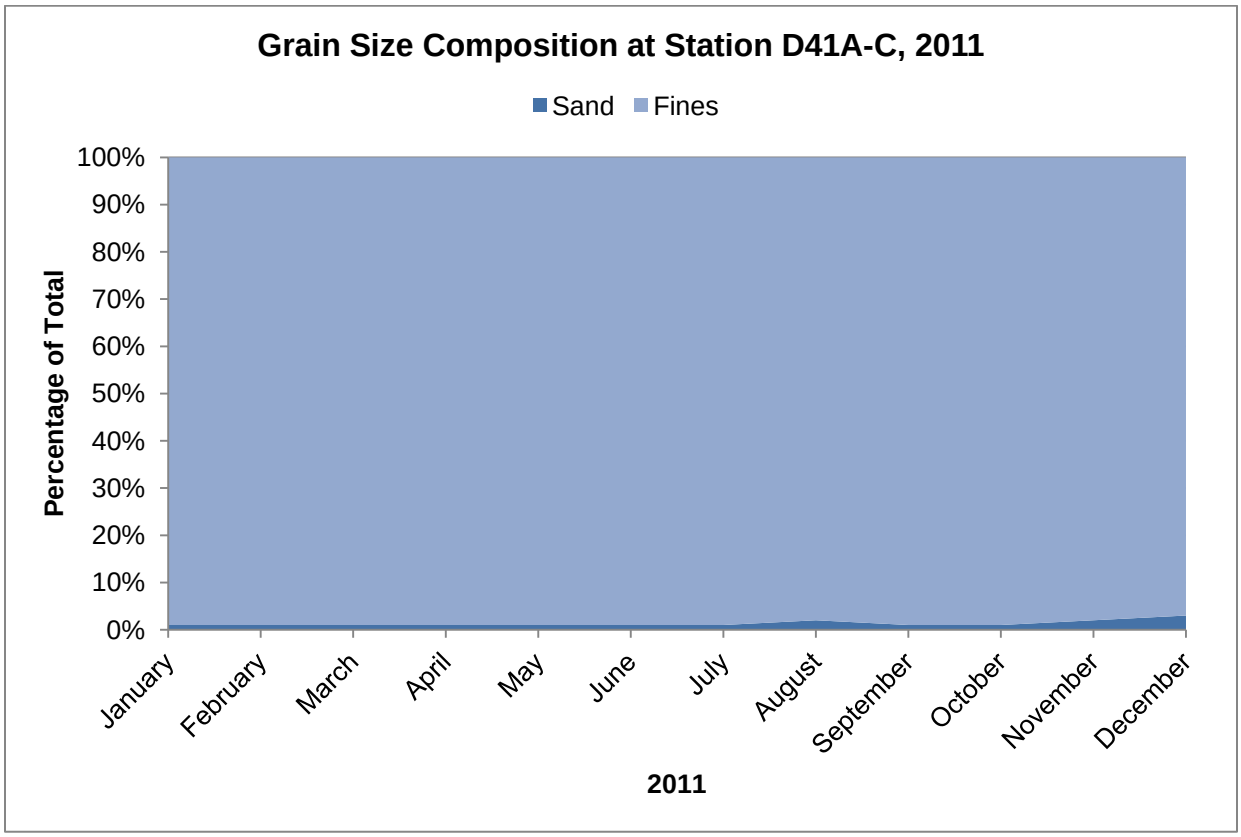


Figure 6-22 Sediment grain size and organic content at D41A, 2011



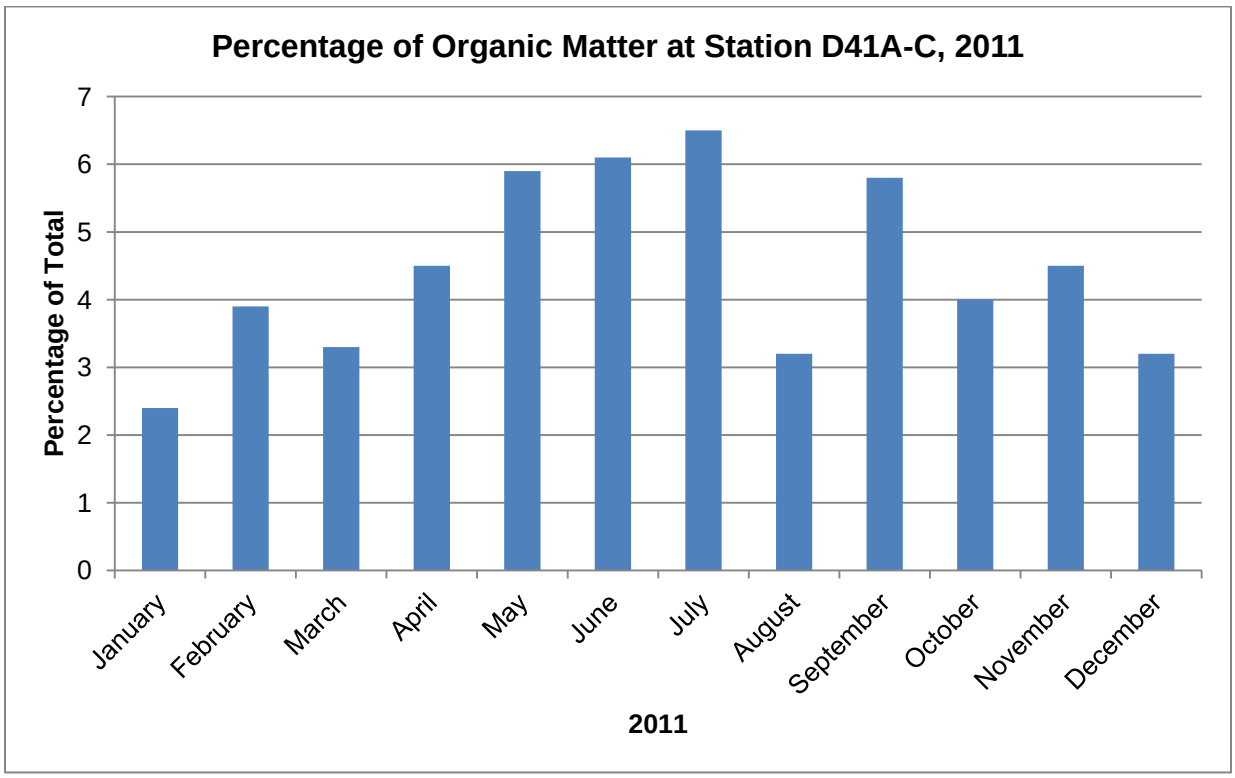


Table 6-1 Macrobenthic monitoring station characteristics, 2011

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: Dissolved Oxygen Monitoring in the Stockton Ship Channel

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Chapter 7. Special Studies: Dissolved Oxygen Monitoring in the Stockton Ship Channel

Introduction

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

As low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the SWRCB established specific water quality objectives to protect these uses. Within the channel, two 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 most recent *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 among 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 2011, the spring barrier was not installed. Instead, a non-physical "bubble barrier" was installed to prevent salmon from entering Old River. This report describes DO monitoring results during the period of June through November 2011.

Methods

Monitoring was conducted approximately every two weeks by vessel on 12 monitoring cruises from June 15 to November 23, 2011. During each of the monitoring cruises, 14 sites were sampled at low water slack, beginning at Prisoners Point (station 1) in the central Delta and ending at the Stockton Turning Basin at the terminus of the channel (station 14 in 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 (one meter from the surface) and bottom (one meter from the bottom) of the water column at each station at low water slack and analyzed for DO concentrations and temperature. Top DO samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom dissolved oxygen samples were measured using a YSI 6600 multiparameter data sonde equipped with a Rox optical dissolved oxygen sensor. Surface and bottom water temperatures and specific conductance were measured using a YSI 6600 multiparameter data sonde.

Flow data for the San Joaquin River at Vernalis was obtained from station data recorded at the Vernalis monitoring station, which is 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[13]. Due to low inflows, upstream agricultural diversions, and export pumping, net daily flows at Stockton can frequently approach zero and can sometimes reverse direction. However, during the 2011 study period, net flow at Stockton did not approach zero or reverse direction.

Results

During the period of this study, DO levels varied by season and exhibited similar ranges between regions within the channel excluding the Turning Basin. Overall study period range was 6.3 to 9.8 mg/L at the surface and 6.5 to 9.4 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 6.3 to 9.6 mg/L at the surface and 6.6 to 9.4 mg/L at the bottom. In the central portion of the channel, DO concentrations were variable, ranging from 6.6 to 9.4 mg/L at the surface and 6.5 to 9.3 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 7.1 to 9.8 mg/L at the surface and 7.3 to 9.1 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 12,583 cfs in July to a low of 1,832 cfs in November. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 5,880 cfs in July to a low of 548 cfs in November (Figure 7-2).

The findings for the summer and fall of 2011 are briefly summarized by month as follows. Because of the unique hydro-morphology of station 14 (the Stockton Turning Basin), the findings for this station are discussed separately from those of the other channel stations.

June

Monitoring was conducted on June 15 and 28. Surface DO levels ranged from 7.0 mg/L at station 4 to 9.4 mg/L at station 12. Bottom DO levels ranged from 7.0 mg/L at stations 3 and 4 to 9.0 mg/L at stations 12 and 13 (Figure 7-3).

Water temperatures ranged from 18.8 ^{o}C (station 13) to 22.4 ^{o}C (station 4) at the surface and 18.2 ^{o}C (station 11) to 22.1 ^{o}C (stations 1 and 2) at the bottom (Figure 7-3).

Flows on the San Joaquin River near Vernalis during the month of June ranged from 9,799 to 11,333 cfs. Net flow in the San Joaquin River near Stockton during June ranged from 4,540 to 5,410 cfs (Figure 7-2).

[13] 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.

July

Monitoring cruises were conducted on July 11 and 28. Surface DO levels ranged from 6.3 mg/L at station 4 to 9.1 mg/L at station 13. Bottom DO levels ranged from 6.5 mg/L at stations 6, 7, and 8 to 9.0 mg/L at station 13 (Figure 7-4).

Water temperatures ranged from 19.8 ^{o}C (station 13) to 23.5 ^{o}C (stations 2 and 3) at the surface and 19.7 ^{o}C (station 13) to 23.5 ^{o}C (station 2) at the bottom (Figure 7-4).

Flows on the San Joaquin River near Vernalis during the month of July ranged from 4,208 to 12,583 cfs. Net flow in the San Joaquin River near Stockton during July ranged from 1,450 to 5,880 cfs (Figure 7-2).

August

Monitoring cruises were conducted on August 15 and 26. Surface DO levels ranged from 6.6 mg/L at station 4 to 9.8 mg/L at stations 12 and 13. Bottom DO levels ranged from 6.7 mg/L at station 4 to 9.1 mg/L at station 13 (Figure 7-5). Water temperatures ranged from 20.5 ^{o}C (station 13) to 23.6 ^{o}C (station 4) at the surface and 20.1 ^{o}C (station 12) to 23.4 ^{o}C (station 3) at the bottom (Figure 7-5).

Flows on the San Joaquin River near Vernalis during the month of August ranged from 4,233 to 7,056 cfs. Net flow in the San Joaquin River near Stockton during August ranged from 1,760 to 3,460 cfs (Figure 7-2).

September

Monitoring cruises were conducted on September 9 and 27. Surface DO levels ranged from 6.9 mg/L at station 6 to 8.5 mg/L at station 11. Bottom DO levels ranged from 7.0 mg/L at stations 4– 7 to 8.5 mg/L at station 13 (Figure 7-6). Water temperatures ranged from 19.3 ^{o}C (station 13) to 22.1 ^{o}C (stations 2, 3 and 4) at the surface and 19.1 ^{o}C (station 12) to 22.1 ^{o}C (stations 2, 3, and 4) at the bottom (Figure 7-6).

Flows on the San Joaquin River near Vernalis during the month of September ranged from 3,729 to 5,942 cfs. Net flow in the San Joaquin River near Stockton during September ranged from 1,520 to 2,980 cfs (Figure 7-2).

October

Monitoring cruises were conducted on October 11 and 26 of 2011. Surface DO levels ranged from 7.4 mg/L at stations 4, 5, and 6 to 8.6 mg/L at station 13. Bottom DO levels ranged from 7.3 mg/L at stations 4 and 5 to 8.6 mg/L at station 13 (Figure 7-7).

Water temperatures at the surface ranged from 16.3 ^{o}C (station 13) to 18.1 ^{o}C (station 2) and 16.0 ^{o}C (station 13) to 18.0 ^{o}C (stations 2 and 3) at the bottom (Figure 7-7).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 4,280 to 5,375 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 1,840 to 2,820 cfs (Figure 7-2).

November

Monitoring cruises were conducted on November 10 and 23. Surface DO levels ranged from 8.6 mg/L at stations 7 and 8 to 9.6 mg/L at stations 1 and 3. Bottom DO levels ranged from 8.6 mg/L at stations 6 – 9 and 11 to 9.4 mg/L at stations 3, 4, and 5 (Figure 7-8).

Water temperatures ranged from 11.8 ^{o}C (station 11) to 13.2 ^{o}C (stations 1 – 5) at the surface, and 12.1 ^{o}C (stations 1 – 4 and 11) to 13.2 ^{o}C (stations 2 – 5) at the bottom (Figure 7-8).

Flows on the San Joaquin River near Vernalis during the month of November ranged from 1,832 to 4,350 cfs. Net flow in the San Joaquin River near Stockton during November ranged from 548 to 1,960 cfs (Figure 7-2).

Stockton Turning Basin (Station 14)

DO levels in the Stockton Turning Basin did not fall below SWRCB objectives during the study period. DO levels in June ranged from 11.7 mg/L at the surface to 7.4 mg/L at the bottom (Figure 7-9). DO levels in July ranged from 10.2 mg/L at the surface to 6.6 mg/L at the bottom. DO levels in August ranged from 11.2 mg/L at the surface to 7.3 mg/L at the bottom. September DO levels at the surface and bottom ranged from 9.7 to 7.2 mg/L, respectively. DO levels in October ranged from 7.9 mg/L at the surface to 7.3 mg/L at the bottom. November DO readings ranged from 8.8 mg/L at the surface to 8.2 mg/L at the bottom (Figure 7-9).

Summary

DO concentrations in the channel and Stockton Turning Basin did not fall below the SWRCB's 5.0 mg/L and 6.0 mg/L objectives during the study period. Flows on the San Joaquin River near Vernalis ranged from a low of 1,832 cfs in November to a high of 12,583 cfs in July. Net daily flow on the San Joaquin River past Stockton ranged from a low of 548 cfs in November to a high of 5,880 cfs in July. The head of Old River barrier was not installed during this sampling season.

Further monitoring operations for the summer and fall 2011 special study were suspended after November 23, 2011.

References

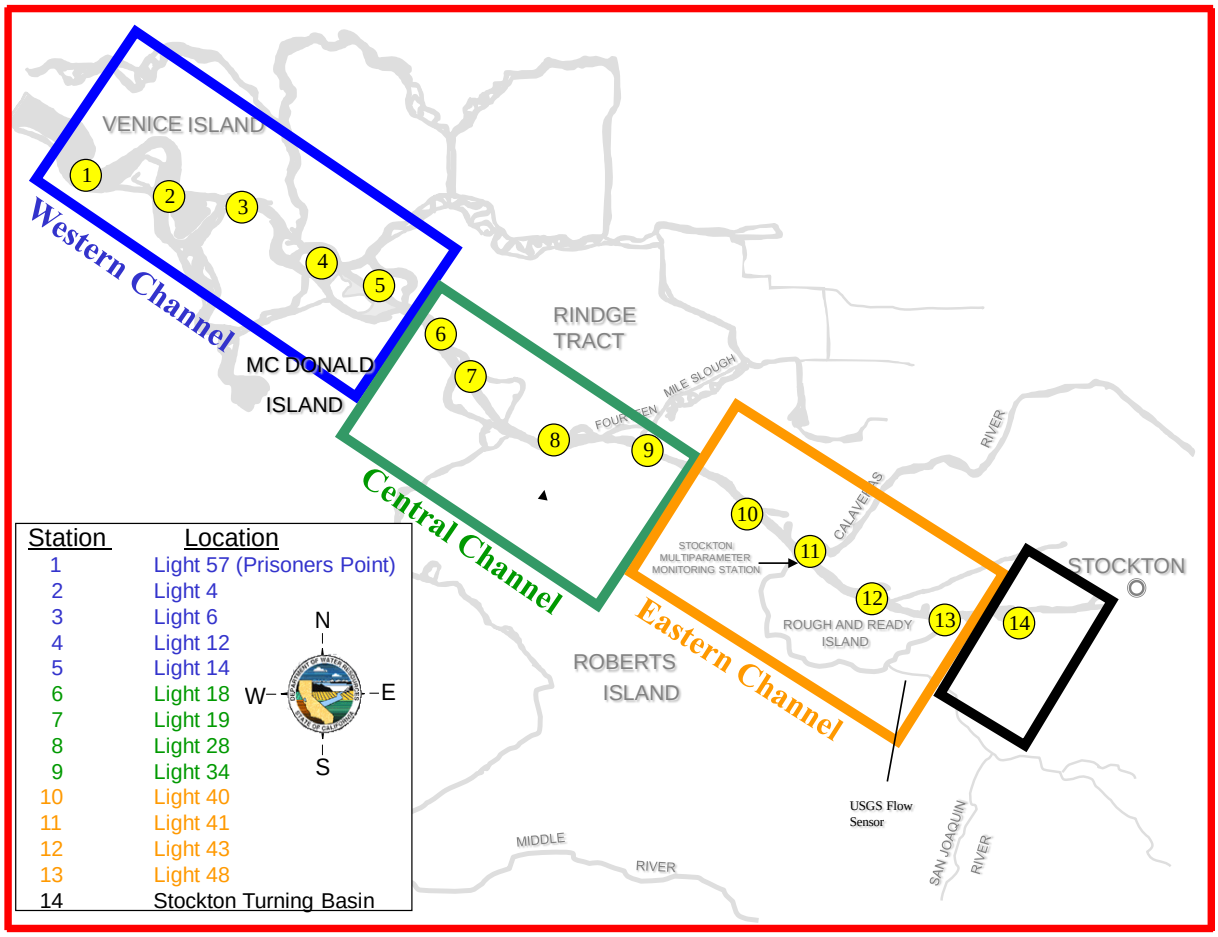
[APHA] American Public Health Association, American Water Works Association, and Water Environmental Federation. 1998. *Standard Methods for the Examination of Water and Wastewater* [*Standard Methods*] (20th edition). Washington DC.

[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 edition).

[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



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

Figure 7-2 San Joaquin River's mean daily flow during summer/fall 2011

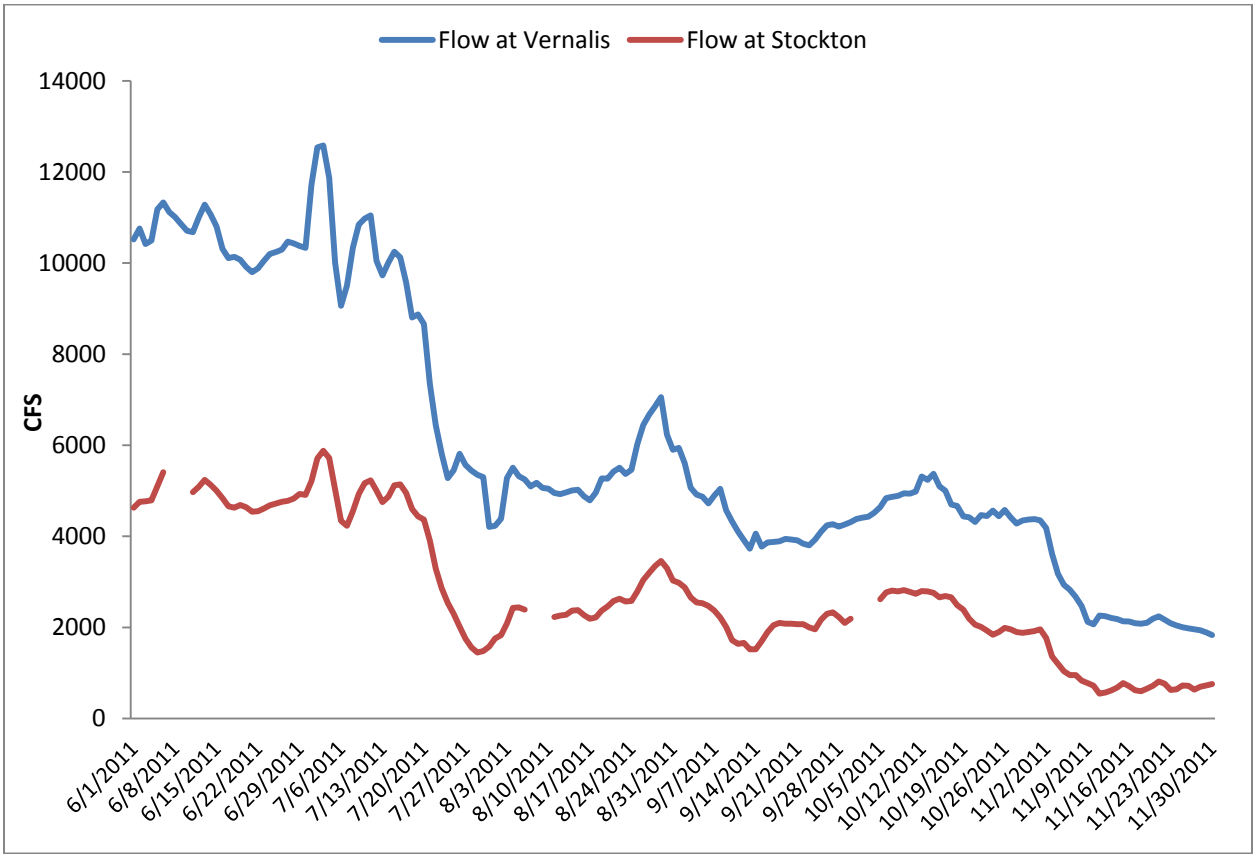


Figure 7-3 Surface and bottom DO and water temperature values in the channel, June 2011

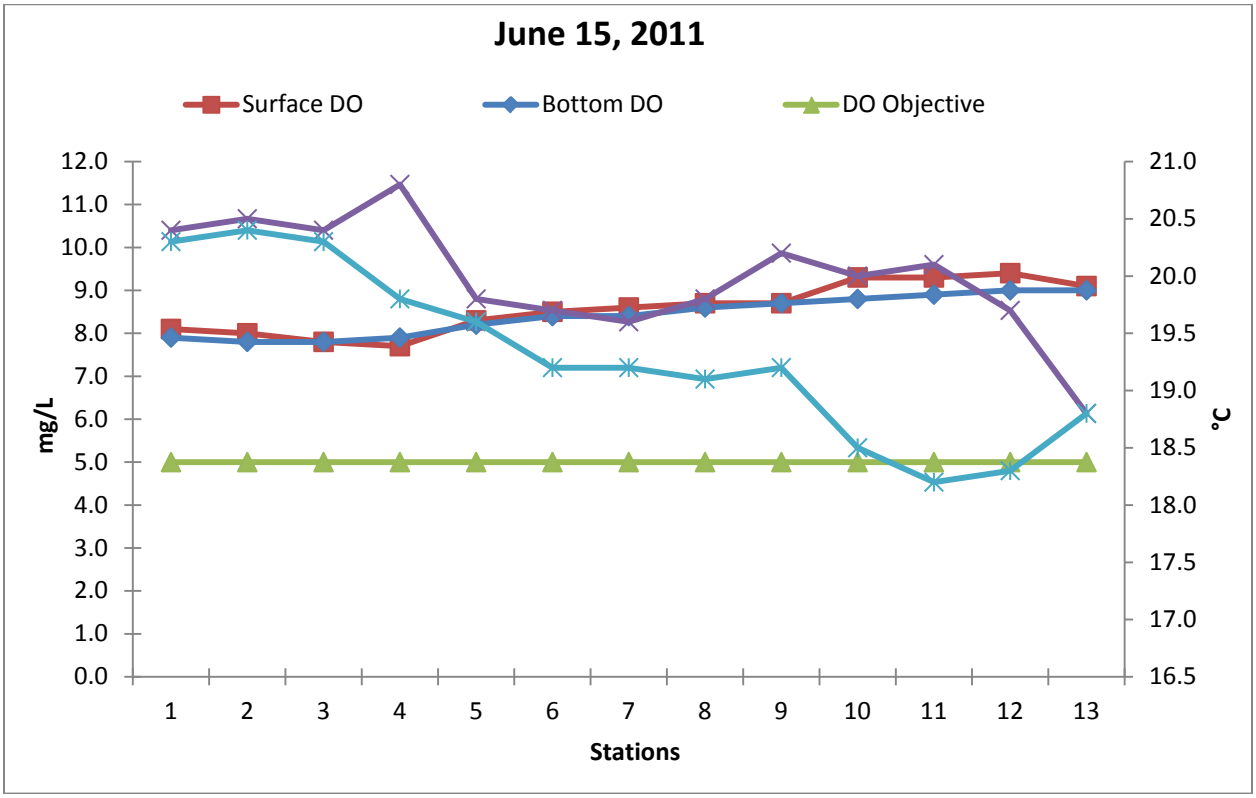
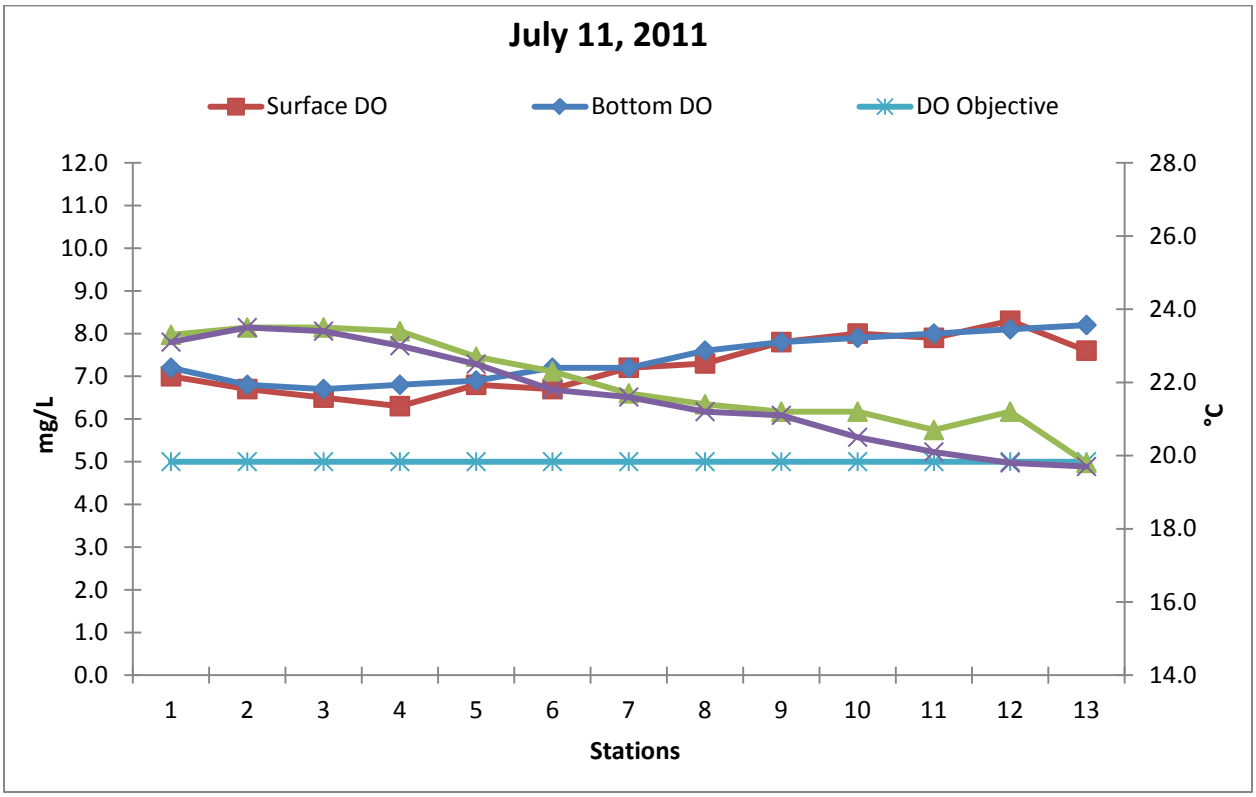


Figure 7-4 Surface and bottom DO and water temperature values in the channel, July 2011



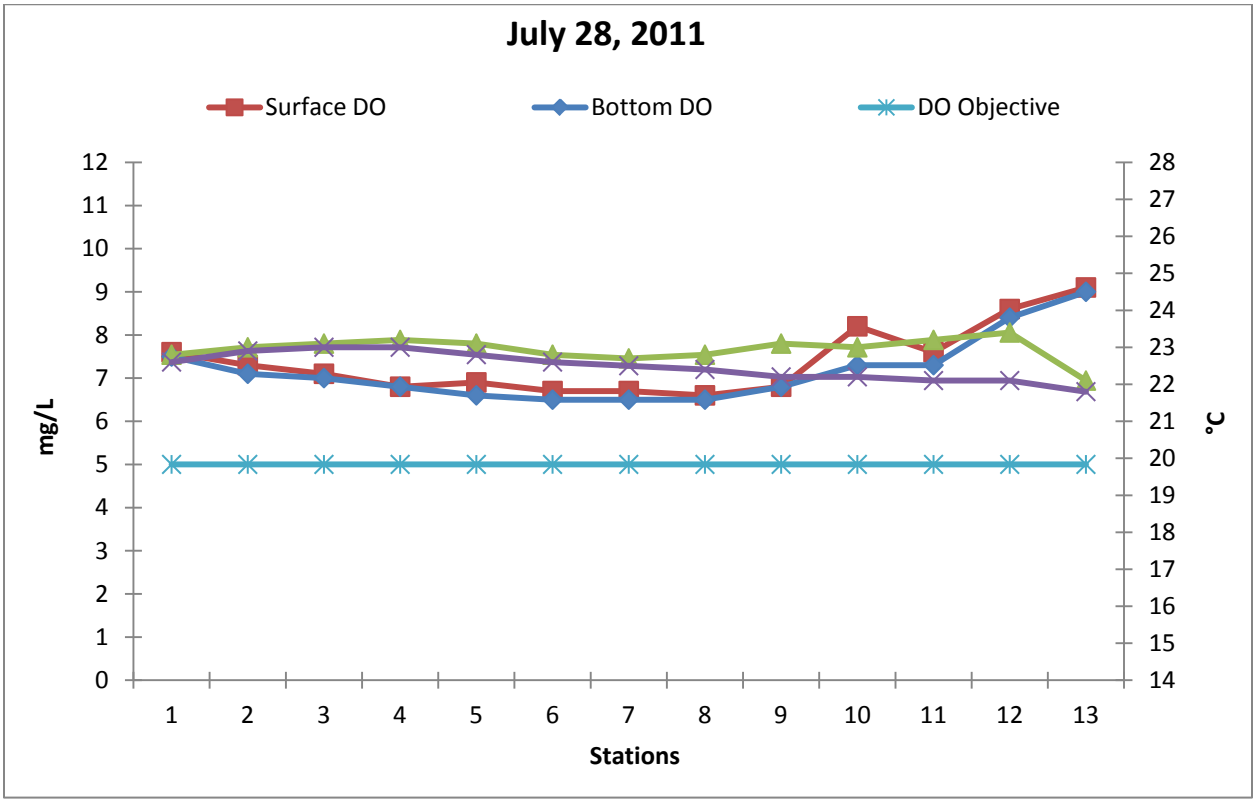
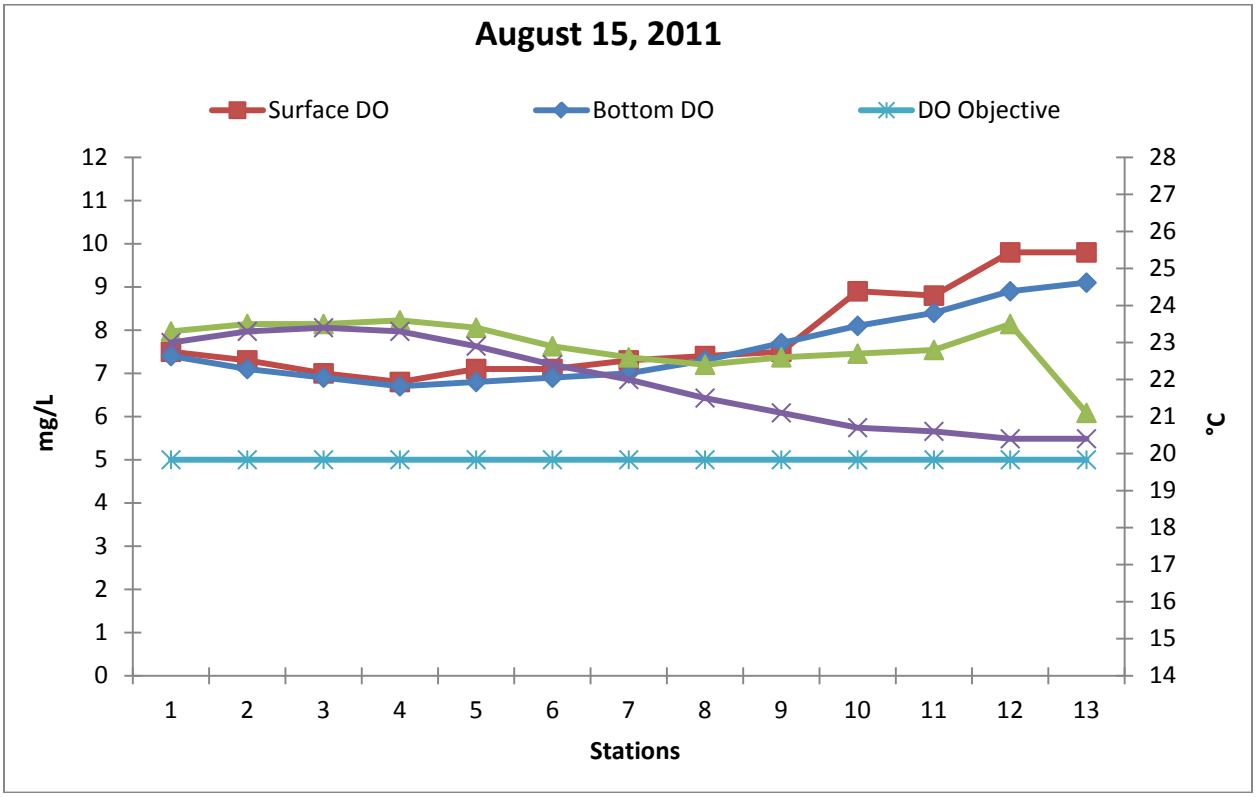


Figure 7-5 Surface and bottom DO and water temperature values in the channel, August 2011



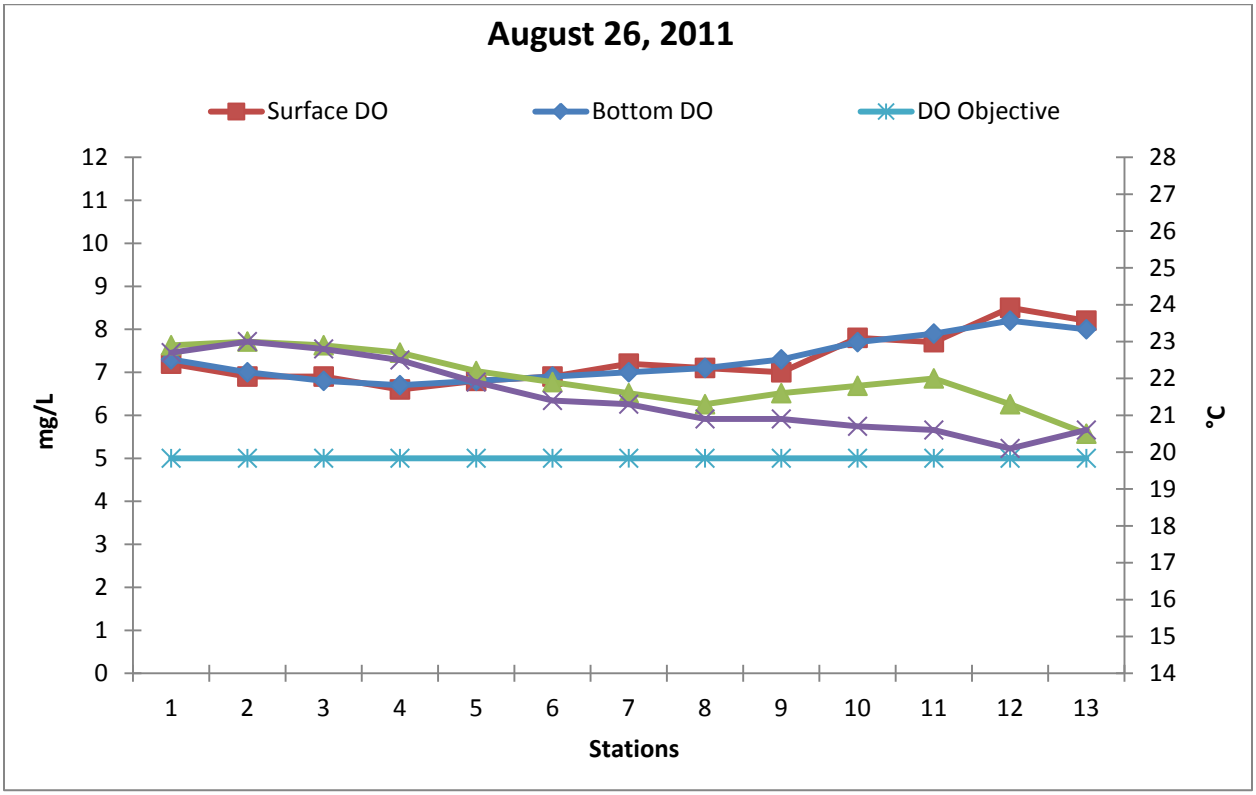
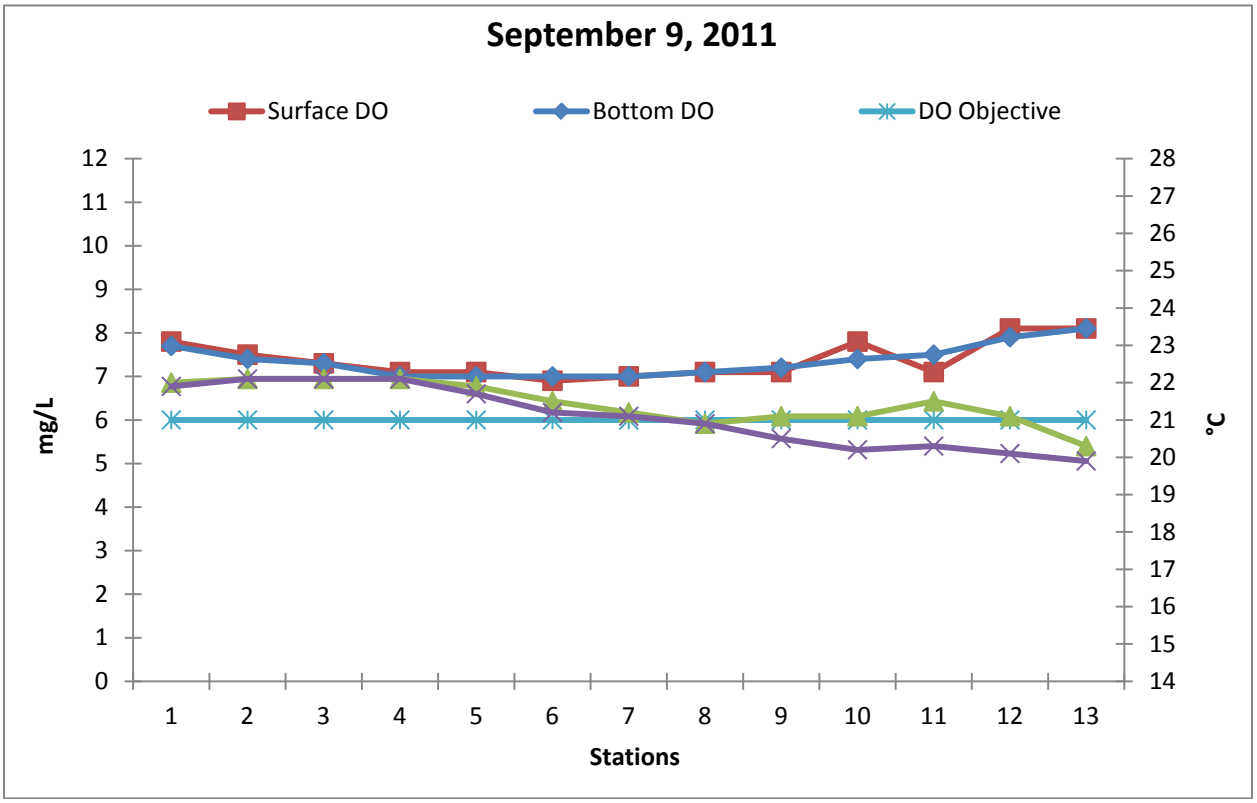


Figure 7-6 Surface and bottom DO and water temperature values in the channel, September 2011



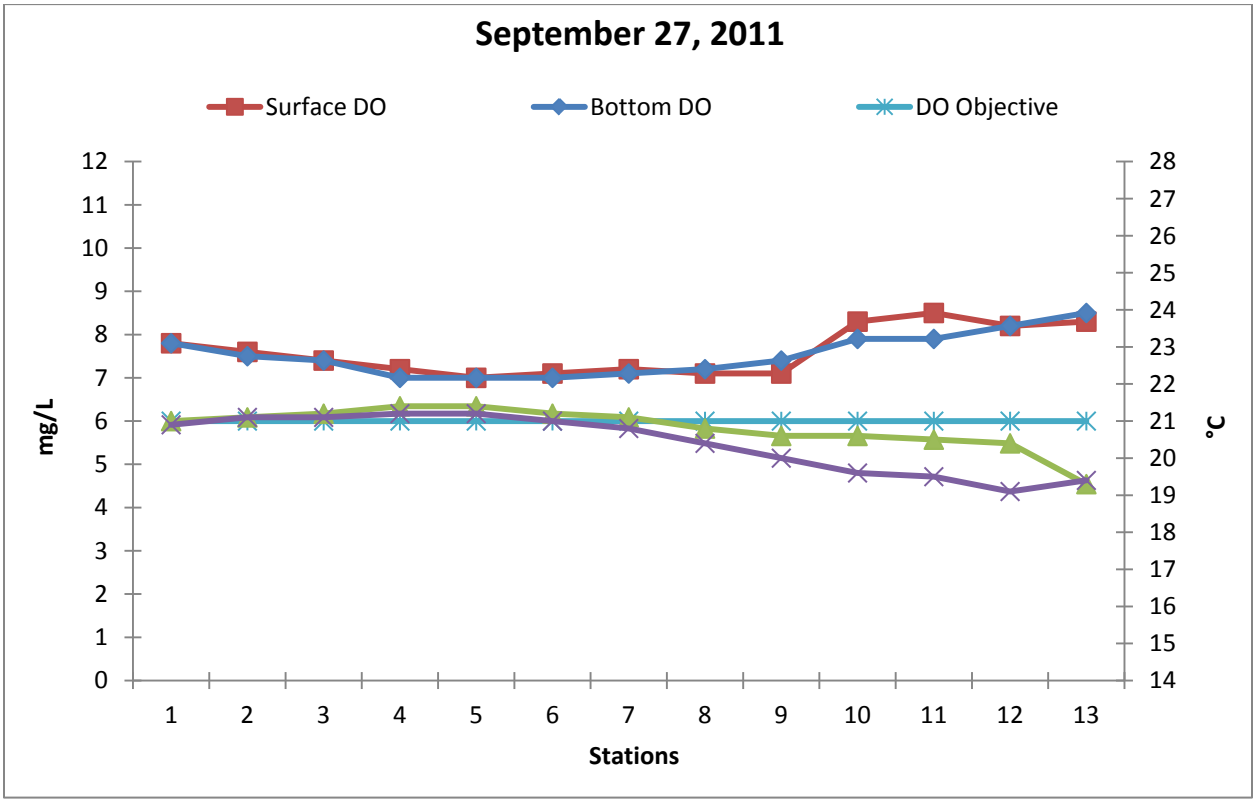
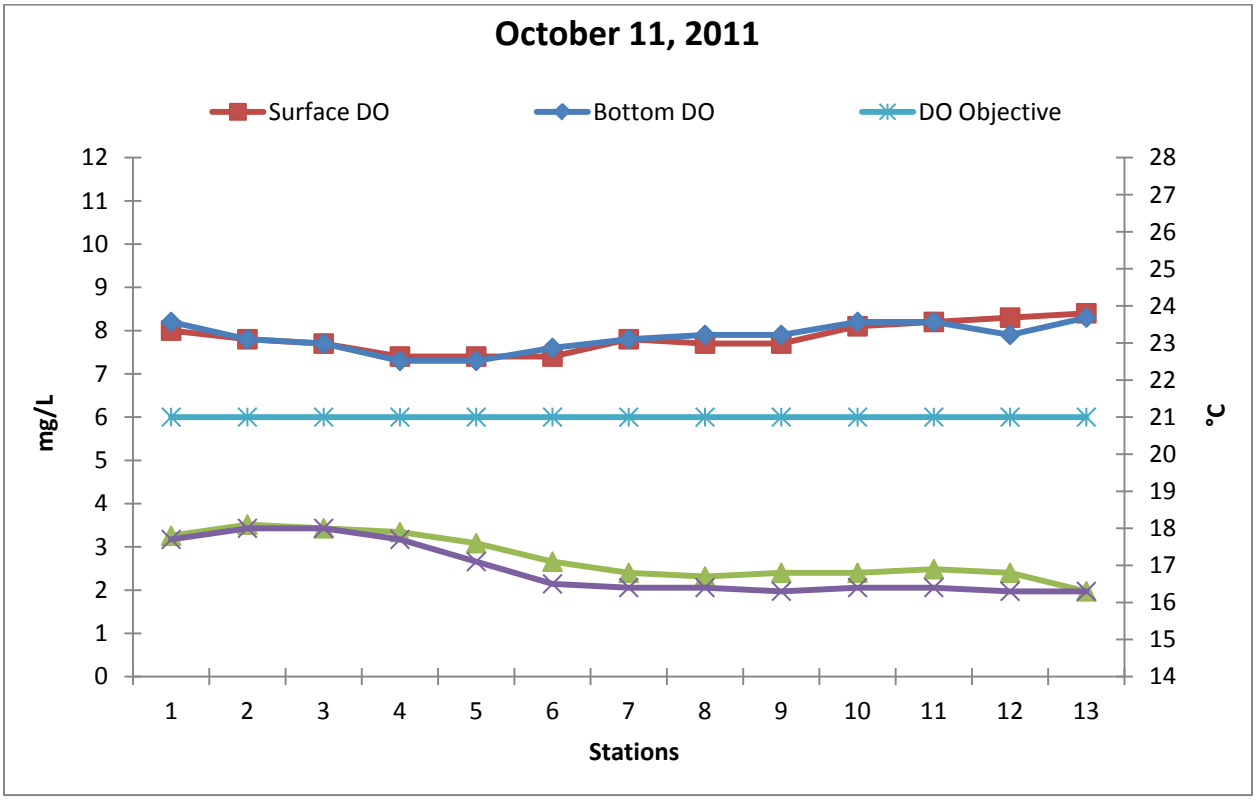


Figure 7-7 Surface and bottom DO and water temperature values in the channel, October 2011



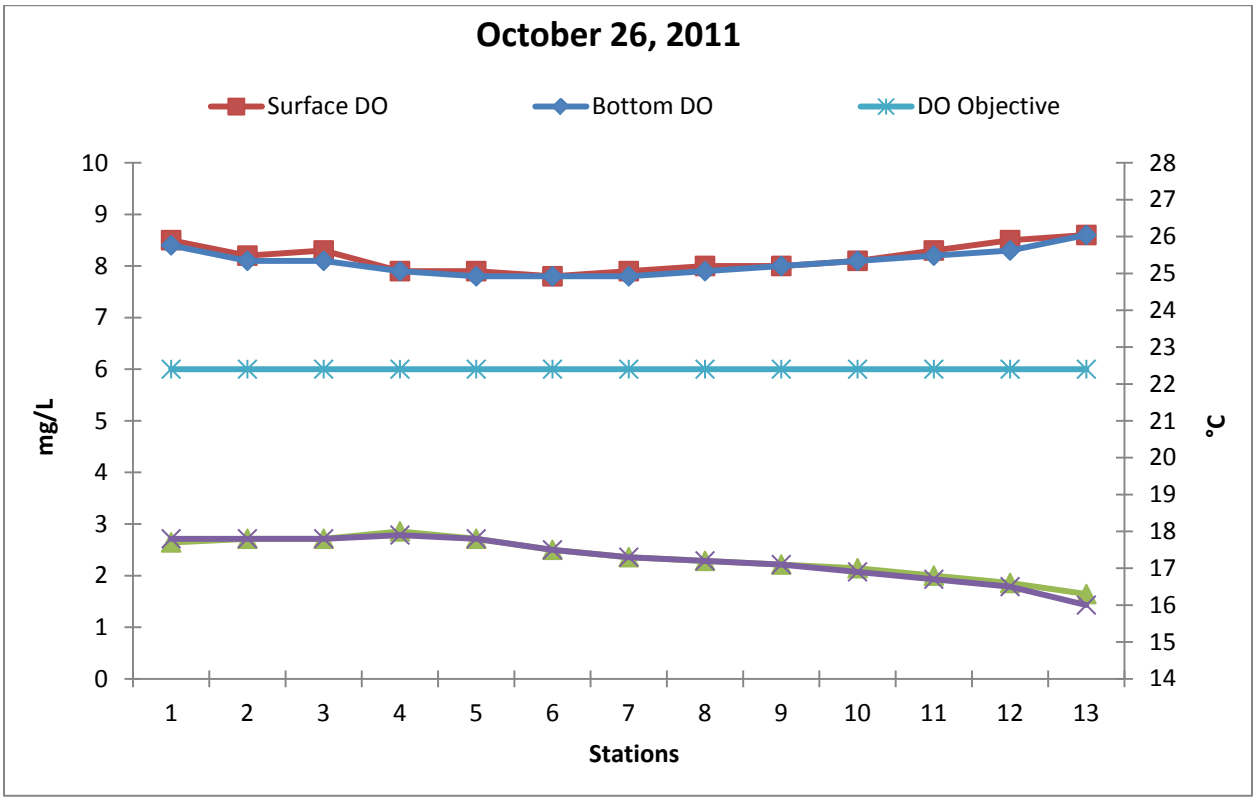


Figure 7-8 Surface and bottom DO and water temperature values in the channel, November 2011

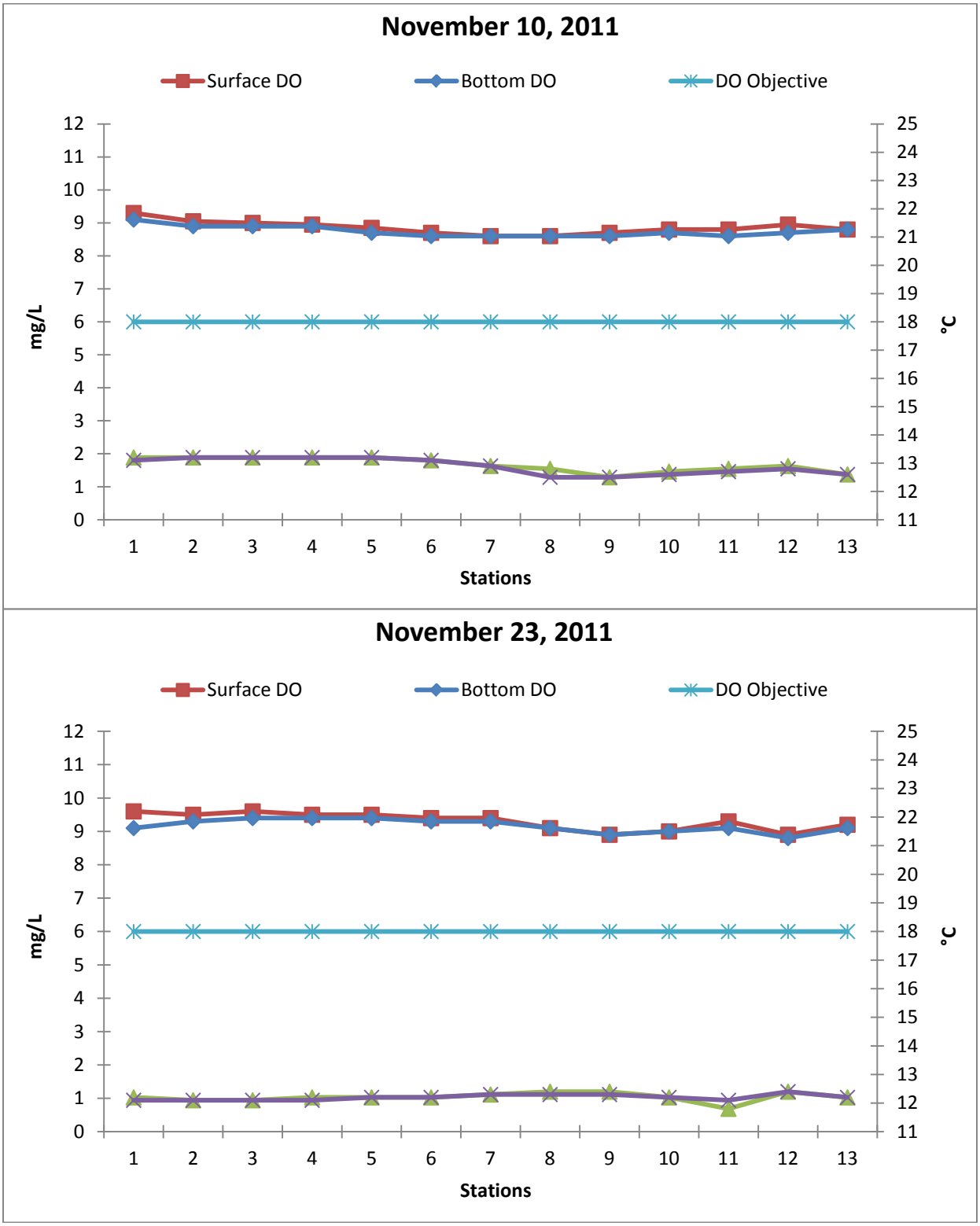
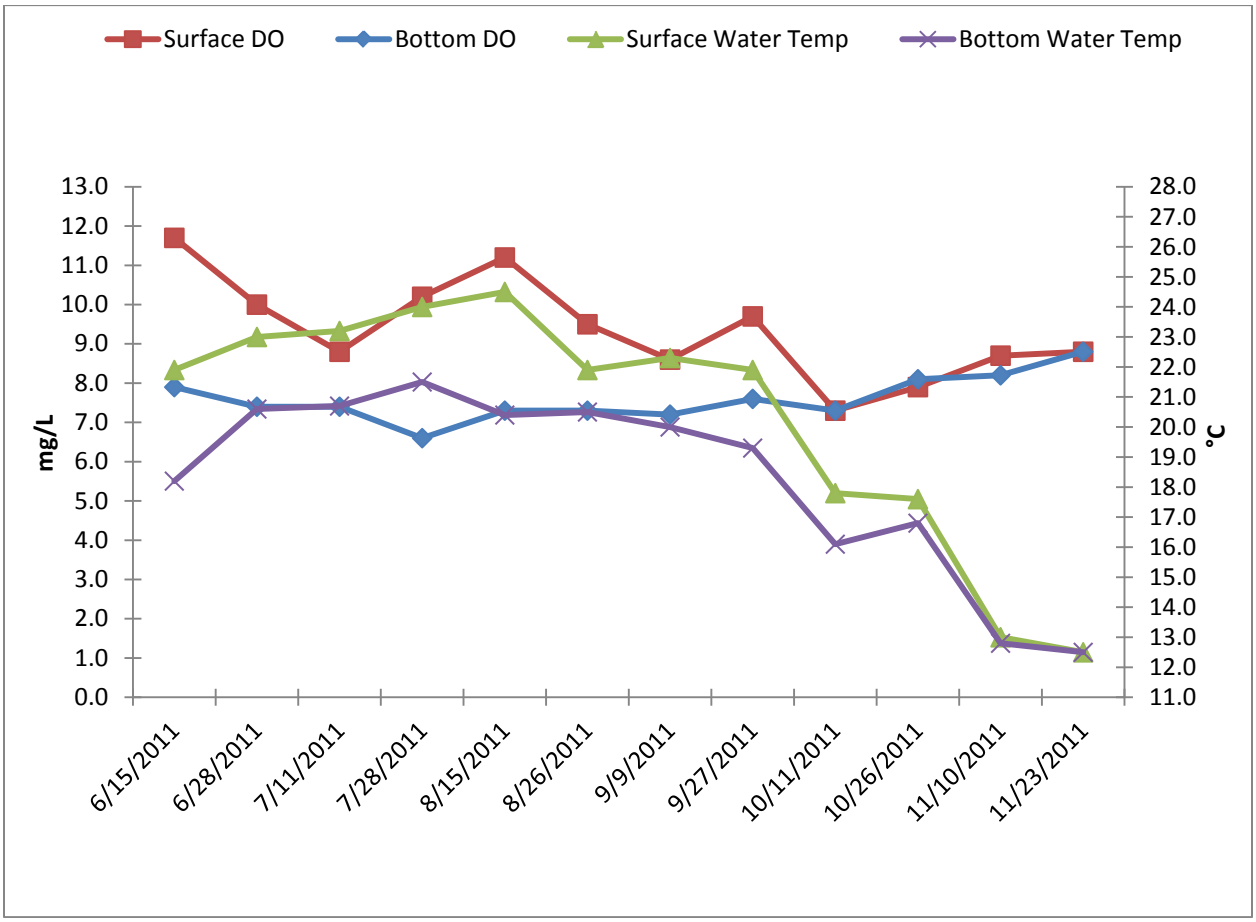


Figure 7-9 Surface and bottom DO and water temperature values in the Stockton Turning Basin from June through November 2011



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 State Water Project and the Central Valley Project to assess the impacts of the project operations and to adjust project operations to comply with mandated water quality standards. The continuous monitoring program has been in operation since 1983. This chapter summarizes the results of continuous water quality monitoring at 9 stations for calendar year 2011. 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, dissolved oxygen (DO), surface specific conductance (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 was measured), Prisoners Point, Vernalis, and Hood stations as part of D-1641's Table 3 objectives (SWRCB 1999). The only environmental parameter analyzed 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 surface of the water using a float-mounted YSI 6600 multi-parameter water quality sonde. 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 2011 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 7.3 °C in December 2011 at the Vernalis and Mossdale stations on the San Joaquin River to 24.3 °C in July 2011 at the Stockton station on the San Joaquin River (Figure 8-2). The range of water temperature values was similar to the range observed in the same time period in 2010.

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 August through September at the San Joaquin River stations of Stockton, Mossdale, Prisoner's Point, and Vernalis.

DO

Average daily DO values for the 9 monitoring stations ranged from 6.7 mg/L to 12.9 mg/L (Figure 8-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton, Mossdale, and Vernalis in August 2011. These three stations ranged from a daily average of 6.7 mg/L at the Vernalis station in April 2011 to a value of 12.9 mg/L at the Stockton station in December 2011. All other stations showed daily averages between 7.3 mg/L and 11.1 mg/L. The daily averages of the tidally influenced stations of Antioch and Mallard followed a consistent trend with values that did not vary greatly from each other in 2011.

All compliance monitoring stations 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, Mossdale, and Vernalis stations recorded low daily averages of 6.7 to 6.9 mg/L in the beginning of April 2011. The Stockton station showed a slight, but not significant, DO sag in the months of July through September, when compared to the exaggerated DO sag observed in the 2010 summer months. The daily averages recorded in the Stockton station stayed mostly consistent with the three other San Joaquin river stations during the summer months.

Daily average DO values at the Mossdale and Vernalis stations showed a familiar pattern of increase from August through September of 2011 when compared to the observed increase in the summer months of 2010. However, the highest observed value in August 2011, at the Mossdale station, was about 3.0 mg/L lower than the high value recorded around the same time in August 2010. This demonstrates a decrease in daily averages of the Mossdale and Vernalis stations in 2011 when compared to the high daily averages of 2010. The DO did not begin to increase at the Mossdale and Vernalis stations until the end of July 2011, which occurred later than the 2010 summer increase. The high summer DO averages seen at the Mossdale and Vernalis stations in 2011 coincided with high chlorophyll *a* fluorescence during the same period (Figure 8-8a).

SC

Daily average surface SC for the estuary ranged from 103 µS/cm to 26,945 µS/cm, with the lower values at the Vernalis station and the higher values at the more tidally influenced Martinez station (Figure 8-4a). Data collected at the Vernalis, Mossdale, and Stockton stations on the San Joaquin River, upstream of the confluence of the Sacramento and San Joaquin rivers, shows a higher average SC gradually increasing from July through December than the data collected from the Hood and Rio Vista stations, which did not vary greatly (Figure 8-4b).

All stations showed a decrease in SC in early 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). The

Vernalis, Mossdale, and Stockton stations on the San Joaquin River showed a slight decrease in surface SC in April through June 2011 after the April VAMP pulse (Figure 8-4b). SC levels from these three stations remained low until late July.

The Martinez, Mallard, and Antioch stations showed similar trends in SC data as observed in 2010. The SC daily averages from the Stockton, Mossdale, Vernalis, and Prisoner's Point stations in 2011 varied from the values observed in 2010. For example, the highest SC observed from the San Joaquin River stations in 2011 was 853 µS/cm at the Mossdale station in late December, compared to an observed high of 1013 µS/cm at the Mossdale station in January 2010. Likewise, the lowest observed SC daily average in July of 2011 was 103 µS/cm at the Vernalis station, compared to a low of 143 µS/cm observed in July 2010 at the Prisoner's Point station. As seen in previous years, bottom SC measured in 2011 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 in 2011 ranged from 7.1 to 8.2 (Figure 8-6). In 2011, all stations showed a slight decrease in pH in early April. The Stockton station showed a slight dip in pH in early April through late May of 2011. The daily pH averages for the Stockton station then proceeded to gradually increase from October through December.

The pH daily averages observed in 2011 for the tidally influenced stations of Martinez, Mallard, and Antioch were consistent and did not have significant spikes in pH. In comparison, the Mossdale and Vernalis stations had a significant increase in daily pH averages in late July through mid August. This was somewhat similar to 2010, where the Mossdale and Vernalis stations saw higher pH levels than the other stations from July through September. However, the Mossdale and Vernalis stations reached a high pH value of 8.2 in 2011, which is lower than the value of 9.4 observed in the same period of 2010. 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 2.4 °C in January 2011 at the Sacramento River station of Rio Vista to 28.1 °C in July 2011 at the Rio Vista station (Figure 8-7). The range of daily average air temperature values for 2011 was similar to the values observed in 2010.

Chlorophyll *a* Fluorescence

Daily average chlorophyll *a* fluorescence recorded at all the stations ranged from a low of 0.55 FU in October 2011 at the Hood station on the Sacramento River to a high of 25.06 FU in September 2011 at the Mossdale station on the San Joaquin River (Figure 8-8, a through d). In general, the values recorded in 2011 exhibited a data range that greatly contrasts the values from 2010. For example the maximum value of 25.06 FU recorded in 2011 was significantly lower than the maximum value of 109.68 FU recorded in 2010. This demonstrates that the major algal blooms observed in 2011 were much smaller than the blooms in 2010.

For most of the 2011 calendar year, daily chlorophyll *a* fluorescence averages at the Vernalis, Mossdale, and Stockton stations were typically higher than the other stations (Figure 8-8a). Major algal blooms at the Mossdale and Vernalis stations were observed in late July, August,

and September. Major algal blooms observed at the Stockton station occurred in mid March through April as well as late December. Moderate blooms were observed at the Antioch, Mallard Island, and Prisoners Point stations in April.

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 March, 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 March 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 Prisoner's Point station in November 2011 and the Stockton station in December to a high of 128 NTU at the Rio Vista station on the Sacramento River in March 2011 (Figure 8-9, a through d). These results are in contrast with those values observed in 2010, in that the 2011 turbidity values were significantly lower. The very low turbidity values in 2011 coincide with the low chlorophyll *a* fluorescence values also recorded in 2011 (Figures 8-8, a through d). In 2011, turbidity was at its highest for most stations in late March (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 in Figure 8-1) 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 2011 at the Stockton station on the San Joaquin River (Figure 8-10). The range of average monthly DO values in 2011 at the Stockton station was overall consistent from month to month. The largest range of DO values occurred in June 2011. The smallest range of DO values in 2011 was observed in January and February. Monthly average DO values from 2011 only showed a 2.7 unit swing from high to low values of 10.5 mg/L to 7.8 mg/L, which is lower than the 3.1 mg/L swing observed in 2010. The lowest DO value occurred in August and September 2011, while the highest value occurred in December 2010.

The quarter-hourly values for the Stockton station ranged from 5.5 mg/L to 13.6 mg/L. The minimum value of 5.5 mg/L was recorded in August and September 2011, while the maximum value of 13.6 mg/L was recorded in December 2011. As seen in previous years, the DO levels dropped in August and September and had recovered by October.

DWR's oxygen aeration facility did not operate in 2011, and conducted only minimal testing from June to September 2010. For 2011, 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. The 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 2011 were in the expected range of values for water temperature, DO, SC, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. In 2011, 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, particularly in September and August. In addition, the Mossdale and Vernalis stations showed higher DO values in August than any other station in the estuary, while the Stockton station showed the lowest values for DO in August and September. Last, the pH values at the Mossdale and Vernalis stations on the San Joaquin River increased during the month of August, but did not vary much from the pH values of the Martinez and Antioch stations. The Mossdale and Vernalis pH values returned to 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 2011 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 edition).

[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, 2011

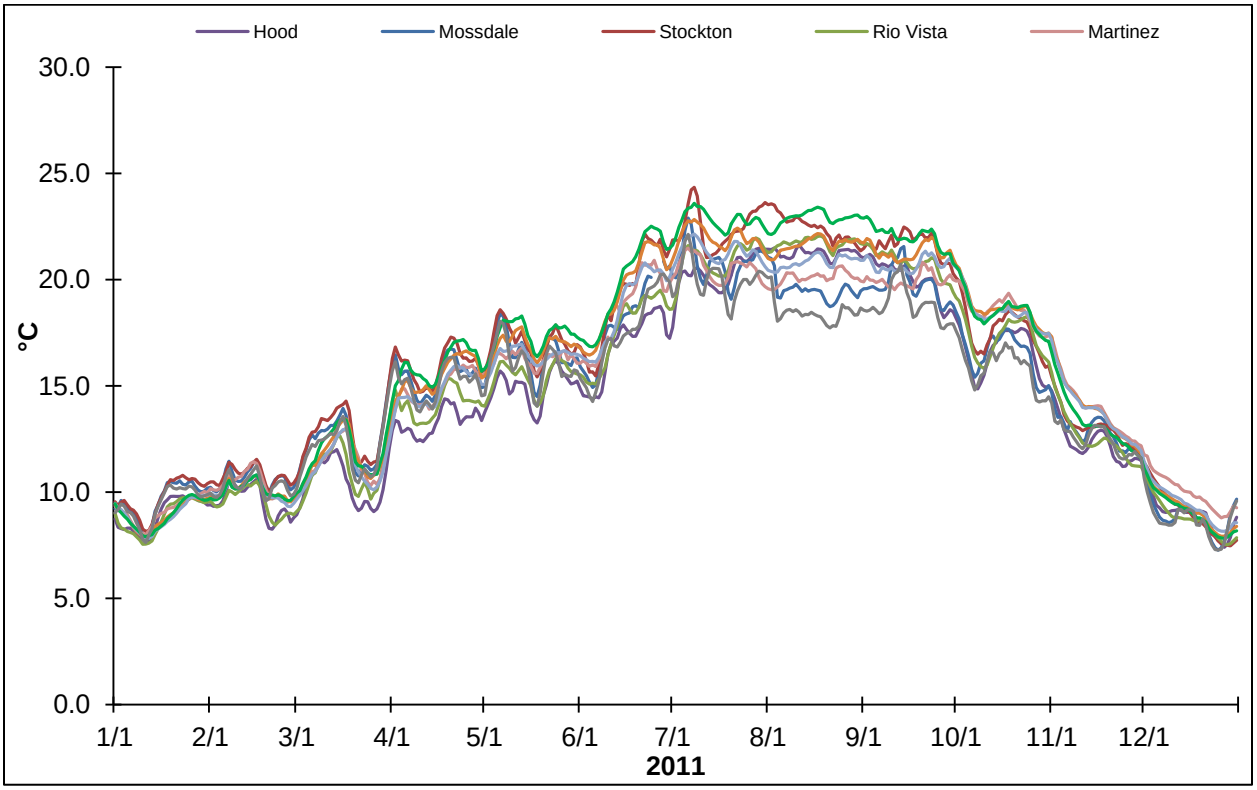


Figure 8-3 Average daily DO at 9 stations, 2011

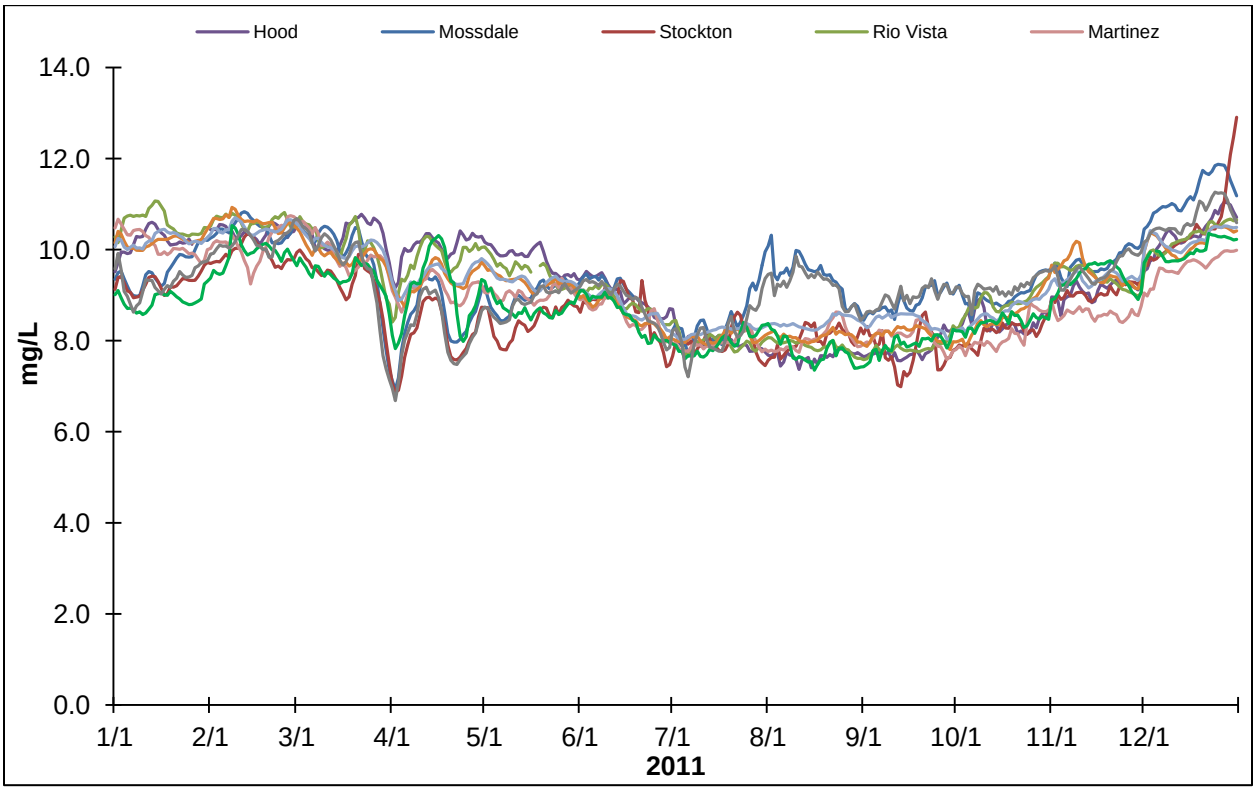


Figure 8-4a Average daily surface SC at 9 stations, 2011

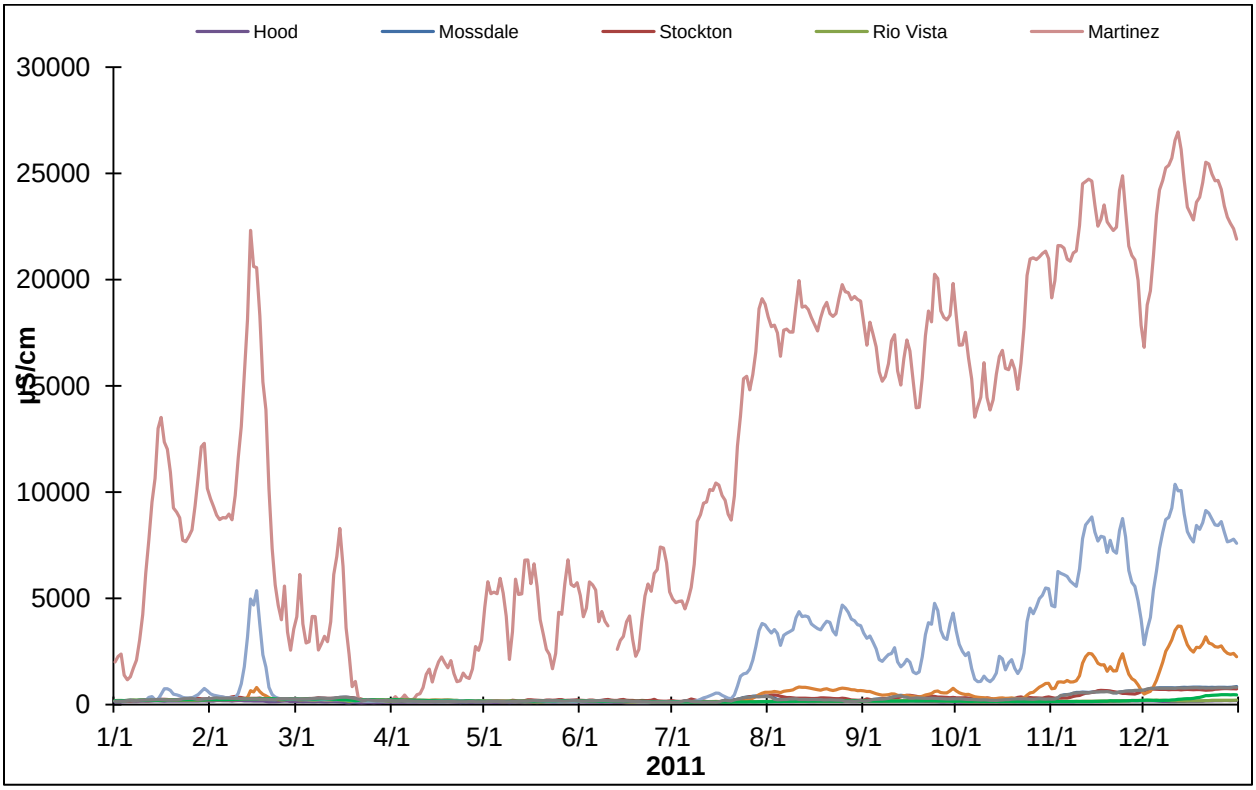


Figure 8-4b Average daily surface SC at 6 stations, 2011

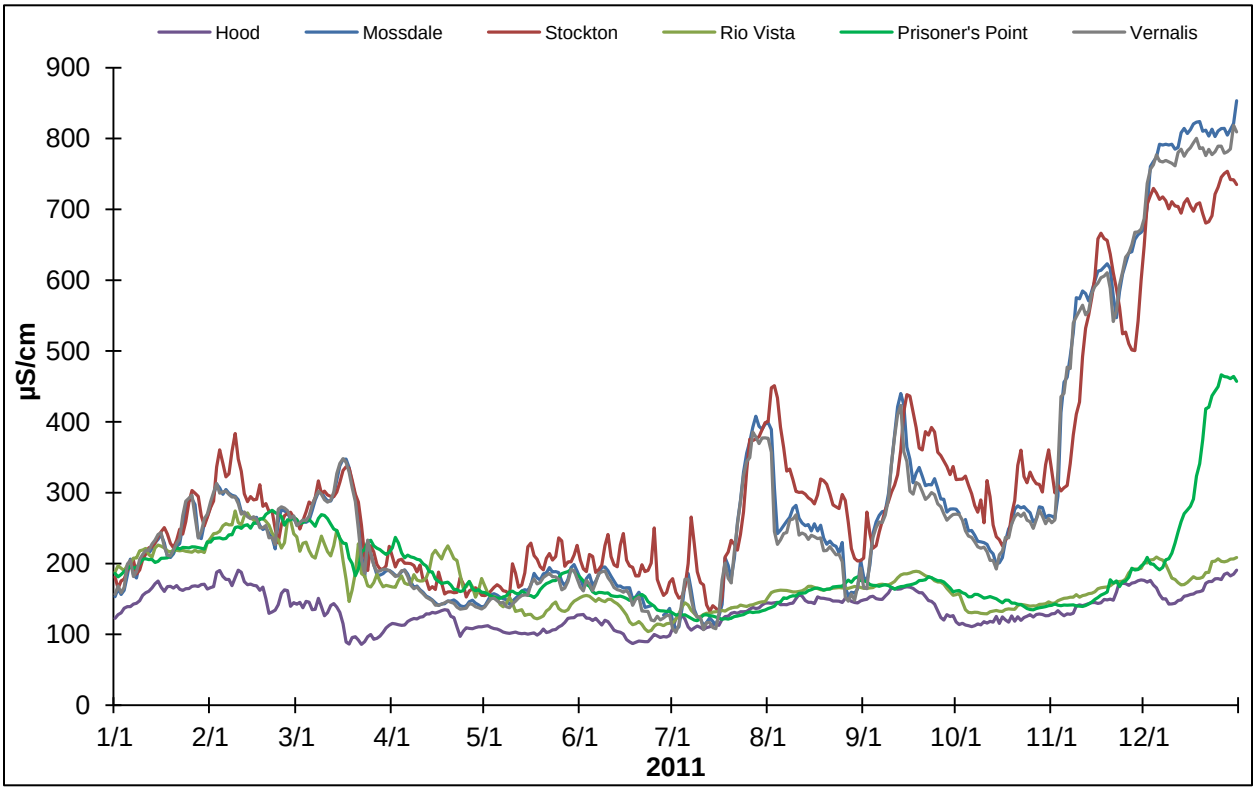


Figure 8-5 Average daily surface and bottom SC at 3 tidally influenced stations, 2011

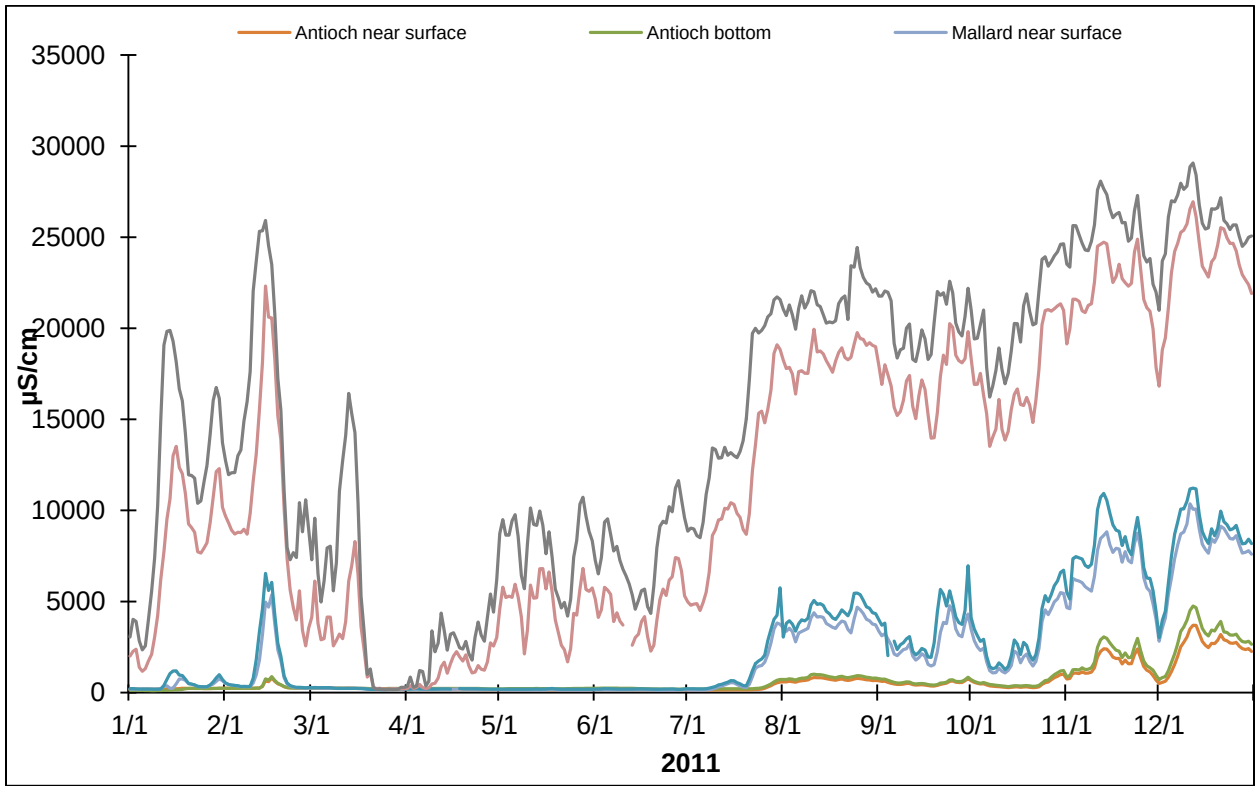


Figure 8-6 Average daily pH at 9 stations, 2011

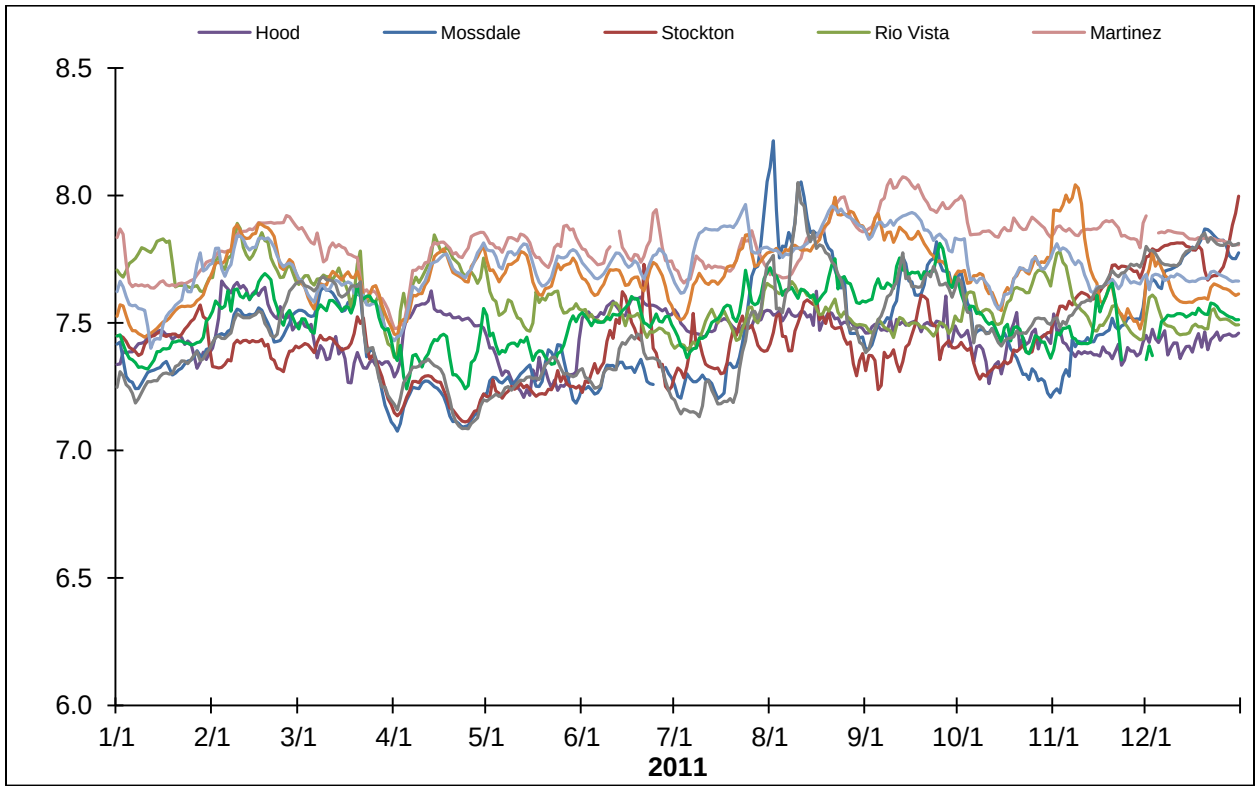


Figure 8-7 Average daily air temperature at 6 stations, 2011

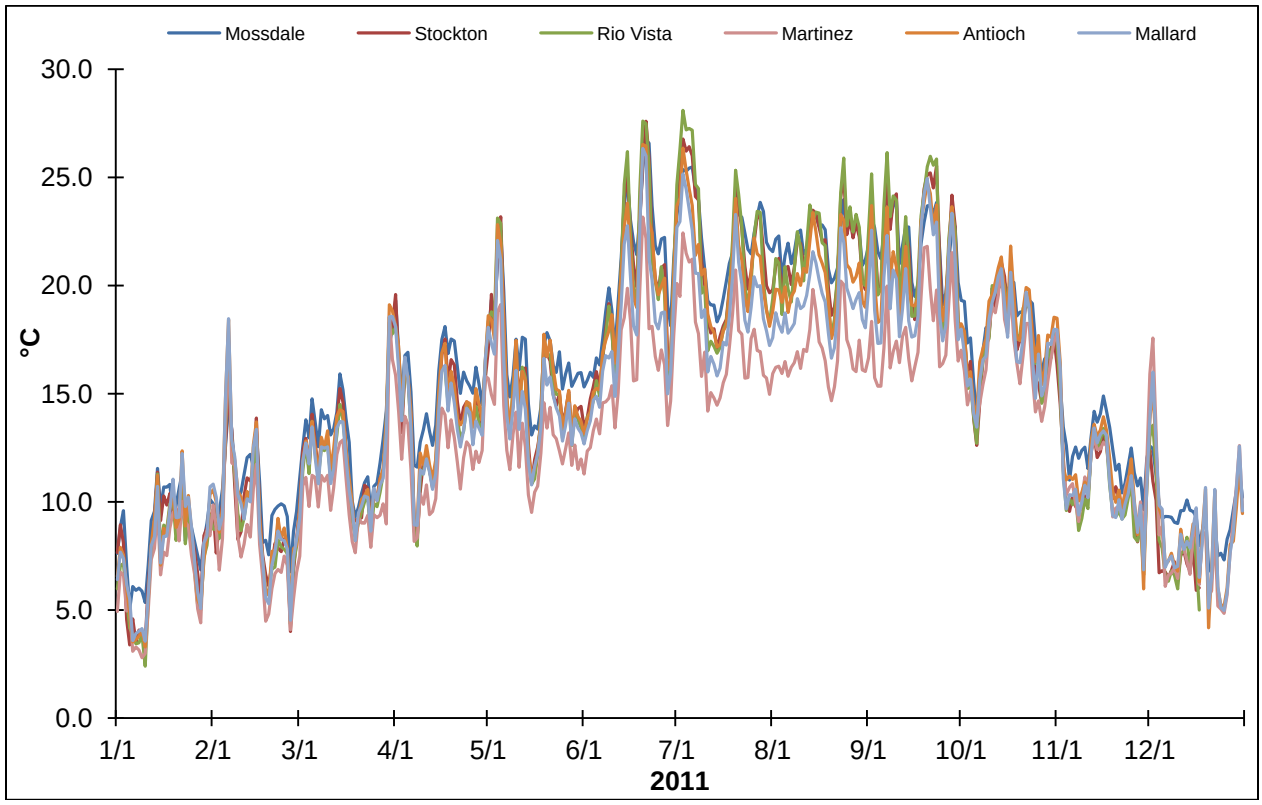


Figure 8-8a Average daily chlorophyll *a* fluorescence at 9 stations, 2011

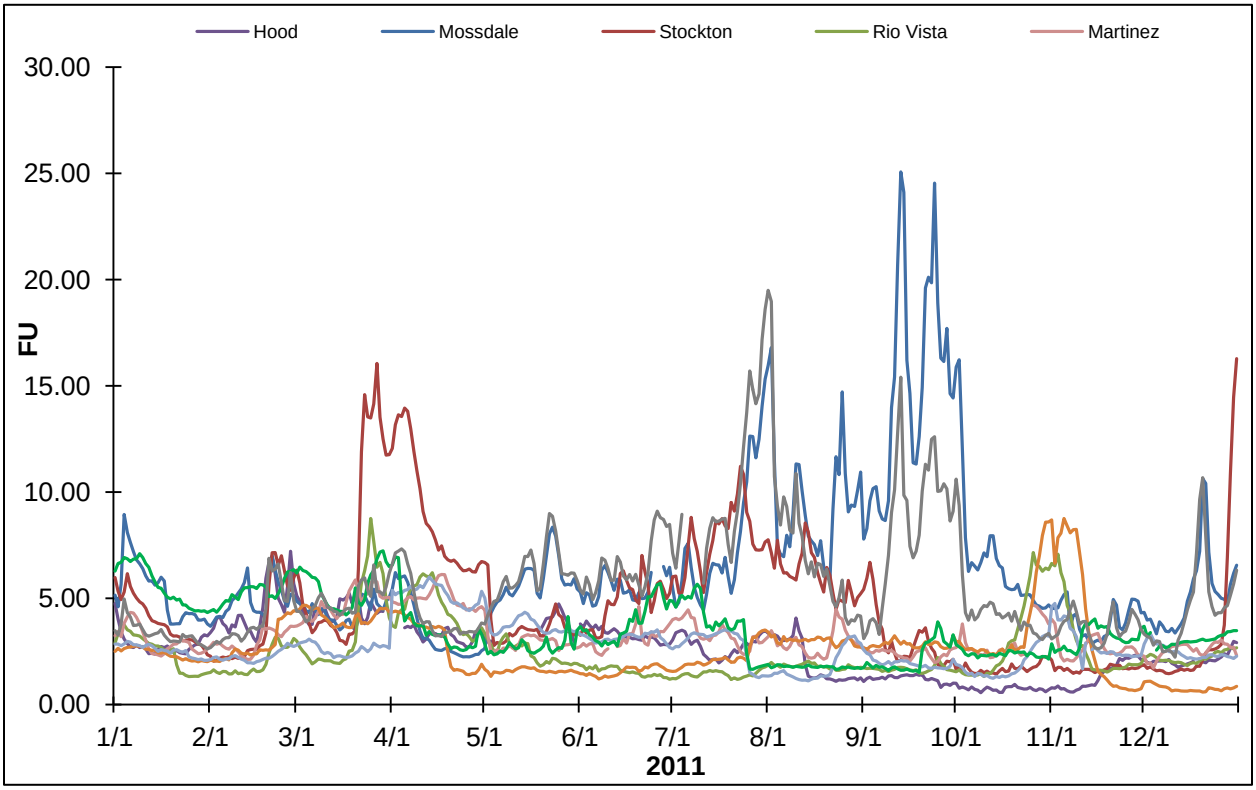


Figure 8-8b Average daily chlorophyll *a* fluorescence at 2 Sacramento River stations, 2011

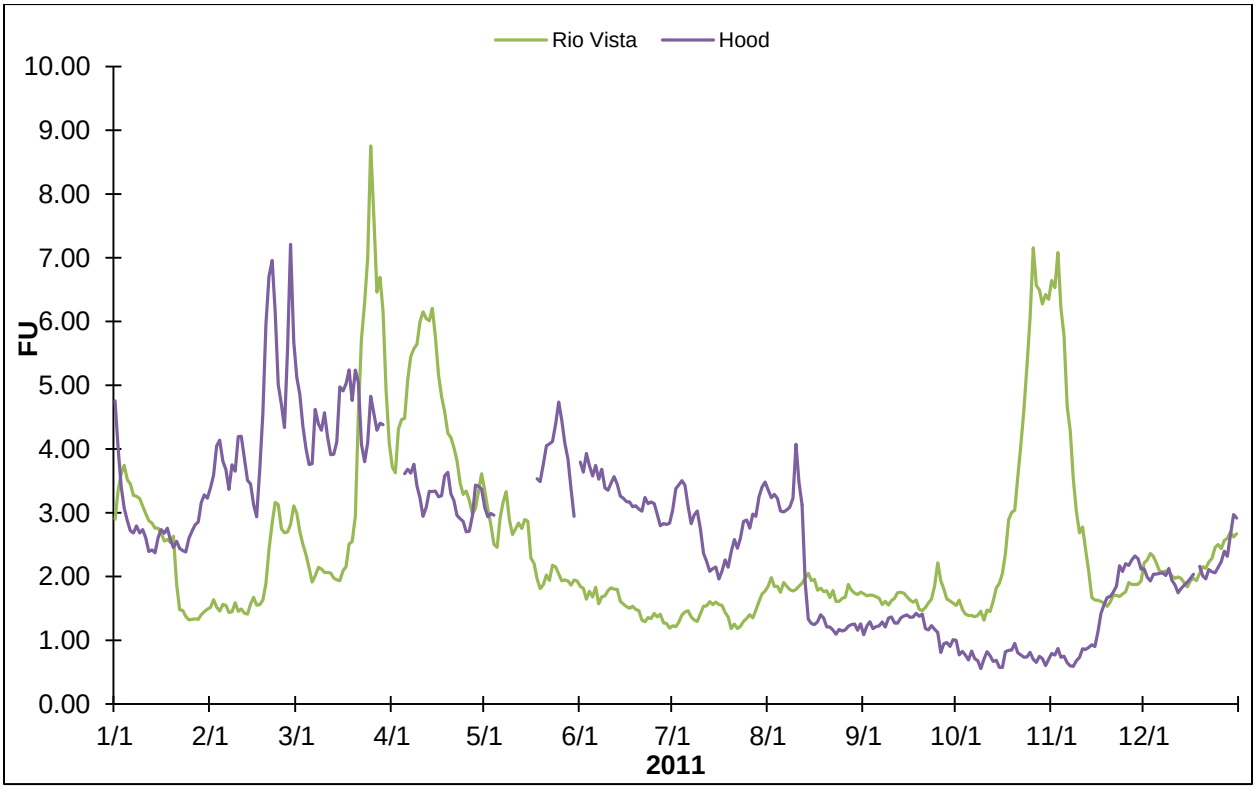


Figure 8-8c Average daily chlorophyll *a* fluorescence at 4 San Joaquin River stations, 2011

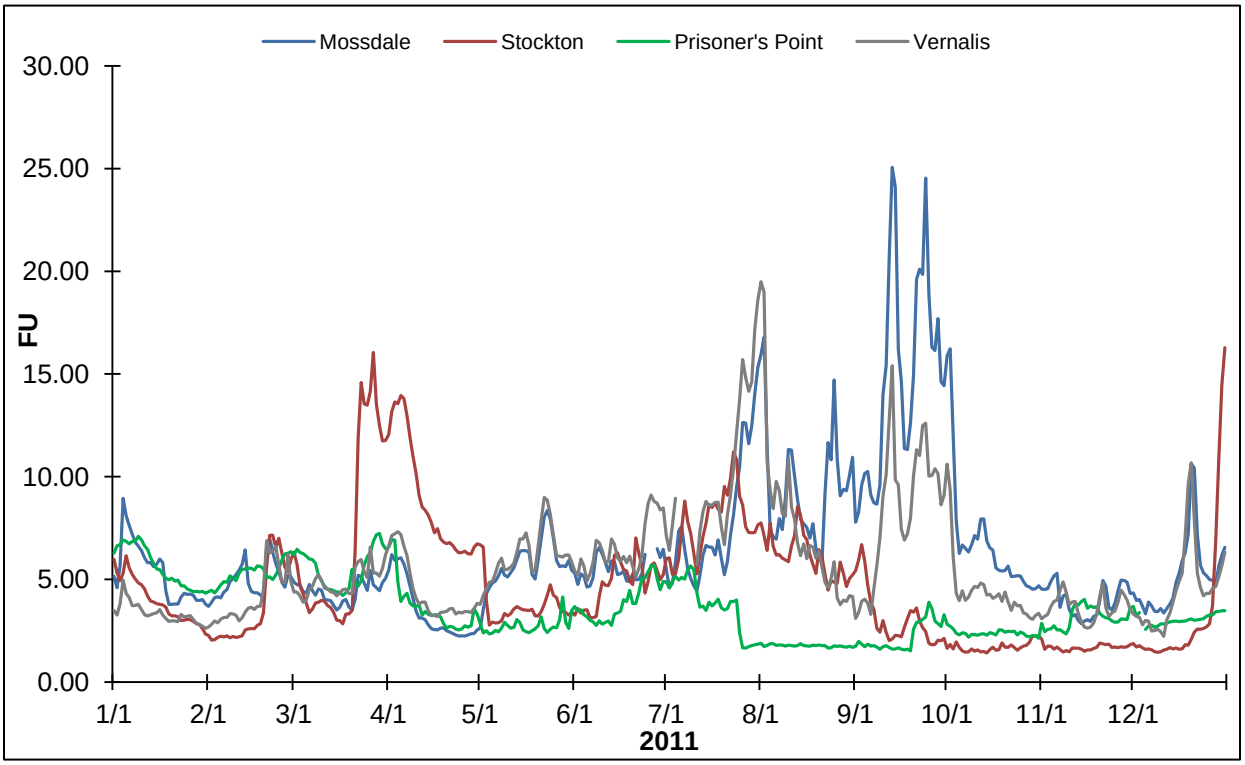


Figure 8-8d Average daily chlorophyll *a* fluorescence at 3 tidally influenced stations, 2011

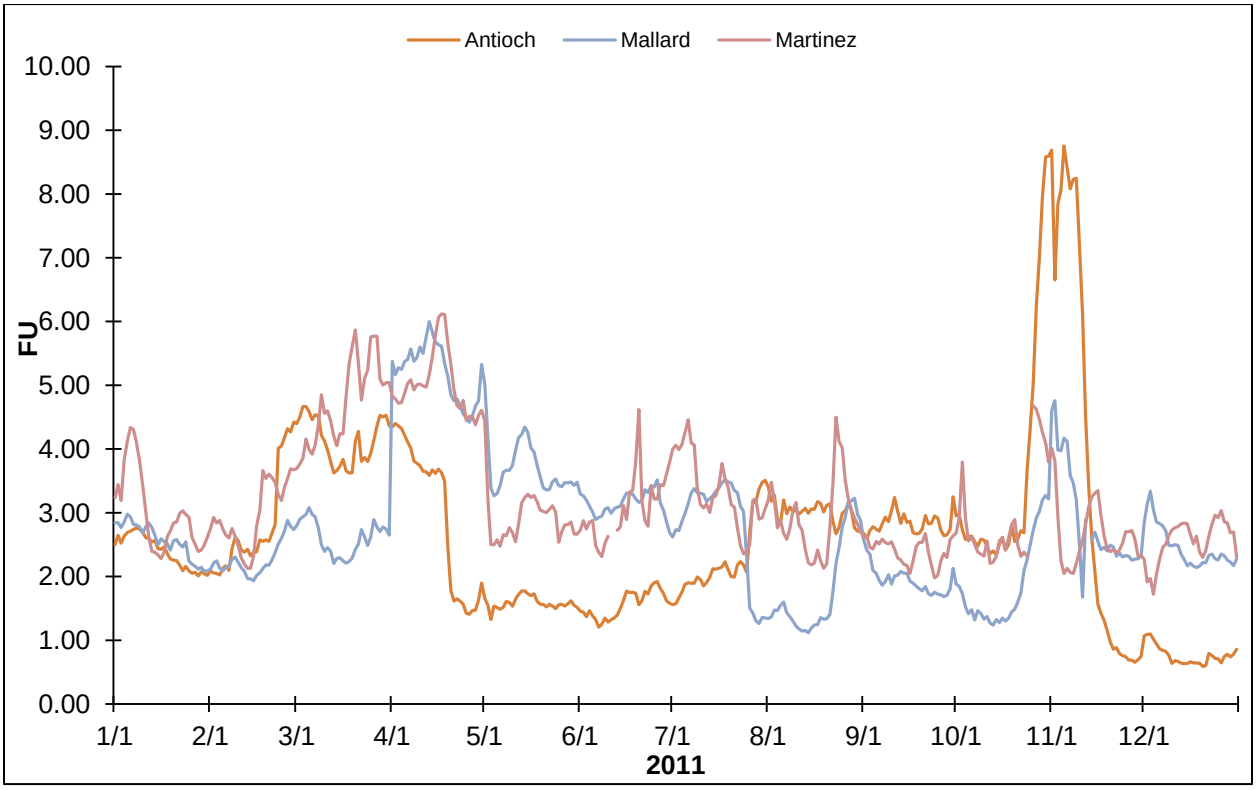


Figure 8-9a Average daily turbidity at 9 stations, 2011

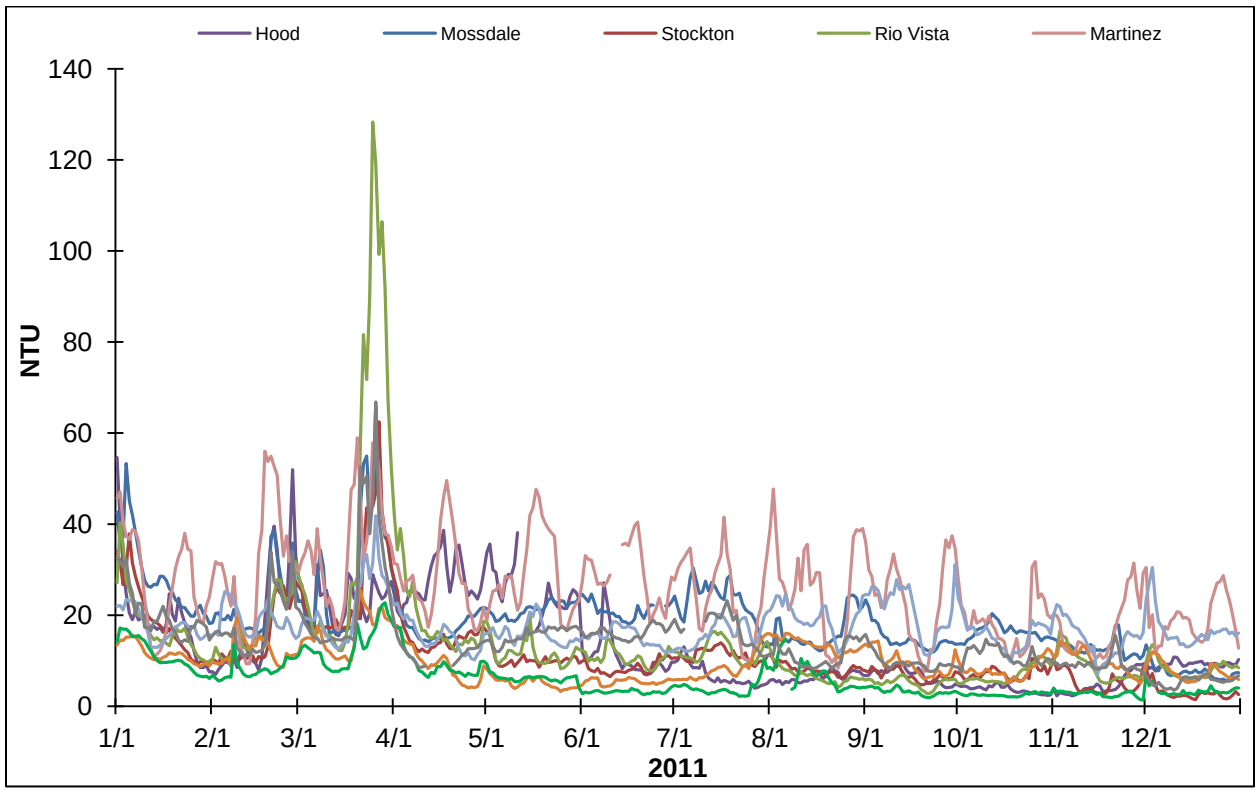


Figure 8-9b Average daily turbidity at 2 Sacramento River stations, 2011

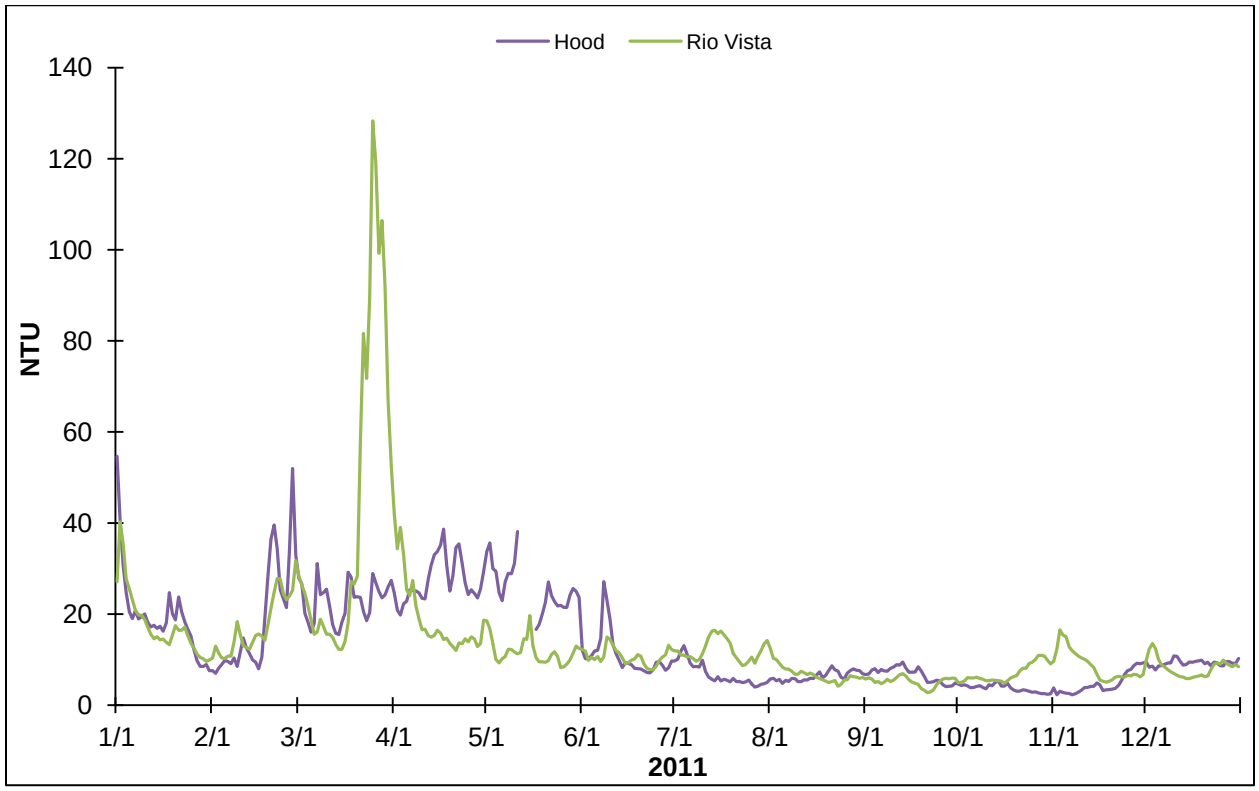


Figure 8-9c Average daily turbidity at 4 San Joaquin River stations, 2011

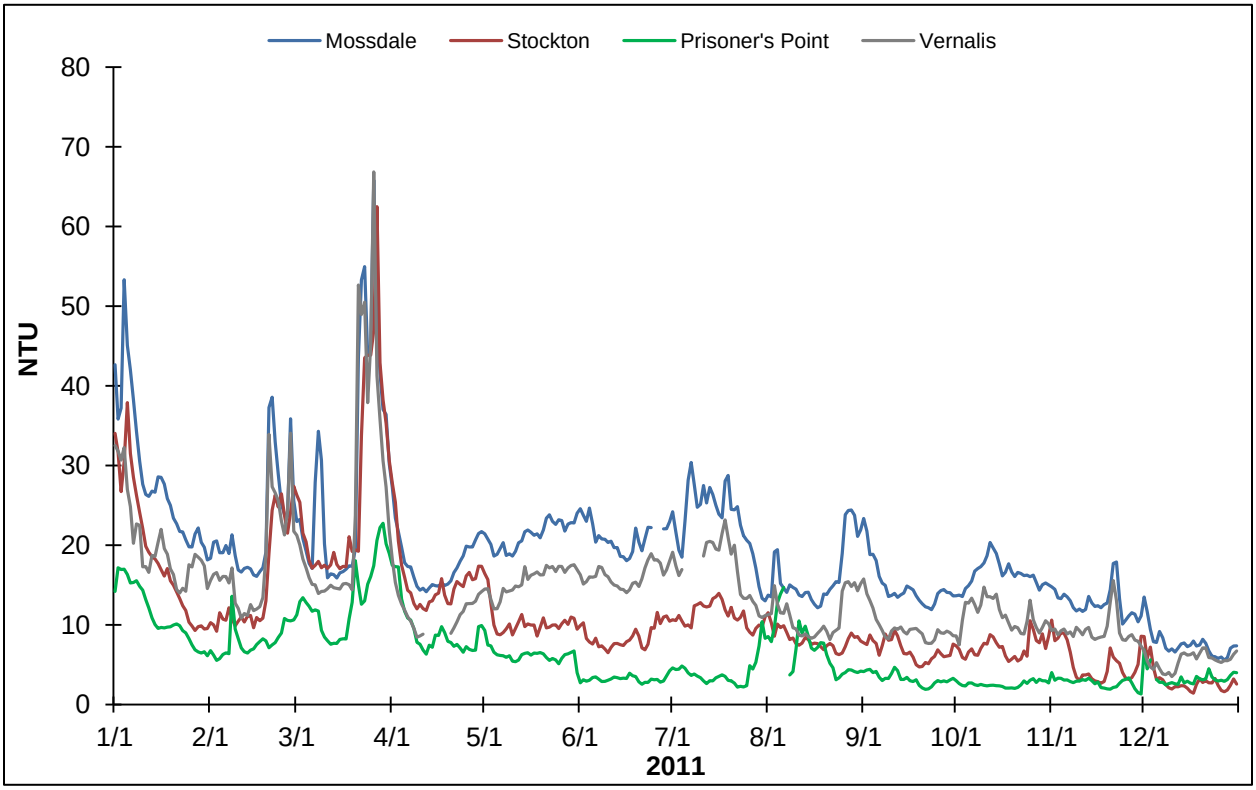


Figure 8-9d Average daily turbidity at 3 tidally influenced stations, 2011

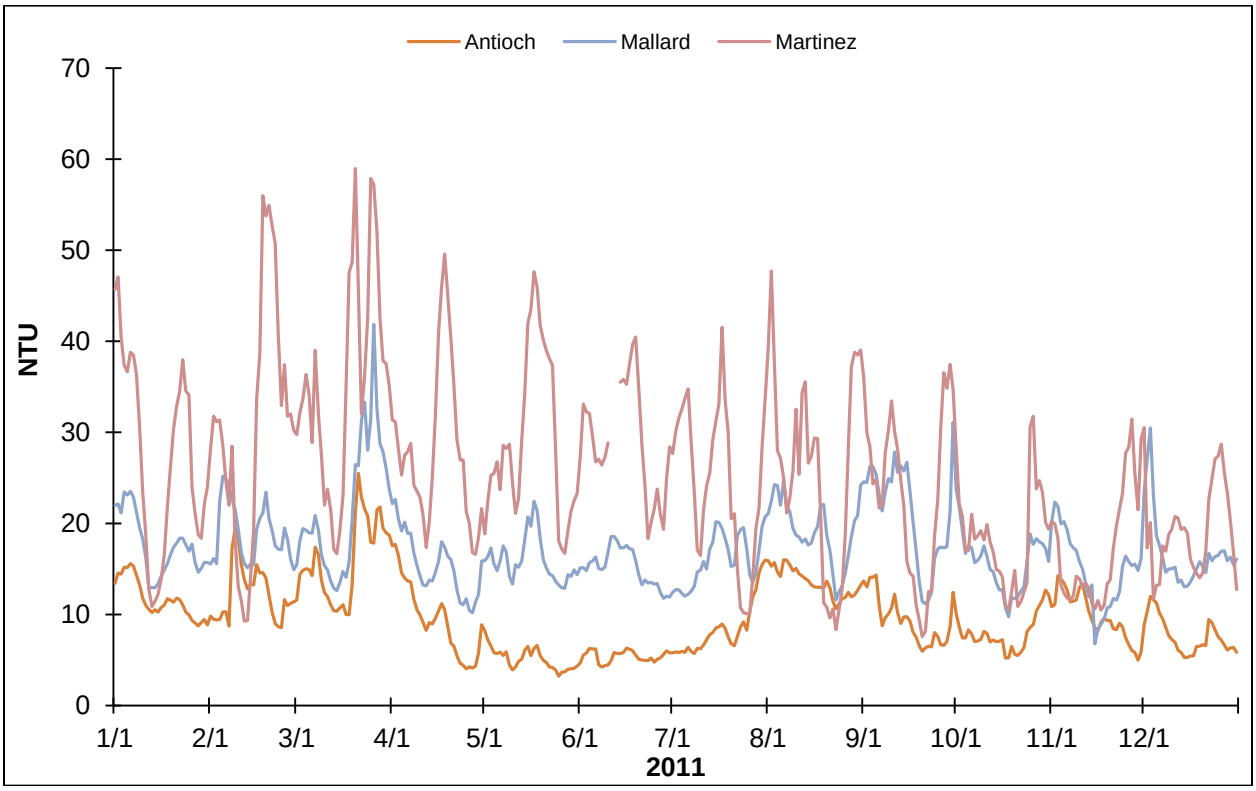
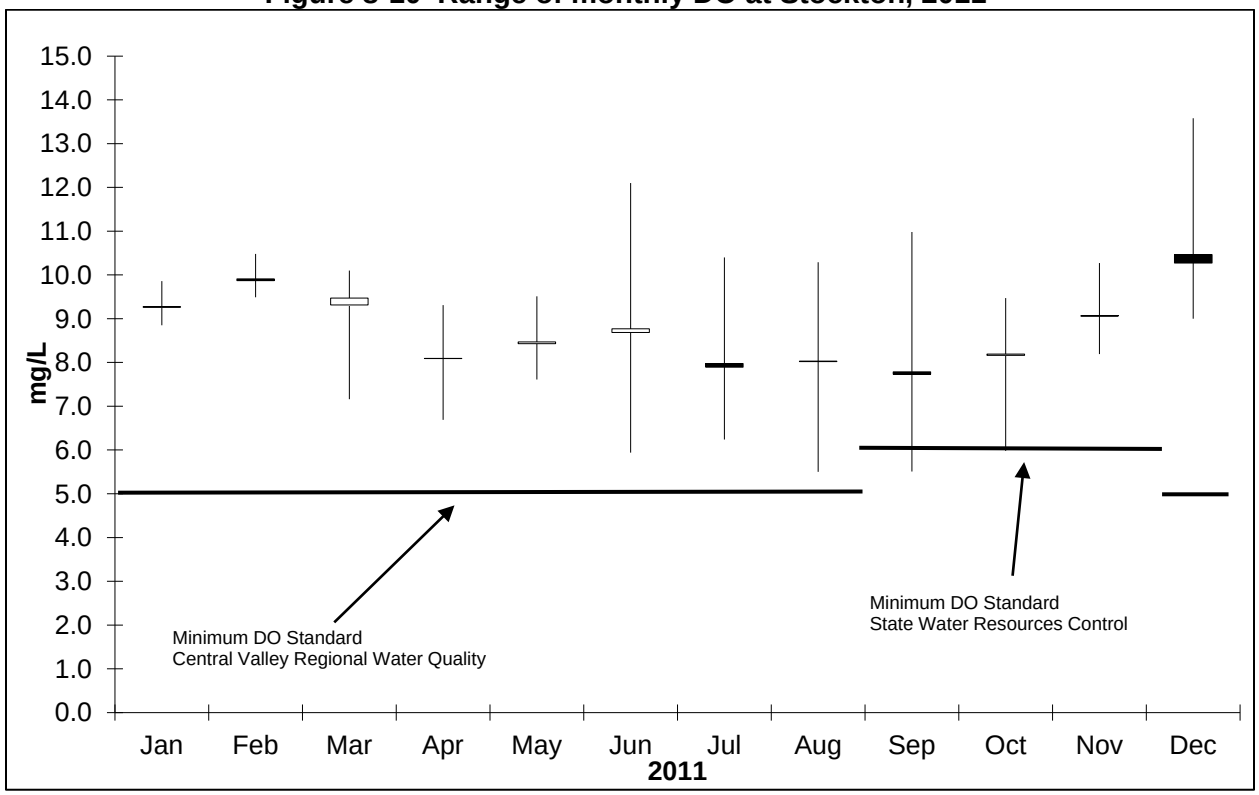


Figure 8-10 Range of monthly DO at Stockton, 2011



Note: Solid boxes shown 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 (see footnote 9 on page 3-3) 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 brianne.sakata@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 mike.dempsey@water.ca.gov.

Benthic and Sediment Data

Laboratory identification and enumeration of macrobenthic organisms in each sample is performed by Hydrozoology (see footnote 11 on page 6-2). The results are reported to DWR on standard datasheets. Laboratory analysis of sediment samples is performed by the DWR Soils and Concrete Laboratory (see footnote 12 on page 6-2). The results of the sediment analyses are reported in writing to EMP staff.

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 heather.fuller@water.ca.gov.

Phytoplankton Data

Phytoplankton sampling sites are surveyed monthly, primarily by vessel. EcoAnalysts, Inc. (see footnote 10 on page 4-2) 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 tiffany.brown@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 april.hennessy@wildlife.ca.gov.