State of California
The Resources Agency
Department of Water Resources
Division of Environmental Services

Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2001-2002

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

October 2005

Executive Summary, 2001-2002

This report summarizes the results of water quality monitoring and special studies conducted by the Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR) within the Sacramento-San Joaquin Delta and the Suisun and San Pablo bays (the upper San Francisco Estuary) from 2001 through 2002. This monitoring is mandated by Water Right Decision 1641(D-1641) of December 1999. This report is being submitted to fulfill the reporting requirements of this decision.

DWR and USBR monitored water quality using a revised protocol implemented in 1996. Under this monitoring protocol, eleven sampling sites representing eight regions of the upper San Francisco Estuary (Estuary) were monitored for a variety of physical and chemical water quality parameters. The results gathered from the sampling of 14 parameters are described in this report. Parameters such as water temperature, Secchi disk depth, dissolved oxygen concentration, specific conductance, dissolved inorganic nitrogen, orthophosphate, and volatile suspended solids were within their historical range. Measured parameters often exhibited seasonal and inter-annual variation, as well as changes in response to significant rainfall events, and/or changes in flow rates. No major discernable long-term trends were seen in these data.

In addition to monitoring physical and chemical water quality parameters, biological sampling was conducted to monitor productivity and community composition of phytoplankton and benthic communities. Samples for chlorophyll *a* and pheophytin *a* were taken at 15 sampling sites in the Estuary. Chlorophyll *a* concentrations showed seasonal patterns. The highest chlorophyll *a* concentrations occurred during the spring for most stations, with a second increase usually occurring during the late summer or early fall. Pheophytin *a* concentrations remained fairly constant and did not show apparent seasonal patterns. Chlorophyll *a* and pheophytin *a* concentrations for 2001-2002 were generally below 10 µg/L for most regions. Concentrations generally ranged between 0.5 µg/L and 15 µg/L throughout the Estuary.

Monthly zooplankton monitoring throughout the Estuary showed that mean monthly densities of most taxa remained relatively stable throughout 2001 and 2002. However, changes in the relative abundance of mysids and calanoid copepods in the upper Estuary were evident. Generally, native species were less abundant in 2002, relative to introduced species, than in 2001.

Benthic monitoring was conducted at ten representative stations throughout the Estuary to document substrate composition and the distribution, diversity and abundance of benthic organisms within the Estuary. The benthic community was determined to be a diverse assemblage of organisms including annelids (worms), crustaceans, aquatic insects and mollusks (clams and snails). Of the eight phyla identified, Annelida, Arthropoda, and Mollusca constituted 99.4% of the organisms collected during the study period.

DWR also conducted a series of special studies to monitor dissolved oxygen (DO) levels within the Stockton Ship Channel (Channel) during the late summer and early the fall of calendar years 2001 and 2002. The studies were conducted to determine if DO levels dropped below State (5.0 mg/L) and regional (6.0 mg/L) water quality objectives established for the Channel. Monitoring was typically conducted biweekly from August through November 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 in the Channel consistently fell below both the 5.0 mg/L and 6.0 mg/L objectives in both 2001 and 2002 due, in part, to relatively low net flows in the San Joaquin River past Stockton and warm water temperatures.

Dr. Dean F. Messer, Chief
Bay-Delta Monitoring and Analysis Section
Division of Environmental Services

Contents

Executive Summary iii

Chapter 1 Introduction 1-1

Chapter 2 Hydrologic Conditions, 2001-2002 2-1
Introduction 2-1
Methods 2-1
Summary 2-2
References 2-3

Chapter 3 Water Quality Monitoring, 2001-2002 3-1
Introduction 3-1
Parameters Measured 3-2
Water Temperature 3-2
Dissolved Oxygen 3-2
Specific Conductance 3-3
Secchi Disk Depth 3-4
Turbidity 3-4
Orthophosphate 3-5
Total Phosphorus 3-5
Kjeldahl Nitrogen 3-6
Dissolved Inorganic Nitrogen 3-6
Dissolved Organic Nitrogen 3-7
Total Dissolved Solids 3-7
Total Suspended Solids 3-8
Volatile Suspended Solids 3-8
Silica 3-9
Chloride 3-9
Summary 3-9
References 3-10

Chapter 4 Phytoplankton and Chlorophyll, 2001-2002 4-1
Introduction 4-1
Methods 4-2
Phytoplankton 4-2
Chlorophyll *a* 4-3
Results 4-3
Phytoplankton Identification 4-3
Pigment Concentrations 4-3
Site C3: North Delta 4-4

Site MD10: East Delta....4-4
Site C10: South Delta....4-5
Site P8: South Delta....4-5
Site D28A: Central Delta....4-6
Site D26: Lower San Joaquin River....4-6
Site D4: Lower Sacramento River....4-6
Site D8: Suisun Bay....4-7
Site D7: Suisun Bay....4-7
Site D6: Suisun Bay....4-8
Site D41: San Pablo Bay....4-8
References....4-9

Chapter 5 Zooplankton and Mysid Shrimp, 2001-2002....5-1
Methods....5-1
Results....5-2
Mysids....5-3
Calanoid Copepods....5-3
Cyclopoid Copepods....5-4
Cladocera....5-4
Rotifers....5-5
Summary....5-6

Chapter 6 Benthic Monitoring, 2001-2002....6-1
Introduction....6-1
Methods....6-1
Benthic Organisms....6-1
Sediment....6-3
Results....6-3
Benthic Organisms....6-3
Site C9: Benthic Abundance (Figure 6-3)....6-5
Site P8: Benthic Abundance (Figure 6-3)....6-5
Site D28A: Benthic Abundance (Figure 6-4)....6-6
Site D16: Benthic Abundance (Figure 6-4)....6-6
Site D24: Benthic Abundance (Figure 6-5)....6-6
Site D4: Benthic Abundance (Figure 6-5)....6-7
Site D6: Benthic Abundance (Figure 6-6)....6-7
Site D7: Benthic Abundance (Figure 6-6)....6-8
Site D41: Benthic Abundance (Figure 6-7)....6-8
Site D41A: Benthic Abundance (Figure 6-7)....6-9
Sediment....6-9
Site C9: Sediment Composition (Figure 6-8)....6-9
Site P8: Sediment Composition (Figure 6-8)....6-9
Site D16: Sediment Composition (Figure 6-9)....6-9

Site D28A: Sediment Composition (Figure 6-9) 6-10
Site D24: Sediment Composition (Figure 6-10) 6-10
Site D4: Sediment Composition (Figure 6-10) 6-10
Site D6: Sediment Composition (Figure 6-11) 6-10
Site D7: Sediment Composition (Figure 6-11) 6-11
Site D41: Sediment Composition (Figure 6-12) 6-11
Site D41A: Sediment Composition (Figure 6-12) 6-11
Summary 6-11
References 6-11

Chapter 7 Dissolved Oxygen Monitoring in the Stockton Ship Channel, 2001-2002 7-1
Introduction 7-1
Methods 7-2
Results 7-3
Dissolved Oxygen Levels in 2001 7-4
Dissolved Oxygen Levels in 2002 7-5
Summary 7-9
References 7-9

Chapter 8 Data Management, 2001-2002 8-1
Introduction 8-1
Data Management Procedures 8-2
Discrete Water Quality Data 8-2
Continuous Water Quality Data 8-2
Benthic Data 8-3
Phytoplankton Data 8-3
Zooplankton Data 8-3

Chapter 9 Continuous Monitoring, 2001-2002 9-1
Introduction 9-1
Methods 9-1
Results 9-2
Water Temperature 9-2
Dissolved Oxygen 9-2
Specific Conductance 9-3
pH 9-3
Air Temperature 9-4
Chlorophyll Fluorescence 9-4
Stockton Ship Channel Dissolved Oxygen 9-4
Summary 9-5
References 9-5

Figures

Figure 2-1 Sacramento and San Joaquin Valley unimpaired flow from 1992 through 2002, with water year designation. Values given in million acre-feet (MAF) 2-5
Figure 2-2 Net Delta outflow—average daily flow from water year 1999 through water year 2002 2-6

Figure 3-1 Water quality monitoring stations 3-11
Figure 3-2 Bay-Delta temperatures—comparison of sampling sites, 2001-2002 3-12
Figure 3-3 Temperatures at specific Bay-Delta sampling sites, 2001-2002 3-13
Figure 3-4 Dissolved oxygen—comparison of Bay-Delta sampling sites, 2001-2002 3-14
Figure 3-5 Dissolved oxygen at specific Bay-Delta sampling sites, 2001-2002 3-15
Figure 3-6 Specific conductance—comparison of Bay-Delta sampling sites, 2001-2002 3-16
Figure 3-7 Specific conductance at specific Bay-Delta sampling sites, 2001-2002 3-17
Figure 3-8 Secchi disk depth—comparison of Bay-Delta sampling sites, 2001-2002 3-18
Figure 3-9 Secchi disk depth at specific Bay-Delta sampling sites, 2001-2002 3-19
Figure 3-10 Turbidity—comparison of Bay-Delta sampling sites, 2001-2002 3-20
Figure 3-11 Turbidity at specific Bay-Delta sampling sites, 2001-2002 3-21
Figure 3-12 Orthophosphate concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-22
Figure 3-13 Orthophosphate concentrations at specific Bay-Delta sampling sites, 2001-2002 3-23
Figure 3-14 Total phosphorous concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-24
Figure 3-15 Total phosphorous concentrations at specific Bay-Delta sampling sites, 2001-2002 3-25
Figure 3-16 Kjeldahl nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-26
Figure 3-17 Kjeldahl nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002 3-27
Figure 3-18 Dissolved inorganic nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-28
Figure 3-19 Dissolved inorganic nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002 3-29
Figure 3-20 Dissolved organic nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-30
Figure 3-21 Dissolved organic nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002 3-31
Figure 3-22 Total dissolved solids—comparison of Bay-Delta sampling sites, 2001-2002 3-32
Figure 3-23 Total dissolved solids at specific Bay-Delta sampling sites, 2001-2002 3-33
Figure 3-24 Total suspended solids—comparison of Bay-Delta sampling sites, 2001-2002 3-34

Figure 3-25 Total suspended solids at specific Bay-Delta sampling sites, 2001-2002 3-35
Figure 3-26 Volatile suspended solids—comparison of Bay-Delta sampling sites, 2001-2002....3-36
Figure 3-27 Volatile suspended solids at specific Bay-Delta sampling sites, 2001-2002 3-37
Figure 3-28 Silica concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-38
Figure 3-29 Silica concentrations at specific Bay-Delta sampling sites, 2001-2002 3-39
Figure 3-30 Chloride concentrations—comparison of Bay-Delta sampling sites, 2001-2002 3-40
Figure 3-31 Chloride concentrations at specific Bay-Delta sampling sites, 2001-2002 3-41

Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations 4-11
Figure 4-2 Total phytoplankton contribution by family at all stations 4-12
Figure 4-3 Chlorophyll *a* and pheophytin *a* concentrations at station C3, 2001-2002 4-12
Figure 4-4 Chlorophyll *a* and pheophytin *a* concentrations at station MD10, 2001-2002 4-13
Figure 4-5 Chlorophyll *a* and pheophytin *a* concentrations at station C10, 2001-2002 4-13
Figure 4-6 Chlorophyll *a* and pheophytin *a* concentrations at station P8, 2001-2002 4-14
Figure 4-7 Chlorophyll *a* and pheophytin *a* concentrations at station D28A, 2001-2002 4-14
Figure 4-8 Chlorophyll *a* and pheophytin *a* concentrations at station D26, 2001-2002 4-15
Figure 4-9 Chlorophyll *a* and pheophytin *a* concentrations at station D4, 2001-2002 4-15
Figure 4-10 Chlorophyll *a* and pheophytin *a* concentrations at station D8, 2001-2002 4-16
Figure 4-11 Chlorophyll *a* and pheophytin *a* concentrations at station D7, 2001-2002 4-16
Figure 4-12 Chlorophyll *a* and pheophytin *a* concentrations at station D6, 2001-2002 4-17
Figure 4-13 Chlorophyll *a* and pheophytin *a* concentrations at station D41, 2001-002 4-17

Figure 5-1 Zooplankton monitoring stations....5-7
Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002....5-8
Figure 5-3 Monthly *Neomysis kadiakensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002....5-8
Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002....5-8
Figure 5-5 Monthly *Acanthomysis hwanhaiensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002....5-9

Figure 5-6 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-9
Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-9
Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-10
Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-10
Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-10
Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-11
Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-11
Figure 5-13 Monthly *Bosmina* spp. abundance upstream. in, and downstream of the entrapment zone, 2001 and 2002 5-11
Figure 5-14 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-12
Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-12
Figure 5-16 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-12
Figure 5-17 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-13
Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-13
Figure 5-19 Monthly *Synchaeta bicornis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002 5-13

Figure 6-1 Location of 10 Environmental Monitoring Program benthic sampling sites 6-13
Figure 6-2 Total contribution by phyla for all stations 2001-2002 6-14
Figure 6-3 Benthic abundance at stations C9 and P8, 2001-2002 6-15
Figure 6-4 Benthic abundance at stations D28A and D16, 2001-2002 6-16
Figure 6-5 Benthic abundance at stations D24 and D4, 2001-2002 6-17
Figure 6-6 Benthic abundance at stations D6 and D7, 2001-2002 6-18
Figure 6-7 Benthic abundance at stations D41 and D41A, 2001-2002 6-19
Figure 6-8 Percent sediment composition at sampling stations C9 and P8, 2001-2002 6-20
Figure 6-9 Percent sediment composition at sampling stations D16 and D28A, 2001-2002 6-21
Figure 6-10 Percent sediment composition at sampling stations D24 and D4, 2001-2002 6-22
Figure 6-11 Percent sediment composition at sampling stations D6 and D7, 2001-2002 6-23
Figure 6-12 Percent sediment composition at sampling stations D41 and D41A, 2001-2002 6-24

Figure 7-1 Monitoring sites in the Stockton Ship Channel 7-11

Figure 7-2 Dissolved oxygen levels, Aug 1–Dec 5, 2001 7-12
Figure 7-3 Surface and bottom water temperatures, Aug 1–Dec 5, 2001 7-13
Figure 7-4 Average net daily flows in the San Joaquin River at Stockton and Vernalis, Jul 1–Dec 30, 2001 7-14
Figure 7-5 Surface and bottom dissolved oxygen, Jul 23–Dec 18, 2002 7-15
Figure 7-6 Surface and bottom water temperatures, Jul 23–Dec 18, 2002 7-16
Figure 7-7 Average net daily flow in the San Joaquin River at Vernalis and Stockton, Jul 1–Dec 30, 2002 7-17

Figure 9-1 Monitoring Station Locations 9-7
Figure 9-2 Average monthly water temperature at seven stations, 2001-2002 9-8
Figure 9-3 Average monthly dissolved oxygen at seven stations, 2001-2002 9-9
Figure 9-4a Average monthly surface specific conductance at seven stations, 2001-2002 9-10
Figure 9-4b Average monthly surface specific conductance at four stations, 2001-2002 9-10
Figure 9-5 Average monthly surface and bottom specific conductance at three stations, 2001-2002 9-11
Figure 9-6 Average monthly pH at seven stations, 2001-2002 9-12
Figure 9-7 Average monthly air temperature at six stations, 2001-2002 9-13
Figure 9-8 Average monthly chlorophyll fluorescence at four stations, 2001-2002 9-14
Figure 9-9 Hourly and average monthly dissolved oxygen. San Joaquin River at Stockton, 2001 9-15
Figure 9-10 Hourly and average monthly dissolved oxygen. San Joaquin River at Stockton, 2002 9-16

Tables

Table 2-1 Summary of the major hydrological characteristics of water years 2001 and 2002 2-2
Table 2-2 Average Sacramento and San Joaquin River streamflow for water years 2001 and 2002 2-2

Table 3-1 Water quality parameters measured 3-1
Table 3-2 Water quality sampling sites and regions 3-2

Table 4-1 All genera found in each family in the upper San Francisco Estuary 4-18

Table 6-1 Benthic monitoring station characteristics, 2001-2002 6-2
Table 6-2 New Species 2001-2002 6-4

Table 9-1 Parameters Measured by the Continuous Monitoring Program 9-2

State of California
Arnold Schwarzenegger, Governor

The Resources Agency
Mike Chrisman, Secretary for Resources

Department of Water Resources
Lester A. Snow, Director

P. Joseph Grindstaff
Chief Deputy Director

Brian E. White
Assistant Director Legislative Affairs

Nancy J. Saracino
Chief Counsel

Susan Sims-Teixeira
Assistant Director Public Affairs

Peter S. Garris
Deputy Director

Stephen W. Verigin
Deputy Director

Vernon T. Glover
Deputy Director

Gerald E. Johns
Deputy Director

Division of Environmental Services
Barbara McDonnell
Chief, Division of Environmental Services

This report was prepared under the supervision of

Dean F. Messer
Chief, Bay-Delta Monitoring and Analysis Section

By

Michael Dempsey .... Control System Tech. II
Karen Gehrts .... Environmental Scientist
Philip Giovannini .... Environmental Scientist
Lee Mecum .... Fisheries Biologist
Shaun Philippart .... Environmental Scientist
Marc Vayssières .... Environmental Scientist

With assistance from:
Lloyd Brenn .... Chief Engineer, Fisheries Vessel
Eric Santos .... Chief Engineer, Fisheries Vessel
Scott Waller .... Water Resource Engineering Associate

Editorial and design services were provided by

Nikki Blomquist .... Research Writer, Division of Planning and Local Assistance
Marilee Talley .... Research Writer, Division of Planning and Local Assistance

Acknowledgements

The chapters in this report were written by the following Department of Water Resources (DWR) and Department of Fish and Game (DFG) staff:

Chapter 1: Introduction. Dean F. Messer (DWR)

Chapter 2: Hydrological Conditions. Philip Giovannini (DWR)

Chapter 3: Water Quality Monitoring. Philip Giovannini (DWR)

Chapter 4: Phytoplankton and Chlorophyll *a*. Shaun Philippart

Chapter 5: Zooplankton and Mysid Shrimp. Lee Mecum (DFG)

Chapter 6: Benthic and Sediment. Karen Gehrts (DWR)

Chapter 7: Special Studies: Dissolved Oxygen Monitoring in the Stockton Ship Channel. Philip Giovannini (DWR)

Chapter 8: Data Management. Marc Vayssières (DWR)

Chapter 9: Continuous Monitoring. Mike Dempsey (DWR)

Chapter 1
Introduction

The State Water Resources Control Board (SWRCB) establishes water quality objectives and monitoring plans to protect the beneficial uses of water within the upper San Francisco Estuary. The SWRCB ensures that these objectives are met through a series of water right decisions issued to the California Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) as a condition for operating the State Water Project (SWP) and Central Valley Project (CVP), respectively. These objectives include minimum outflows, limits to water exports by the SWP and CVP, and maximum allowable salinity levels. In addition, these water right decisions mandate that DWR and USBR conduct a comprehensive monitoring program to determine compliance with the water quality objectives and report the findings to the SWRCB. This mandated monitoring is conducted by DWR and USBR under the auspices of the Environmental Monitoring Program (EMP). Water quality objectives were issued in December 1999 by Water Right Decision 1641 (D-1641) (SWRCB 1999).

Collected since 1975 by the EMP, monitoring data are stored and managed by DWR and the California Department of Fish and Game (DFG). DWR manages the environmental water quality data, as well as phytoplankton data and benthic organism data, from discrete and continuous monitoring stations. DFG manages the zooplankton data, which is collected at the EMP's discrete monitoring stations. The EMP data are available to view and download through the Bay Delta and Tributaries Database (BDAT) at http://baydelta.ca.gov/. For specific questions about the EMP data on BDAT, contact Karl Jacobs, Chief of the Interagency Information System Services Section, by mail at Department of Water Resources, Division of Environmental Services, 3251 S Street, Sacramento, CA, 95816-7017; by telephone at (916) 227-0435; or by e-mail at kjacobs@water.ca.gov.

This report, entitled *Water Quality Conditions in the Sacramento-San Joaquin Delta and Suisun and San Pablo Bays during 2001-2002*, summarizes the findings of the EMP for calendar years 2001 and 2002. 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.

Reference

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

Chapter 2
Hydrologic Conditions, 2001-2002

Introduction

Hydrologic conditions are typically discussed using "water years", which begin on October 1 of one calendar year and end on September 30 of the following year. The January 2001 through December 2002 chronological period covered by this report includes parts of three water years, i.e., the last nine months of water year 2001 (January 2001 through September 2001), the entire twelve months of water year 2002 (October 2001 through September 2002), and the first three months of water year 2003 (October 2002 through December 2002). In order to concisely describe hydraulic conditions in the Bay-Delta during this period, this chapter will discuss water years 2001 through 2002 (October 2001 through September 2002) unless otherwise noted.

Methods

Water years are classified in this report using two indices: the Sacramento Valley 40-30-30 Water Year Hydrologic Classification Index[1,2] (Sacramento Valley Index), and the San Joaquin Valley 60-20-20 Water Year Hydrologic Classification Index[3,4] (San Joaquin Valley Index) (SWRCB 1999). The Sacramento Valley Index is used to characterize water years statewide because most precipitation falls in the northern half of California, and much of that precipitation flows through the San Francisco Estuary (SWRCB 1999). The San Joaquin Valley Index is used predominantly for regional applications; however, this index provides supporting information concerning water conditions within the San Joaquin Valley. According to both indices[5,6] water years 2001 and 2002 were classified as "Dry."

---

[1] The Sacramento Valley 40-30-30 Water Year Hydrological Classification Index is equal to 0.4 X current April to July unimpaired runoff + 0.3 X current October to March unimpaired runoff + 0.3 X 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 Valley 60-20-20 Water Year Hydrological Classification Index is equal to 0.6 X current April to July unimpaired runoff + 0.2 X current October to March unimpaired runoff + 0.2 X previous year's index (if the previous year's index exceeds 4.5, then 4.5 is used).

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

[5] 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 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).

[6] 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 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

Summary

The "Dry" conditions indicated by the water year indices are in contrast to recent hydraulic conditions which have been designated as "Wet" or "Above Normal" since water year 1995. Figure 2-1 shows unimpaired runoff, and water year designation for Sacramento and San Joaquin rivers for water years 2001 and 2002, and compares them to historical conditions. Unimpaired runoff was low due to the below normal precipitation, reservoir storage and snow pack water content, for both water years (CDEC 2002). Statewide figures for precipitation, runoff, reservoir storage, and snowpack water content as of May 1 of each water year are summarized in Table 2-1.

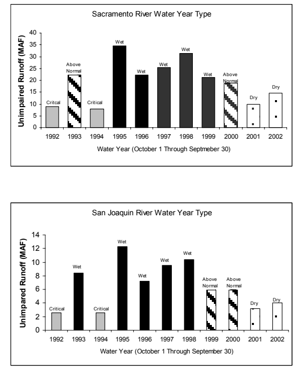


Figure 2-1 Sacramento and San Joaquin Valley unimpaired flow from 1992 through 2002, with water year designation. Values given in million acre-feet (MAF)

Table 2-1 Summary of the major hydrological characteristics of water years 2001 and 2002

	(Percent of normal)			
Water year	Precipitation	Seasonal runoff	Reservoir storage	Snow water content
2001	75	45	100	65
2002	80	80	100	60

Water year 2002 had the highest unimpaired runoff of the study period, with a value of 14.59 million-acre-feet in the Sacramento Valley River Basin and 4.06 million-acre-feet in the San Joaquin Valley River Basin. Table 2-2 summarizes streamflow conditions in these rivers during water years 2001 and 2002.

Table 2-2 Average Sacramento and San Joaquin River streamflow for water years 2001 and 2002

	Average streamflow (in million acre-feet)		
Year	Oct 1–Mar 30	Apr 1–Jul 30	Whole year
Sacramento River			
2001	5.63	3.46	9.81
2002	9.3	4.56	14.59
San Joaquin River			
2001	0.92	2.23	3.18
2002	1.27	2.74	4.06

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).

The Net Delta Outflow (NDO) from the San Francisco Estuary for water year 1999 through water year 2002 is shown in Figure 2-2. This NDO is an estimate of average daily outflow at Chipps Island, and is calculated as:

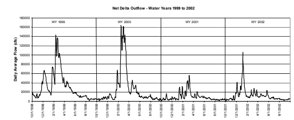


Figure 2-2 Net Delta outflow–average daily flow from water year 1999 through water year 2002

$$\mathbf{NDO = QTot + QPrecp - QGcd - Qmisdv}$$

Where:

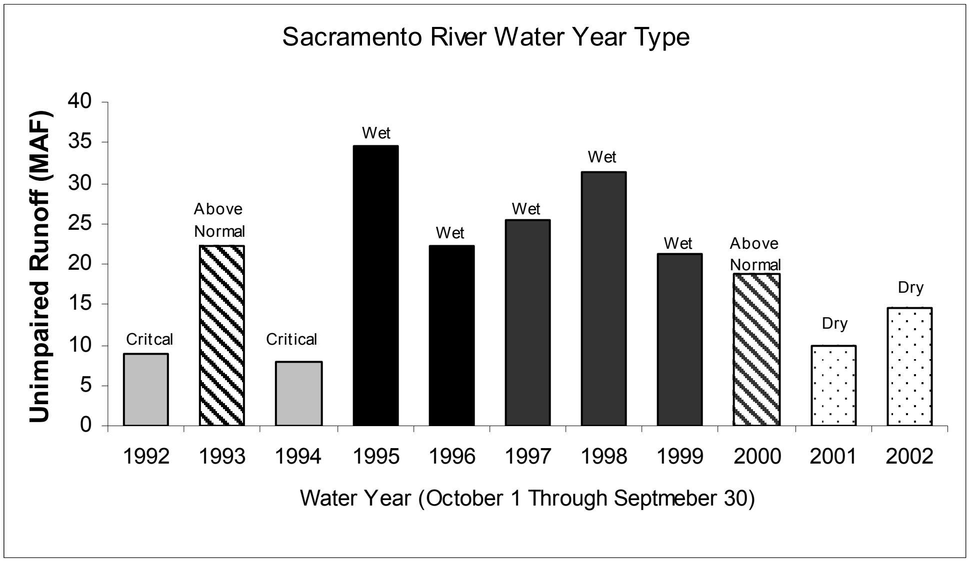
NDO	=	Net delta outflow (cfs)
QTot	=	Total delta inflow (cfs)
QPrecp	=	Total precipitation runoff (cfs)
QGcd	=	Total consumption in delta (cfs)
QMisdv	=	Total flooded island and island storage diversions (cfs)

References

[CDEC] California Data Exchange Center. 2002. Available online at http://cdec.water.ca.gov. Department of Water Resources Cooperative Snow Surveys.

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

Figure 2-1 Sacramento and San Joaquin Valley unimpaired flow from 1992 through 2002, with water year designation. Values given in million acre-feet (MAF)



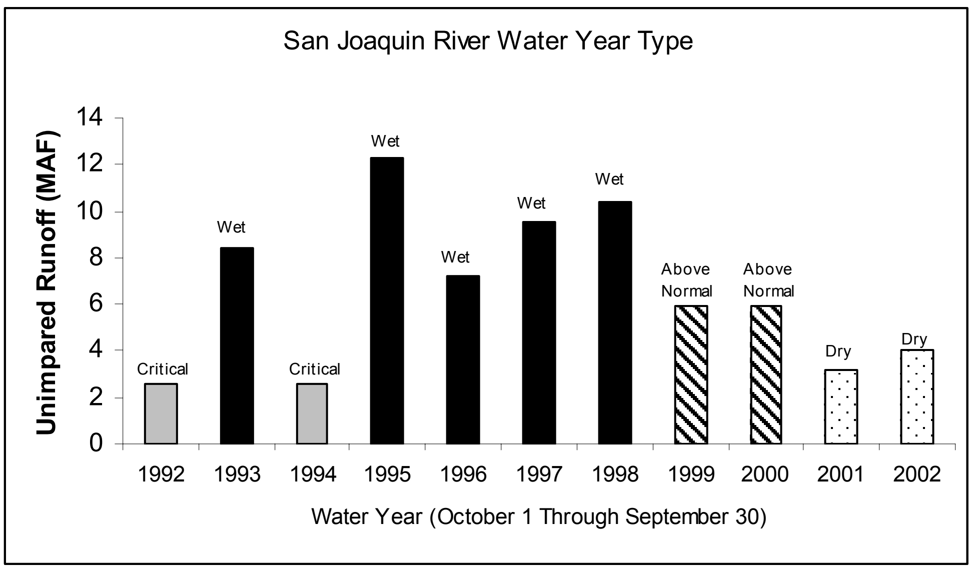
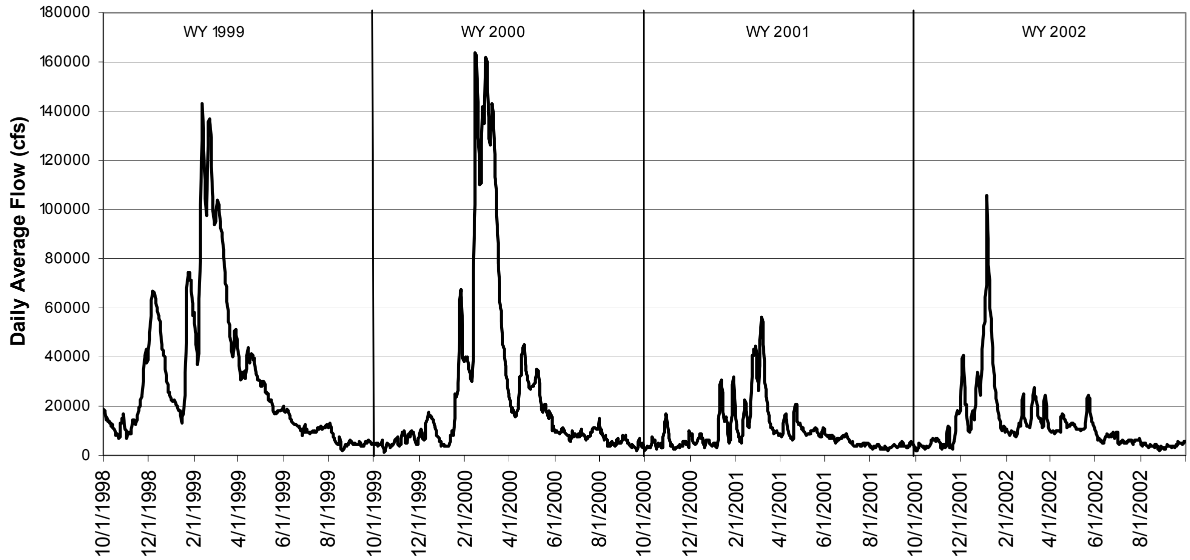


Figure 2-2 Net Delta outflow—average daily flow from water year 1999 through water year 2002



Chapter 3
Water Quality Monitoring, 2001-2002

Introduction

Water quality monitoring from 2001 to 2002 continued according to the amended protocol implemented by the California Department of Water Resources (DWR) in 1996. As described in the 1996 Water Quality Report (Lehman et al. 2001), the number of discrete water quality sampling sites was reduced to 11 representative sites. Discrete samples were taken monthly at each site (Figure 3-1). Data were recorded within one hour of high slack tide and the time of each sample was recorded to the nearest five minutes of Pacific Standard Time. A qualitative statement of weather conditions (i.e., wind conditions and cloud cover) was recorded for each cruise. Samples were analyzed for the15 physical and chemical parameters shown in Table 3-1. The complete database is available online at http://baydelta.water.ca.gov.

Figure 3-1 Water quality monitoring stations

Table 3-1 Water quality parameters measured

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

As shown in Table 3-2, eleven sampling sites are used in this study to represent eight regions of the Bay-Delta system. Water quality conditions in each of six regions are represented by a single sampling site. The south Delta and Suisun Bay, however, are represented by two and three stations respectively.[1] In previous reports, data from multiple sample sites within each region have been averaged according to the hierarchical cluster analysis protocol; however, for clarity, data results in this report are shown for each sample site.

[1] An exception to this protocol exists for Secchi disk depth measurements for the south Delta region. Secchi disk depth measurements for this region are represented by a single sampling at Site P8, as no Secchi disk depth measurements are made at sampling Site C10.

Table 3-2 Water quality sampling sites and regions

Region	Sampling sites
Lower Sacramento River	D4
Lower San Joaquin River	D26
North Delta	C3
Central Delta	D28A
East Delta	MD10
South Delta	C10 and P8
Suisun Bay	D6, D7, and D8
San Pablo Bay	D41

Parameters Measured

Except where noted, all discrete water quality samples are obtained with shipboard sampling equipment using DWR's research vessel, the *San Carlos*. Supplemental discrete samples are taken with mobile laboratory equipment at sites in the south Delta (C10 and C3) that are inaccessible to the vessel *San Carlos*. Secchi disk depth is not taken at site C10 due to restrictions of the sample site, which requires sampling equipment to be deployed from a bridge 50 feet above the water's surface.

Water Temperature

Water temperature was measured in degrees Centigrade (°C) with a YSI thermistor. For all sites except the south Delta, temperatures were measured from water collected from a through-hull pump at a depth of 1 meter. In the south Delta, temperatures were measured by submerging the YSI thermistor to a 1-meter depth.

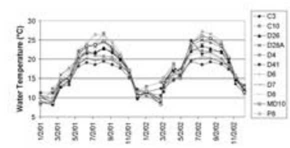


Figure 3-2 Bay-Delta temperatures, 2001-2002

The minimum water temperature for the 2001- 2002 period, 8.1 °C, was recorded in at station C3, in the north Delta (Figures 3-2 and 3-3). This minimum represents an increase of 1 °C over previously recorded minima for the 1997-2000 study period (Gehrts et al. 2003).

The maximum water temperature for the 2001-2002 period, 27.2 °C, was recorded at station P8, in the south Delta. This recorded maximum represents an increase of 0.3 °C over previously recorded maxima for the 1997-2000 study period (Gehrts et al. 2003).

In comparison with water temperatures recorded during the 1997-2000 study period, the coldest water temperatures during the 2001-2002 study period occurred later and the warmest water temperatures occurred earlier (Gehrts et al. 2003). Recorded temperatures exhibited strong seasonal variability, with waters cooling during the winter and warming during the summer.

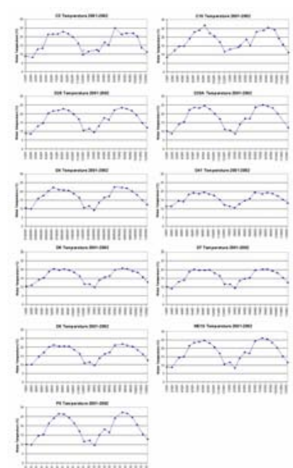


Figure 3-3 Temperatures at specific Bay-Delta sampling sites, 2001-2002

Dissolved Oxygen

Dissolved oxygen was measured using the modified Winkler iodometric method described in Standard Methods (APHA 1992). A sample aliquot was collected from a through-hull pump or from a grab sample, at a depth of

1 meter. The samples were collected in 300-ml glass-stoppered bottles and immediately analyzed onboard.

During the study, dissolved oxygen concentrations ranged from 3.7 mg/L at site P8 in the south Delta in December 2002, to 12.5 mg/L at site MD10 in the east Delta in February 2001 (Figures 3-4 and 3-5). Strong seasonal trends were evident in most regions, with dissolved oxygen concentrations decreasing during the summer and rising in the winter. At sites exhibiting noticeable seasonal changes (C3, D26, D28A, D6, D7, D8), dissolved oxygen levels showed good correlation with changes in water temperature. The decline in dissolved oxygen during increasing summer water temperatures very closely matched the linear function for the decline in oxygen saturation capacity as a function of temperature. This suggests that dissolved oxygen levels at many sites tend to be influenced largely by physical processes (such as temperature and saturation capacity) rather than biological processes (such as respiration and primary production). An exception to this was noted at sites P8 and C10 in the south Delta. Both sites showed poor correlation between temperature and dissolved oxygen levels, and little seasonal patterns. These sites also showed the greatest degree of variability in dissolved oxygen levels, ranging by almost 8 mg/L over the year.

Representing the Suisun Bay, sites D6, D7, and D8, were closely related and showed a yearly variation of about 2 mg/L, which was consistent with the range observed at most other sites.

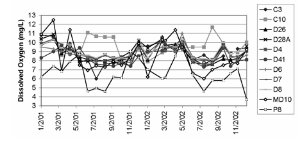


Figure 3-4 Bay-Delta dissolved oxygen, 2001-2002

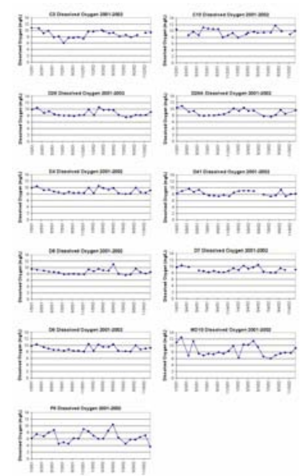


Figure 3-5 Dissolved oxygen in the Bay-Delta, 2001-2002

Specific Conductance

Specific conductance, an estimate of salinity, was determined from samples collected from a through-hull pump at a 1-meter depth. The samples were analyzed for specific conductance using a Seabird model CTD 911+ data logger. Measured values were temperature-compensated to 25 °C.

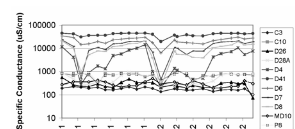


Figure 3-6 Bay-Delta specific conductance, 2001-2002

Specific conductance varied greatly between sites monitored, ranging from 74 µS/cm at site D26 in the lower San Joaquin River in December 2002, to 45,107 µS/cm at site D41 in San Pablo Bay in November 2001 (Figures 3-6 and 3-7).

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

Sites with high, average, specific conductivity (such as D4, D6, D7, D8, and D 41) tended to show stronger seasonal variations, with specific conductance varying from a low in March to a high in November of each year. At sites with lower specific conductance, this seasonal trend was less apparent.

Specific conductance dropped noticeably at all sites in January 2002. A similar decline occurred in March 2001. Downstream sites showed the most variability, especially during winter. Upstream sites with low specific conductance, such as site C3, had the least variation and did not show any apparent seasonal trends.

Figure 3-7 Specific conductance in the Bay-Delta, 2001-2002

Secchi Disk Depth

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

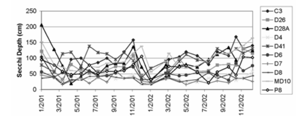


Figure 3-8 Bay-Delta Secchi disk depth, 2001-2002

A Secchi depth minimum of 160 cm was recorded at sampling sites D7 and D8 in the Suisun Bay during March 2001, December 2001, and January 2002 (Figures 3-8 and 3-9). A Secchi depth maximum of 206 cm was recorded at sampling site D28A in the central Delta in January 2001.

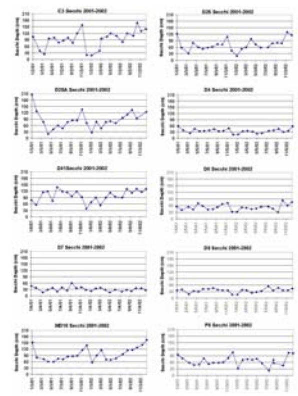


Figure 3-9 Secchi disk depth in the Bay-Delta, 2001-2002

Secchi disk depth varied considerably between sites, with little apparent seasonal correlation. A marked decrease in Secchi depth occurred at all sites from December 2001 to January 2002. At some sites, such as C3, Secchi depth varied considerably. For example between November and December 2001, site C3 Secchi depth changed from 158 cm to 20 cm. By March 2002 the C3 Secchi depth had again increased to 96 cm. A similar decline and rebound occurred at several sites (C3, D26, D28A, D4, D7, and D8) during this general period between November and March.

Overall, Secchi depths were lowest at sites D6, D7, D8 and D4, while sites C3, D28A, and D41 had the highest overall average Secchi depths. As noted earlier, Secchi disk depth measurements are not taken at site P8 in the south Delta.

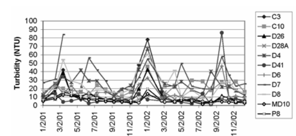


Figure 3-10 Bay-Delta turbidity, 2001-2002

The long-term increase in transparency data noted in previous reports (Lehman et al. 2001) was not discernable in the 2001-2002 data.

Turbidity

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

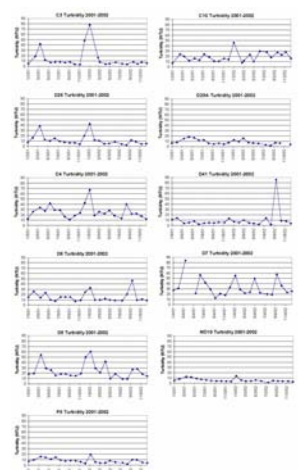


Figure 3-11 Turbidity in the Bay-Delta, 2001-2002

Turbidity was determined from samples collected from a through-hull pump at a 1-meter depth. The samples were pumped through a Turner Model 10 flow-through nephelometer calibrated with a reference sample of formazin suspension at 40 nephelometric turbidity units (NTU) according to Standard Reference protocol 214-A (APHA 1992).

Turbidity varied greatly among sampled sites (Figures 3-10 and 3-11). Values ranged from 1.3 NTU at sites D41 and D28A (San Pablo Bay and central Delta region) in August 2002, to 86 NTU at site D41 in September 2002.

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

A large increase in turbidity was observed at most sites in January 2002. A similar increase occurred in March 2001; however, this increase was not observed at all sites. These pulses of turbidity appear to coincide with marked decreases in specific conductance, which suggests that increased runoff could be causing increased turbidity from resuspension of sediment, or overland contaminants.

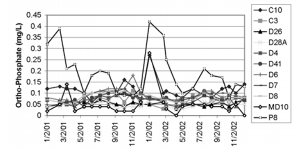


Figure 3-12 Bay-Delta orthophosphate, 2001-2002

Orthophosphate

Orthophosphate is soluble inorganic phosphate, the phosphorus compound most immediately available for assimilation by phytoplankton. Orthophosphate concentrations were measured by first collecting sample aliquots from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory[2] for analysis according to the USEPA (1983) colormetric automated ascorbic acid method 365.1. The minimum reporting limit for orthophosphate was 0.01 mg /L.

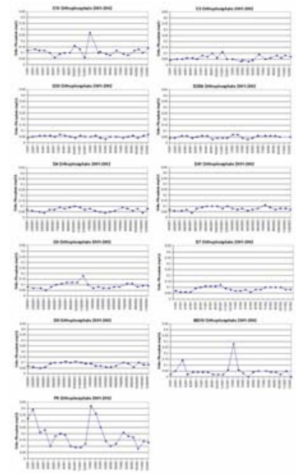


Figure 3-13 Orthophosphate concentrations at specific Bay-Delta sampling sites, 2001-2002

Values for orthophosphate varied considerably between sites and across seasons (Figures 3-12 and 3-13). The lowest values were recorded in the east Delta at site MD10 in April and December 2002, in which orthophosphate levels were below the detectable limit of 0.01 mg/L. The highest value of orthophosphate, 0.42 mg/L, was recorded at site P8 in January 2002.

Total Phosphorus

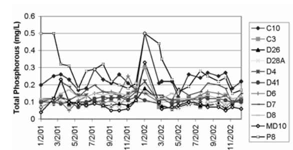


Figure 3-14 Bay-Delta phosphorous, 2001-2002

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

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

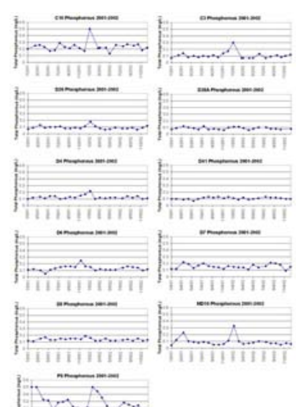


Figure 3-15 Total phosphorous concentrations in the Bay-Delta, 2001-2002

Values for total phosphate varied considerably between sites and across seasons (Figures 3-14 and 3-15). The lowest value of 0.04 mg/L was recorded in the east Delta at site MD10 in January 2001. The highest values for total phosphate were recorded in the south Delta at sites P8 and C10. Maximum values of 0.5 mg/L were recorded at these sites in January 2001 and 2002, as well as in February 2001.

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

Most sites showed total phosphorous levels averaging about 0.1 mg/L. A pulse increase in total phosphorous was seen at half of the sampling sites during winter 2002. Sites P8 and C10 in the south Delta had the highest degree of variability, with P8 showing a pronounced winter increase in concentrations; however, no clear pattern of interannual variation was seen in these data.

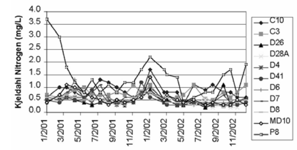


Figure 3-16 Bay-Delta Kjeldahl nitrogen, 2001–2002

Kjeldahl Nitrogen

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

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

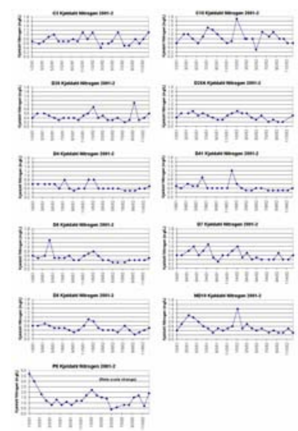


Figure 3-17 Kjeldahl nitrogen concentrations in the Bay-Delta, 2001-2002

Kjeldahl nitrogen concentrations ranged from 3.70 mg/L at station P8 in the south Delta in January 2001, to 0.20 mg/L at stations D26, D28A, and D8 from July to October 2002 (Figures 3-16 and 3-17). Aside from a pronounced seasonal change in concentrations at site P8, no strong seasonal or interannual trends were apparent, although sites showed winter increases in January and December 2002. However, this winter increase was not seen in 2001.

Site P8 had both the highest concentrations, as well as the greatest variability. Average values of Kjeldahl nitrogen in all sampled sites, excluding P8, was 0.57 mg/L.

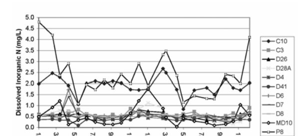


Figure 3-18 Bay-Delta dissolved inorganic nitrogen, 2001–2002

Dissolved Inorganic Nitrogen

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

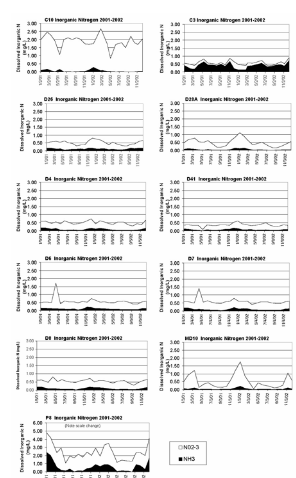


Figure 3-19 Dissolved inorganic nitrogen concentrations in the Bay-Delta, 2001–2002

DIN concentrations ranged from 0.14 mg/L at station MD10 in the east Delta in September 2001, to 4.8 mg/L at station P8 in the south Delta in January 2002 (Figures 3-18 and 3-19). These minima and maxima, and their locations, correspond closely to the results observed in 1997-2000 (Gehrts et al. 2003).

Peak DIN concentrations were observed in winter 2001 (December and January), a period when seasonal runoff is high at several sites, including MD10, D4, D41, D28A, D26, and C10. Concentrations in these regions generally were lowest in August and September, when water temperatures and phytoplankton growth were highest and inflows were lowest. Concentrations in the south Delta showed the greatest degree of variability, both seasonally and interannually. By contrast, DIN concentrations in the Suisun Bay (D6, D7, and D8) varied little on a seasonal or interannual basis, except for a sharp peak in the DIN concentrations in April 2001.

Dissolved Organic Nitrogen

Organic nitrogen is defined functionally as nitrogen that is bound to carbon containing compounds in the tri-negative oxidation state (APHA 1992). This form of nitrogen must be mineralized or decomposed before it can be used by the plant communities in aquatic and terrestrial environments. It does not include all organic nitrogen compounds, but does include proteins, peptides, nucleic acids, urea, and numerous synthetic organic compounds (APHA 1992).

Dissolved organic nitrogen (DON) was measured by first pumping water samples from a 1-meter depth into new, rinsed polyethylene bottles. The samples were then filtered through a pre-washed membrane filter with a 0.45-micron pore size. The filtrate was immediately frozen and later transported to Bryte Laboratory for analysis according to the USEPA (1983) colormetric, semi-automated method 351.2. The minimum reporting limit for DON was 0.10 mg /L.

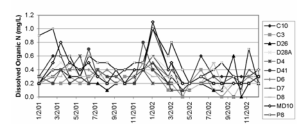


Figure 3-20 Bay-Delta dissolved organic nitrogen, 2001–2002

DON concentrations ranged from 1.10 mg/L at station MD10 in the east Delta in January 2002, to concentrations that fell below undetectable levels (i.e., < 0.10 mg/L) at several stations (C10, C3, D26, D4, D41, D6, and D8) in 2002 (Figures 3-20 and 3-21). DON concentrations showed no clear seasonal or interannual pattern of variation; however, a general increase in DON concentrations was seen at most sites in December 2001 and January 2002. This increase generally corresponds to the increase in Kjeldahl nitrogen concentrations observed during the same period. These data also show that DON concentrations decreased somewhat from 2001 to 2002, as evidenced by the large number of sites with undetectable concentrations in 2002.

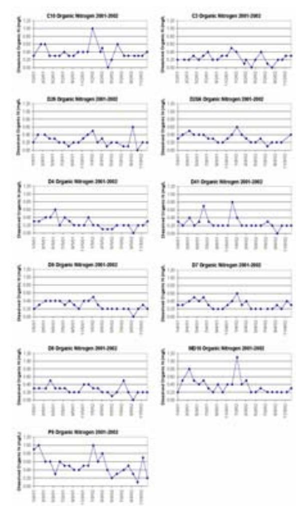


Figure 3-21 Dissolved organic nitrogen concentrations in the Bay-Delta, 2001–2002

Total Dissolved Solids

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

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

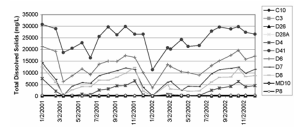


Figure 3-22 Bay-Delta total dissolved solids, 2001–2002

TDS in the Bay-Delta varied over a wide range from 30,780 mg/L in January 2001 at site D41 in the San Pablo Bay, to 82 mg/L in April 2001 at site C3 in the north Delta (Figures 3-22 and 3-23). The high values seen in San Pablo Bay are likely due to tidal influences of seawater with high TDS entering the Delta at San Pablo Bay. Low TDS values seen at site C3 are likely due to spring inflows of fresh water, with lower TDS concentrations from the Sacramento River.

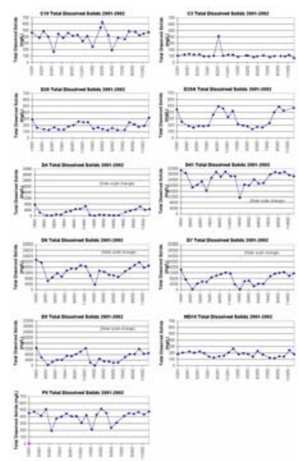


Figure 3-23 Total dissolved solids in the Bay-Delta, 2001–2002

All sites subject to significant tidal exchange (sites D41, D6, D7, D8, and D4) show TDS concentrations in proportion to their proximity to the coast (Figure 3-1).

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 in response to higher flow rates, as higher velocities increase water's capacity to hold or carry suspended solids. Runoff from heavy rains can simultaneously introduce large amounts of solids into surface waters and provide the capacity for their suspension. Therefore, suspended solids concentrations can vary significantly over relatively short time periods.

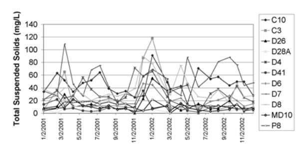


Figure 3-24 Bay-Delta total suspended solids, 2001–2002

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

TSS in the San Francisco Bay-Delta varied over a wide range from 118 mg/L in January 2001 at site C3 in the north Delta, to values below the reporting limit of 1 mg/L at several sites in both 2001 and 2002 (Figures 3-24 and 3-25). Several sites showed "pulse" increases in TSS that occurred during winter months. For example, TSS levels at site C3 increased from 8 mg/L to 118 mg/L from November 2001 to January 2002, and returned to 8 mg/L again by March 2002. Although winter pulse variations may be due to rain or hydrological events, variations in TSS at other sites occurred inter-seasonally and may reflect changing levels of organic matter.

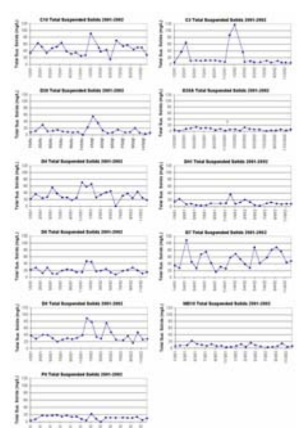


Figure 3-25 Total suspended solids in the Bay-Delta, 2001–2002

Volatile Suspended Solids

The measurement of volatile suspended solids (VSS) provides a relative indicator of the amount of organic matter present in the water sample. Water samples for VSS analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for VSS according to

EPA Method 160.4 (EPA 1983). The minimum reporting level for VSS in these analyses was 1.0 mg/L.

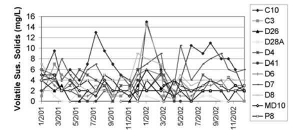


Figure 3-26 Bay-Delta volatile suspended solids, 2001–2002

Volatile suspended solid levels occasionally fell below minimum reporting levels (<1 mg/L) in most regions from 2001 to 2002, and reached a high of 15 mg/L at site C10 in the lower Sacramento River in January 2001 (Figures 3-26 and 3-27). Sites C10 in the south Delta and C3 in the north Delta showed the highest degree of variability, with VSS levels ranging from 0 to 15 mg/L VSS. Other sites showed a narrower range of values; however, no apparent seasonal or interannual variation was seen in these data.

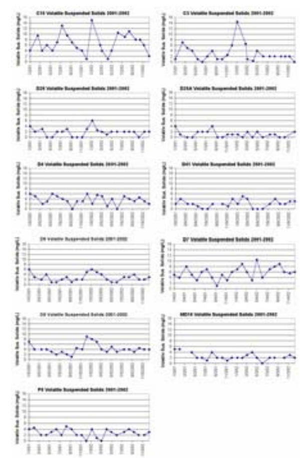


Figure 3-27 Volatile suspended solids in the Bay-Delta, 2001–2002

Silica

Water samples for silica analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for silica according to EPA Method 200.7 (EPA 1983). The minimum reporting level for silica in these analyses was 0.1 mg/L.

Silica concentrations ranged from 23 mg/L at site D6 in March 2002, to 2.6 mg/L at site C10 in June 2002 (Figures 3-28 and 3-29). Several sites (MD10, D28A, P8, and D26) displayed an apparent seasonal trend of declining silica levels in spring months followed by increased silica concentrations in late summer and winter. Other sites had less consistent variations, with little or no apparent seasonal correlation. No apparent interannual trends were observed in these data.

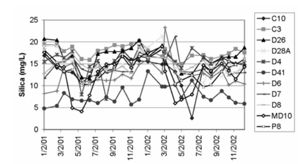


Figure 3-28 Bay-Delta silica, 2001–2002

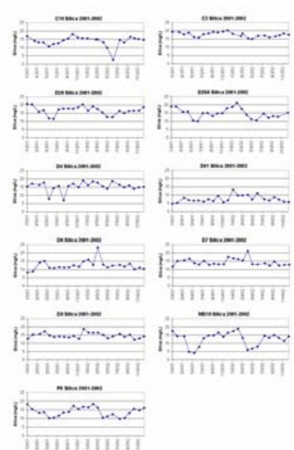


Figure 3-29 Silica concentrations in the Bay-Delta, 2001–2002

Chloride

Water samples for chloride analysis were taken from aliquots collected from a depth of 1 meter, stored in polyethylene bottles, and refrigerated at 4 °C until analyzed at Bryte Laboratory. Samples were analyzed for chloride according to EPA Method 300.0 (EPA 1983).

Chloride concentrations in the Bay-Delta varied over a wide range from 17,200 mg/L in January 2001 at site D41 in the San Pablo Bay, to 4 mg/L in July 2002 at site C3 in the north Delta (Figures 3-30 and 3-31). 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 C3 are likely due to spring flows of fresh water down the Sacramento River. Values of chloride concentrations are closely correlated to values reported for specific conductance and TDS reported earlier in this report.

Summary

The Department's monitoring and reporting of water quality data shown here is mandated in order to ensure compliance with water quality objectives; identify meaningful changes potentially related to the operation of the State Water Project and the Central Valley Project; and to reveal trends in ecological changes potentially related to project operations. Flow rates, influenced by project operations and natural forces, are a primary determinant of water quality dynamics at each site described. However, flow

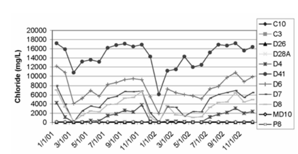


Figure 3-30 Bay-Delta chloride, 2001–2002

rates are not measured as part of this sampling protocol, and therefore a more analytical treatment of these data in relation to flow rates is not included. These data are presented as a snapshot of the system. They allow a historic comparison of a wide range of water quality parameters and show an overall consistency with recent years.

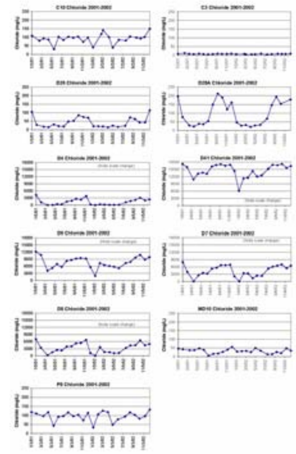


Figure 3-31 Chloride concentrations in the Bay-Delta, 2001–2002

References

Gehrts, K. A., M. Dempsey, P. Giovannini, J. Giulianotti, L. Mecum, S. Philippart, C. Ralston, K. Triboli, and S. Waller. 2003. *Water Quality Conditions in the Sacramento-San Joaquin Delta during 1997-2000*. California Department of Water Resources, Sacramento, California.

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

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

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

[USGS] U.S. Geological Survey. 1985. Methods for the determination of inorganic substances in water and fluvial sediments. In: *Techniques of Water Resources Investigations of USGS*.

Figure 3-1 Water quality monitoring stations

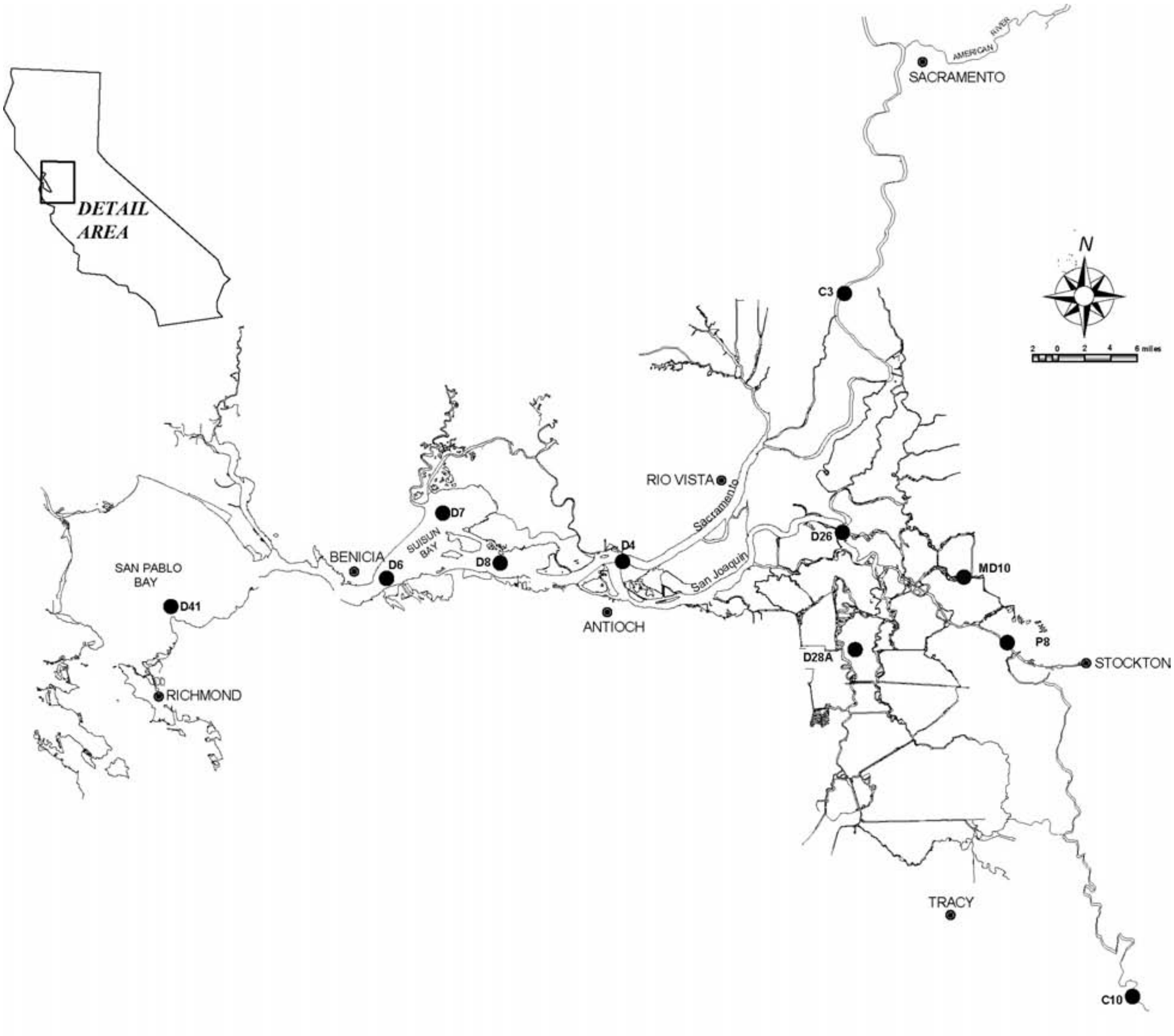


Figure 3-2 Bay-Delta temperatures—comparison of sampling sites, 2001-2002

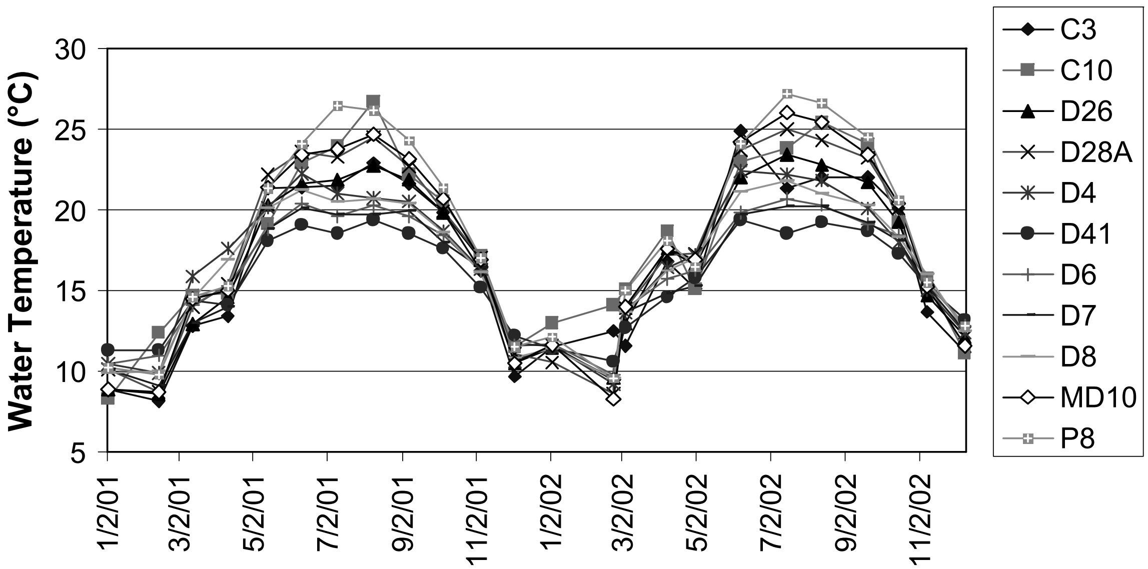


Figure 3-3 Temperatures at specific Bay-Delta sampling sites, 2001-2002

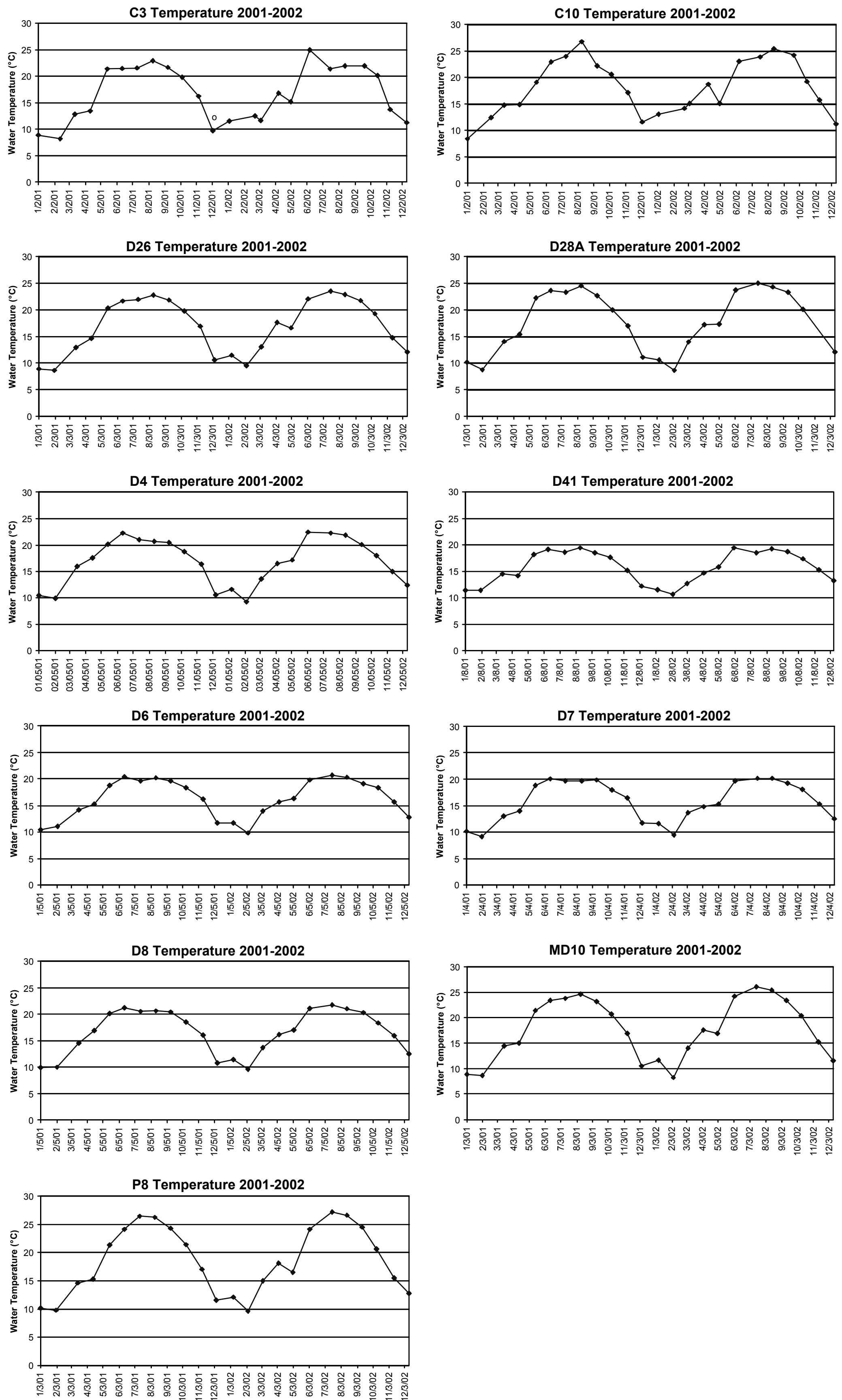


Figure 3-4 Dissolved oxygen—comparison of Bay-Delta sampling sites, 2001-2002

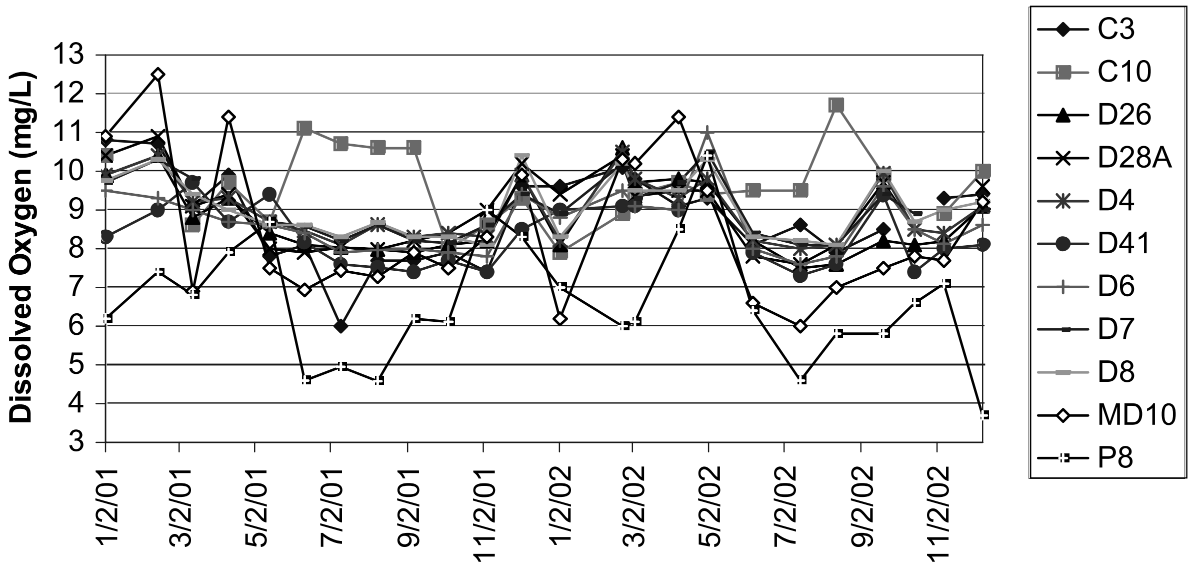


Figure 3-5 Dissolved oxygen at specific Bay-Delta sampling sites, 2001-2002

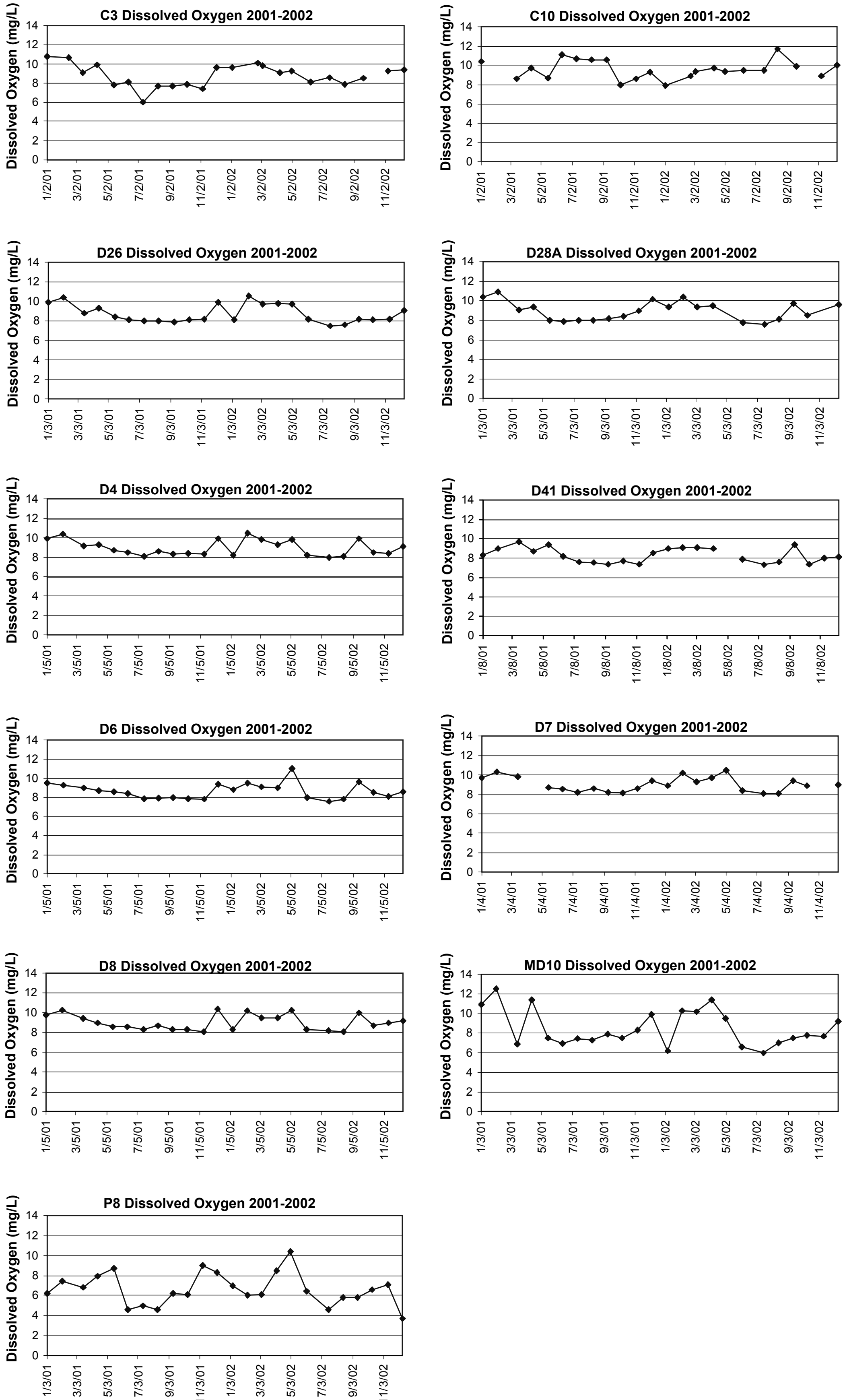


Figure 3-6 Specific conductance—comparison of Bay-Delta sampling sites, 2001-2002

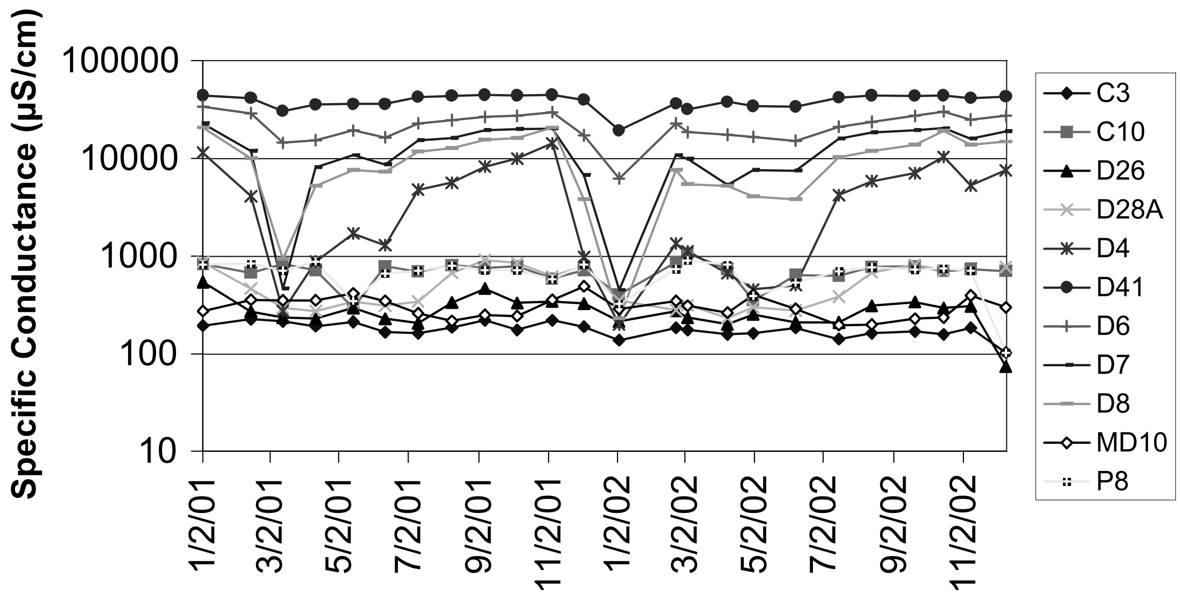


Figure 3-7 Specific conductance at specific Bay-Delta sampling sites, 2001-2002

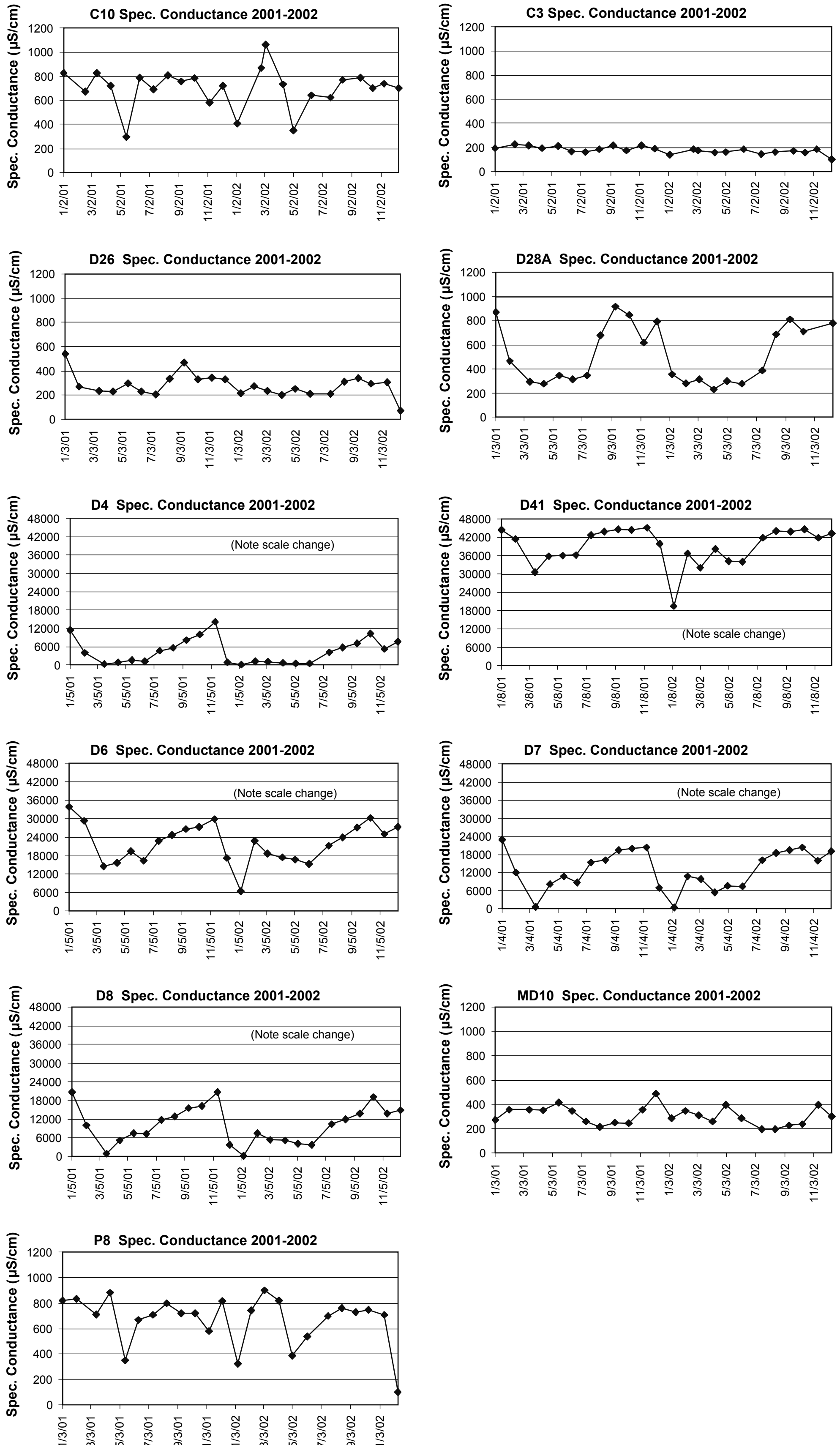


Figure 3-8 Secchi disk depth—comparison of Bay-Delta sampling sites, 2001-2002

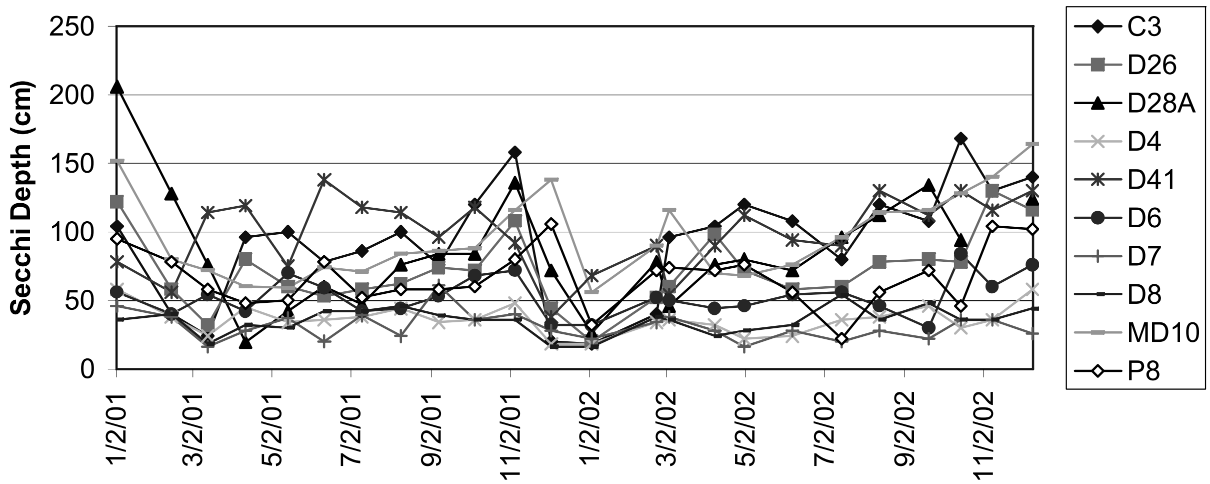


Figure 3-9 Secchi disk depth at specific Bay-Delta sampling sites, 2001-2002

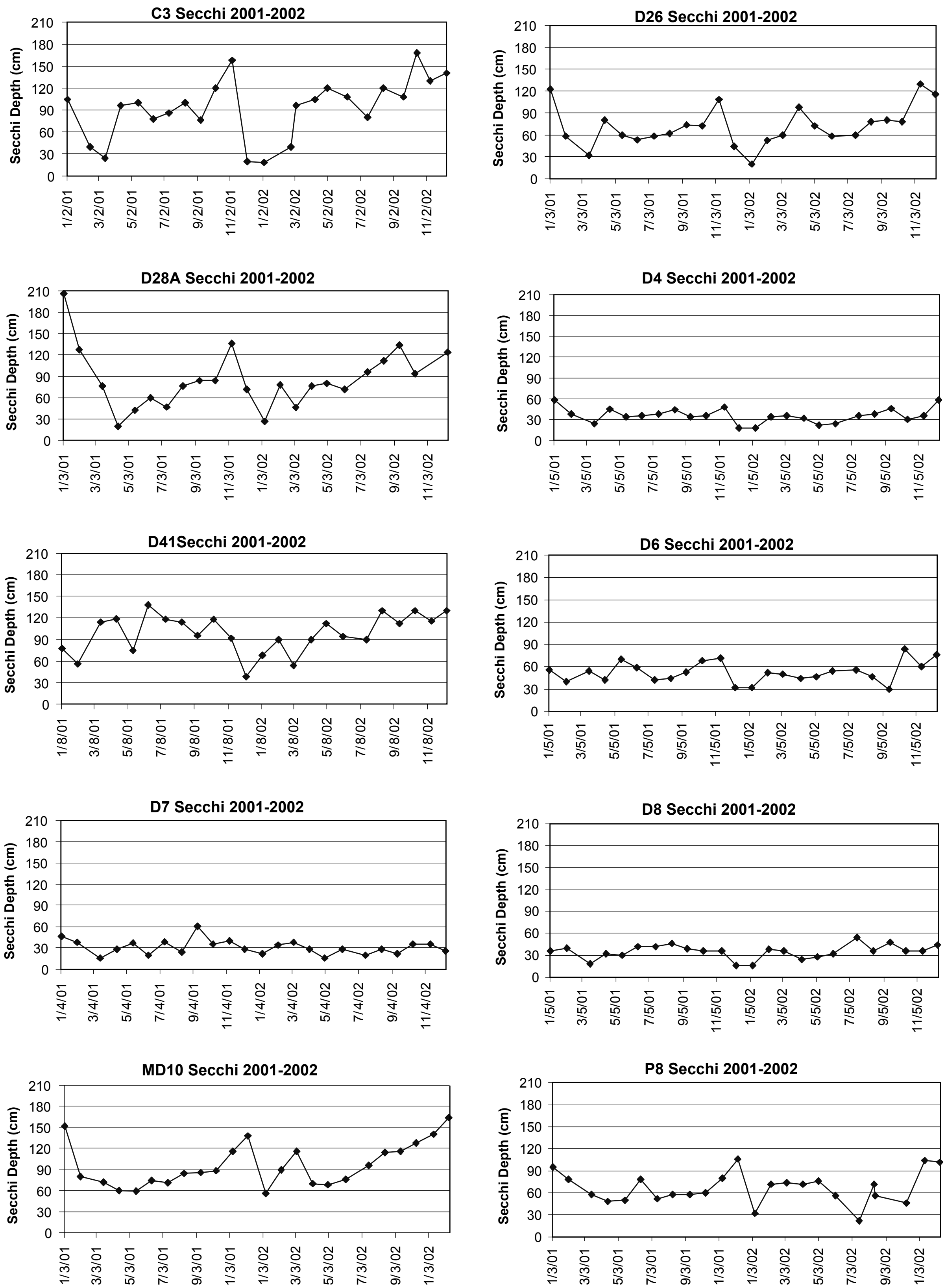


Figure 3-10 Turbidity—comparison of Bay-Delta sampling sites, 2001-2002

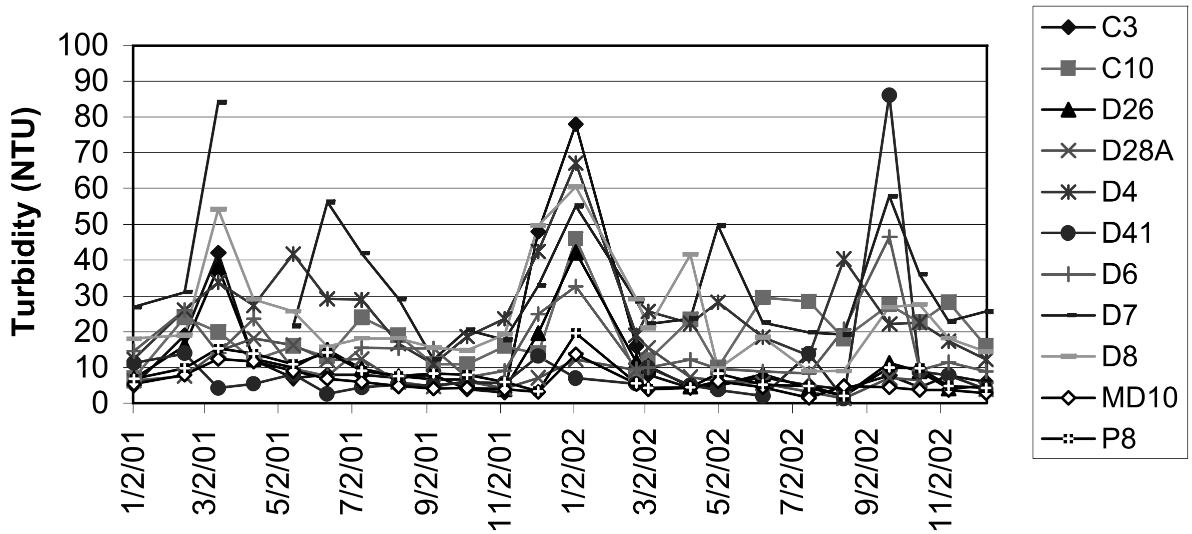


Figure 3-11 Turbidity at specific Bay-Delta sampling sites, 2001-2002

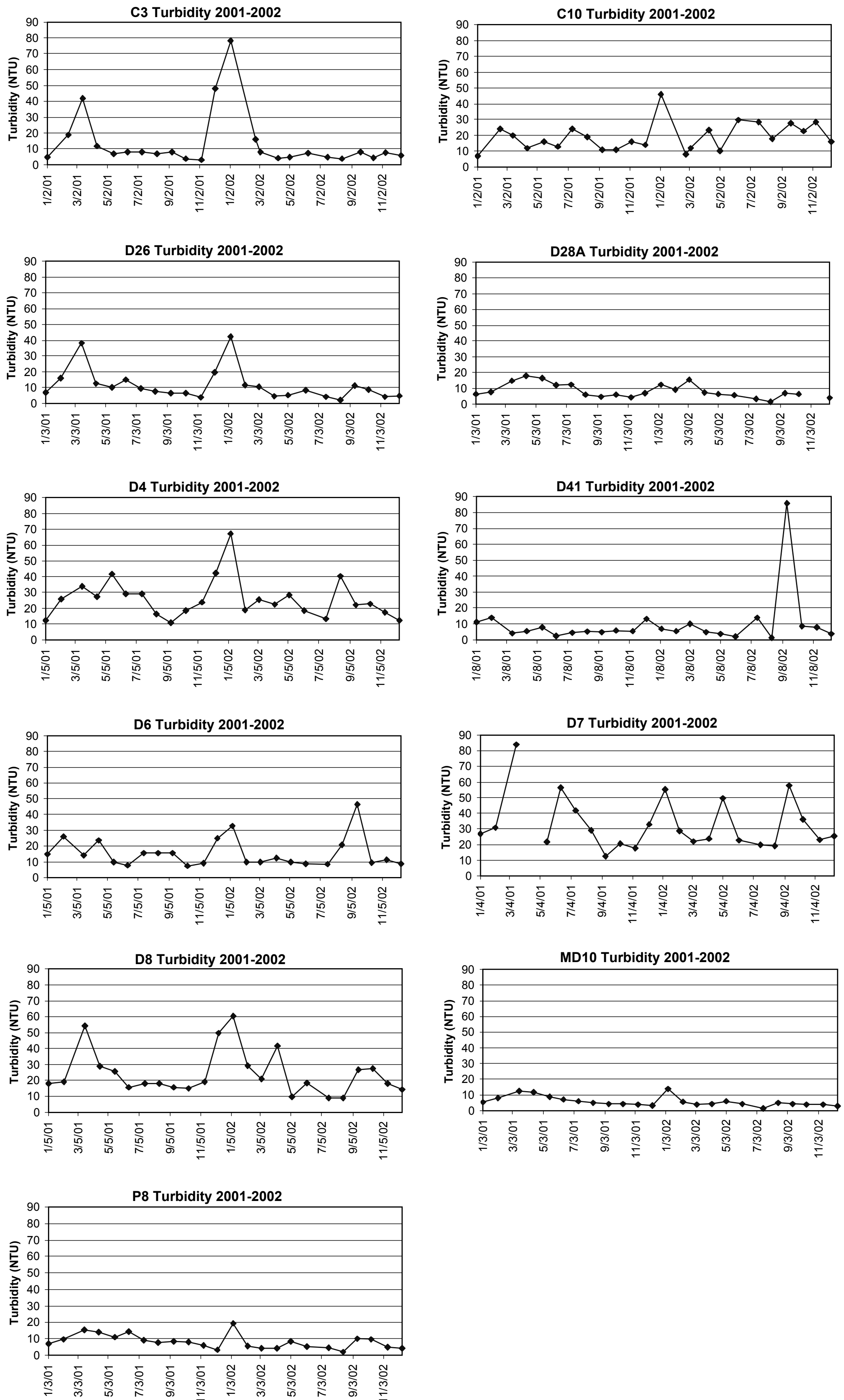


Figure 3-12 Orthophosphate concentrations—comparison of Bay-Delta sampling sites, 2001-2002

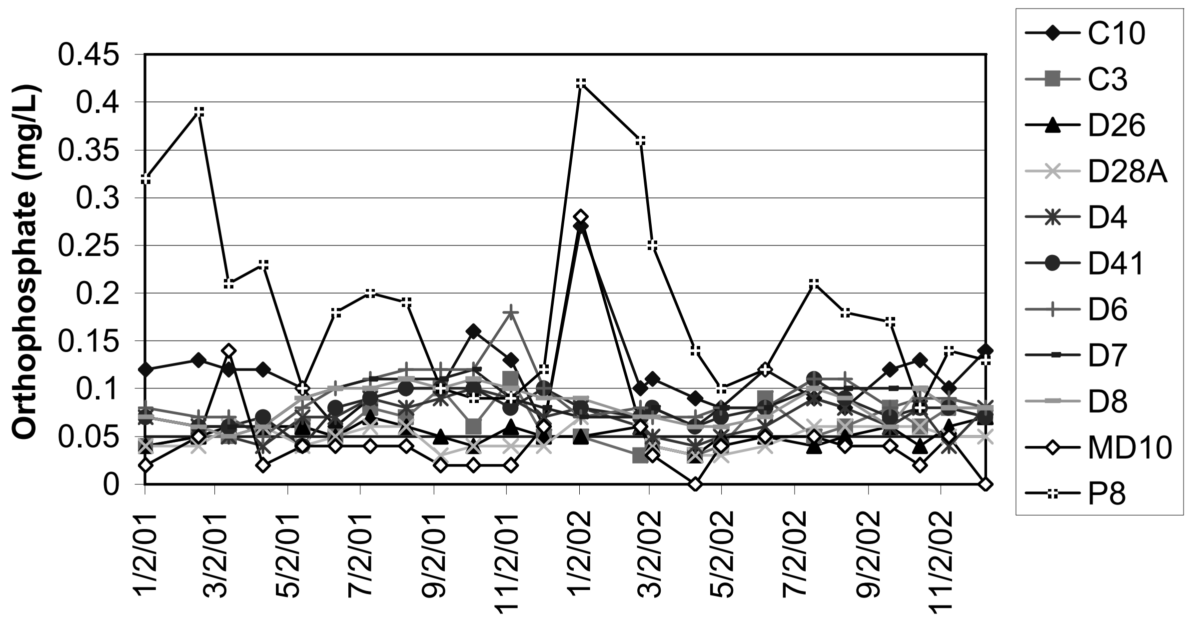


Figure 3-13 Orthophosphate concentrations at specific Bay-Delta sampling sites, 2001-2002

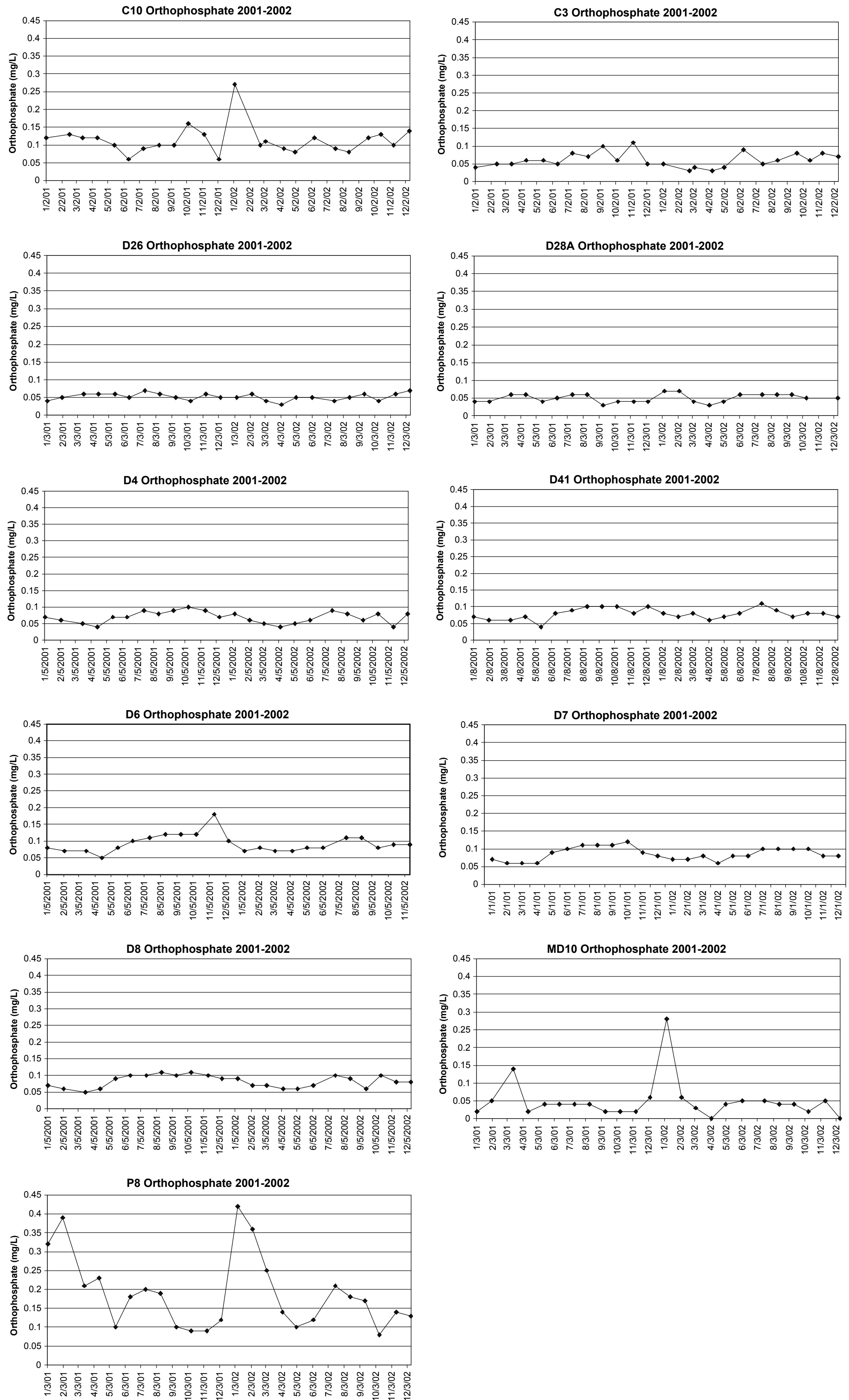


Figure 3-14 Total phosphorous concentrations—comparison of Bay-Delta sampling sites, 2001-2002

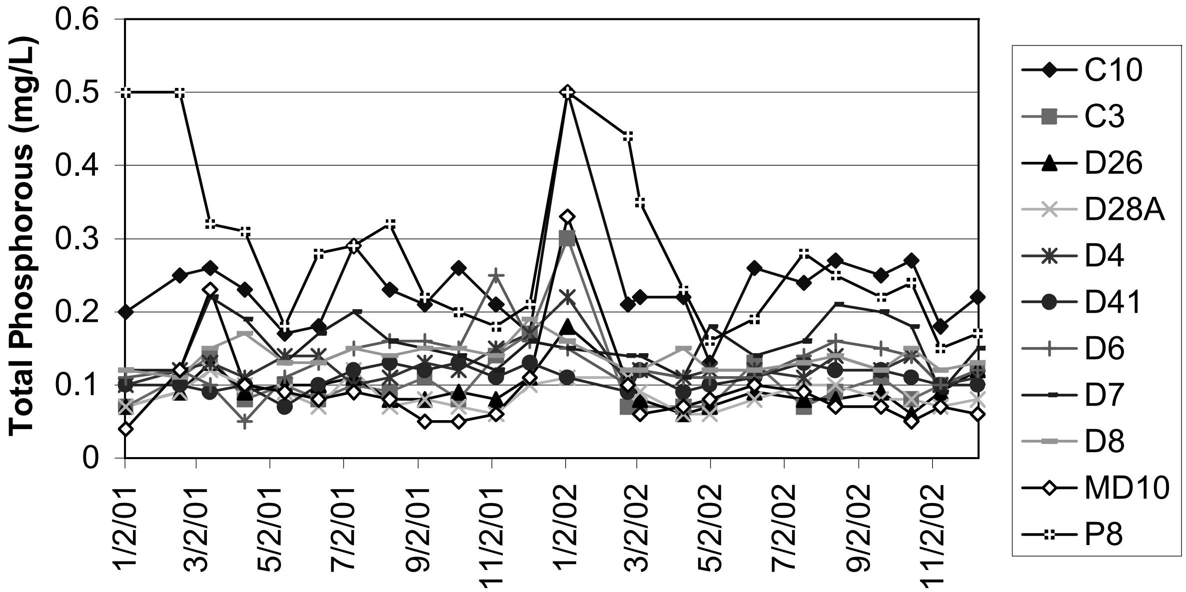


Figure 3-15 Total phosphorous concentrations at specific Bay-Delta sampling sites, 2001-2002

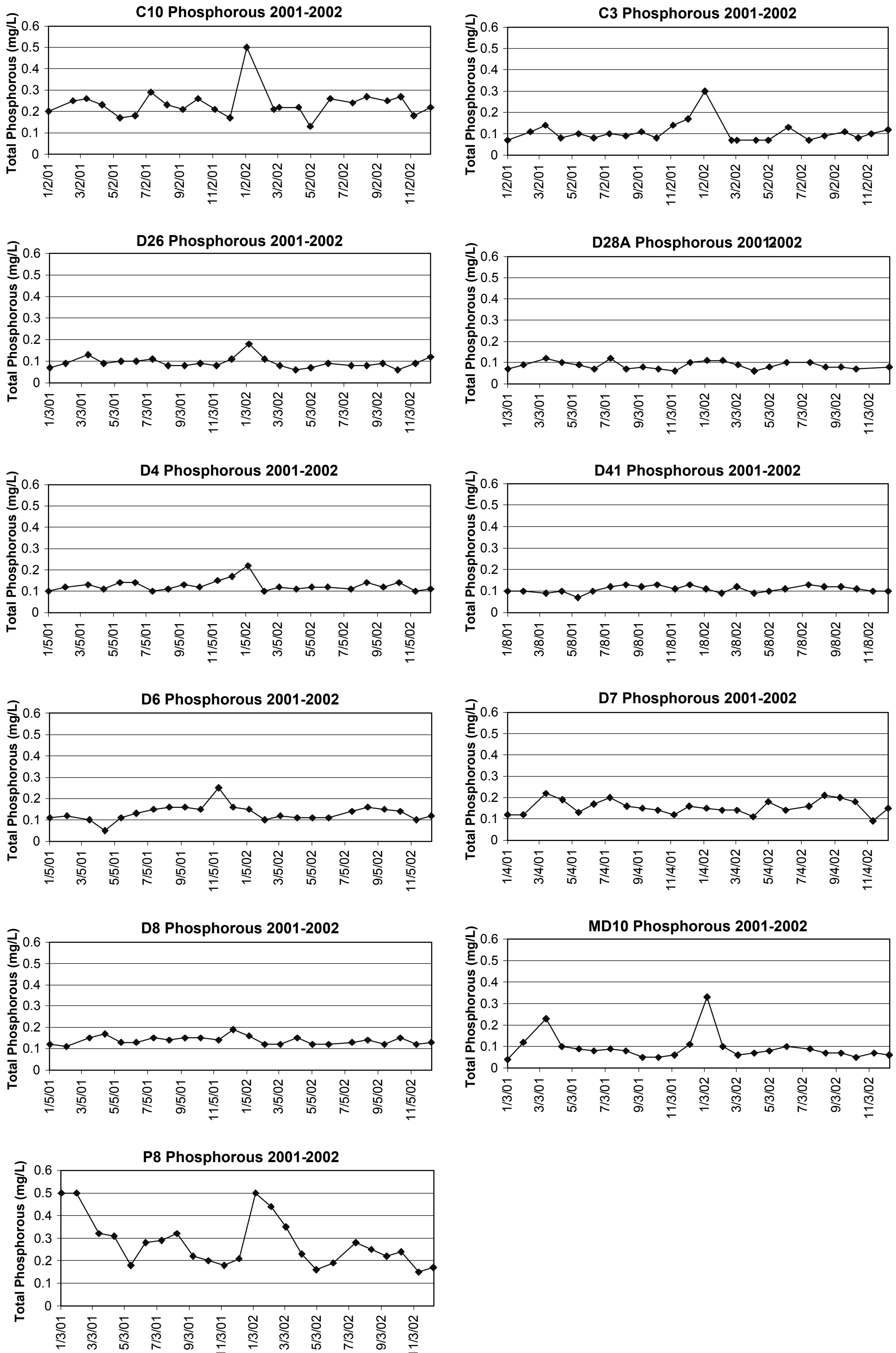


Figure 3-16 Kjeldahl nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002

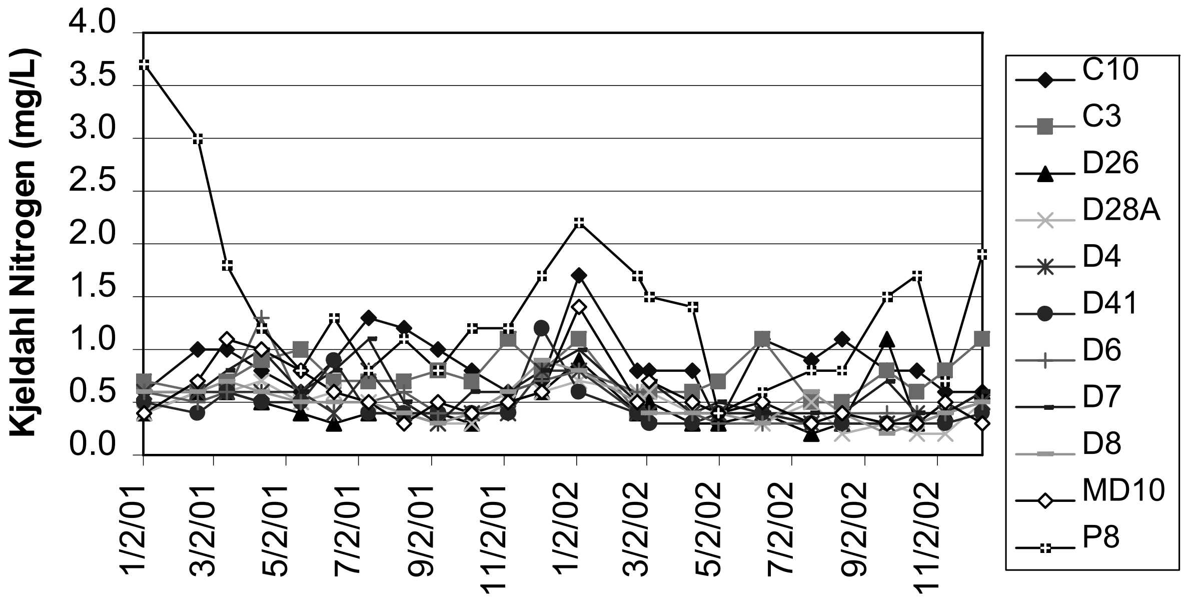


Figure 3-17 Kjeldahl nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002

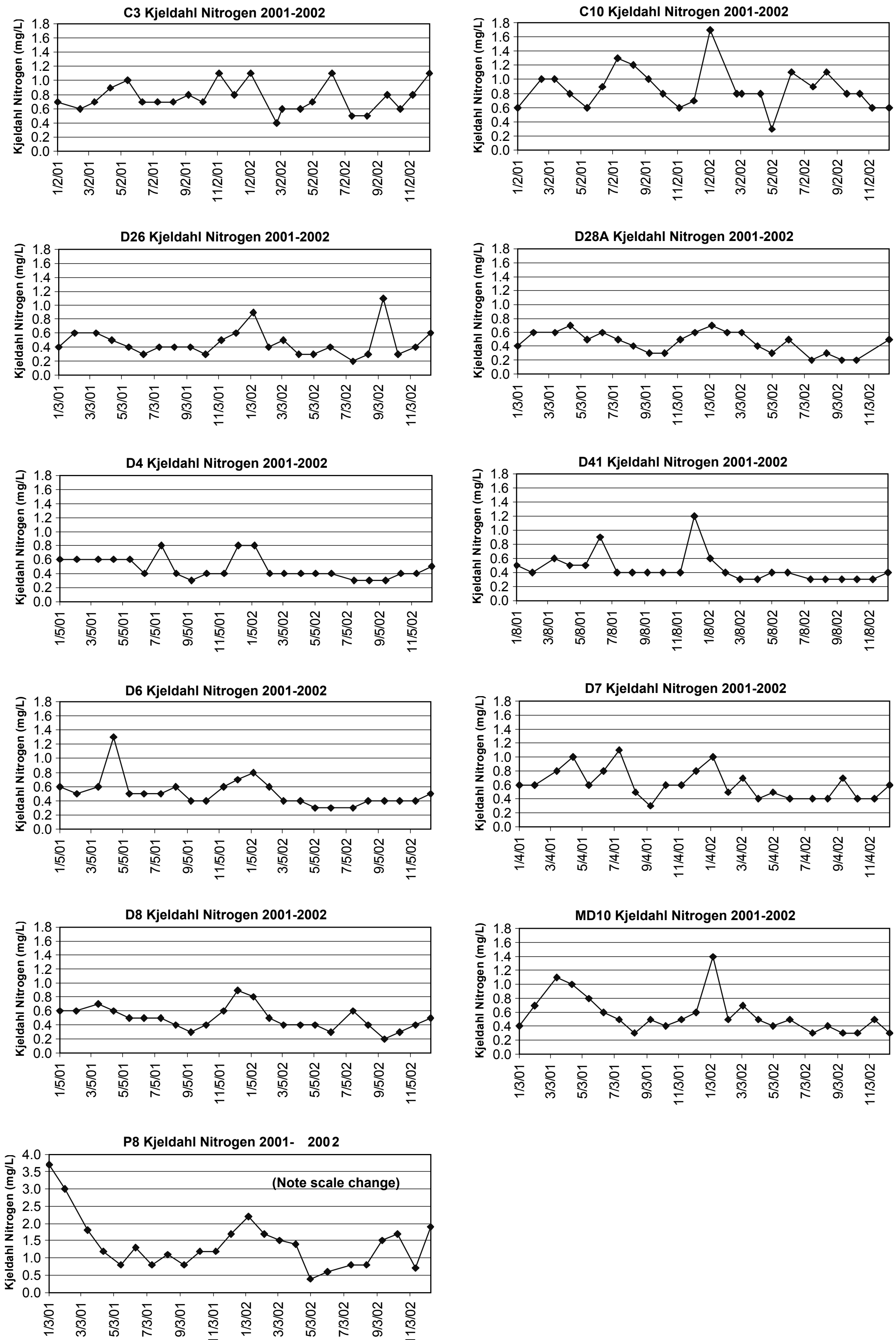


Figure 3-18 Dissolved inorganic nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002

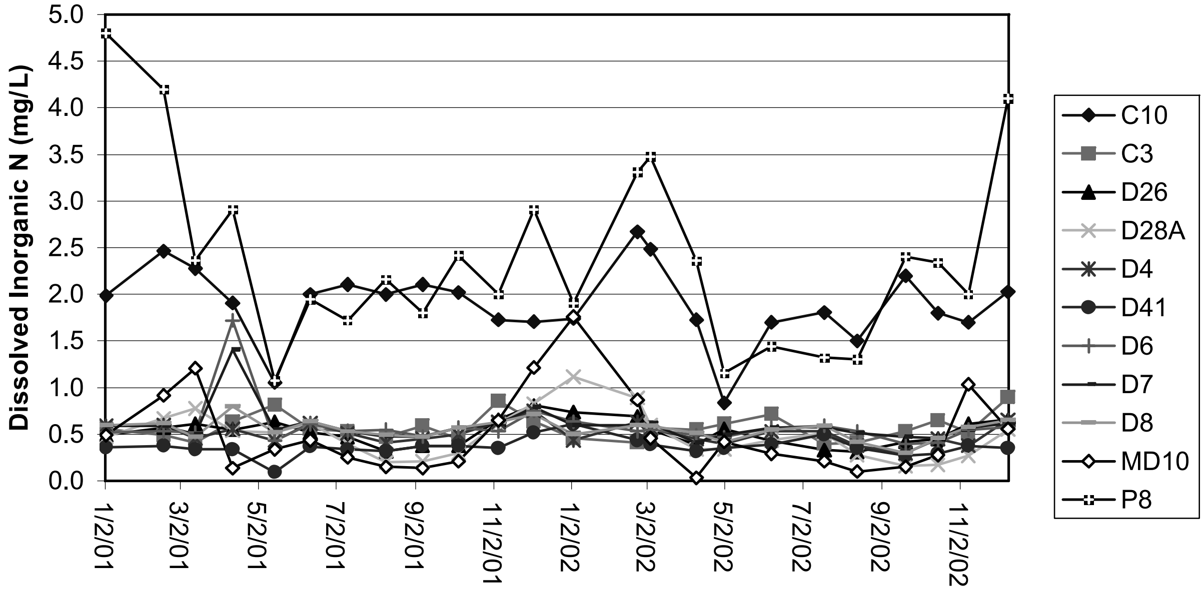


Figure 3-19 Dissolved inorganic nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002

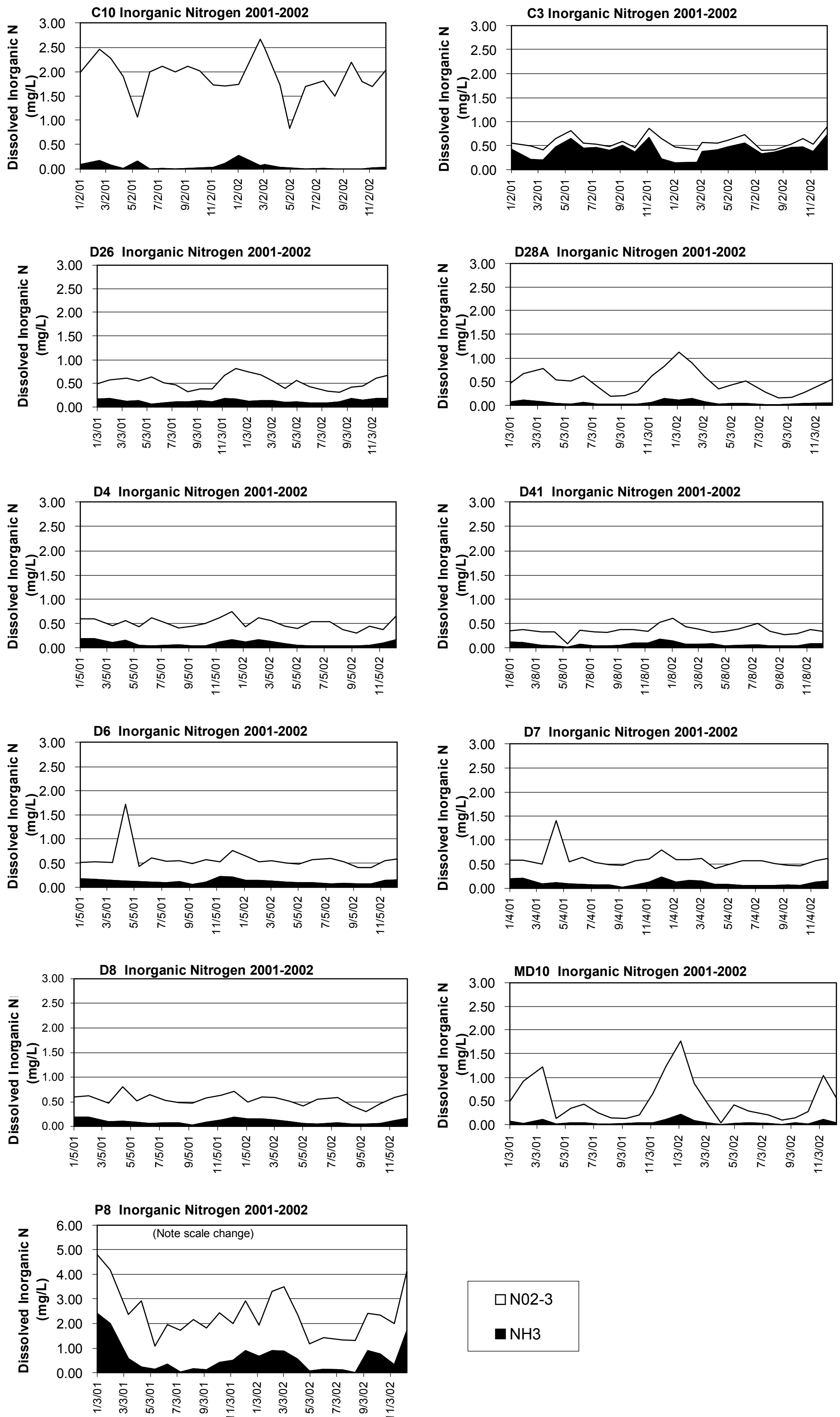


Figure 3-20 Dissolved organic nitrogen concentrations—comparison of Bay-Delta sampling sites, 2001-2002

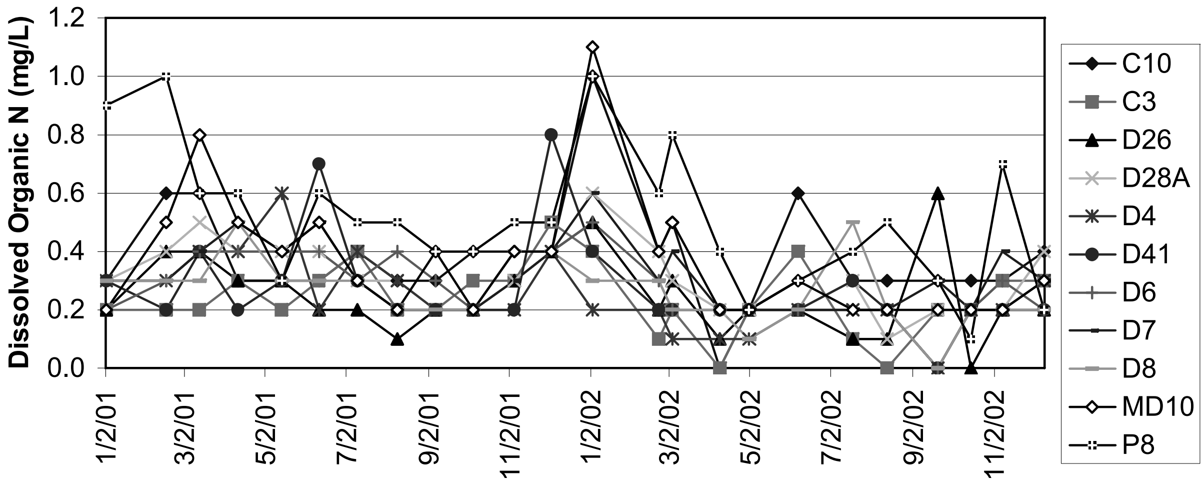


Figure 3-21 Dissolved organic nitrogen concentrations at specific Bay-Delta sampling sites, 2001-2002

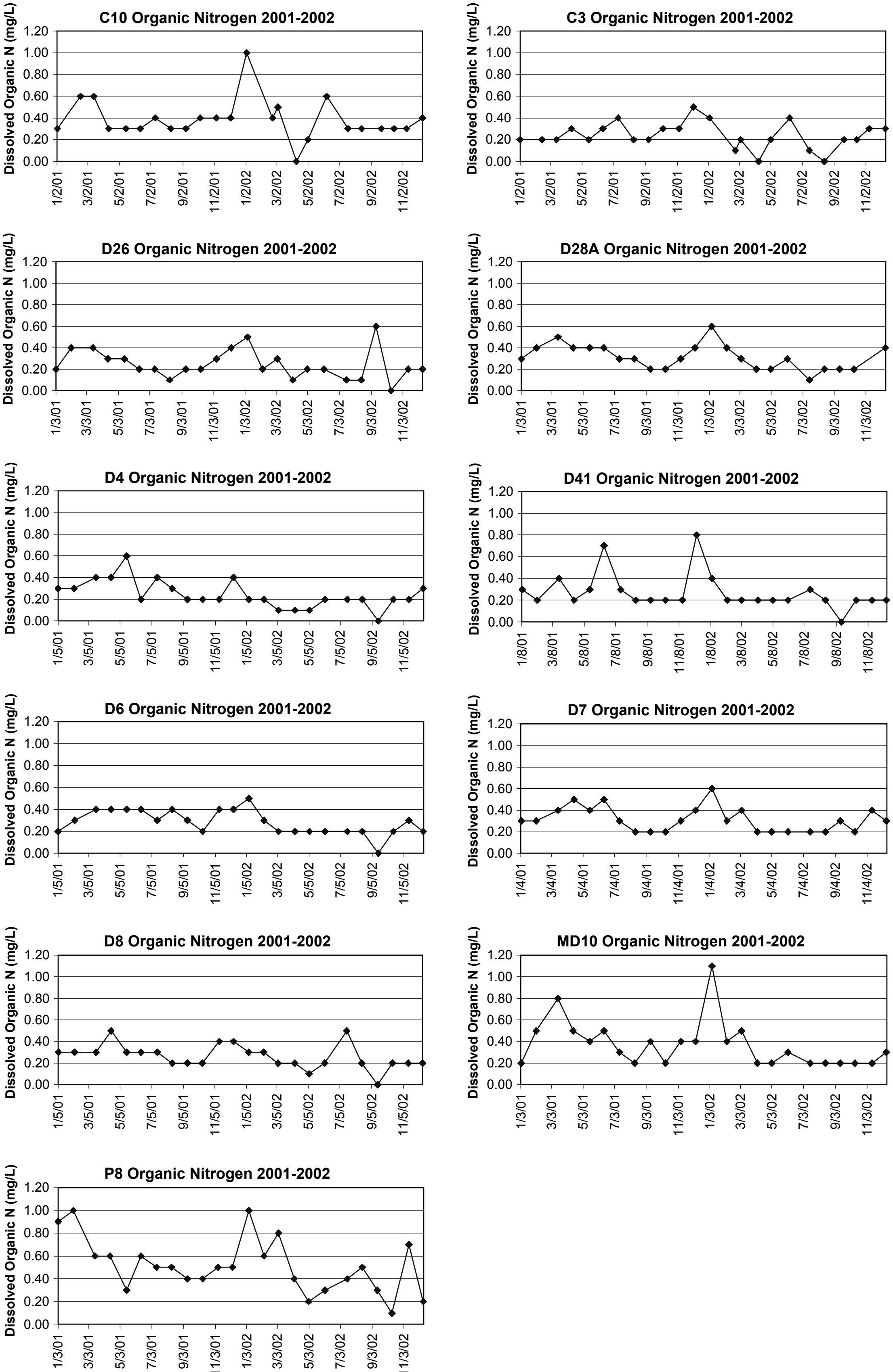


Figure 3-22 Total dissolved solids—comparison of Bay-Delta sampling sites, 2001-2002

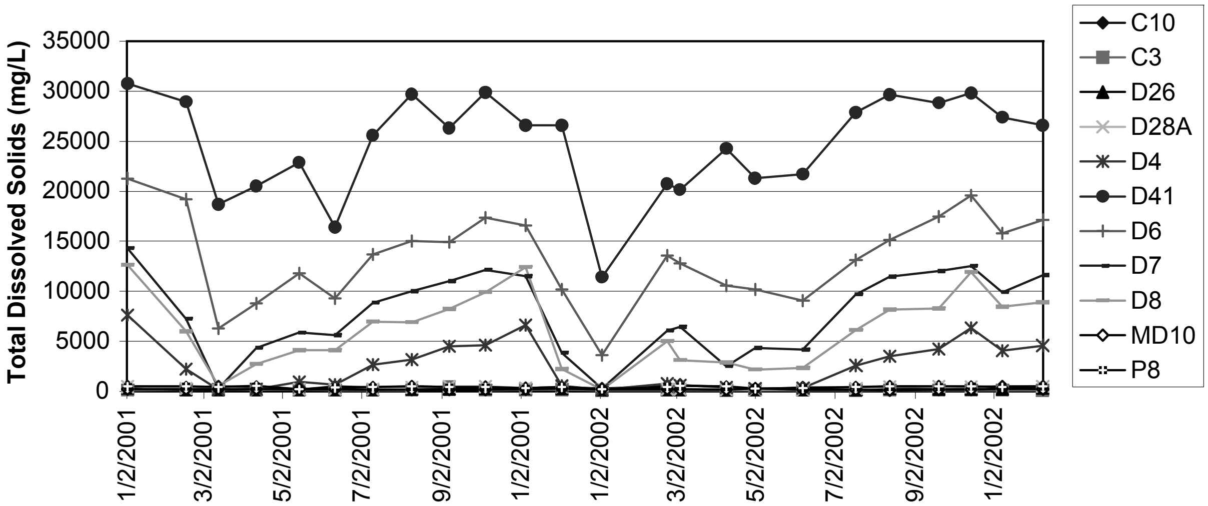


Figure 3-23 Total dissolved solids at specific Bay-Delta sampling sites, 2001-2002

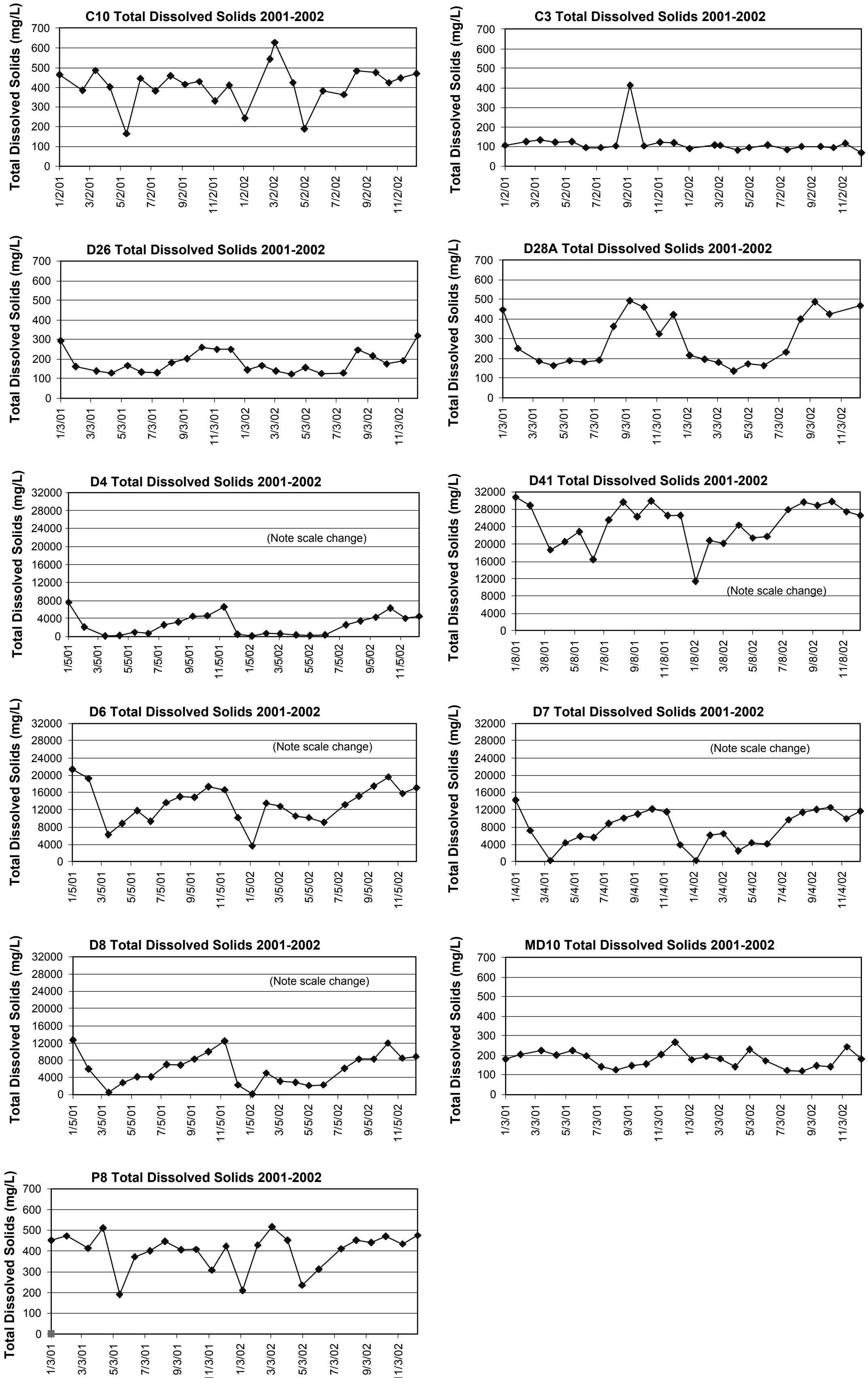


Figure 3-24 Total suspended solids—comparison of Bay-Delta sampling sites, 2001-2002

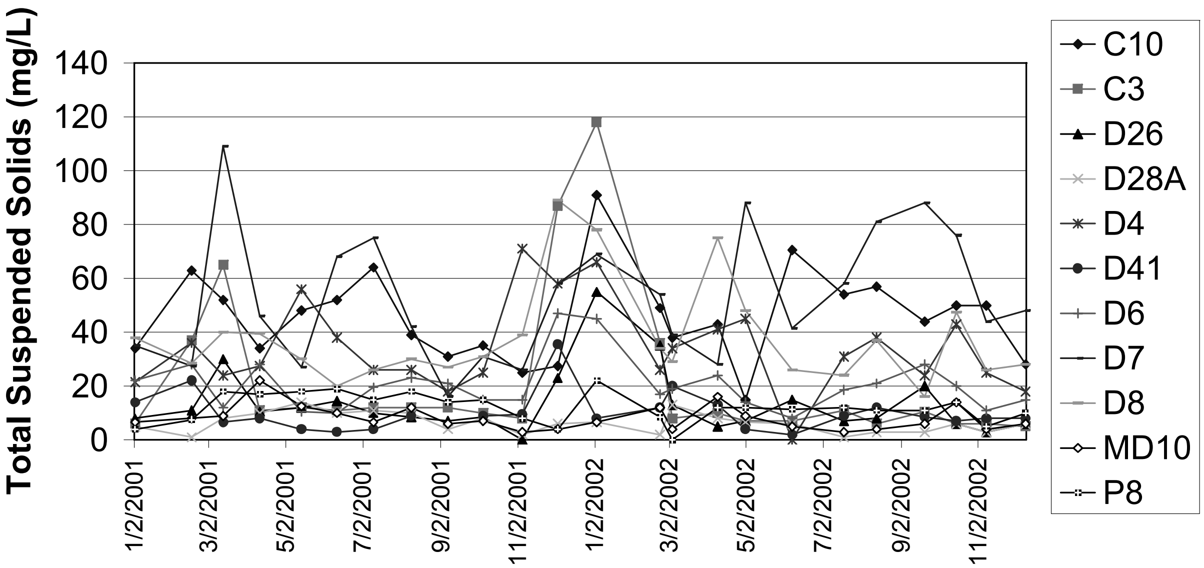


Figure 3-25 Total suspended solids at specific Bay-Delta sampling sites, 2001-2002

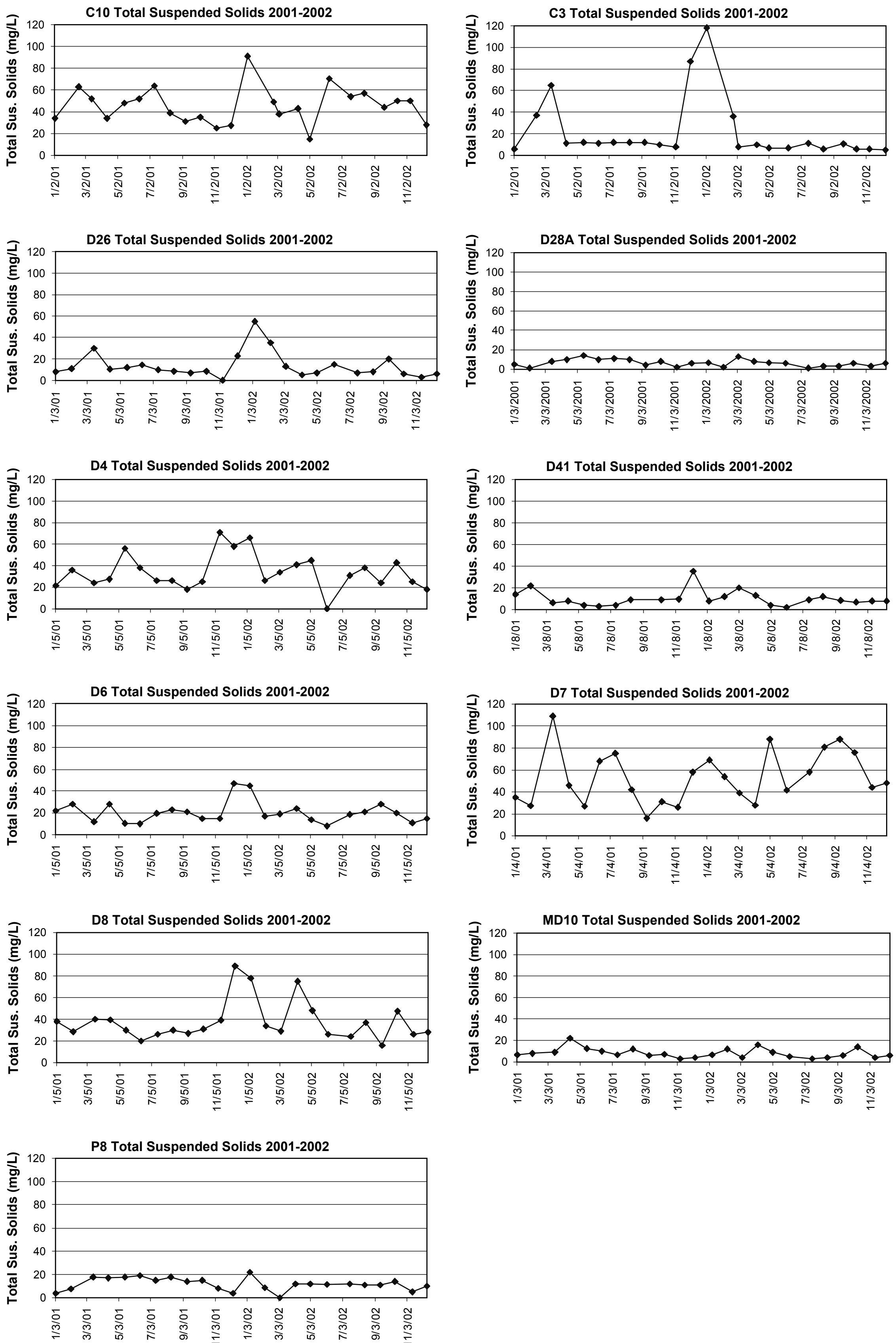


Figure 3-26 Volatile suspended solids—comparison of Bay-Delta sampling sites, 2001-2002

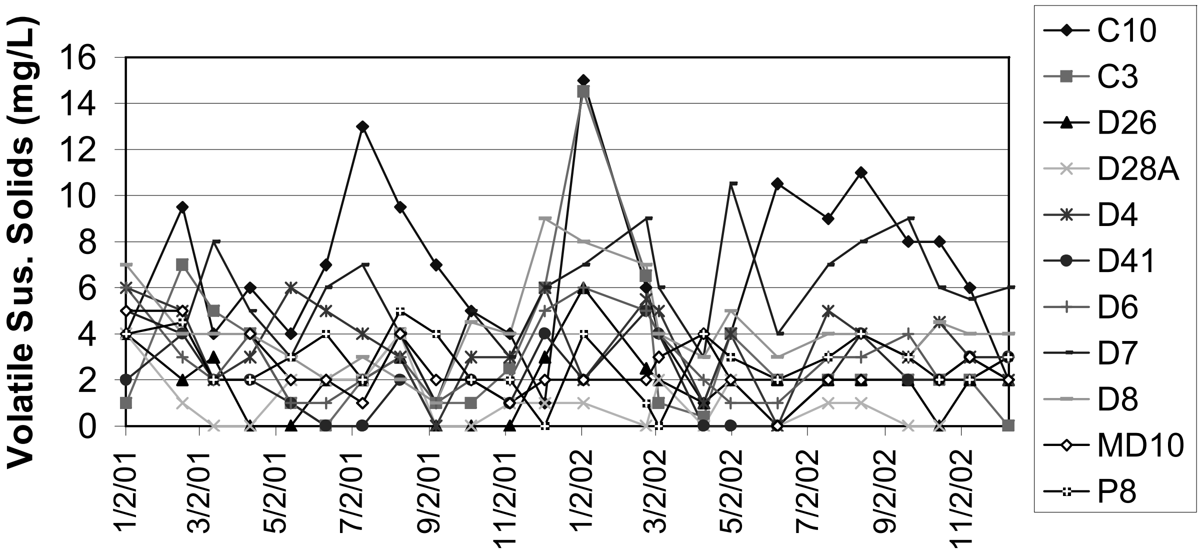


Figure 3-27 Volatile suspended solids at specific Bay-Delta sampling sites, 2001-2002

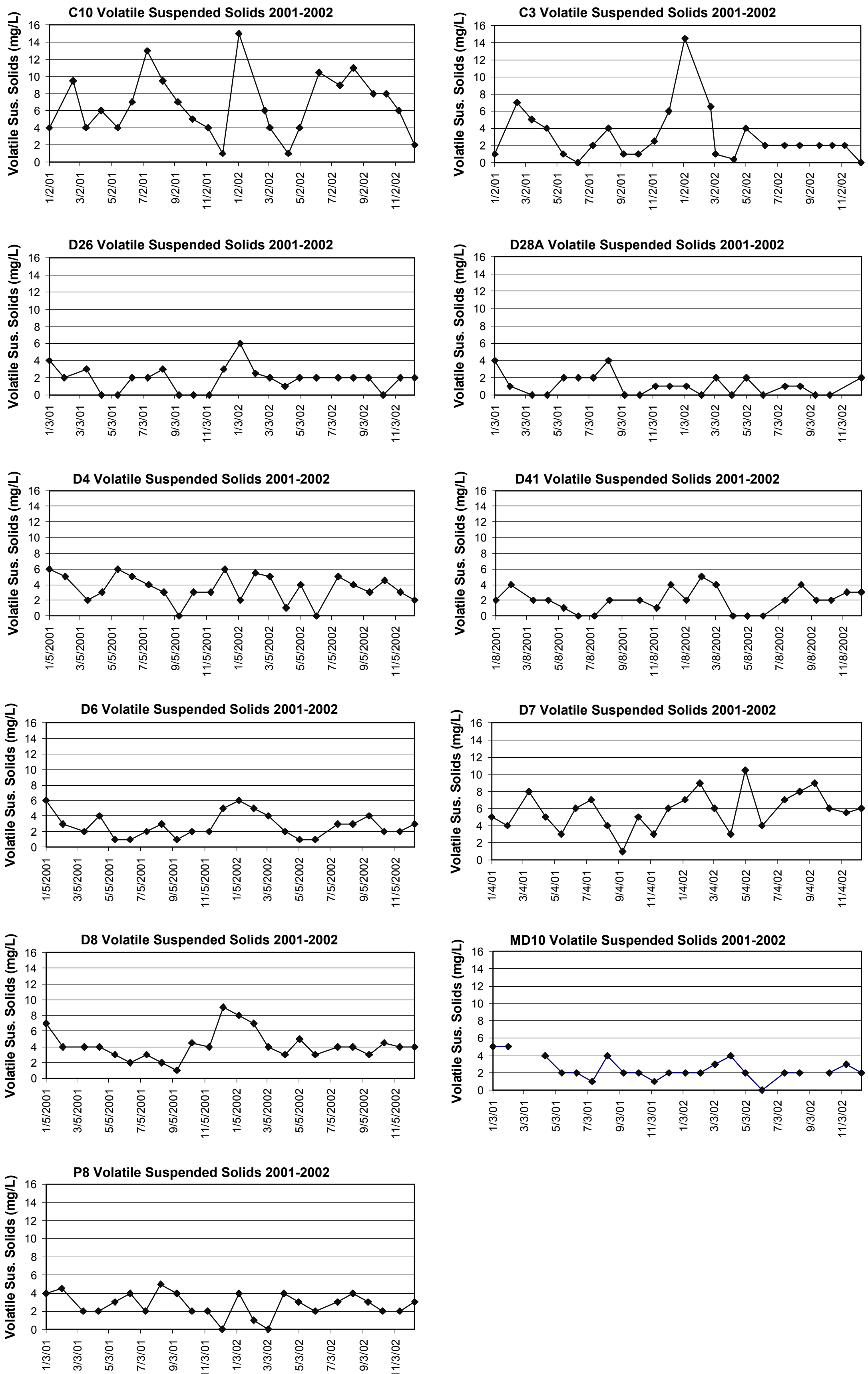


Figure 3-28 Silica concentrations—comparison of Bay-Delta sampling sites, 2001-2002

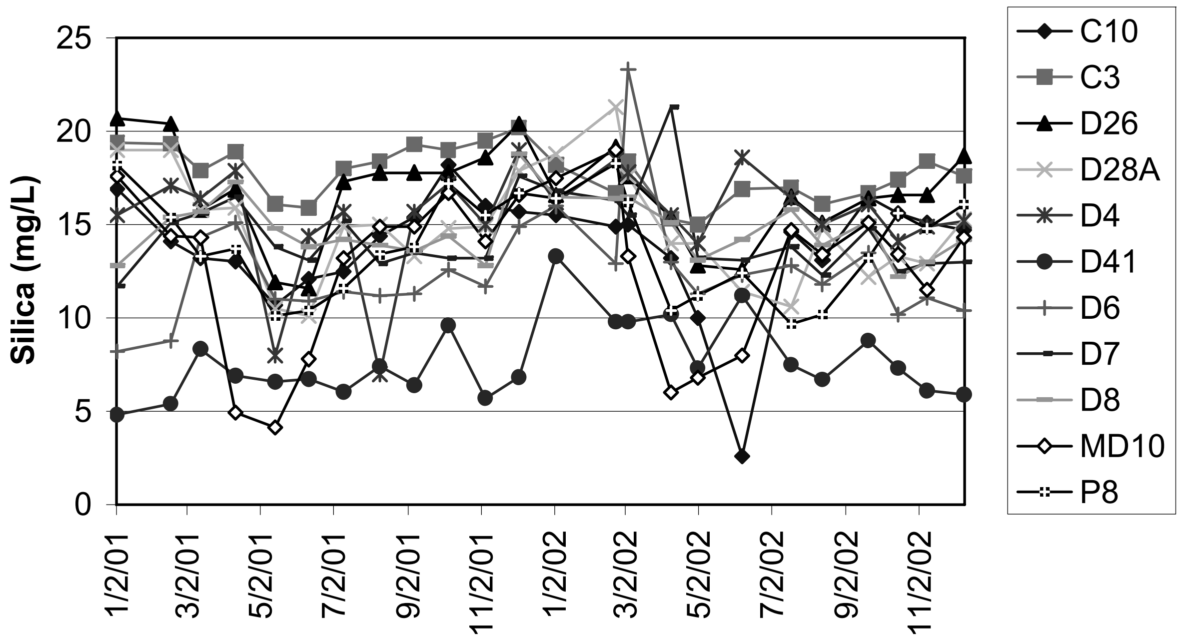


Figure 3-29 Silica concentrations at specific Bay-Delta sampling sites, 2001-2002

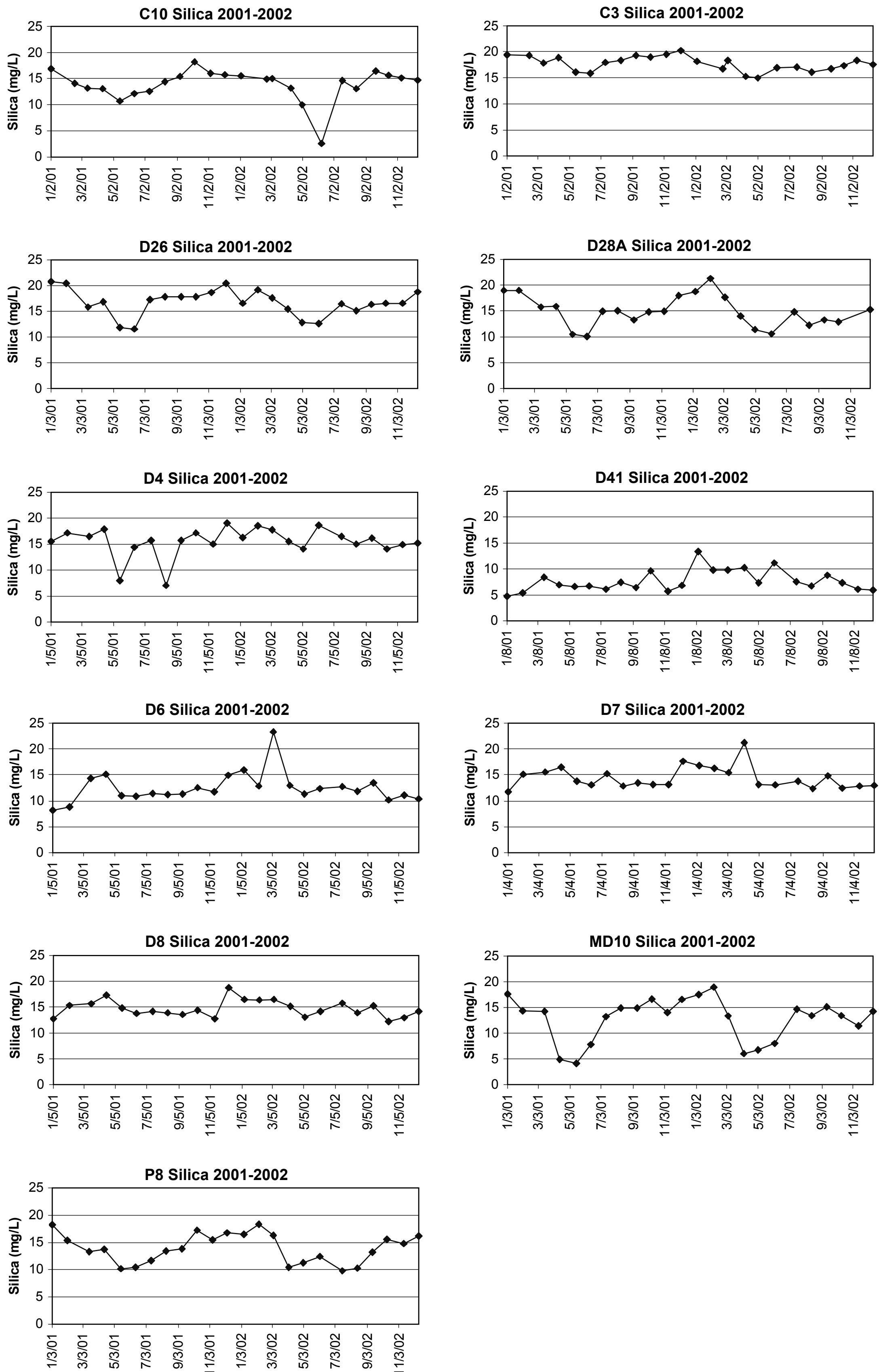


Figure 3-30 Chloride concentrations—comparison of Bay-Delta sampling sites, 2001-2002

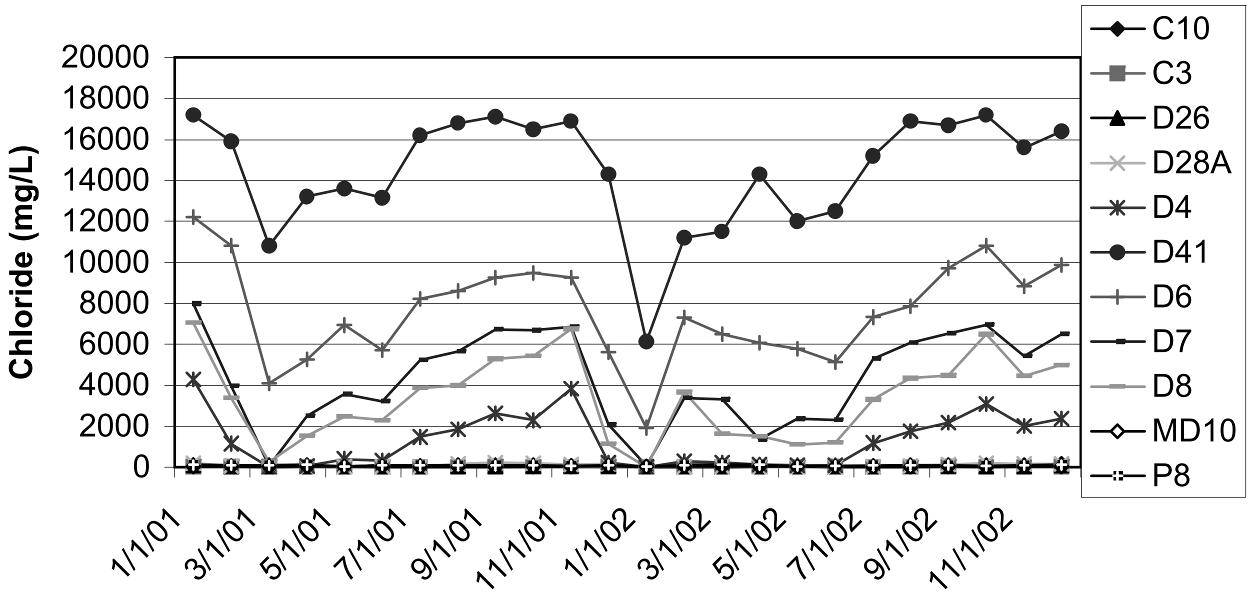
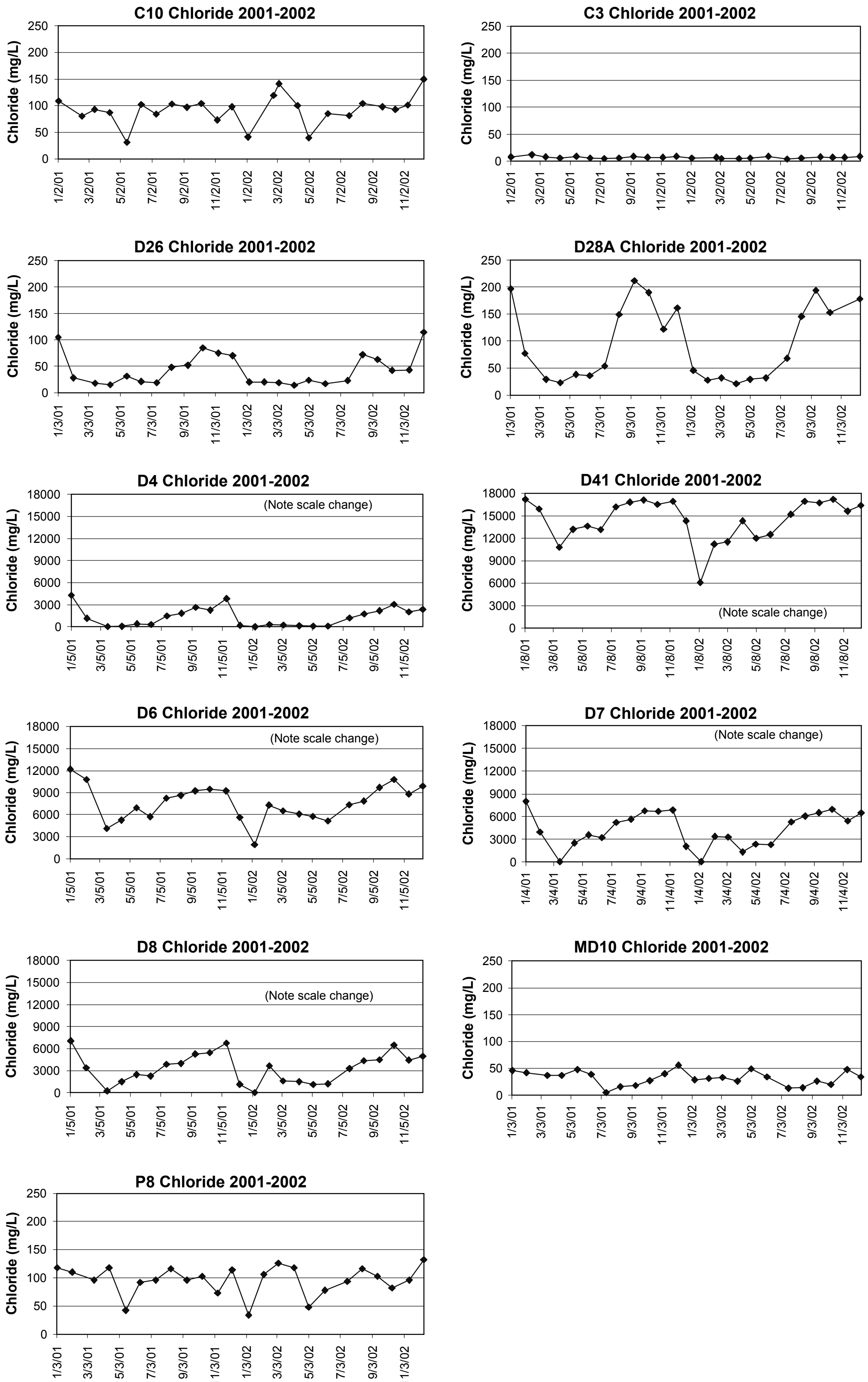


Figure 3-31 Chloride concentrations at specific Bay-Delta sampling sites, 2001-2002



Chapter 4
Phytoplankton and Chlorophyll, 2001-2002

Introduction

The Department of Water Resources (DWR) and the United States Bureau of Reclamation (USBR) collect phytoplankton and chlorophyll *a* samples in order to monitor algal community composition and biomass in the San Francisco Estuary (Estuary) in compliance with D-1641. The eleven sampling sites range from San Pablo Bay east to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. These sites represent a variety of aquatic habitats, from narrow, freshwater channels in the Delta to broad, estuarine bays. This chapter describes the results of these monitoring efforts for calendar years 2001 and 2002.

Primary production (carbon fixation through photosynthesis) by phytoplankton is one of the key processes that influence water quality in the Estuary. 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). Phytoplankton are small, free-floating organisms that occur as unicellular, colonial or filamentous forms (Horne and Goldman 1994). In addition to their being an important food source for zooplankton, invertebrates, and some species of fish, phytoplankton species assemblages can also be useful in assessing water quality (Gannon and Stemberger 1978). Due to their short life cycles, phytoplankton respond quickly to environmental changes, and hence their standing crop and species composition are indicative of the quality of the water mass in which they are found (APHA 1998). However, because of their transient nature, patchiness and free movement in a lotic environment, the utility of phytoplankton as water quality indicators is limited, and should be interpreted in conjunction with physiochemical and other biological data (APHA 1998).

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

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

Phytoplankton biomass and 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). Well-established benthic populations of *P. amurensis* in Suisun and San Pablo bays are thought to have contributed to the low chlorophyll *a* concentrations (and increased water clarity) measured in these westerly bays since the mid-1980s (Alpine and Cloern 1992).

Methods

Phytoplankton

Phytoplankton samples were collected monthly at 11 monitoring sites throughout the upper Estuary (Figure 4-1). Samples were collected using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed.

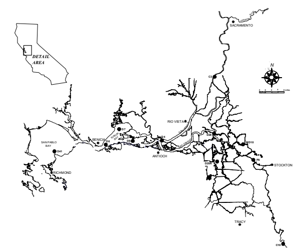


Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

Phytoplankton identification and enumeration were performed at the DWR's Bryte Laboratory according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 15 hours. The aliquot volume, normally 10 mL, was adjusted according to the algal population density and turbidity of the sample. Phytoplankton were enumerated in twenty randomly chosen fields of a Whipple ocular micrometer grid for each settled aliquot. Sample analysis was conducted at a magnification of 700X using a Wilde M-40 inverted microscope.

Organism counts for each sample can be converted to organisms/ml using the following formula:

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

Where:

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

This simplifies to:

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

Where:

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

Chlorophyll *a*

Chlorophyll *a* samples were collected monthly at 11 monitoring sites throughout the upper Estuary (Figure 4-1) using a Van Dorn water sampler or a submersible pump from 1 meter below the water's surface. Approximately 500 mL of water was passed through a 47 mm diameter glass fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to Standard Methods (APHA 1998) spectrophotometric procedure. Samples were processed by mechanically grinding the glass fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1992). In addition, percent chlorophyll *a* was calculated as the ratio of chlorophyll *a* concentration to chlorophyll *a* plus pheophytin *a* concentrations multiplied by 100.

Results

Phytoplankton Identification

Of the eight families identified, Bacillariophyceae, Chlorophyceae, and unidentified flagellates constituted 94.1% of the organisms collected during 2001 and 2002. Figure 4-2 shows the total phytoplankton contribution by family for all sites. Table 4-1 lists the genera found in each family in the upper Estuary.

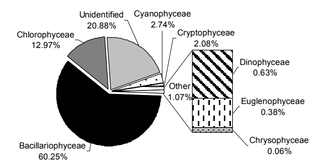


Figure 4-2 Total phytoplankton contribution by family at all stations

All organisms collected during the 2001 and 2002 fell into these eight families:

- Bacillariophyceae (Diatoms)
- Chlorophyceae (Green algae)
- Chrysophyceae (Yellow-brown algae)
- Cryptophyceae (Cryptomonads)
- Cyanophceae (Blue-green algae)
- Dinophyceae (Dinoflagellates)
- Euglenophyceae (Euglenoids)
- Unidentified flagellates (Flagellates)

Family	Genus	Family	Genus
Bacillariophyceae	Achnanthes	Chlorophyceae	Actinastrum
	Amphiprora		Ankistrodesmus
	Amphora		Carteria
	Asterionella		Chlamydomonas
	Bacillaria		Chlorella
	Ceratoneis		Closteriopsis
	Cocconeis		Closterium
	Cosinodiscus		Coelastrum
	Cyclotella		Crucigenia
	Cymbella		Desmidium
	Diatoma		Dictyosphaerium
	Fragilaria		Dimorphococcus
	Gomphonema		Elakatothrix
	Gyrosigma		Eudorina
	Melosira		Micractinium
	Navicula		Oocystis
	Neidium		Pandorina
			Pediastrum
Chrysophyceae	Synura		Pyramimonas
			Scenedesmus
Cryptophyceae	Cryptomonas		Schroederia
	Rhodomonas		Selenastrum
			Sphaerocystis
Cyanophyceae	Agmenellum		Staurastrum
	Anabaena		Tetraedron
	Anabaenopsis		Tetrastrum
	Anacystis		Ulothrix
	Aphanizomenon		Xanthidium
	Gomphosphaeria		
	Oscillatoria		
	Spirulina		
Dinophyceae	Ceratium		
	Glenodinium		
	Gymnodinium		
	Peridinium		
Euglenophyceae	Euglena		
	Trachelomonas		
Unidentified	Unidentified Flagellates		

Table 4-1 All genera found in each family in the upper San Francisco Estuary

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

Pigment Concentrations

Chlorophyll *a* concentrations showed seasonal patterns. The highest chlorophyll *a* concentrations occurred during the spring for most stations, with a second increase usually occurring during the late summer or early fall. Pheophytin *a* concentrations remained fairly constant and did not show apparent seasonal patterns.

With the exception of high values seen at three stations in the south and east Delta (C10, P8, and MD10) chlorophyll *a* and pheophytin *a* concentrations were generally in the range of 0.5 µg/L and 15 µg/L throughout the upper Estuary. The highest concentrations of chlorophyll *a* occurred at Vernalis (station C10) on the San Joaquin River during July 2001 (109.4 µg/L) and July 2002 (79.45 µg/L), at Disappointment Slough (station MD10) on the Mokelumne River during April 2001 (62.8 µg/L) and April 2002 (49.6 µg/L), and at Buckley Cove (station P8) on the San Joaquin River during October 2001 (22.9 µg/L) and September 2002 (21.2 µg/L). These stations are located in the southern and eastern regions of the Sacramento-San Joaquin Delta.

From east to west, the concentration of chlorophyll *a* showed a decreasing trend, with the exception of station C3 (Sacramento River at Hood). Figures 4-3 through 4-13 show the results of chlorophyll *a* and pheophytin *a* analysis. All chlorophyll *a* and pheophytin *a* data can be found at http://www.iep.ca.gov/emp/Data_access.html.

Site C3: North Delta

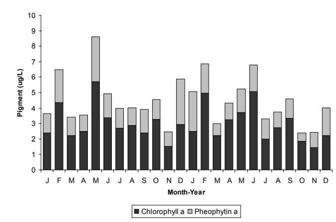


Figure 4-3 Chlorophyll *a* and pheophytin *a* concentrations at station C3, 2001–2002

The maximum chlorophyll *a* concentration during 2001 occurred in May (5.70 µg/L) (Figure 4-3). The minimum concentration during 2001 occurred in November (1.52 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in June (5.07 µg/L). The minimum chlorophyll *a* concentration during 2002 occurred in November (1.45 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

The maximum pheophytin *a* concentration during 2001 occurred in December (2.96 µg/L). No phytoplankton were found in the December 2001 sample. The minimum concentration occurred in November 2001 (0.95 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in January (2.59 µg/L). The minimum pheophytin *a* concentration occurred in March (0.77 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in pheophytin *a*.

Station C3 demonstrated a clear seasonal pattern with the highest chlorophyll *a* concentrations recorded during the spring and the lowest recorded during the fall.

Site MD10: East Delta

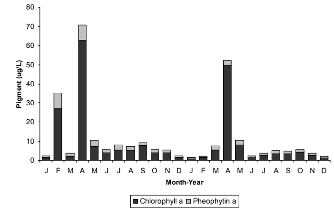


Figure 4-4 Chlorophyll *a* and pheophytin *a* concentrations at station MD10, 2001–2002

The maximum chlorophyll *a* concentration during 2001 occurred in April (62.8 µg/L) (Figure 4-4). The minimum concentration during 2001 occurred in December (1.53 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in April (49.6 µg/L). The minimum concentration during 2002 occurred in January (0.68 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

In 2001, the maximum pheophytin *a* concentration occurred in April (7.95 µg/L) and was associated with diatoms (Bacillariophyceae). The minimum concentration occurred in January 2001 (0.83 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in April

(2.69 µg/L) and was also associated with diatoms (Bacillariophyceae). The minimum concentration of pheophytin *a* occurred in December 2002 (0.65 µg/L).

Station MD10 demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring and the lowest recorded during the winter.

Site C10: South Delta

The maximum chlorophyll *a* concentration during 2001 occurred in July (109.4 µg/L) (Figure 4-5). The minimum concentration during 2001 occurred in December (3.83 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in August (118.0 µg/L). The minimum concentration during 2002 occurred in January (5.1 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

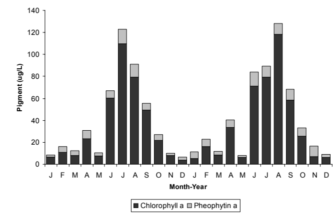


Figure 4-5 Chlorophyll *a* and pheophytin *a* concentrations at station C10, 2001–2002

The maximum pheophytin *a* concentration during 2001 occurred in July (13.66 µg/L). The minimum concentration occurred in November (2.13 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in June (12.85 µg/L). The minimum pheophytin *a* concentration occurred in May (2.03 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in pheophytin *a*.

Station C10 demonstrated a clear seasonal pattern with the highest pigment concentrations recorded during the summer and early fall, and the lowest recorded during the winter.

Site P8: South Delta

The maximum chlorophyll *a* concentration during 2001 occurred in October (22.95 µg/L) (Figure 4-6). The minimum concentration during 2001 occurred in June (3.01 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in September (21.15 µg/L). The minimum concentration during 2002 occurred in January (3.36 µg/L). Diatoms (Bacillariophyceae) and green algae (Chlorophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

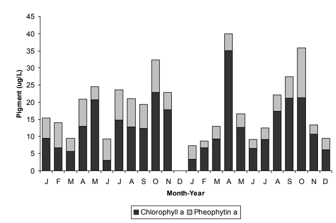


Figure 4-6 Chlorophyll *a* and pheophytin *a* concentrations at station P8, 2001–2002

The maximum pheophytin *a* concentration during 2001 occurred in October (9.45 µg/L). This peak was associated with unidentified flagellates and green algae (Chlorophyceae). The minimum concentration occurred in May (3.81 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in October (14.4 µg/L). The phytoplankton family associated with this peak was unidentified flagellates. The minimum concentration occurred in February 2002 (1.96 µg/L).

Station P8 demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring and an additional peak during the fall. The lowest recorded concentrations occur during the winter and summer.

Site D28A: Central Delta

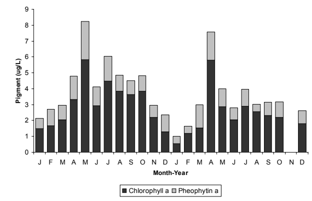


Figure 4-7 Chlorophyll *a* and pheophytin *a* concentrations at station D28A, 2001–2002

The maximum chlorophyll *a* concentration during 2001 occurred in May (5.83 µg/L) (Figure 4-7). Diatoms (Bacillariophyceae) were primarily responsible for this peak. The minimum concentration during 2001 occurred in December (1.27 µg/L). The maximum chlorophyll *a* concentration at D28A during 2002 occurred in April (5.81 µg/L). The minimum concentration during 2002 occurred in January (0.55 µg/L). Unidentified flagellates were primarily responsible for this observed peak.

The maximum pheophytin *a* concentration during 2001 occurred in April (2.40 µg/L). Diatoms (Bacillariophyceae) and unidentified flagellates were primarily responsible for this peak. The minimum concentration occurred in January (0.67 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in April (1.76 µg/L). Unidentified flagellates were primarily responsible for this peak. The minimum concentration occurred in August (0.46 µg/L).

Station D28A demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring and summer and the lowest recorded are during the winter.

Site D26: Lower San Joaquin River

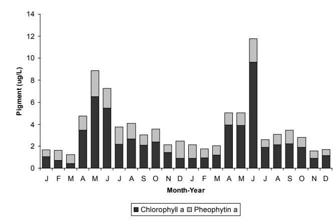


Figure 4-8 Chlorophyll *a* and pheophytin *a* concentrations at station D26, 2001–2002

The maximum chlorophyll *a* concentration during 2001 occurred in May (6.52 µg/L) (Figure 4-8). The minimum concentration during 2001 occurred in February (0.71 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in June (9.63 µg/L). Minimum concentration during 2002 occurred in January (0.88 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

The maximum pheophytin *a* concentration during 2001 occurred in May (2.36 µg/L). The minimum concentration occurred in January (0.61 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in June (1.16 µg/L). The minimum concentration occurred in December (0.56 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

Station D26 demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring and summer and the lowest recorded were during the winter months.

Site D4: Lower Sacramento River

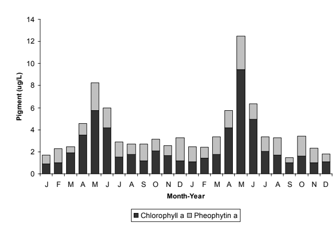


Figure 4-9 Chlorophyll *a* and pheophytin *a* concentrations at station D4, 2001–2002

The maximum chlorophyll *a* concentration during 2001 occurred in May (5.76 µg/L) (Figure 4-9). Diatoms (Bacillariophyceae) were primarily responsible for this peak. The minimum concentration during 2001 occurred in January (0.92 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in May (9.44 µg/L). Green algae (Chlorophyceae) and diatoms (Bacillariophyceae) were primarily responsible for this observed peak. The minimum concentration during 2002 occurred in September (0.99 µg/L).

The maximum pheophytin *a* concentration during 2001 occurred in May (2.48 µg/L). The phytoplankton family associated with this peak was diatoms (Bacillariophyceae). The minimum concentration occurred in March (0.58 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in May (3.04 µg/L). The minimum concentration occurred in September (0.47 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in pheophytin *a*.

Station D4 demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring and summer and the lowest during the fall and winter.

Site D8: Suisun Bay

The maximum chlorophyll *a* concentration during 2001 occurred in June (3.63 µg/L) (Figure 4-10). Diatoms (Bacillariophyceae) were primarily responsible for this observed peak. The minimum concentration during 2001 occurred in December (0.90 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in May (3.75 µg/L). Cryptomonads (Cryptophyceae) were primarily responsible for this observed peak. The minimum concentration during 2002 occurred in January (1.07 µg/L).

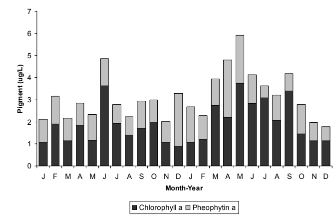


Figure 4-10 Chlorophyll *a* and pheophytin *a* concentrations at station D8, 2001–2002

The maximum pheophytin *a* concentration during 2001 occurred in December (2.37 µg/L). No phytoplankton were collected at this station in December 2001. The minimum concentration occurred in August (0.83 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in April (2.59 µg/L). Unidentified flagellates were primarily responsible for this observed peak. The minimum concentration occurred in July (0.54 µg/L).

Chlorophyll *a* and pheophytin *a* levels remained low and stable (range 0.54 to 3.75 µg/L) for both years. A peak of 3.63 µg/L occurred in June in 2001. A seasonal pattern was demonstrated in 2002 with the highest concentrations during the spring and the lowest during the winter.

Site D7: Suisun Bay

The maximum chlorophyll *a* concentration during 2001 occurred in July (2.35 µg/L) (Figure 4-11). Diatoms (Bacillariophyceae) were primarily responsible for this observed peak. The minimum concentration during 2001 occurred in June (1.02 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in March (11.70 µg/L). Unidentifiable flagellates were primarily responsible for this observed peak. The minimum concentration during 2002 occurred in November (0.84 µg/L).

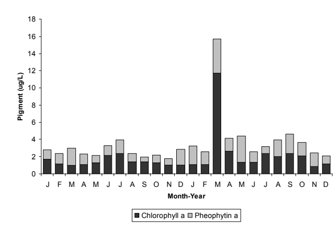


Figure 4-11 Chlorophyll *a* and pheophytin *a* concentrations at station D7, 2001–2002

The maximum pheophytin *a* concentration during 2001 occurred in March with 2.02 µg/L. No phytoplankton were identified in the March 2001 sample. The minimum concentration occurred in November (0.73 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in March (3.96 µg/L). Unidentified flagellates were primarily responsible for this observed peak. The minimum concentration occurred in July (0.81 µg/L).

The chlorophyll *a* and pheophytin *a* concentrations were stable (concentrations below 2.35 µg/L) at this station with the exception of one peak in May 2002.

Site D6: Suisun Bay

The maximum chlorophyll *a* concentration during 2001 occurred in May (3.01 µg/L) (Figure 4-12). The minimum concentration during 2001 occurred in November (0.69 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in March (3.51 µg/L). The minimum concentration during 2002 occurred in January (0.77 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for the observed peaks in chlorophyll *a*.

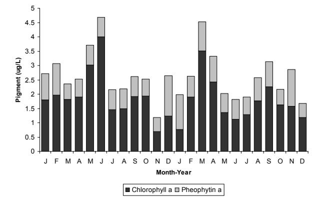


Figure 4-12 Chlorophyll *a* and pheophytin *a* concentrations at station D6, 2001–2002

The maximum pheophytin *a* concentration during 2001 occurred in December (1.41 µg/L). Diatoms (Bacillariophyceae) and unidentified flagellates were primarily responsible for this observed peak. The minimum concentration occurred in November (0.50 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in November (1.28 µg/L). Unidentified flagellates were primarily responsible for this observed peak. The minimum concentration occurred in December (0.49 µg/L).

Station D6 demonstrated a clear seasonal pattern with the highest concentrations recorded during the spring.

Site D41: San Pablo Bay

The maximum chlorophyll *a* concentration during 2001 occurred in May (6.66 µg/L) (Figure 4-13). Unidentified flagellates were primarily responsible for this observed peak. The minimum concentration during 2001 occurred in December (1.43 µg/L). The maximum chlorophyll *a* concentration during 2002 occurred in May (4.78 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for this observed peak. The minimum concentration during 2002 occurred in December (2.0 µg/L).

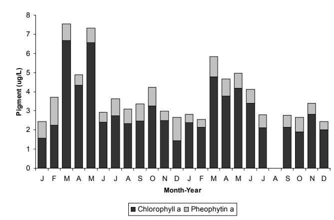


Figure 4-13 Chlorophyll *a* and pheophytin *a* concentrations at station D41, 2001-2002

The maximum pheophytin *a* concentration during 2001 occurred in February (1.45 µg/L). Diatoms (Bacillariophyceae) were primarily responsible for this observed peak. The minimum concentration occurred in November (0.50 µg/L). The maximum pheophytin *a* concentration during 2002 occurred in May (1.05 µg/L). Unidentifiable flagellates were primarily responsible for this observed peak. The minimum concentration occurred in February (0.41 µg/L).

Station D41 demonstrated a clear seasonal pattern with the highest chlorophyll *a* concentrations recorded during the spring and the lowest occurring during the winter.

Summary

DWR and USBR collect phytoplankton samples in order to monitor algal community composition and biomass in the San Francisco Estuary. In 2001 and 2002 all phytoplankton species collected fell into the families: Bacillariophyceae (Diatoms), Chlorophyceae (Green algae), Chrysophyceae (Yellow-brown algae), Cryptophyceae (Cryptomonads), Cyanophyceae

(Blue-green algae), Dinophyceae (Dinoflagellates), Euglenophyceae (Euglenoids), and unidentified flagellates (Flagellates). Of the eight families identified; the Bacillariophyceae, Chlorophyceae, and unidentified flagellates constituted 94.1% of the organisms collected.

Chlorophyll *a* concentrations showed seasonal patterns. The highest chlorophyll *a* concentrations occurred during the spring for most stations, with a second increase most often occurring during the late summer or early fall. From east to west, the concentration of chlorophyll *a* showed a decreasing trend. Chlorophyll *a* and pheophytin *a* concentrations were generally in the range of 0.5 µg/L and 15 µg/L throughout the upper Estuary, with the exception of high values seen at three stations in the south and east Delta.

References

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

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

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

[DWR] Department of Water Resources, 1999. Water Quality Conditions in the Sacramento-San Joaquin Delta During 1995. *A Report to the State Water Resources Control Board in Accordance with Water Right Decision 1485, Order 4(f)*. Department of Water Resources, Sacramento, California.

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

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

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

Figure 4-1 Map of chlorophyll and phytoplankton monitoring stations

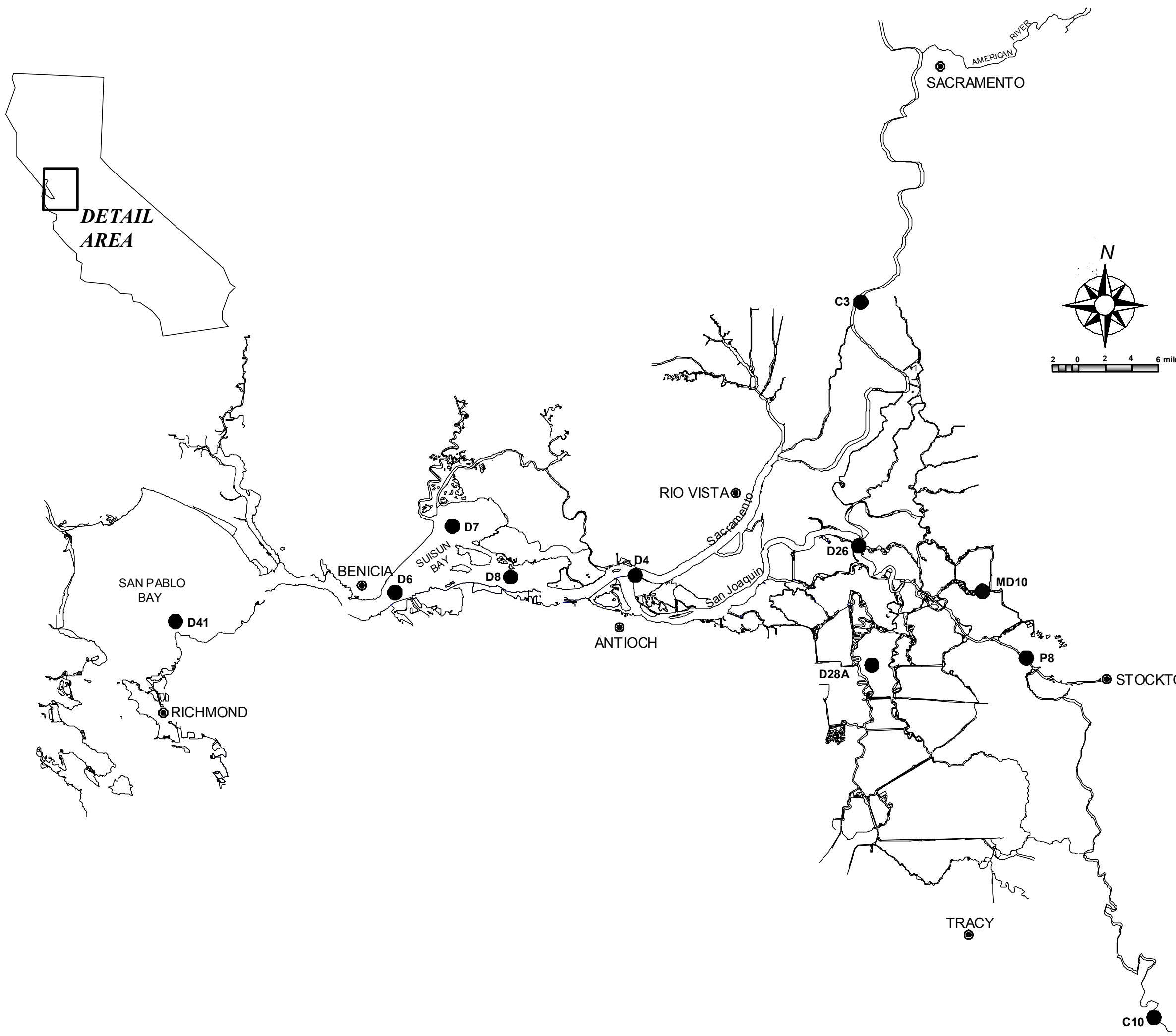


Figure 4-2 Total phytoplankton contribution by family at all stations

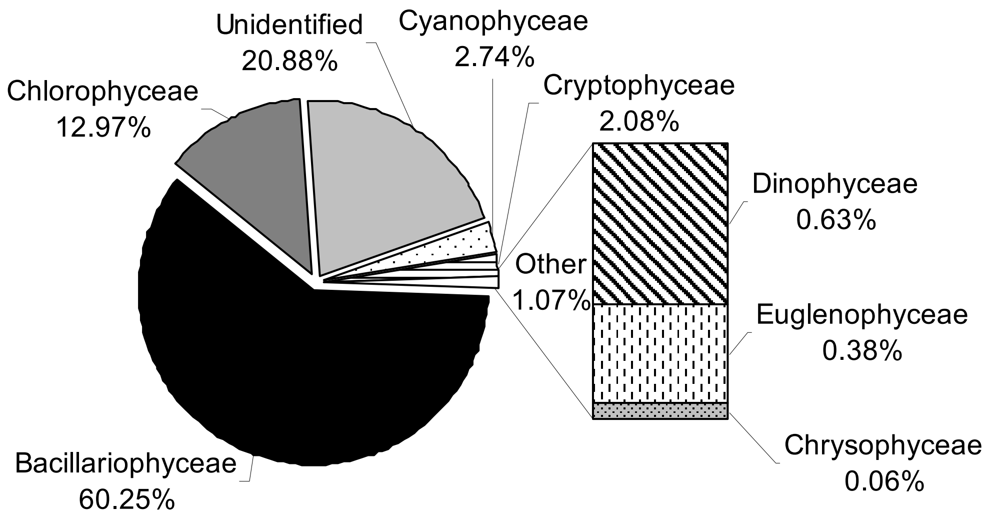


Figure 4-3 Chlorophyll *a* and pheophytin *a* concentrations at station C3, 2001-2002

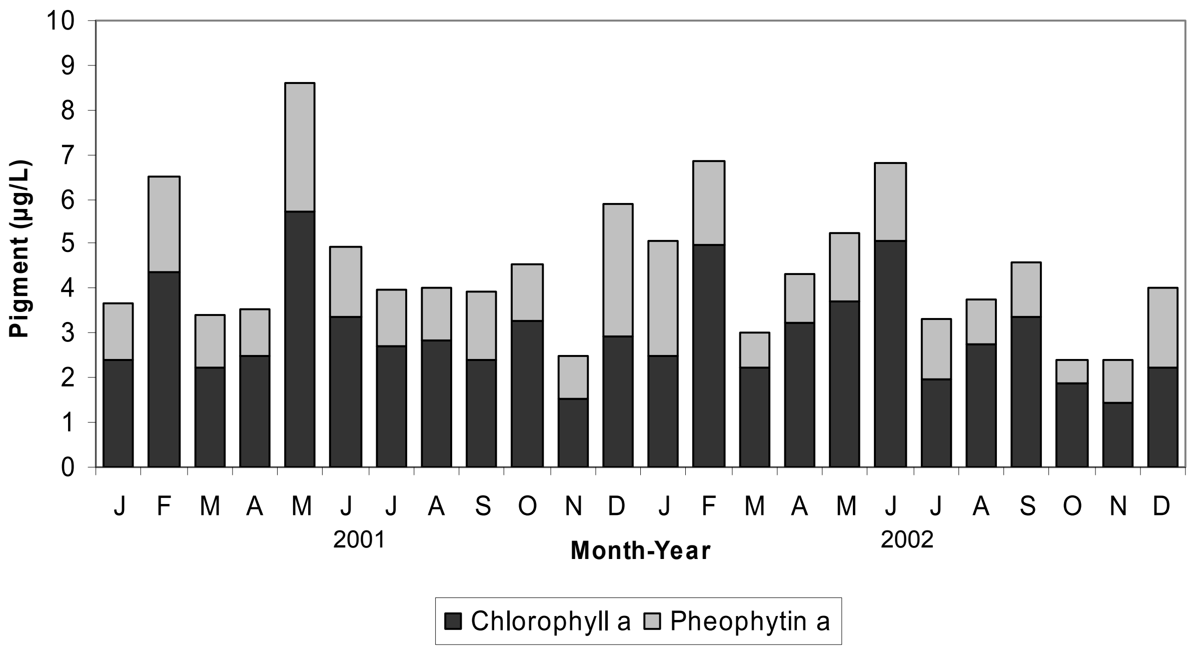


Figure 4-4 Chlorophyll *a* and pheophytin *a* concentrations at station MD10, 2001-2002

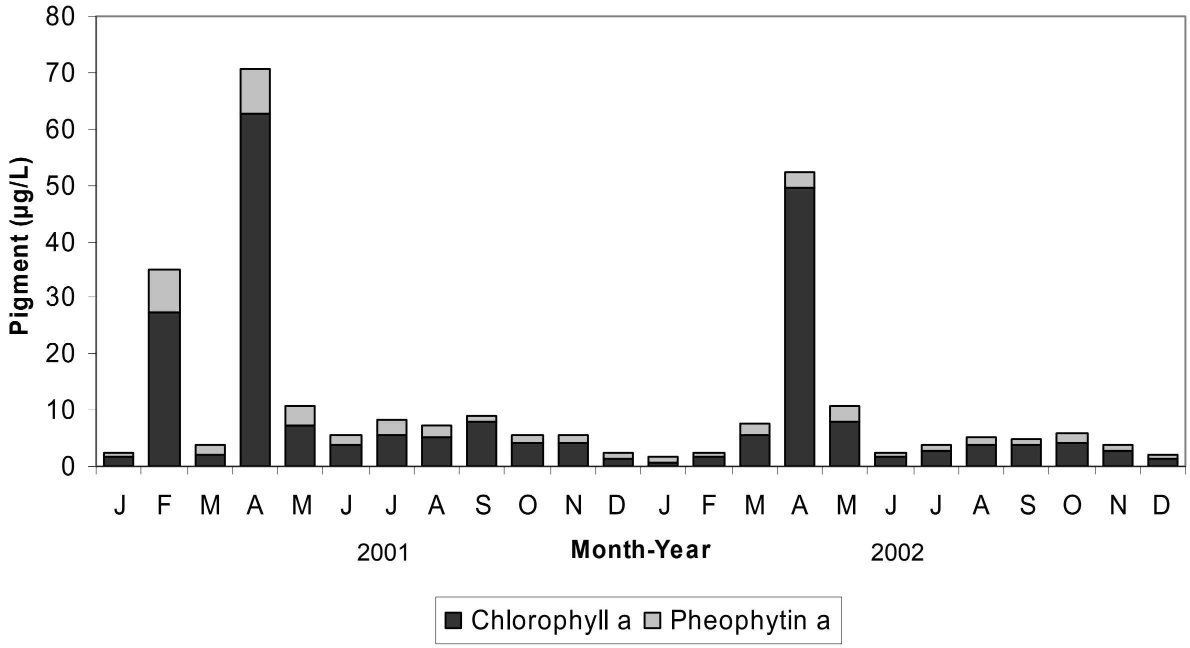


Figure 4-5 Chlorophyll *a* and pheophytin *a* concentrations at station C10, 2001-2002

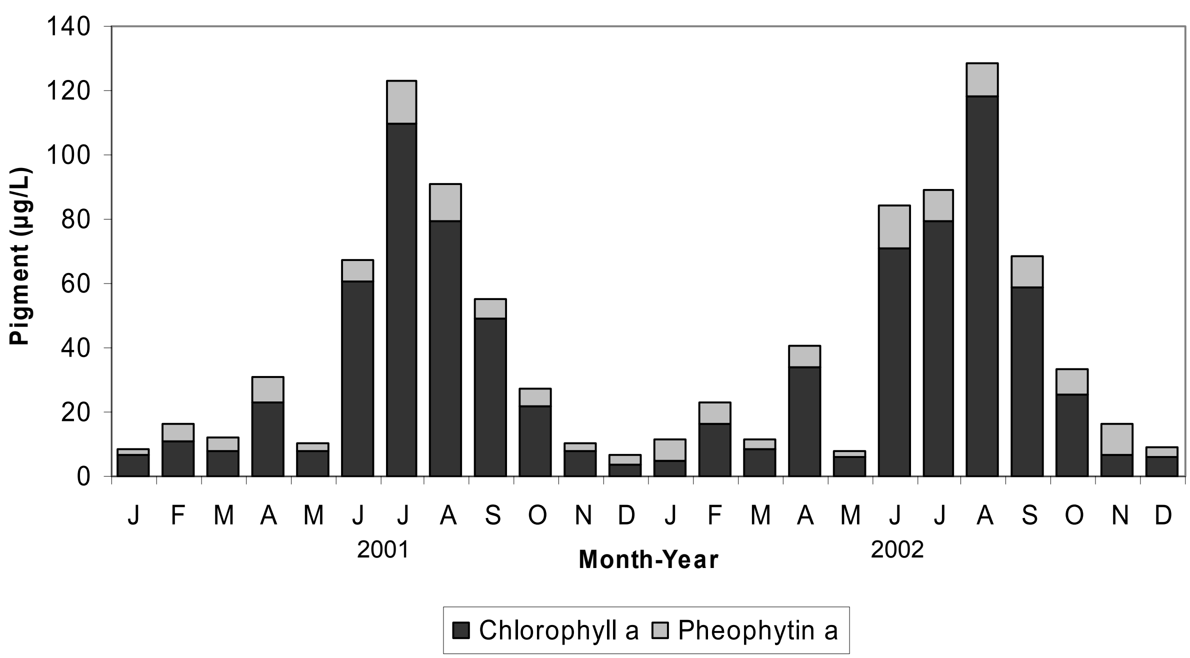


Figure 4-6 Chlorophyll *a* and pheophytin *a* concentrations at station P8, 2001-2002

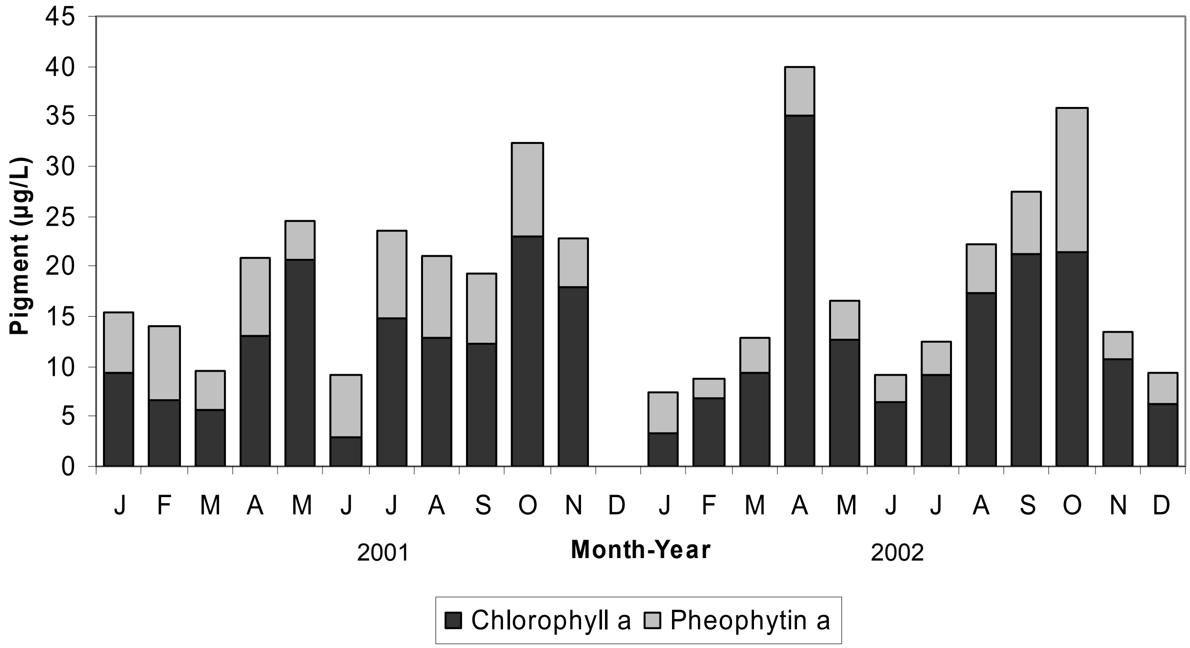


Figure 4-7 Chlorophyll *a* and pheophytin *a* concentrations at station D28A, 2001-2002

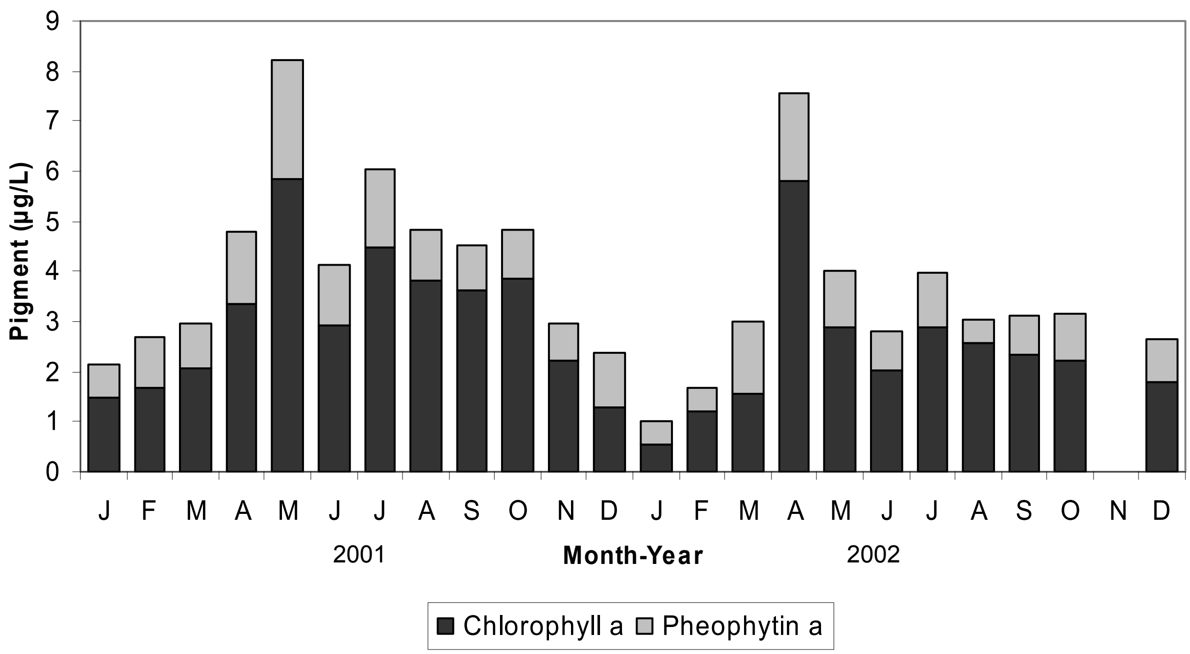


Figure 4-8 Chlorophyll *a* and pheophytin *a* concentrations at station D26, 2001-2002

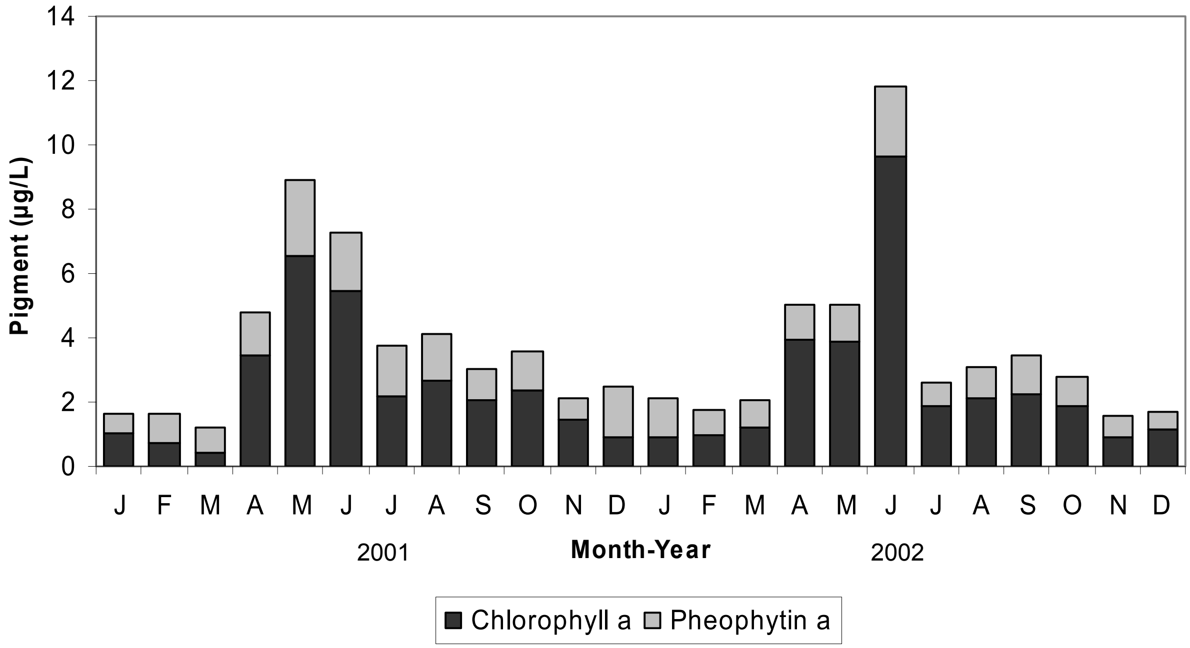


Figure 4-9 Chlorophyll *a* and pheophytin *a* concentrations at station D4, 2001-2002

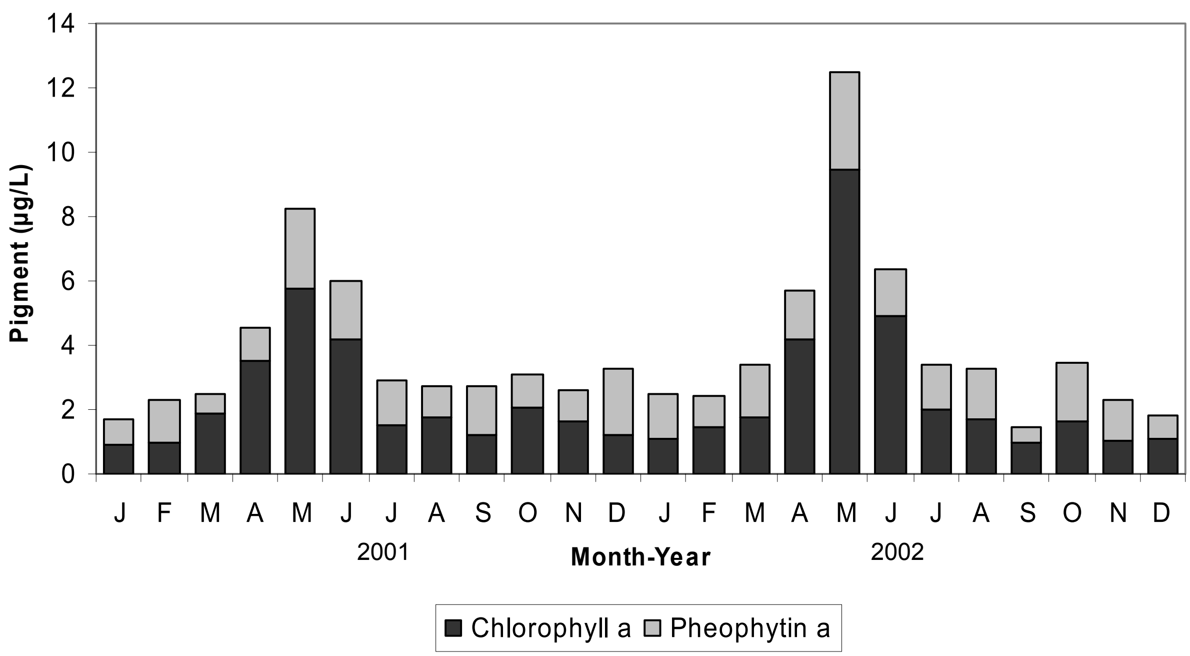


Figure 4-10 Chlorophyll *a* and pheophytin *a* concentrations at station D8, 2001-2002

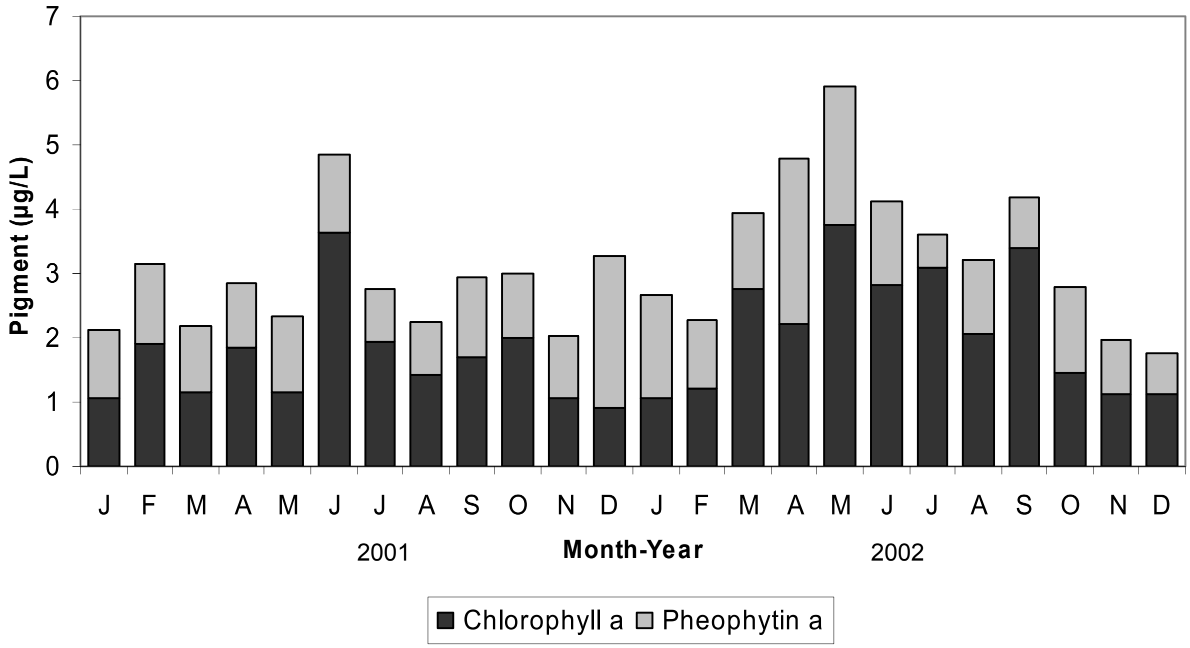


Figure 4-11 Chlorophyll *a* and pheophytin *a* concentrations at station D7, 2001-2002

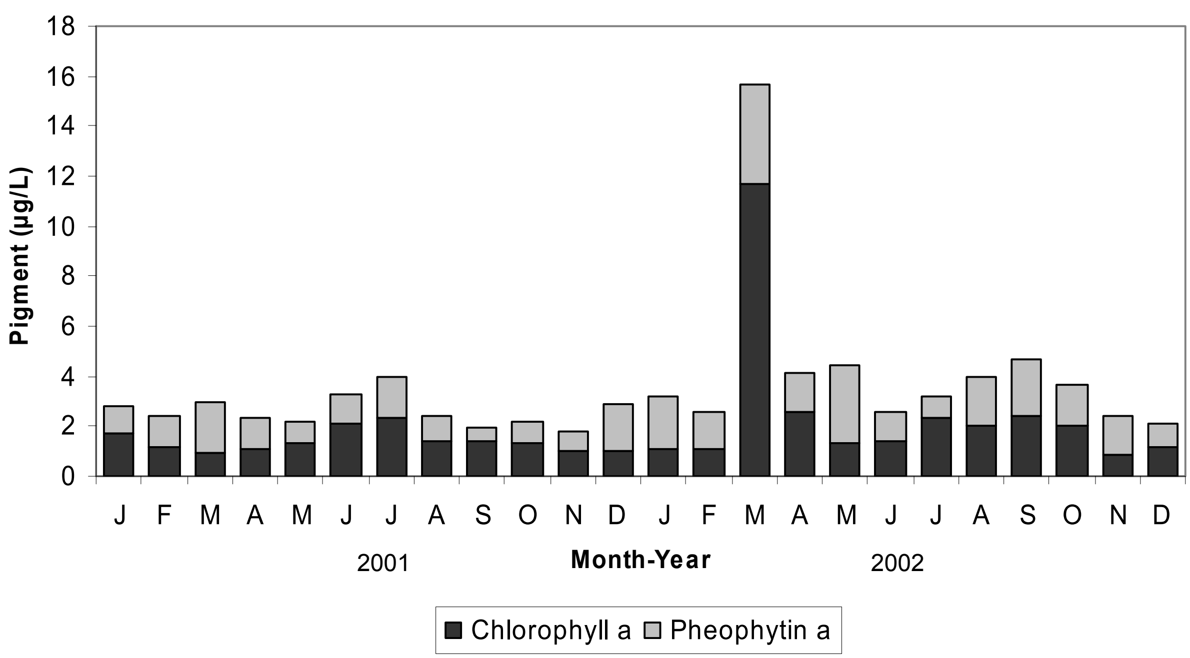


Figure 4-12 Chlorophyll *a* and pheophytin *a* concentrations at station D6, 2001-2002

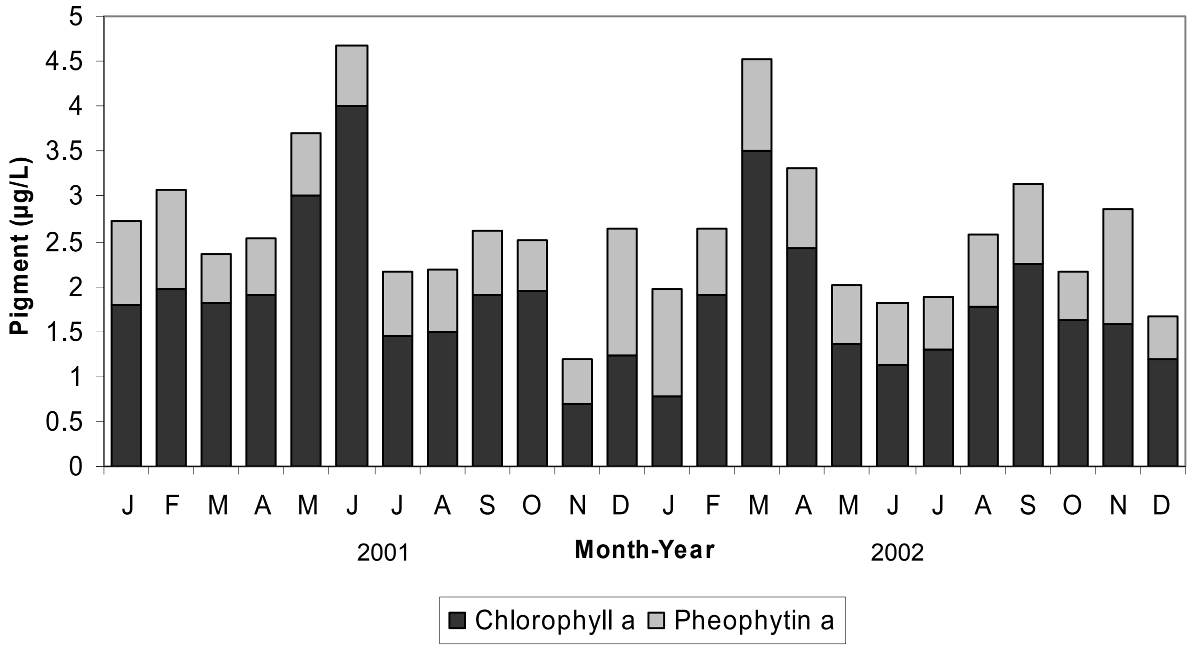


Figure 4-13 Chlorophyll *a* and pheophytin *a* concentrations at station D41, 2001-2002

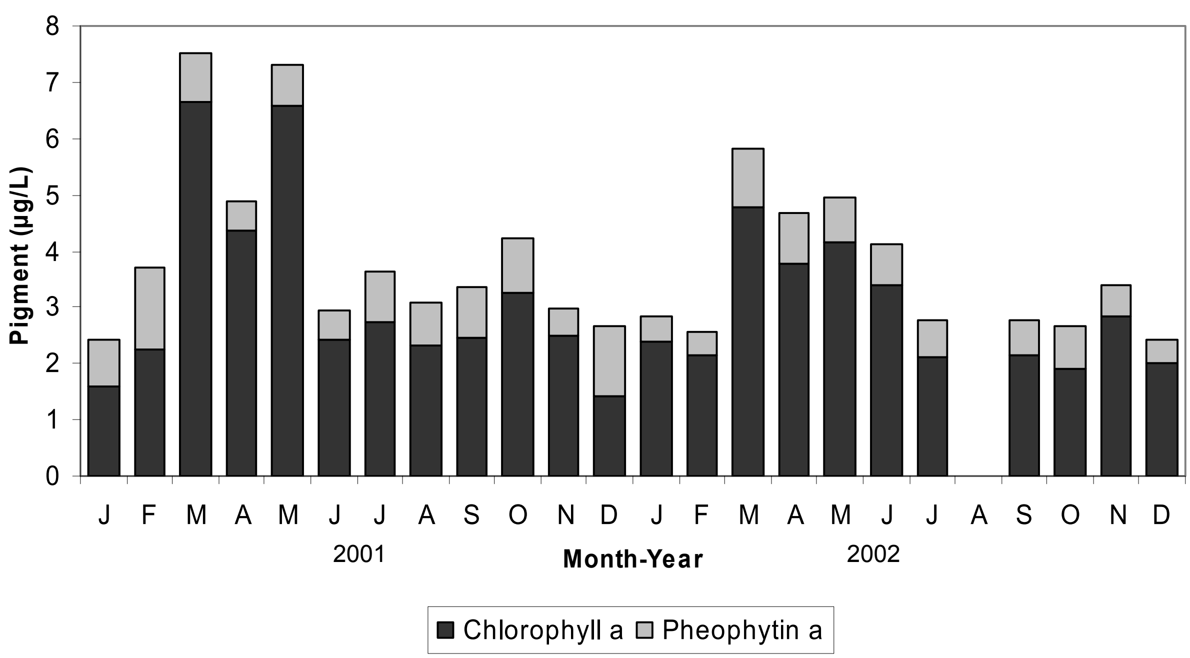


Table 4-1 All genera found in each family in the upper San Francisco Estuary

Family	Genus	Family	Genus
Bacillariophyceae	*Achnanthes*	Chlorophyceae	*Actinastrum*
	Amphiprora		*Ankistrodesmus*
	Amphora		*Carteria*
	Asterionella		*Chlamydomonas*
	Bacillaria		*Chlorella*
	Ceratoneis		*Closteriopsis*
	Cocconeis		*Closterium*
	Cosinodiscus		*Coelastrum*
	Cyclotella		*Crucigenia*
	Cymbella		*Desmidium*
	Diatoma		*Dictyosphaerium*
	Fragilaria		*Dimorphococcus*
	Gomphonema		*Elakatothrix*
	Gyrosigma		*Eudorina*
	Melosira		*Micractinium*
	Navicula		*Oocystis*
	Neidium		*Pandorina*
			Pediastrum
Chrysophyceae	*Synura*		*Pyramimonas*
			Scenedesmus
Cryptophyceae	*Cryptomonas*		*Schroederia*
	Rhodomonas		*Selenastrum*
			Sphaerocystis
Cyanophyceae	*Agmenellum*		*Staurastrum*
	Anabaena		*Tetraedron*
	Anabaenopsis		*Tetrastrum*
	Anacystis		*Ulothrix*
	Aphanizomenon		*Xanthidium*
	Gomphosphaeria		
	Oscillatoria		
	Spirulina		
Dinophyceae	*Ceratium*		
	Glenodinium		
	Gymnodinium		
	Peridinium		
Euglenophyceae	*Euglena*		
	Trachelomonas		
Unidentified	Unidentified Flagellates		

Chapter 5
Zooplankton and Mysid Shrimp, 2001-2002

Mysid shrimp and zooplankton are important food organisms for larval, juvenile, and small fish, such as delta smelt, juvenile salmon, striped bass, and small splittail. The *Neomysis*/Zooplankton Study investigates the annual population level of *Neomysis mercedis*, other mysids, and various zooplankton species and genera in order to assess the size of the food resource for fish. The study also seeks to detect the presence of exotic species recently introduced to the San Francisco Estuary (Estuary), to monitor the distribution and abundance of these exotics, and to determine their impacts on native species. The study began to monitor *N. mercedis* in June 1968 and was expanded to include copepods, cladocera, and rotifers in January 1972.

Methods

Macro-, meso-, and micro-zooplankton were sampled monthly at 15 to 20 stations in the Delta and Suisun Bay (Figure 5-1). Eighteen of these stations were at fixed geographic locations. Two additional stations were identified as existing at the points where the bottom electrical conductance was 2 and 6 millisiemens per centimeter (mS/cm) respectively; these are considered "floating" stations. Additionally, one station in San Pablo Bay and two stations in Carquinez Strait were sampled only when their surface salinity was less than 20 mS/cm.

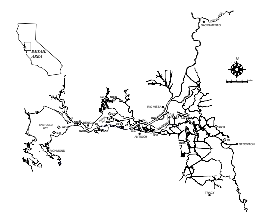


Figure 5-1 Zooplankton monitoring stations

At each station three types of gear were deployed: a *Neomysis* net, (1.48-m long and with a 29-cm mouth diameter and a mesh size of 0.505 mm) mounted on a towing frame made of steel tubing, with a General Oceanics net meter at its mouth; a Clarke-Bumpus net for zooplankton (with a mouth diameter of 12.5 cm and a mesh size of 154 µm) that was mounted above the *Neomysis* net on the same frame as the first net; and a 15-liter per minute-capacity pump. At each station, while underway, the towing frame was lowered to the bottom and retrieved obliquely in several steps over a 10-minute period. Zooplankton small enough to pass through the Clarke-Bumpus net (mostly copepod nauplii, rotifers, and Oithonids) were sampled with the pump. At each station, the pump intake was lowered to the bottom, raised slowly to the surface, and then lowered and raised a second time. The pumped water was discharged into a 19-liter carboy that was shaken and then a 1.5 to 1.9 liter sample was decanted into a jug. All samples were preserved in buffered 10% formalin and returned to the laboratory for identification. Temperature and specific conductance were measured at surface and bottom, both before and after each tow, using a Seabird model CTD 911+ data logger that was lowered through the water column.

To calculate monthly abundance indices, the sample area was divided into the following three zones based on bottom specific conductance: (1) the entrapment zone (1.8 mS/cm to 6.6 mS/cm); (2) upstream of the entrapment zone (< 1.8 mS/cm); and (3) downstream of the entrapment zone (> 6.6 mS/cm). The density for each taxon was calculated as the number of organisms per cubic meter (org/m^3). Monthly abundance was calculated as the mean monthly density of each taxon in each zone. The number of stations in each zone varied from month to month based on upstream and downstream shifts in the salinity gradient. Although no species was present at all stations in every month, averaging the density by the total number of stations sampled in each zone provided a common and consistent base for comparing taxon densities. A grand mean abundance was calculated for each taxon in number per cubic meter of all stations sampled in 2001 and 2002. Abundance data were log transformed (log10(abundance+1)) before they were plotted to improve interpretation by reducing variability from month to month.

N. mercedis has been identified and counted since 1968 and *Acanthomysis bowmani* since 1994. Identification and counting of the other five mysid species (*A. aspera, A. hwanhaiensis, A. macropsis, Deltamysis holmquistae,* and *N. kadiakensis*) became standard operating procedure in 1998.

For brevity, zooplankton were divided into the following four groups: calanoid copepods, cyclopoid copepods, cladocera, and rotifers. The trends of the three or four most abundant taxa in each group are presented in this report.

Results

The mean monthly densities of most of the taxa discussed remained stable throughout 2001 and 2002. Only the mysids *N. kadiakensis* and *N. mercedis* declined from 2001 to 2002. The mean densities of the mysid *A. hwanhaiensis* and the calanoid copepod *Acartia* spp. increased slightly.

The years 2001 and 2002 were characterized by changes in the relative abundance of mysids and calanoid copepods in the upper Estuary. Generally, native species were less abundant in 2002, relative to introduced species, than in 2001. Once the dominant mysid of the upper Estuary, *N. mercedis* has become rare and has been all but replaced by two mysid species. *A. bowmani* was introduced in 1988 and *N. kadiakenis* only occasionally came into the upper Estuary. *A. bowmani* has become the dominant mysid throughout the upper Estuary. *N. kadiakensis* has been increasing in relative abundance downstream of the entrapment zone and has been the second most abundant mysid species in the upper Estuary since 2001.

Acartia spp. is the only calanoid copepod that has remained relatively dominant through time within the upper Estuary. A year after its introduction in 1988, *Pseudodiaptomus forbesi* became the dominant calanoid, thus replacing *Sinocalanus doerrii*, which had replaced earlier *Eurytemora affinis* as the dominant calanoid. In 2001, *Acartiella sinensis* became the third most dominant calanoid, thus reducing *E. affinis* to the lowest rank it has held since it was first counted by the project.

Mysids

A. bowmani (grand mean abundance = 9.257) was the most abundant mysid in all areas in 2001 and 2002 (Figure 5-2). *A. bowmani* abundance was highest in the entrapment zone and downstream of the entrapment zone. Peak *A. bowmani* abundance occurred from May through November 2001 and from May through September in 2002, except downstream of the entrapment zone where the peak abundance period lasted through November.

Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

N. kadiakensis (grand mean abundance = 0.153), the second most abundant mysid, was found primarily downstream of the entrapment zone, with few found within and very few found upstream of the entrapment zone (Figure 5-3). Downstream of the entrapment zone, peak abundance occurred in April through September. Except for July to September, *N. kadiakensis* was less abundant in 2001 than in 2002 downstream of the entrapment zone. *N. kadiakensis* abundance has been steadily increasing in the upper Estuary since 1998. In 1998, *N. kadiakensis* was the fourth most abundant mysid overall. In 1999 it was the third most abundant, and since 2001 it has been the second most abundant mysid in the upper Estuary.

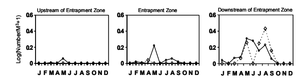


Figure 5-3 Monthly *Neomysis kadiakensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

N. mercedis (grand mean abundance = 0.055), the third most abundant mysid, was caught primarily upstream, as well as inside, of the entrapment zone. Peak *N. mercedis* abundance occurred in May and June in 2001 and 2002 (Figure 5-4). The abundance of *N. mercedis* has been declining steadily since the introduction of *Potamocorbula amurensis* in 1989; the 2001 and 2002 levels are the lowest on record. *N. mercedis* was virtually absent downstream, as well as inside, of the entrapment zone in 2002. Prior to about 1996, the native mysid *N. kadiakensis* was found almost exclusively downstream of the sampling area; however, in 2001 and 2002 it appears to have taken *N. mercedis*' place as the second most abundant mysid in and downstream of the entrapment zone.

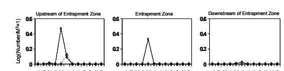


Figure 5-4 Monthly *N. mercedis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The fourth most abundant mysid, *A. hwanhaiensis* (grand mean abundance = 0.033), occurred almost exclusively downstream of the entrapment zone and was abundant only in 2001 (Figure 5-5). Peak *A. hwanhaiensis* abundance occurred in December 2001.

Figure 5-5 Monthly *Acanthomysis hwanhaiensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Calanoid Copepods

The native *Acartia* spp. (grand mean abundance = 306) was the most abundant calanoid copepod in the upper Estuary. It occurred primarily downstream of the entrapment zone (Figure 5-6). *Acartia* abundance was high downstream of the entrapment zone from January through June, with peak abundance from March through May and minimal abundance occurring from August through November. *Acartia* abundance was higher in all three zones in 2002 than in 2001. During winter and spring 2002, *Acartia* was found in greater than normal numbers just upstream of and in the entrapment zone.

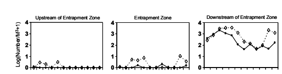


Figure 5-6 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The introduced *Pseudodiaptomus forbesi* (grand mean abundance = 285) was the second most abundant calanoid copepod in the upper Estuary during 2001 and 2002 (Figure 5-7). *P. forbesi* abundance was greatest upstream of the entrapment zone and almost as high in the entrapment zone. In 2001, peak *P.*

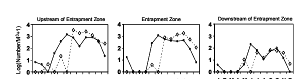


Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

forbesi abundance was from May through November in all areas. In 2002, peak *P. forbesi* abundance was from July through November in all areas, with an early spike in May.

The third most abundant calanoid copepod was the introduced *Acartiella sinensis* (grand mean abundance = 148) (Figure 5-8). The highest concentrations of this copepod were found in and downstream of the entrapment zone, although large numbers were also found upstream of the entrapment zone. *A. sinensis* abundance showed a definite annual cycle; the annual low was in May or June and the annual high was in October. This cycle was observed in all three zones for both years.

Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Another introduced species, *Sinocalanus doerrii* (grand mean abundance = 106) was the fourth most abundant calanoid copepod (Figure 5-9). *S. doerrii* abundance reached high levels upstream of and in the entrapment zone. Its abundance started to increase in April and peaked in May or June. By July, *S. doerrii* abundance declined to a base level where it remained generally stable for most of 2001 and 2002.

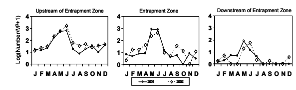


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Cyclopoid Copepods

Limnoithona tetraspina (grand mean abundance = 11,176) has been the most abundant cyclopoid copepod since its introduction in 1994 (Figure 5-10). *L. tetraspina* was abundant in all three zones, but was most abundant in and downstream of the entrapment zone. The abundance pattern was similar for both 2001 and 2002. Beginning in January of both years, abundance in all three areas tended to increase gradually until September or October and then drop toward the January level.

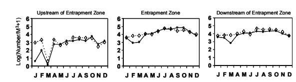


Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The introduced *Oithona davisae* (grand mean abundance = 293) was the second most abundant cyclopoid copepod and occurred primarily downstream of the entrapment zone (Figure 5-11). *O. davisae* was also abundant in the entrapment zone and occurred sporadically upstream of the entrapment zone. Downstream of the entrapment zone, high abundance occurred from July through January, followed by a decline in February and March and a sharp dip in April of 2001 and 2002. In the entrapment zone, the abundance peak occurred in July in both years. In 2001 there was another smaller peak in March. Upstream of the entrapment zone, *O. davisae* abundance was generally low except for a sharp peak that occurred in October of 2001 and 2002.

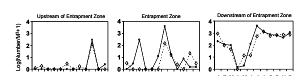


Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The native *Acanthocyclops vernalis* (grand mean abundance = 23) was the third most abundant cyclopoid copepod. It was abundant throughout the sampling area, but declined from upstream of the entrapment zone to downstream (Figure 5-12). Its abundance peak was from February through July or August, with a secondary peak in the fall that varied in timing among the three zones.

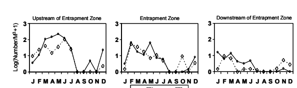


Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Cladocera

Bosmina longirostris (grand mean abundance = 293) was the most abundant cladoceran in the upper Estuary in 2001 and 2002 (Figure 5-13). It was abundant throughout the year upstream of the entrapment zone, with a

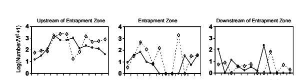


Figure 5-13 Monthly *Bosmina* spp. abundance upstream. in, and downstream of the entrapment zone, 2001 and 2002

nominal peak from April through June in 2001 and April through July in 2002. *B. longirostris* was absent from the entrapment zone from June through September in 2001 and in July and August in 2002, but was present for the remainder of those years. Its presence downstream of the entrapment zone was variable and it was not detected for several months in either 2001 or 2002.

Daphnia spp. (grand mean abundance = 118) was the second most abundant cladoceran for 2001, but was third most abundant for 2002. It was most abundant upstream of the entrapment zone where its peak abundance occurred from April through June in 2002 or April through July in 2001 (Figure 5-14). In the entrapment zone, *Daphnia* peaked from January through April of both years. Its abundance downstream of the entrapment zone was lower and more variable than in the other areas.

Figure 5-14 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Diaphanosoma spp., the least abundant of the identified cladocera for 2001 and 2002 (grand mean abundance = 103), was taken almost exclusively upstream of the entrapment zone (Figure 5-15). Peak abundance for this genus typically occurs from June through October and followed this pattern in 2001 and 2002. In the entrapment zone, *Diaphanosoma* was caught in low numbers from late spring until early fall of 2001 and 2002. *Diaphanosoma* rarely occurred downstream of the entrapment zone. However, in 2002, *Diaphanosoma* was the second most abundant cladoceran in the sampling area.

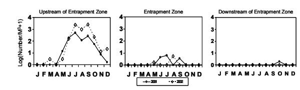


Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Rotifers

The genus *Synchaeta* (excluding *Synchaeta bicornis*) (grand mean abundance = 4,992) was the most abundant rotifer taxon (Figure 5-16). Although abundant in all areas, *Synchaeta* was slightly less abundant in the entrapment zone than the other two zones. Except for 2001, *Synchaeta* abundance dropped to zero in July and August both upstream and downstream of the entrapment zone. The peak abundance period for *Synchaeta*, as usual, began in October and continued through May of the following year. In the entrapment zone, abundance during the off peak period was variable.

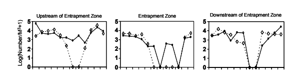


Figure 5-16 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The genus *Polyarthra* (grand mean abundance = 3,599) was the second most abundant rotifer (Figure 5-17). It was most abundant upstream of the entrapment zone and least abundant downstream of the entrapment zone. Upstream of the entrapment zone, *Polyarthra* abundance remained fairly uniform throughout both years. Inside the entrapment zone, *Polyarthra* was abundant from January through April, but was very erratic throughout the rest of the year. *Polyarthra* was absent from the entrapment zone from July until November in 2001. In 2002 *Polyarthra* abundance varied considerably through the same period. Downstream of the entrapment zone, *Polyarthra* abundance was erratic, with several nominal peaks varying monthly from year to year.

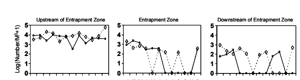


Figure 5-17 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

The third most abundant rotifer taxon was the genus *Keratella* (grand mean abundance = 3,087) (Figure 5-18). The highest *Keratella* abundance occurred upstream of the entrapment zone where there was an abundance peak from February through April or May (2001). Inside the entrapment zone during 2001, *Keratella* abundance varied from month to month. From February

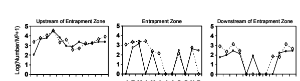


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

through April in 2002 there was a peak that coincided with the peak upstream of the entrapment zone. Thereafter *Keratella* abundance variations were similar to those in 2001. Downstream of the entrapment zone, *Keratella* was stable from January through April and from September or October through December, but was variable for the other months.

The fourth most abundant rotifer taxon was *Synchaeta bicornis* (grand mean abundance = 699) (Figure 5-19). This species was most abundant downstream of the entrapment zone and least abundant upstream of the entrapment zone. Its abundance upstream and downstream of the entrapment zone peaked in October of both 2001 and 2002; while inside the entrapment zone, its abundance peaked in July 2001 and August 2002.

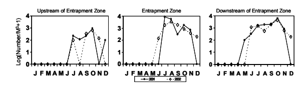


Figure 5-19 Monthly *Synchaeta bicornis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Summary

The monthly abundance figures for most of the common zooplankton taxa in the upper Estuary were stable during 2001 and 2002, but *N. mercedis* and *N. kadiakensis* abundance declined during this period.

During 2001 and 2002, the abundance of native mysid and calanoid copepod species declined relative to that of introduced species. Prior to the introduction of *A. bowmani* in 1993, *N. mercedis* was virtually the only mysid species in the upper Estuary. In 2001 *N. mercedis* became the third most abundant mysid in the upper Estuary after *A. bowmani* and *N. kadiakensis*.

Figure 5-1 Zooplankton monitoring stations

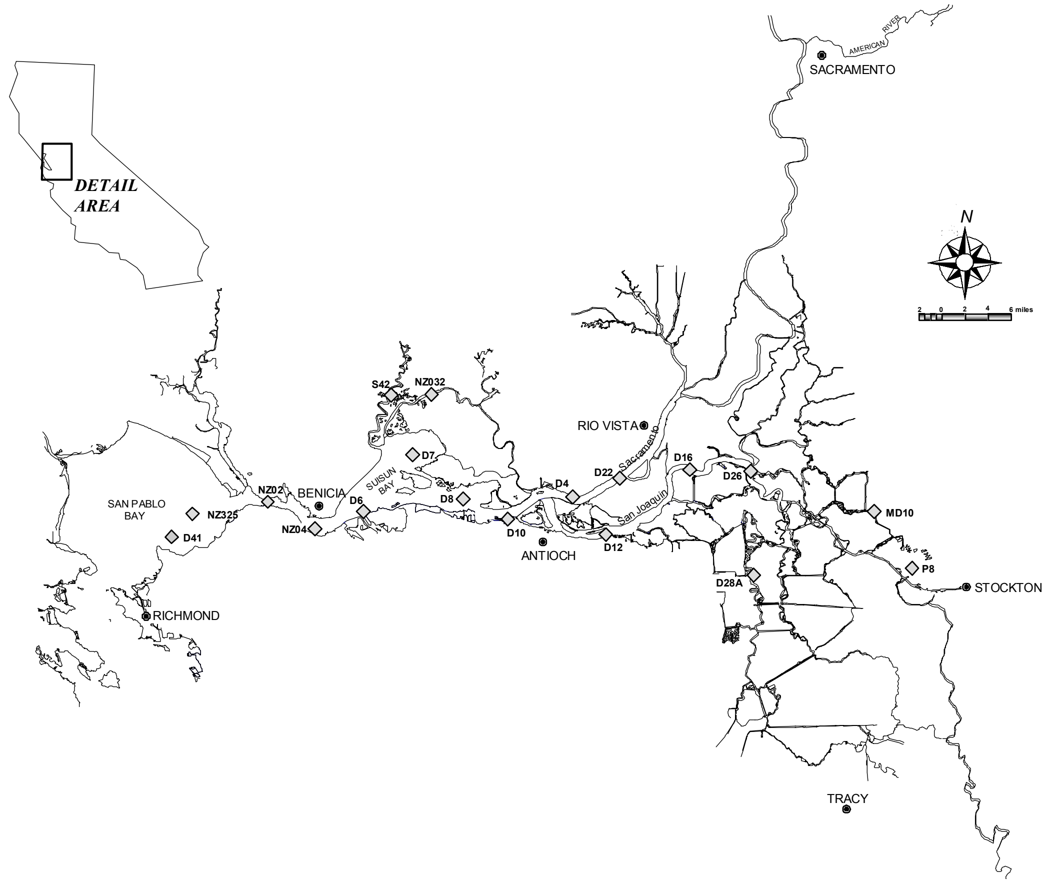


Figure 5-2 Monthly *Acanthomysis bowmani* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

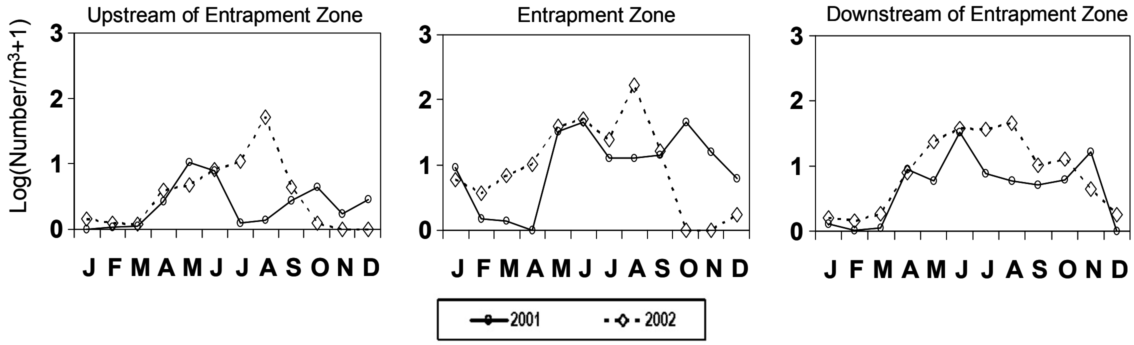


Figure 5-3 Monthly *Neomysis kadiakensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

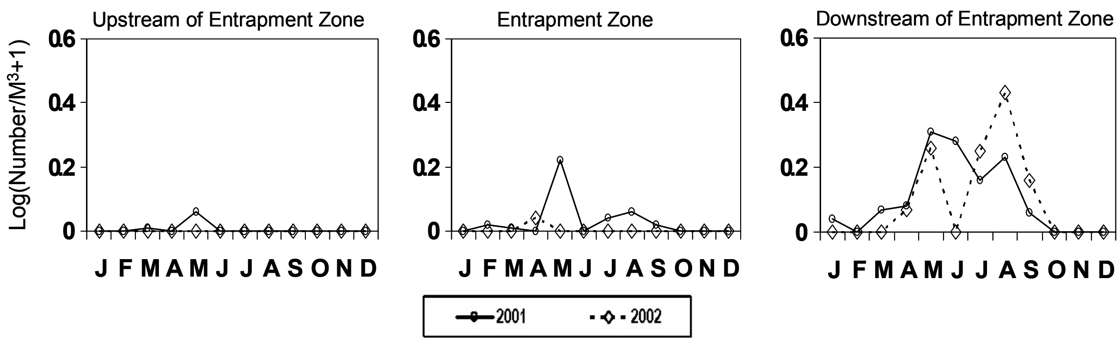


Figure 5-4 Monthly *Neomysis mercedis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

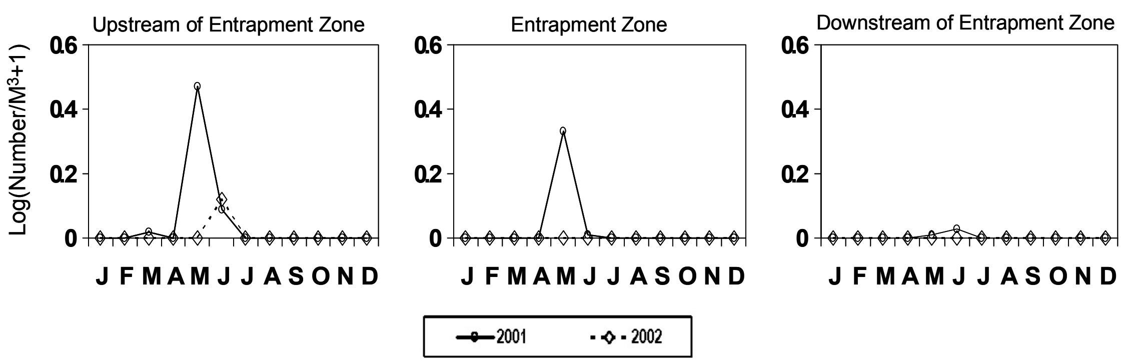


Figure 5-5 Monthly *Acanthomysis hwanhaiensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

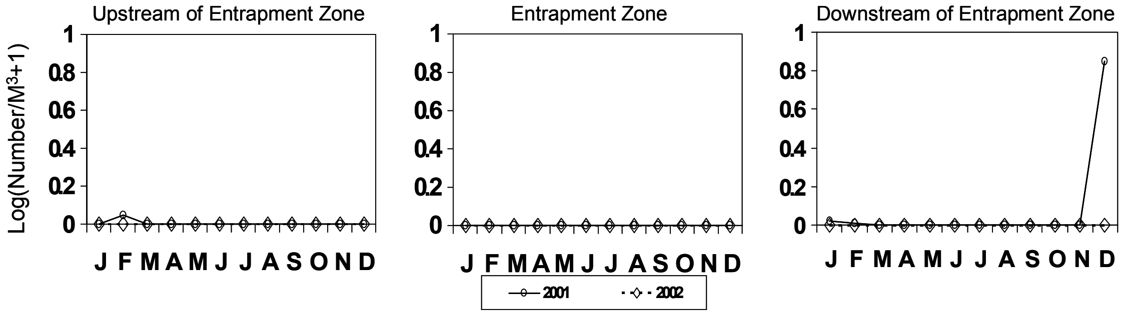


Figure 5-6 Monthly *Acartia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

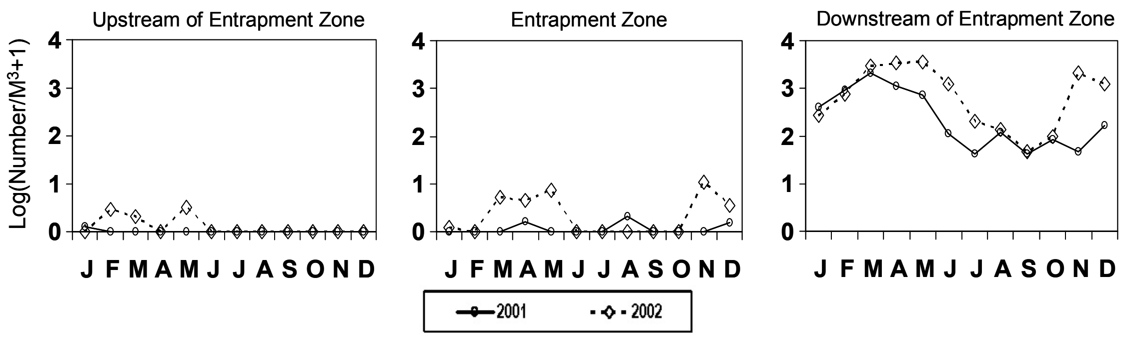


Figure 5-7 Monthly *Pseudodiaptomus forbesi* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

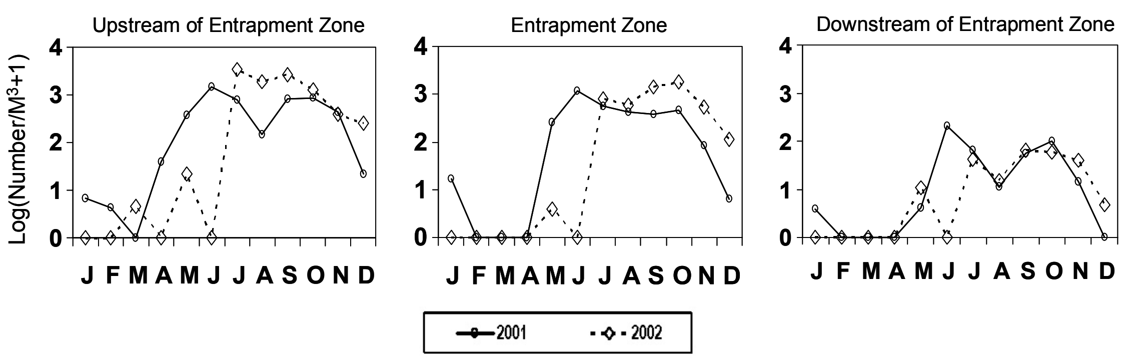


Figure 5-8 Monthly *Acartiella sinensis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

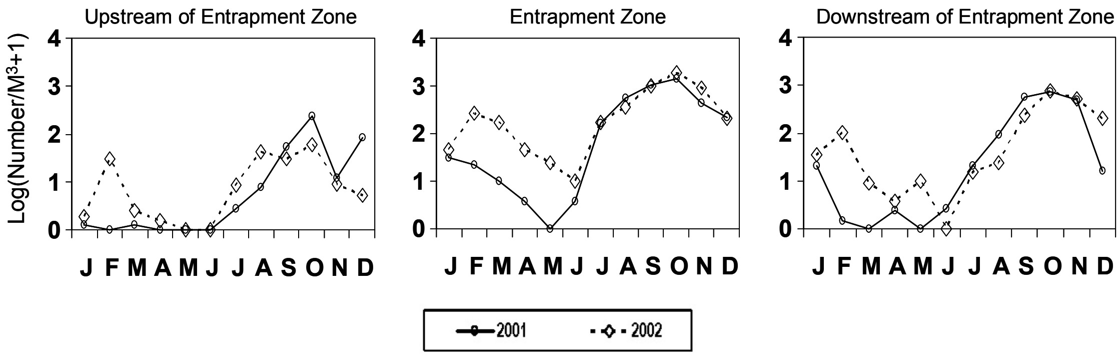


Figure 5-9 Monthly *Sinocalanus doerrii* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

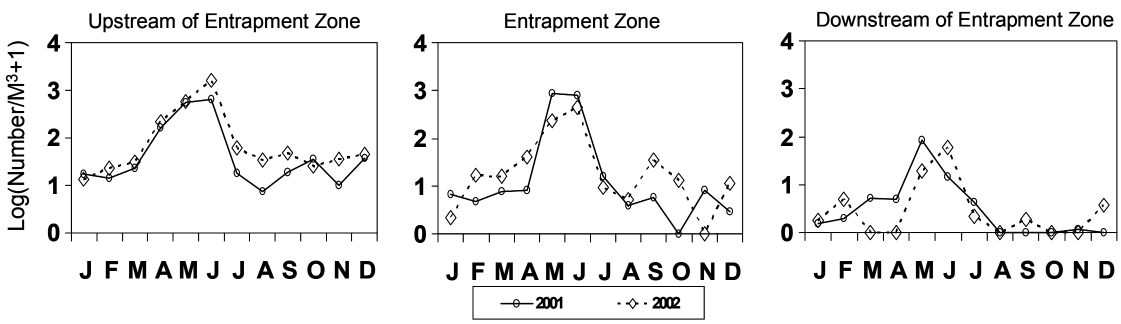


Figure 5-10 Monthly *Limnoithona tetraspina* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

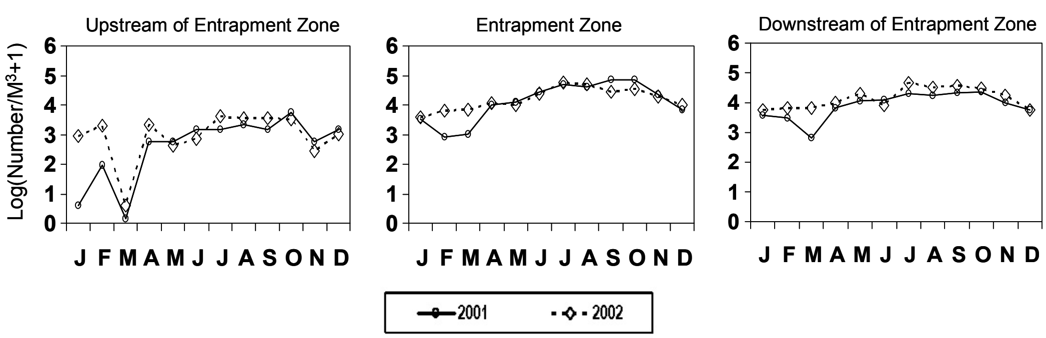


Figure 5-11 Monthly *Oithona davisae* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

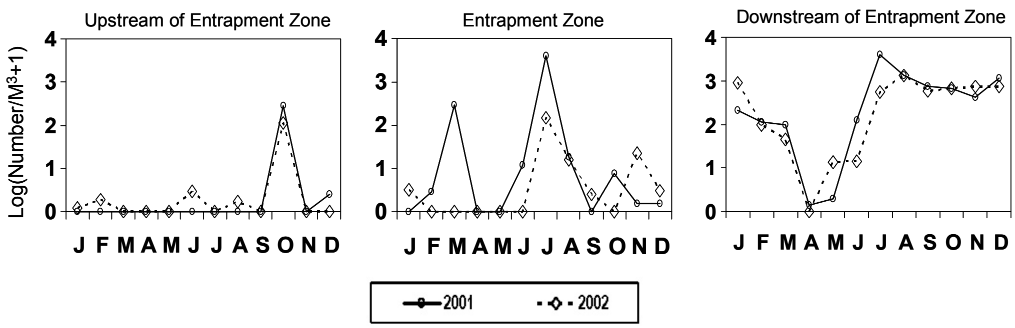


Figure 5-12 Monthly *Acanthocyclops vernalis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

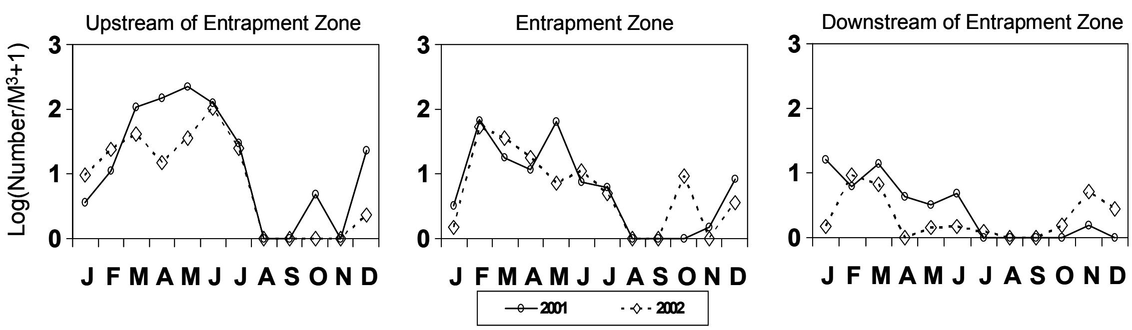


Figure 5-13 Monthly *Bosmina* spp. abundance upstream. in, and downstream of the entrapment zone, 2001 and 2002

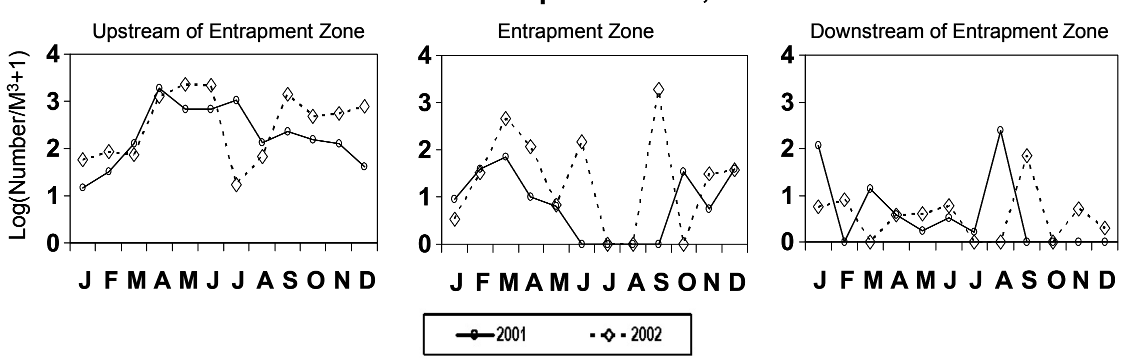


Figure 5-14 Monthly *Daphnia* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

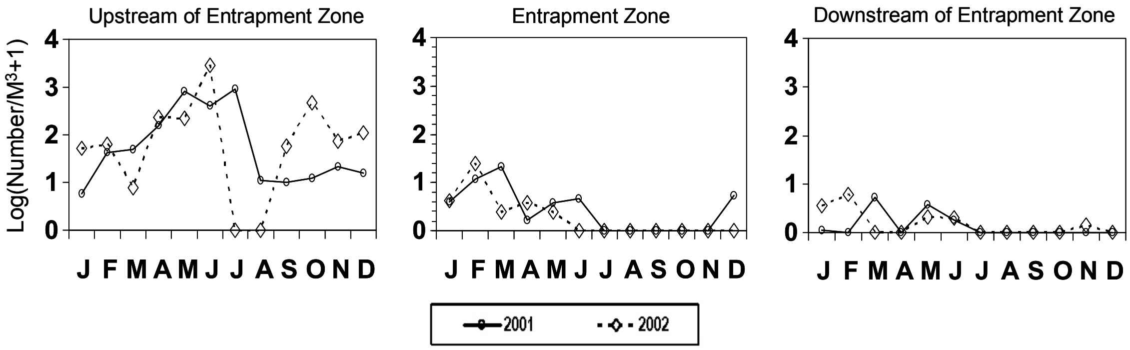


Figure 5-15 Monthly *Diaphanosoma* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

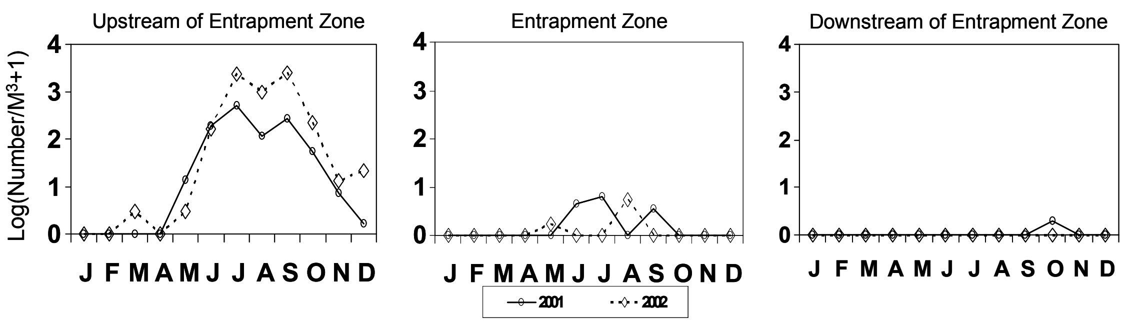


Figure 5-16 Monthly *Synchaeta* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

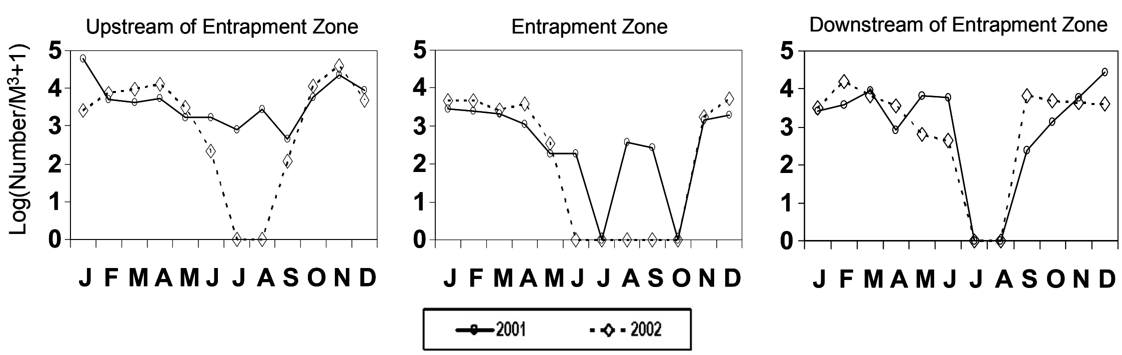


Figure 5-17 Monthly *Polyarthra* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

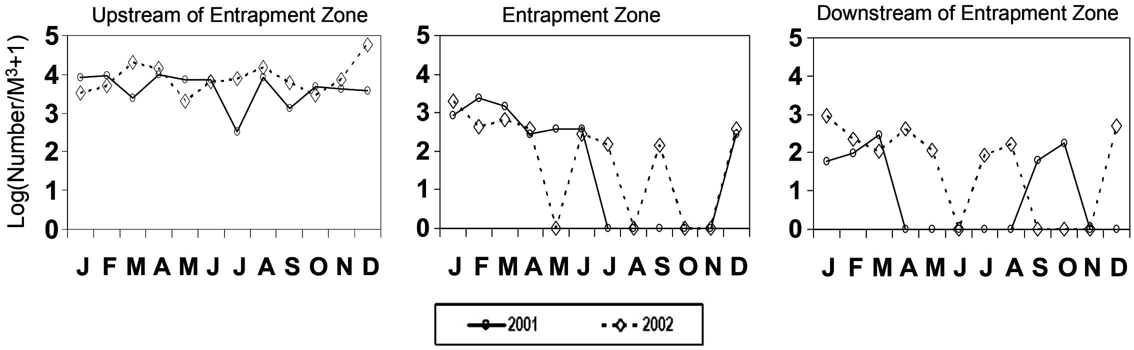


Figure 5-18 Monthly *Keratella* spp. abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

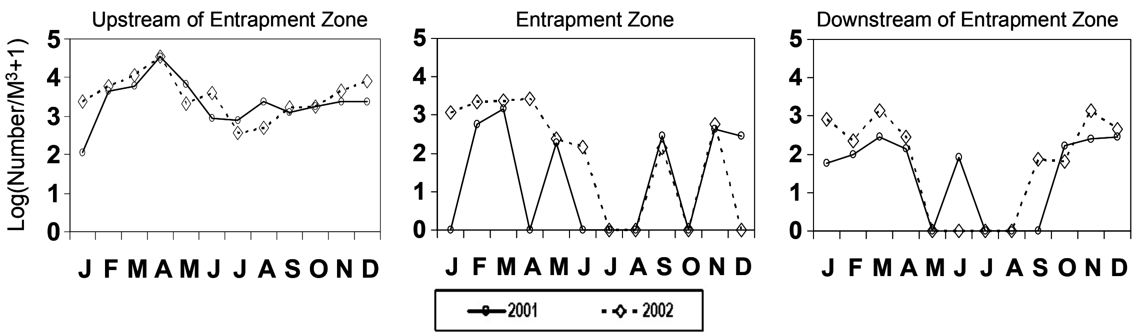


Figure 5-19 Monthly *Synchaeta bicornis* abundance upstream, in, and downstream of the entrapment zone, 2001 and 2002

Chapter 6
Benthic Monitoring, 2001-2002

Introduction

The benthic monitoring program is designed to document the distribution, diversity and abundance of benthic (bottom dwelling) organisms in the upper San Francisco Estuary (Estuary). Geographic coverage of the sampling sites ranges from San Pablo Bay east through the Sacramento-San Joaquin Delta to the mouths of the Sacramento, Mokelumne, and San Joaquin rivers. The benthic community of the upper Estuary is a diverse assemblage of organisms, which includes worms, crustaceans, insects, and molluscs. The Environmental Monitoring Program (EMP) monitors benthic macrofauna, which are organisms larger than 0.5 mm (DWR 2001), and collects sediment composition data. General trends in sediment composition are documented where benthic samples are collected and when changes in the benthic community at a particular site can be directly related to changes in the sediment.

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 five sites. In 1995, major programmatic revisions were implemented to form the current program. More detailed information about the location, number, and characteristics of the historical sites can be found in Interagency Ecological Program (IEP) Technical Report 12 (Markmann 1986) and IEP Technical Report 38 (Hymanson et al. 1994). Since 1996, monitoring has been conducted monthly at ten sites. These sites represent a wide variety of habitats that vary in size and physical make-up, as well as in water quality and sediment composition.

Methods

Benthic Organisms

Field sampling is conducted at the ten EMP benthic sites monthly using the Research Vessel (RV) *San Carlos*, which is equipped with a hydraulic winch and a Ponar dredge. Figure 6-1 shows the location and Table 6-1 summarizes the latitude and longitude, salinity range, and substrate composition of each site. The Ponar dredge samples a bottom area of 0.053 m^2. The contents of the dredge are washed over a Standard No. 30 stainless steel mesh screen with 0.595 mm openings. Each sample is washed carefully to remove as much of the substrate as possible. All material remaining on the screen after washing is preserved in approximately 20% buffered formalin containing Rose Bengal dye for laboratory analysis. The benthic macroinvertebrate sampling methodology used in this program is described in Standard Methods for the Examination of Water and Wastewater (APHA 1998).

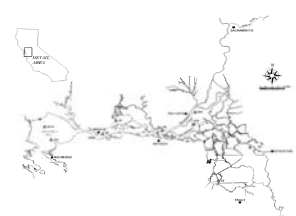


Figure 6-1 Location of 10 Environmental Monitoring Program benthic sampling sites

Table 6-1 Benthic monitoring station characteristics, 2001-2002

Station # and region	Latitude/ longitude	Substrate composition	Approx. salinity range (µS/cm)
C9 Delta-Old River	37° 49' 50"/ 121° 33' 09"	Consistent; over 90% sand	200-800
P8 Delta-San Joaquin River	37° 58' 42"/ 121° 22' 55"	Consistent; high sand content (60%)	175-750
D28A Delta-Old River	37° 58' 14"/ 121° 34' 19"	Mixed composition of sand and fines	200-350
D16 Delta-San Joaquin River	38° 05' 50"/ 121° 40' 05"	Consistent; mostly fines with some organic materials	130-500
D24 Delta-Sacramento River	38° 09' 27"/ 121° 41' 01"	Consistent; high sand content (80%)	200-1,200
D4 Delta-Sacramento River	38° 03' 45"/ 121° 49' 10"	Mixed composition of sand, fines, and organic materials	130-8,000
D6 Suisun Bay	38° 02' 40"/ 122° 07' 00"	Fairly equal mixture of sand and fines	135-30,000
D7 Grizzly Bay	38° 07' 02"/ 122° 02' 19"	Consistent; mostly fines with some organic materials	200-20,000
D41 San Pablo Bay	38° 01' 50"/ 122° 22' 15"	Consistent; high content of fine material (87%)	20,000-45,000
D41A San Pablo Bay	38° 03' 75"/ 122° 24' 40"	Consistent; high content of fine material (90%)	30,000-44,000

Hydrozoology[1], a private laboratory under contract with DWR, identified and enumerated organisms in the benthic samples. 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. A stereoscopic dissecting microscope (70-120X) was used to identify most organisms. When taxonomic features were too small for identification under the dissecting scope, the organism was permanently mounted on a slide and examined under a compound microscope. If more than four hours of sorting were required, and a sample contained many organisms but few species, a one-fourth subsample was chosen at random. The subsample was sorted and the results multiplied by four to represent the total sample. The remainder of the sample was inspected to make sure no taxa were overlooked. Individual species counts were multiplied by 19 to convert the number of organisms per grab sample to organisms per square meter (where $19 = 1.0\ m^2 / 0.53\ m^2$, and $0.53\ m^2$ = sample area of the ponar dredge). All organisms identified and

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

enumerated were recorded onto datasheets by Hydrozoology staff. These datasheets were returned to DWR staff for entry into the benthic monitoring program's database.

Sediment

Understanding sediment conditions is essential in understanding the organisms that occur in a specific area or reach of the river, for example, *Corbicula fluminea* is a freshwater clam that is most abundant in coarse sediment types that are well oxygenated (McMahon 1983). *C. fluminea* first appeared in the San Francisco estuary in 1946 (McMahon 1983) and has become the most abundant and widespread freshwater clam in California (Cohen 1995). It is because of these reasons that sediment composition samples were collected monthly in the field from the hydraulic winch and Ponar dredge on the RV *San Carlos*. A random subsample of the sediment was placed into a 1-liter plastic jar for storage and transport to DWR's Soils and Concrete Laboratory for analysis.

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

Results

Benthic Organisms

The benthic monitoring program collects a large number of organisms, but a relatively small number of species. Of the 166 species of benthic macrofauna collected during 2001-2002, ten species represented approximately 90% of all organisms collected. These ten species include: (1) the amphipods, *Americorophium stimpsoni, Americorophium spinicorne, Corophium alienense, Monocorophium acherusicum*, and *Ampelisca abdita*; (2) the cumaceans, *Nippoleucon hinumensis* and *Gammarus daiberi*; (3) the aquatic oligocheate, *Varichaetadrilus angustipenis*; and (4) the Asian clams, *Potamocorbula amurensis* and *C. fluminea*.

Of the ten dominant species, *A. abdita* and *P. amurensis* represent macrofauna that inhabit a more saline environment and they were found in San Pablo, Suisun, and Grizzly bays. *A. stimpsoni* and *A. spinicorne* tolerated a wider range of salinity; they were collected in the more saline western sites, as well as 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 six species are predominantly freshwater species and they were collected at sites east of Suisun Bay.

The EMP maintains a database of 290 benthic organisms identified within the upper Estuary. The benthic database is continuously peer reviewed and updated. 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. During the 2001 to 2002 study period, 21 new organisms were added to the benthic database (Table 6-2). All data is available at www.baydelta.ca.gov.

Table 6-2 New Species 2001-2002

Phylum	Genus species	Date
Annelida	*Paleanotus bellis*	April 2001
Mollusca	*Onchidoris bilamellata*	May 2001
Mollusca	*Ostrea lurida*	May 2001
Nematoda	Unidentified Nematode sp. B	July 2001
Annelida	*Scolelepis* sp. *B*	July 2001
Annelida	*Dorvillea rudolphi*	July 2001
Arthropoda	*Heptacarpus pictus*	July 2001
Arthropoda	*Paranthura elegans*	September 2001
Mollusca	*Cooperella subdiaphana*	September 2001
Platyhelminthes	Unidentified Triclad sp. E	November 2001
Annelida	*Platynereis bicanaliculata*	December 2001
Arthropoda	*Crangon nigromaculata*	January 2002
Arthropoda	*Anisogammarus confervicolus*	February 2002
Arthropoda	*Dirotendipes* sp. *A*	February 2002
Annelida	*Pseudopolydora paucibranchiata*	March 2002
Annelida	*Myxicola infundibulum*	September 2002
Arthropoda	*Paradexamine* sp. *A*	October 2002
Annelida	*Boccardia* sp. *A*	November 2002
Annelida	Unidentified Spionid sp. A	November 2002
Annelida	*Polydora brachycephala*	November 2002
Annelida	*Glycera americana*	December 2002

All organisms collected during 2001-2002 fell into eight phyla:

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

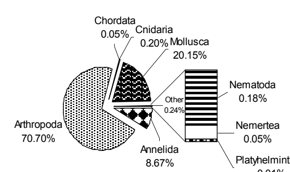


Figure 6-2 Total contribution by phyla for all stations, 2001–2002

Of the eight phyla identified, Annelida, Arthropoda and Mollusca constituted 99.5% of the organisms collected during the study period. Figure 6-2 shows the total percent contribution by phylum for all sites. Figures 6-3 through 6-7 show the total contribution by phylum for each site and organism abundance for each site.

Organism abundance (organism per meter squared or org/m^2) and dominant phyla varied between sites. Temporal changes in organism abundance (e.g., intra- and interannual) also varied greatly between sites. Because of these differences, trends (e.g. maximum, minimum, abundance, dominant species, and seasonal patterns) will be discussed for each individual site (Figures 6-3 through 6-7). Sediment composition will also be discussed for each site (Figures 6-8 through 6-12).

Site C9: Benthic Abundance (Figure 6-3)

Maximum abundance in 2001 occurred in May with a total of 12,350 organisms per meter squared. The dominant species were *G. daiberi* (2,802 org/m^2), *A. stimpsoni* (6,175 org/m^2), and *Limnodrilus udekemianus* (1,320 org/m^2). The minimum abundance in 2001 occurred in February with a total of 251 organisms per meter squared. The dominant species was *C. fluminea* (161 org/m^2).

Maximum abundance in 2002 occurred in June with a total of 36,342 organisms per meter squared. The dominant species were *A. stimpsoni* (25,303 org/m^2), *G. daiberi* (4,854 org/m^2) and *C. fluminea* (4,375 org/m^2). The minimum abundance in 2002 occurred in February with a total of 375 organisms per meter squared. The dominant species was *V. angustipenis* (148 org/m^2).

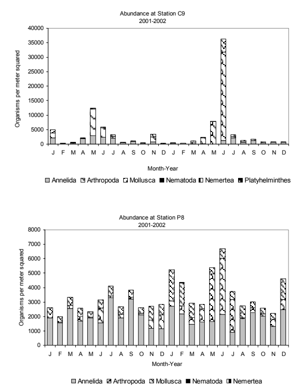


Figure 6-3 Benthic abundance at stations C9 and P8, 2001–2002

Station C9 demonstrates a clear seasonal pattern with the greatest abundance values recorded during the spring and early summer and the lowest values recorded during the winter. During both years (2001 and 2002) *A. stimpsoni*, an amphipod, was the most dominant species collected during the peak events. The annual abundance peak in 2002 was three times higher than the peak in 2001.

Site P8: Benthic Abundance (Figure 6-3)

Maximum abundance in 2001 occurred in July with a total of 4,108 organisms per meter squared. The dominant species were *Limnodrilus hoffmeisteri* (1,325 org/m^2), *Ilyodrilus frantzi* (789 org/m^2), and *Laonome* sp. A (665 org/m^2). The minimum abundance in 2001 occurred in February with a total of 1,995 organisms per meter squared. The dominant species were *L. hoffmeisteri* (765 org/m^2) and *I. frantzi* (375 org/m^2).

Maximum abundance in 2002 occurred in June with a total of 6,702 organisms per meter squared. The dominant species were *A. stimpsoni* (1,677 org/m^2), *L. hoffmeisteri* (1,221 org/m^2), and *Chironomus attenuatus* (1,206 org/m^2). The minimum abundance in 2002 occurred in November with a total of 2,199 organisms per meter squared. The dominant species were *L. hoffmeisteri* (394 org/m^2), *C. attenuatus* (380 org/m^2), and *Laonome* sp. A (351 org/m^2).

Station P8 did not demonstrate any clear inter-annual or intra-annual patterns. This site is typically dominated by annelids with the exception of the late spring and early summer months of 2002 when the site was dominated by amphipods.

Site D28A: Benthic Abundance (Figure 6-4)

Maximum abundance in 2001 occurred in June with a total of 13,642 organisms per meter squared. The dominant species were *A.stimpsoni* (7,049 org/m^2), *A. spinicorne* (1,881 org/m^2), and *V. angustipenis* (1,847 org/m^2). The minimum abundance in 2001 occurred in April with a total of 712 organisms per meter squared. The dominant species was *C. fluminea* (475 org/m^2).

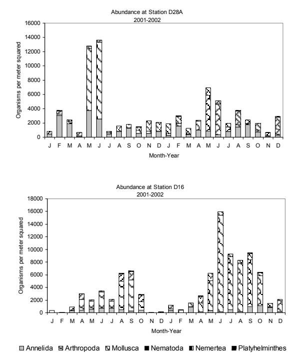


Figure 6-4 Benthic abundance at stations D28A and D16, 2001–2002

Maximum abundance in 2002 occurred in May with a total of 6,949 organisms per meter squared. The dominant species were *A. stimpsoni* (1,809 org/m^2), *G. daiberi* (1,748 org/m^2), and *A. spinicorne* (1,339 org/m^2). The minimum abundance in 2002 occurred in November with a total of 665 organisms per meter squared. The dominant species was *C. fluminea* (451 org/m^2).

Site D28A demonstrates a clear seasonal pattern, with the greatest abundance occurring in the late spring and early summer. Abundance was low to moderate (> 4,000 org/m^2) for the remaining months. Amphipods were the dominant organisms during the abundance peak at this site. During the remaining months, when abundance was low to moderate, annelids and clams were the dominant organisms.

Site D16: Benthic Abundance (Figure 6-4)

Maximum abundance in 2001 occurred in September with a total of 6,579 organisms per meter squared. The dominant species were *A. spinicorne* (2,123 org/m^2), *A. stimpsoni* (1,477 org/m^2), and *C. fluminea* (1,334 org/m^2). The minimum abundance in 2001 occurred in November with a total of 95 organisms per meter squared. The dominant species were *C. fluminea* (48 org/m^2) and *G. daiberi* (43 org/m^2).

Maximum abundance in 2002 occurred in June with a total of 15,955 organisms per meter squared. The dominant species were *A. stimpsoni* (7,638 org/m^2), *A. spinicorne* (5,633 org/m^2), and *G. daiberi* (2,000 org/m^2). The minimum abundance in 2002 occurred in February with a total of 517 organisms per meter squared. The dominant species were *A. spinicorne* (190 org/m^2), *G. daiberi* (190 org/m^2), and *C. fluminea* (85 org/m^2).

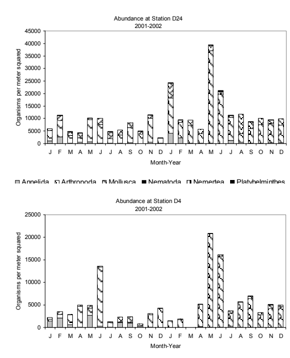


Figure 6-5 Benthic abundance at stations D24 and D4, 2001–2002

Site D16 demonstrated a seasonal pattern that had low abundance during the late fall and winter and greater abundance during the summer and early fall. This site is dominated by amphipods.

Site D24: Benthic Abundance (Figure 6-5)

Maximum abundance in 2001 occurred in November with a total of 11,490 organisms per meter squared. The dominant species were *A. stimpsoni* (9,229 org/m^2) and *C. fluminea* (916 org/m^2). The minimum abundance in

2001 occurred in April with a total of 4,241 organisms per meter squared. The dominant species were *C. fluminea* (1,952 org/m^2) and *A. stimpsoni* (1,639 org/m^2).

Maximum abundance in 2002 occurred in May with a total of 39,453 organisms per meter squared. The dominant species were *A. stimpsoni* (36,805 org/m^2) and *C. fluminea* (2,018 org/m^2). The minimum abundance in 2002 occurred in April with a total of 5,719 organisms per meter squared. The dominant species were *A. stimpsoni* (3,500 org/m^2) and *C. fluminea* (1,696 org/m^2).

In November 2001, *P. amurensis* was found at station D24 with an abundance of 470 organisms per meter squared. This is significant because station D24 is a freshwater site with electrical conductivity ranging between 200 and 1,200 µS/cm. *P. amurensis* is a brackish-water clam, preferring waters with a higher electrical conductivity.

Typically, abundance is stable at this site (>12,000 org/m^2) with the exception of three spikes in 2002: one in January (24,324 org/m^2), one in May (39,453 org/m^2), and one in June (21,161 org/m^2) 2002. Abundance values were higher overall in 2002. This site is dominated by amphipods.

Site D4: Benthic Abundance (Figure 6-5)

Maximum abundance in 2001 occurred in June with a total of 13,647 organisms per meter squared. The dominant species collected were *A. spinicorne* (11,903 org/m^2) and *V. angustipenis* (1,035 org/m^2). The minimum abundance in 2001 occurred in October with a total of 831 organisms per meter squared. The dominant species were *P. amurensis* (356 org/m^2) and *A. spinicorne* (128 org/m^2).

Maximum abundance in 2002 occurred in May with a total of 20,947 organisms per meter squared. The dominant species were *A. spinicorne* (18,354 org/m^2) and *V. angustipenis* (2,147 org/m^2). The minimum abundance in 2002 occurred in January with a total of 1,543 organisms per meter squared. The dominant species was *A. spinicorne* (1,306 org/m^2).

Station D4 exhibited a seasonal pattern of higher abundance values during the spring and early summer months and lower abundance during the rest of the year. *A. spinicorne*, an amphipod, was the overall dominant organism for this site. Data are missing for March 2002 because extremely high winds made sampling conditions unsafe.

Site D6: Benthic Abundance (Figure 6-6)

Maximum abundance in 2001 occurred in January with a total of 15,071 organisms per meter squared. The dominant species was *P. amurensis* (14,639 org/m^2). The minimum abundance in 2001 occurred in May with a total of 3,914 organisms per meter squared. The dominant species were *P. amurensis* (1,876 org/m^2) and *Nippoleucon hinumensis* (1,947 org/m^2).

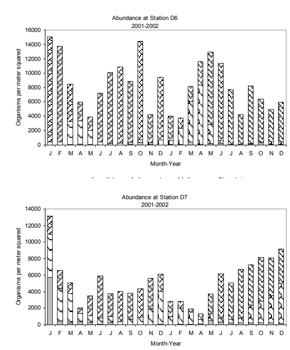


Figure 6-6 Benthic abundance at stations D6 and D7, 2001–2002

Maximum abundance in 2002 occurred in May with a total of 12,924 organisms per meter squared. The dominant species were *P. amurensis* (10,008 org/m^2) and *N. hinumensis* (2,612 org/m^2). The minimum abundance in 2002 occurred in February with a total of 3,757 organisms per meter squared. The dominant species were *P. amurensis* (3,391 org/m^2) and *N. hinumensis* (551 org/m^2).

The invasive Asian clam, *P. amurensis*, is the dominant species found at this site, with the exception of the spring, when the cumacean *N. hinumensis* becomes the dominant species.

Site D7: Benthic Abundance (Figure 6-6)

Maximum abundance in 2001 occurred in January with a total of 13,115 organisms per meter squared. The dominant species were *Corophium alienense* (4,802 org/m^2), *V. angustipenis* (4,085 org/m^2), and *P. amurensis* (2,123 org/m^2). The minimum abundance in 2001 occurred in April with a total of 2,028 organisms per meter squared. The dominant species were *P. amurensis* (679 org/m^2), *C. alienense* (499 org/m^2), and *N. hinumensis* (451 org/m^2).

Maximum abundance in 2002 occurred in December with a total of 9,168 organisms per meter squared. The dominant species were *C. alienense* (4,431 org/m^2) and *P. amurensis* (4,023 org/m^2). The minimum abundance in 2002 occurred in April with a total of 1,297 organisms per meter squared. The dominant species were *N. hinumensis* (551 org/m^2) and *P. amurensis* (631 org/m^2).

During 2001, the greatest abundance occurred at Station D7 in the fall and winter and lower values occurred in the spring. During 2002, the abundance was greatest during the late summer and fall and lowest during the winter and spring. *P. amurensis* had greater abundance during the year at this site, with the exception of winter months. Mollusca abundance appears to be fairly stable, while the changes in overall abundance at this site appear to be due to changes in the arthropod abundance.

Site D41: Benthic Abundance (Figure 6-7)

Maximum abundance in 2001 occurred in July with a total of 75,395 organisms per meter squared. The dominant species were *A. abdita* (51,903 org/m^2), *Monocorophium acherusicum* (15,803 org/m^2), and *Caprella* sp. (2,432 org/m^2). The minimum abundance in 2001 occurred in February with a total of 373 organisms per meter squared. The dominant species were *Balanus improvisus* (152 org/m^2) and *Glycinde armgera* (95 org/m^2).

Maximum abundance in 2002 occurred in June with a total of 86,298 organisms per meter squared. The dominant species were *A. abdita* (61,892 org/m^2), *M. acherusicum* (20,544 org/m^2), and *Ampelisca lobata* (1,710 org/m^2). The minimum abundance in 2002 occurred in January with a total of 3,401 organisms per meter squared. The dominant species were *A. abdita* (2,413 org/m^2) and *Cirriformia spirabrancha* (147 org/m^2).

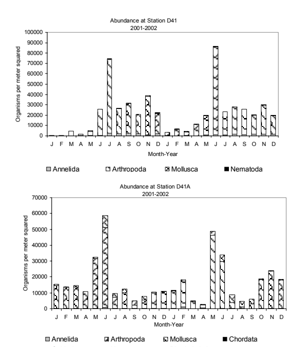


Figure 6-7 Benthic abundance at stations D41 and D41A, 2001–2002

Station D41 exhibits a seasonal pattern with the greatest abundance occurring during the summer and the lowest abundance occurring during the winter. This station is dominated by arthropods and some annelids.

Site D41A: Benthic Abundance (Figure 6-7)

Maximum abundance in 2001 occurred in June with a total of 58,738 organisms per meter squared. The dominant species were *A. abdita* (47,048 org/m^2), *P. amurensis* (4,887 org/m^2), and *Mya arenaria* (2,417 org/m^2). The minimum abundance in 2001 occurred in September with a total of 4,840 organisms per meter squared. The dominant species were *A. abdita* (1,653 org/m^2) and *P. amurensis* (2,323 org/m^2).

Maximum abundance in 2002 occurred in May with a total of 48,744 organisms per meter squared. The dominant species were *A. abdita* (41,558 org/m^2), *M. acherusicum* (2,783 org/m^2) and *P. amurensis* (2,094 org/m^2). The minimum abundance in 2002 occurred in April with a total of 2,712 organisms per meter squared. The dominant species was *Corophium heteroceratum* (1,748 org/m^2).

Station D41A exhibits a seasonal pattern with the greatest abundance occurring during the spring. This site is dominated by arthropods, but molluscs appear during the summer and fall.

Sediment

Site C9: Sediment Composition (Figure 6-8)

Sand was the dominant sediment type at site C9 throughout most of 2001 and 2002 with fines becoming dominant during spring 2001 and during summer and fall 2002. Greater measurements of organic matter at this site coincide with the higher amounts of fines. The dominant phylum at this site in 2001 and 2002 was Arthropoda. Annelids also appeared during the months when finer sediments were found at this station. From 1997 to 2000, sediment characteristics were similar to 2001 and 2002, but Annelida was the dominant phylum from 1997 to 2000.

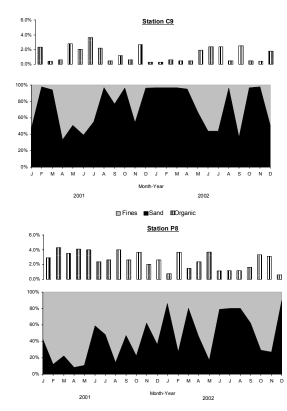


Figure 6-8 Percent sediment composition at sampling stations C9 and P8, 2001–2002

Site P8: Sediment Composition (Figure 6-8)

Fines dominated the sediment at site P8 for most of 2001 and 2002, with a pulse of sand appearing every few months. There was more organic matter at this site during 2001, with the exception of a few months during spring and fall 2002. The dominant phylum at this site over the study period was Annelida. Mollusca populations appeared fairly stable. Arthropods were very numerous during the late spring and early summer months 2002. In contrast, the sediment characteristics did not demonstrate any clear pattern from 1997 to 2000 and the dominant phylum was Annelida.

Site D16: Sediment Composition (Figure 6-9)

During 2001 fines were dominate during the winter and summer and sand was dominate during the spring and fall months. Sand usually dominated sediments in 2002, with fines dominating during June and the fall. The percentage of organic matter at this site appears fairly stable (average 2.4%), with the exception of low values during November 2001, February 2002, and July and August 2002. The dominant phylum in 2001 and 2002 was Arthropoda; however, annelids and molluscs also made up a significant portion of the organisms. In contrast, from 1997 to 2000, the sediments were usually dominated by sand, with fines becoming more prevalent in 2000. Arthropods were the dominant organisms from 1997 to 2000.

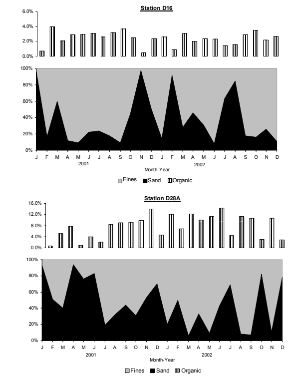


Figure 6-9 Percent sediment composition at sampling stations D16 and D28A, 2001–2002

Site D28A: Sediment Composition (Figure 6-9)

Fines usually dominated the sediment at D28A, with the exception of January through June 2001. More fines appeared at this site beginning in July 2001 and the amount of fines remained high until March 2002. Sand was dominant in July, October, and December 2002. The dominant phylum at this site for 2001 and 2002 was Annelida, with the exception of May and June in both 2001 and 2002 when Arthropoda was dominant. From 1997 to 2000, the same sediment characteristics, fines with high organic matter, were observed and the dominant phylum was Annelida.

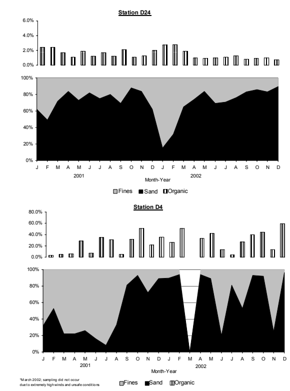


Figure 6-10 Percent sediment composition at sampling stations D24 and D4, 2001–2002

Site D24: Sediment Composition (Figure 6-10)

Sands dominated the sediments at D24, except for one peak of fine sediment in January 2002. The percentage of organic matter at this site remained fairly stable during 2001 and 2002 (average 1.5%). The dominant phylum at this site over the study period was Arthropoda. Molluscs were also common and had a fairly stable population. From 1997 through 2000, this site had similar sediment and phylum characteristics as 2001 and 2002, with sand as the dominant sediment type and Arthropoda as the dominant phylum.

Site D4: Sediment Composition (Figure 6-10)

Fines dominated the sediment at D4 from January to July 2001. From September 2001 to December 2002, the dominant sediment was sand, with the exception of June and November when fines were dominant. The percentage of organic matter at this site was high, with the exception of winter 2001 and July 2002. Arthropoda was the dominant phylum during 2001 and 2002. Fines usually dominated the sediment from 1997 through 2000. Arthropoda was the dominant phylum from 1997 through 2000. Data is missing for March 2002; sampling did not occur due to extremely high winds and unsafe conditions.

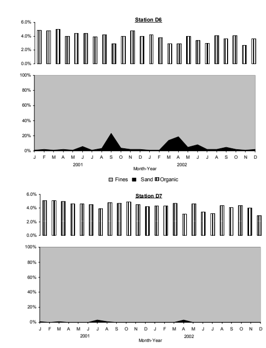


Figure 6-11 Percent sediment composition at sampling stations D6 and D7, 2001–2002

Site D6: Sediment Composition (Figure 6-11)

Fines were the dominant sediment at D6 with the exception of September 2001 and March and April 2002 when sand was more common. Organic matter at this site was stable during 2001 and 2002 (average 3.9%). Mollusca was the dominant phylum during 2001 and 2002. From 1997 through 2000 similar sediment characteristics were exhibited, with fine as the dominant sediment type and Mollusca was the dominant phylum.

Site D7: Sediment Composition (Figure 6-11)

Fines were the dominant sediment at D7 and the organic matter was stable throughout the study period (average 4.3%). Mollusca was the dominant phylum during 2001 and 2002. Arthropoda was also common throughout the study period, with higher numbers during the winter. From 1997 through 2000 similar sediment characteristics were exhibited, with fines as the dominant sediment type and Mollusca as the dominant phylum.

Site D41: Sediment Composition (Figure 6-12)

Fines usually dominated the sediment at D41. However, sand was more common from March to September 2001 and during several spikes in 2002. Overall, the organic matter at this site was stable, with the exception of the summer months. Arthropoda was the dominant phylum during 2001 and 2002. This pattern was different from 1997 through 2000 when the sediment characteristics were unstable. Fines dominated in 1997 and 2000, while no clear pattern seemed apparent in 1998 and 1999. Arthropoda was the dominant phylum from 1997 through 2000.

Site D41A: Sediment Composition (Figure 6-12)

Fines usually dominated the sediment at D41A, with the exception of two small peaks when sand was more common during February and April 2002. The percentage of organic matter at this site was stable (average 3.5%). Arthropoda was the dominant phylum during 2001 and 2002. From 1997 through 2000 similar sediment characteristics were exhibited, with fines as the dominant sediment type and Arthropoda as the dominant phylum.

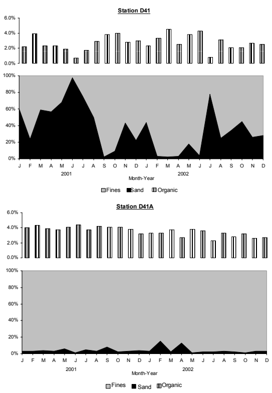


Figure 6-12 Percent sediment composition at sampling stations D41 and D41A, 2001–2002

Summary

The benthic monitoring program is designed to document the distribution, diversity and abundance of benthic organisms in the upper San Francisco Estuary. The monitoring program collects a large number of organisms, but a relatively small number of species. All organisms collected during 2001-2002 fell into eight phyla: Annelida, Arthropoda, Chordata, Cnidaria, Mollusca, Nemertea, Nematoda, and Platyhelminthes. Of these eight phyla, Annelida, Arthropoda and Mollusca constituted 99.5% of the organisms collected during the study period. Ten species represent 90% of all organisms collected during this period. These species are: (1) the amphipods, *Americorophium stimpsoni, Americorophium spinicorne, Corophium alienense, Monocorophium acherusicum*, and *Ampelisca abdita*; (2) the cumaceans, *Nippoleucon hinumensis* and *Gammarus daiberi*; (3) the aquatic oligocheate, *Varichaetadrilus angustipenis*; and (4) the Asian clams, *Potamocorbula amurensis* and *Corbicula fluminea*.

References

[APHA] American Public Health Association, American Waterworks, and Water Environmental Federation. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th ed. Washington, D.C.: American Public Health Association, 10.60-10.74.

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

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

Cohen, A.N., and J.T. Carlton, 1995. *Nonindigenous Aquatic Species in a United States Estuary: A case study of the biological invasions of the San Francisco Bay and Delta.* United States Fish and Wildlife Service, Washington D.C.

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

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

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

McMahon, R.F 1983. Ecology of an invasive pest bivalve, Corbicula. In: Russel-Hunter, W.D, (ed) The Mollusca. Vol. 6, Ecology. Academic Press. 505-561pp.

Figure 6-1 Location of 10 Environmental Monitoring Program benthic sampling sites

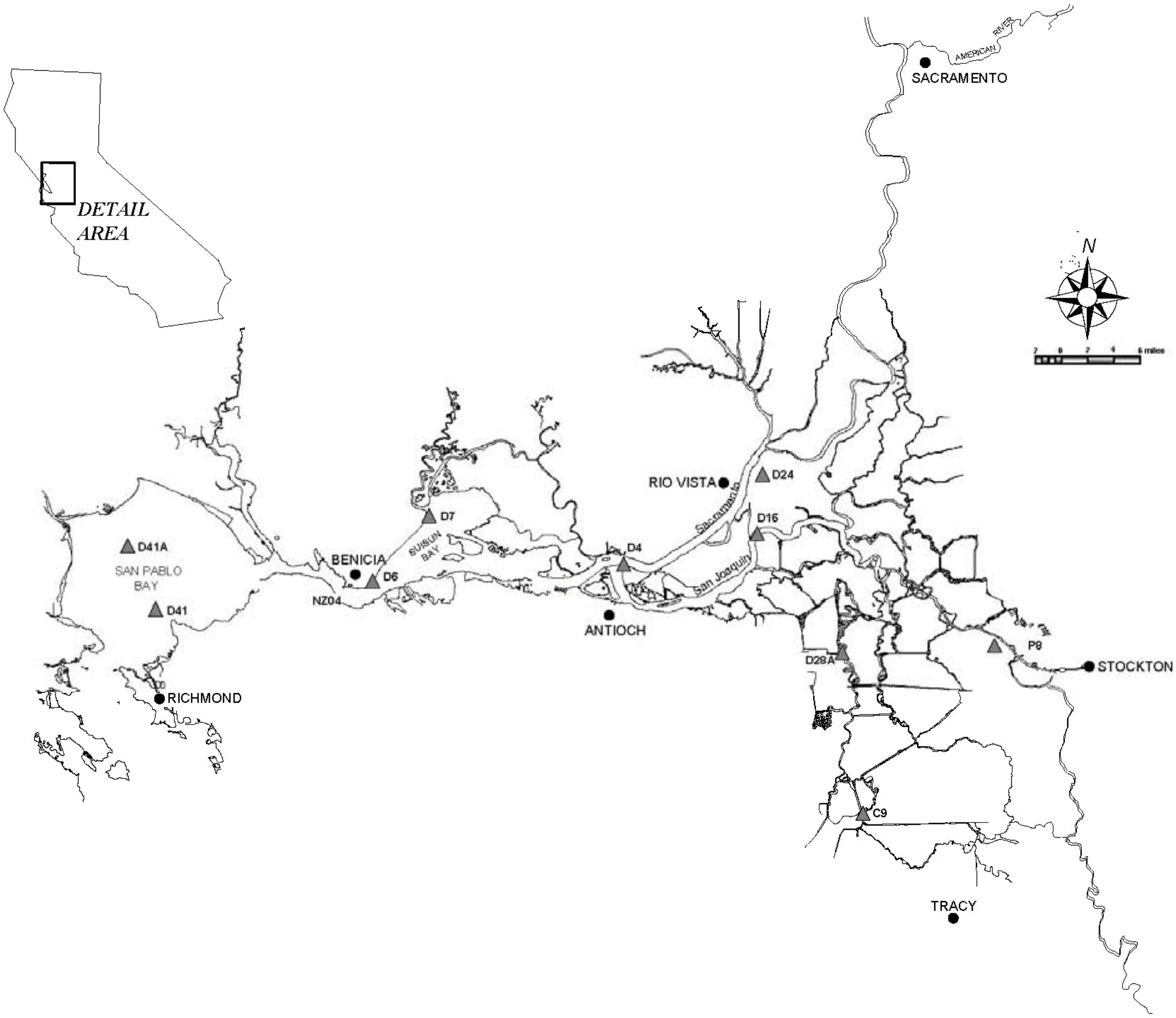


Figure 6-2 Total contribution by phyla for all stations 2001-2002

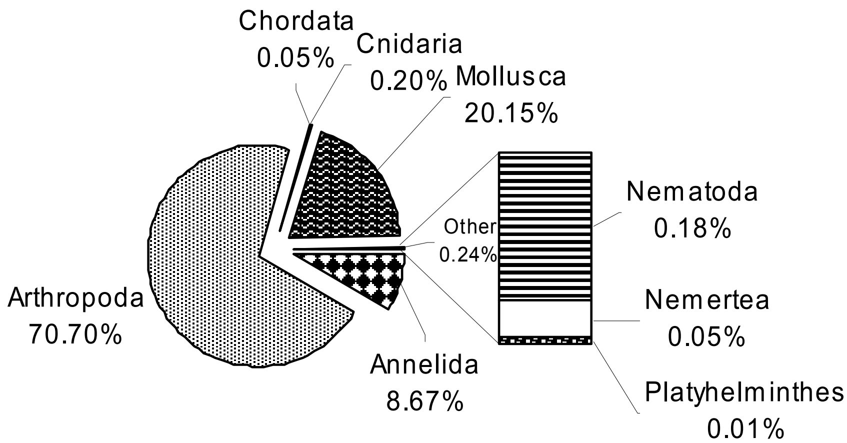
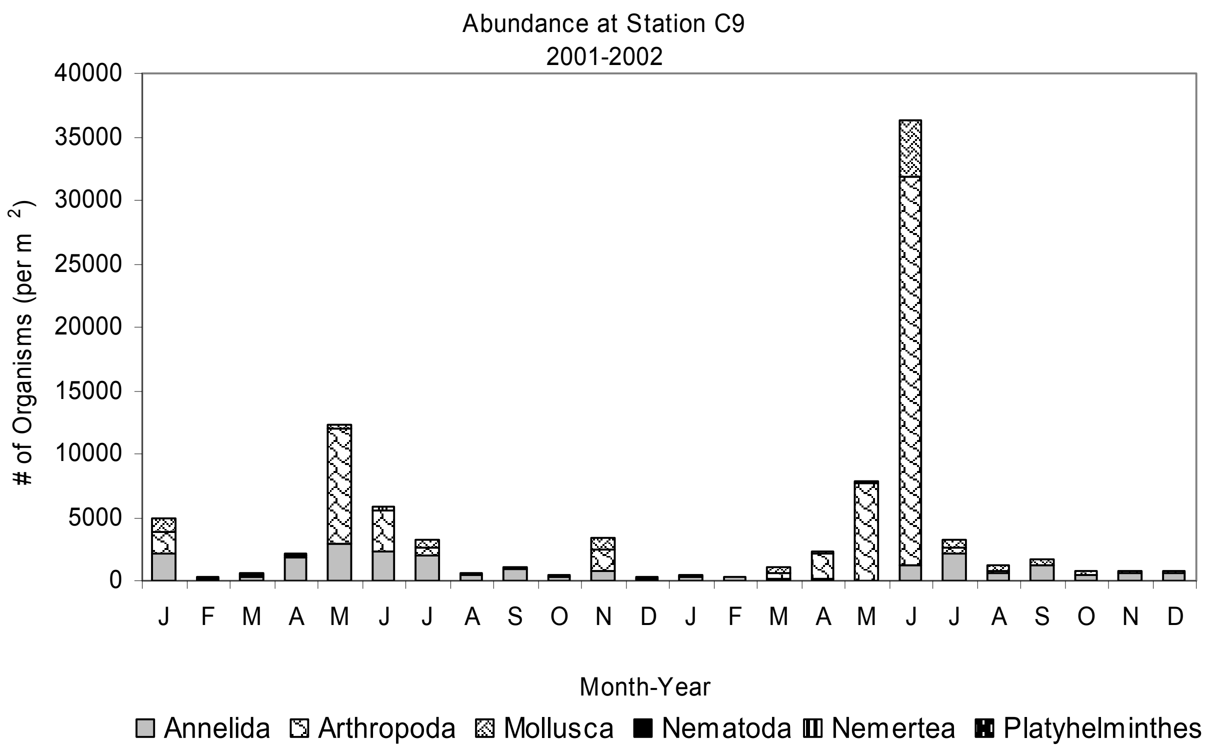


Figure 6-3 Benthic abundance at stations C9 and P8, 2001-2002



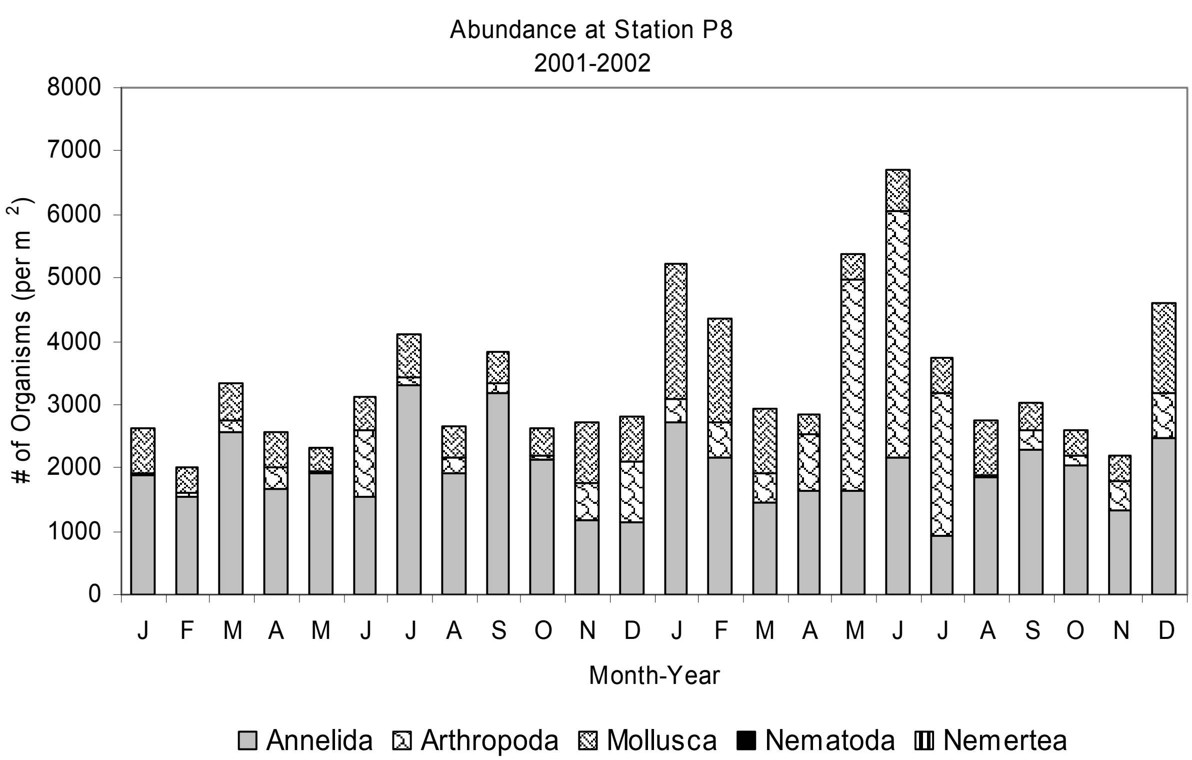
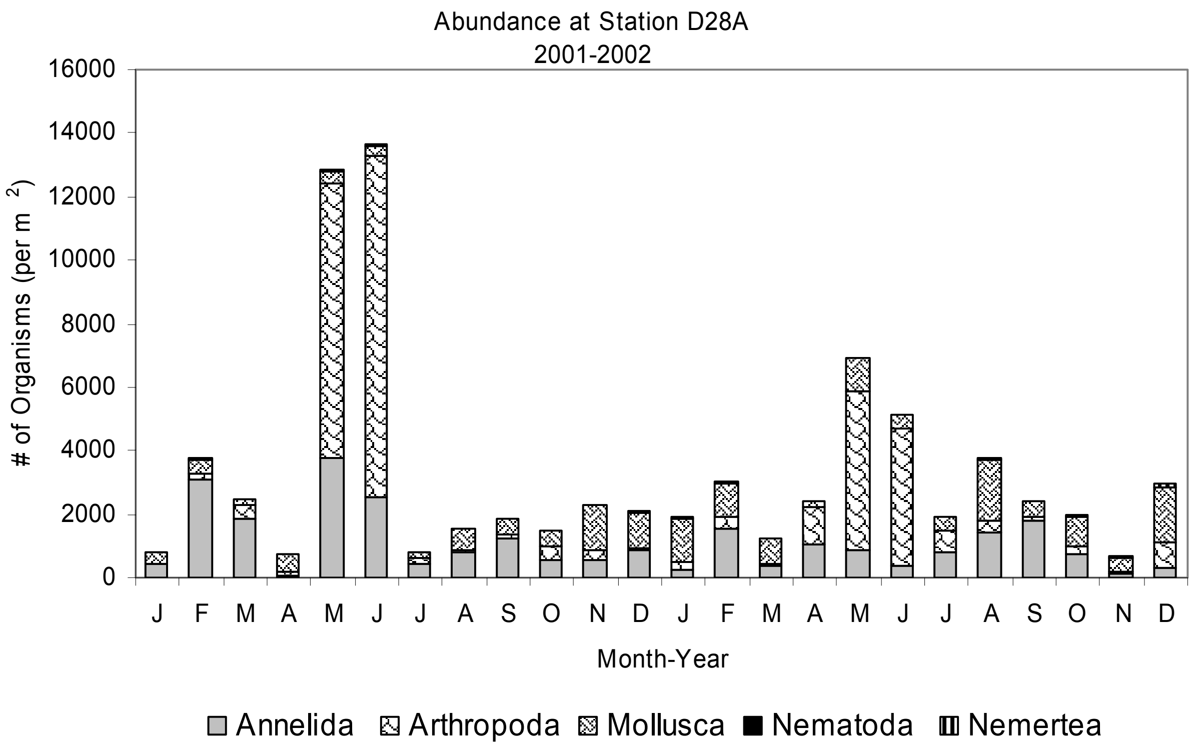


Figure 6-4 Benthic abundance at stations D28A and D16, 2001-2002



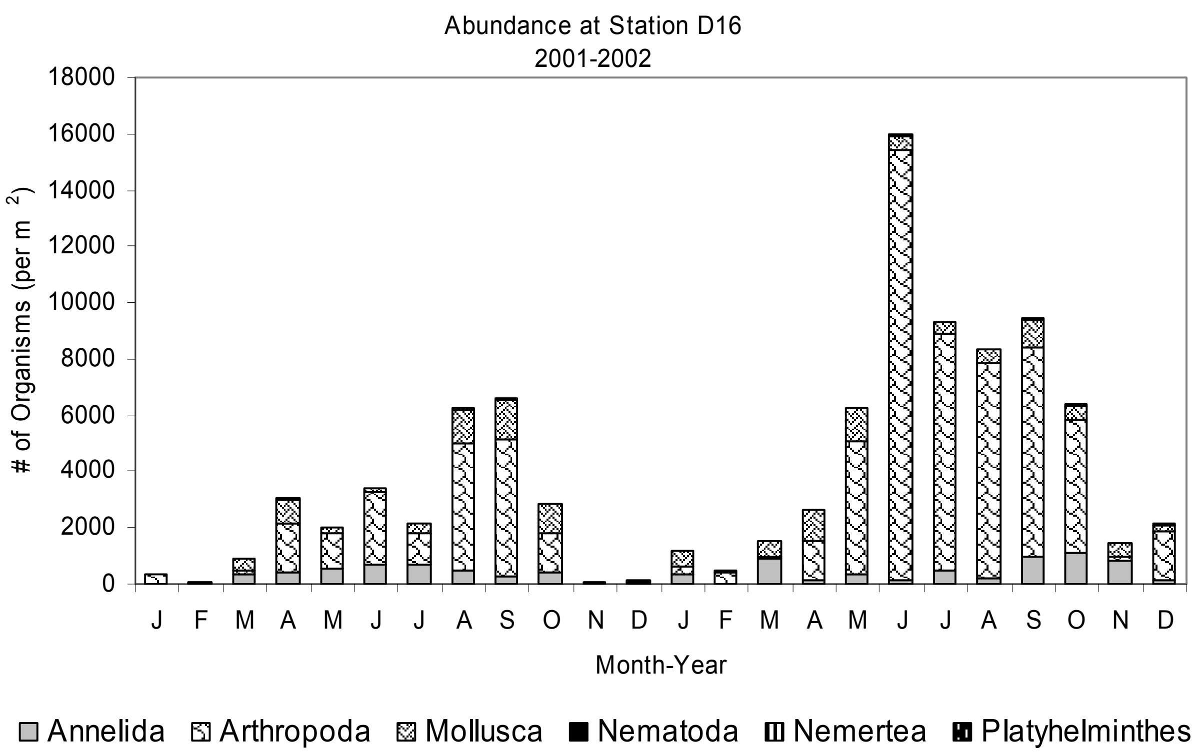
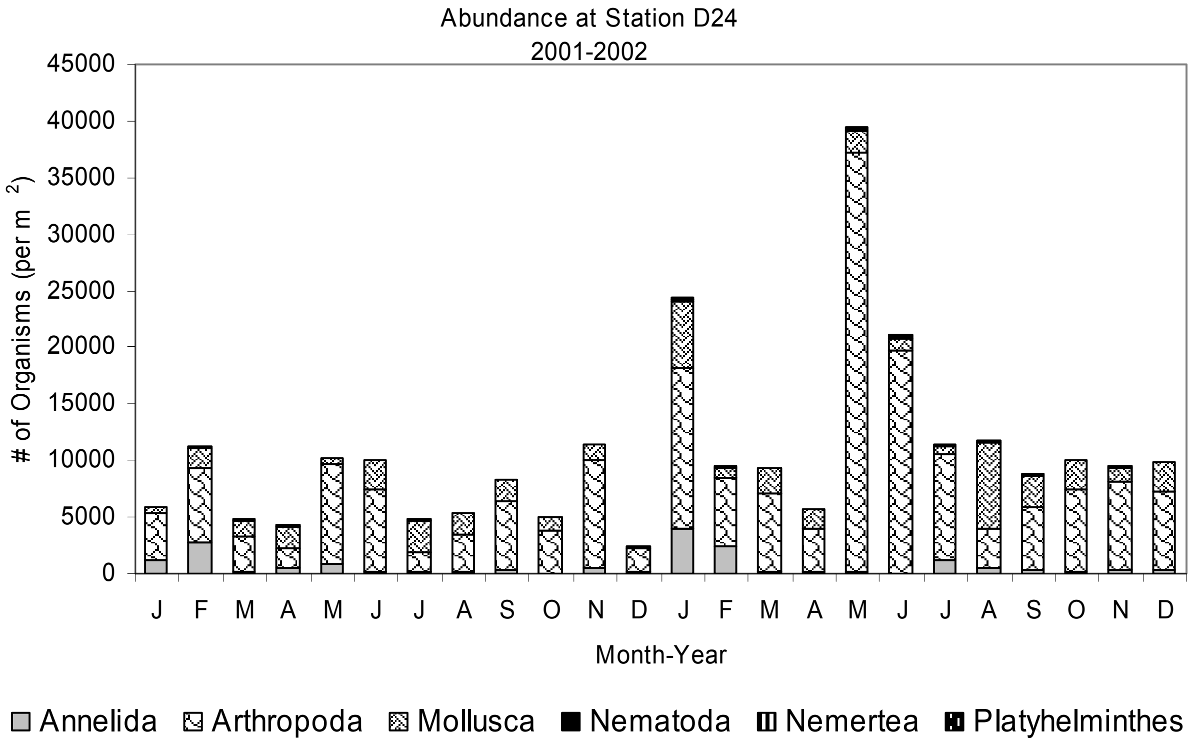


Figure 6-5 Benthic abundance at stations D24 and D4, 2001-2002



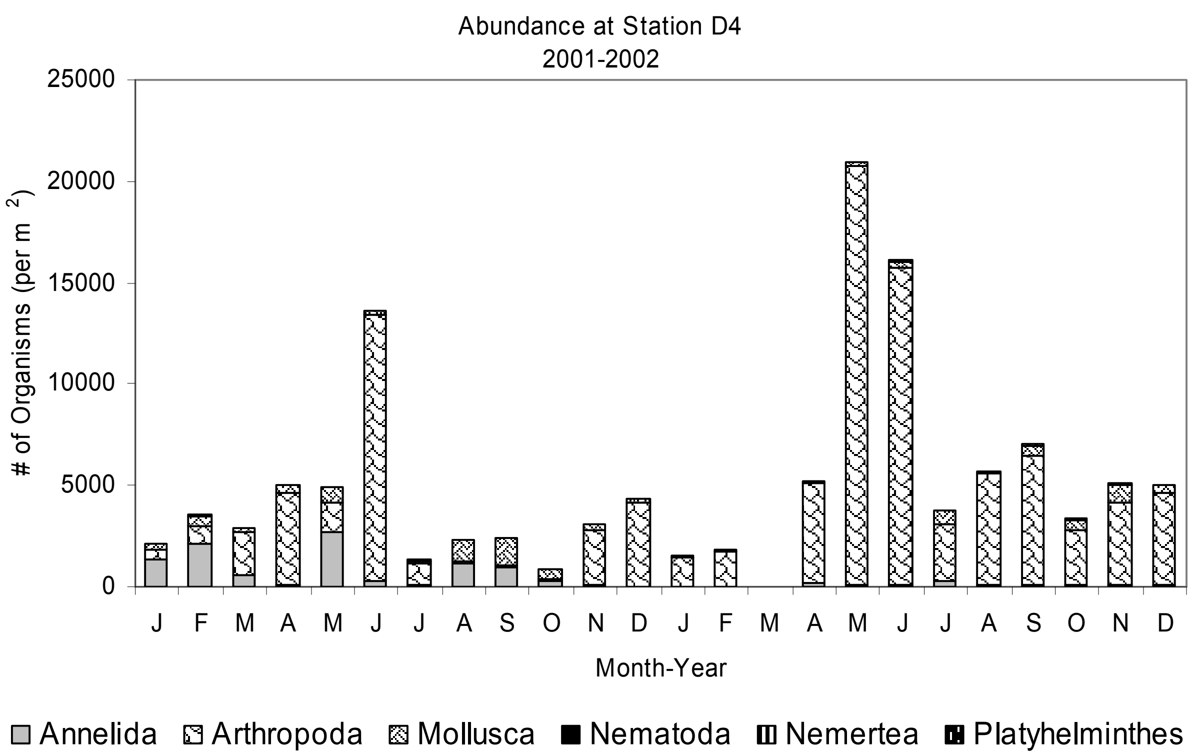
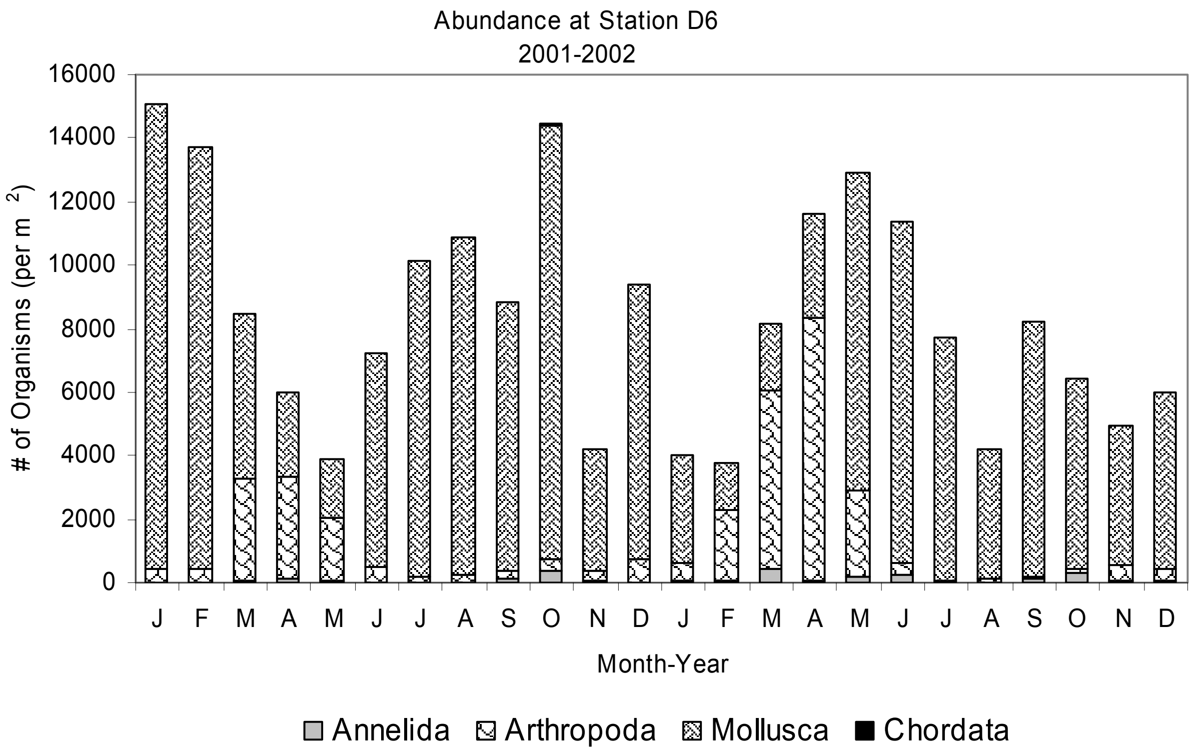


Figure 6-6 Benthic abundance at stations D6 and D7, 2001-2002



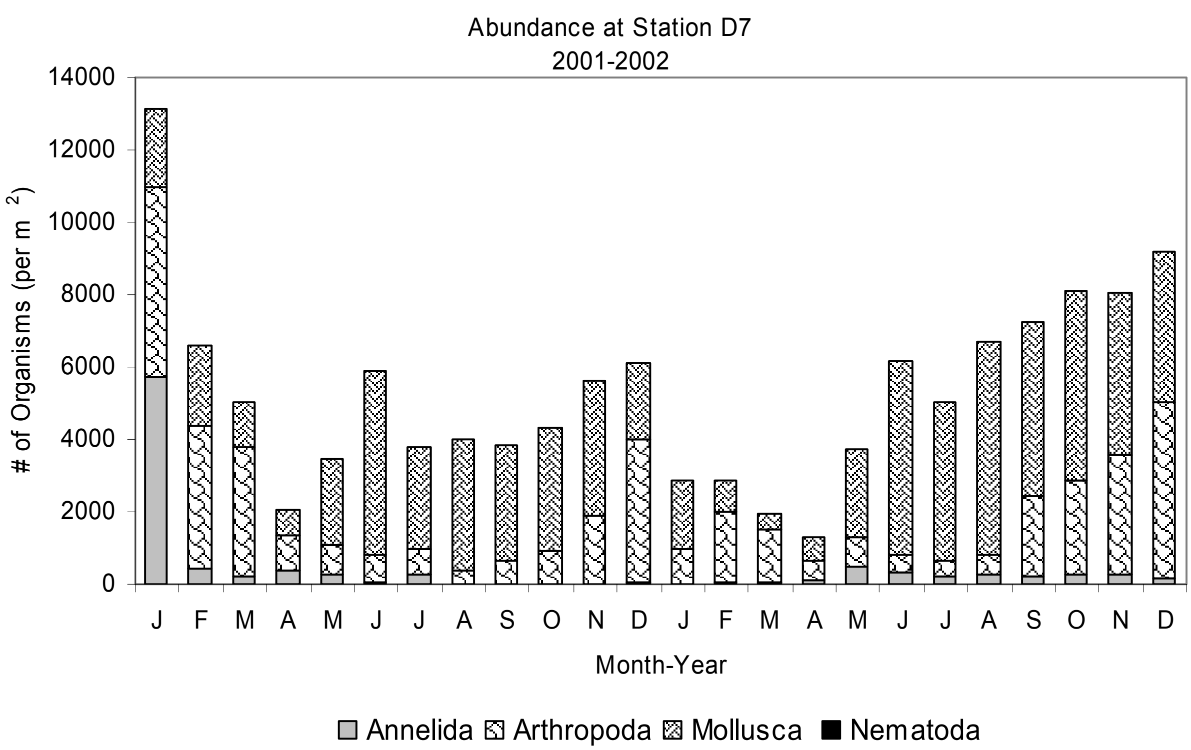
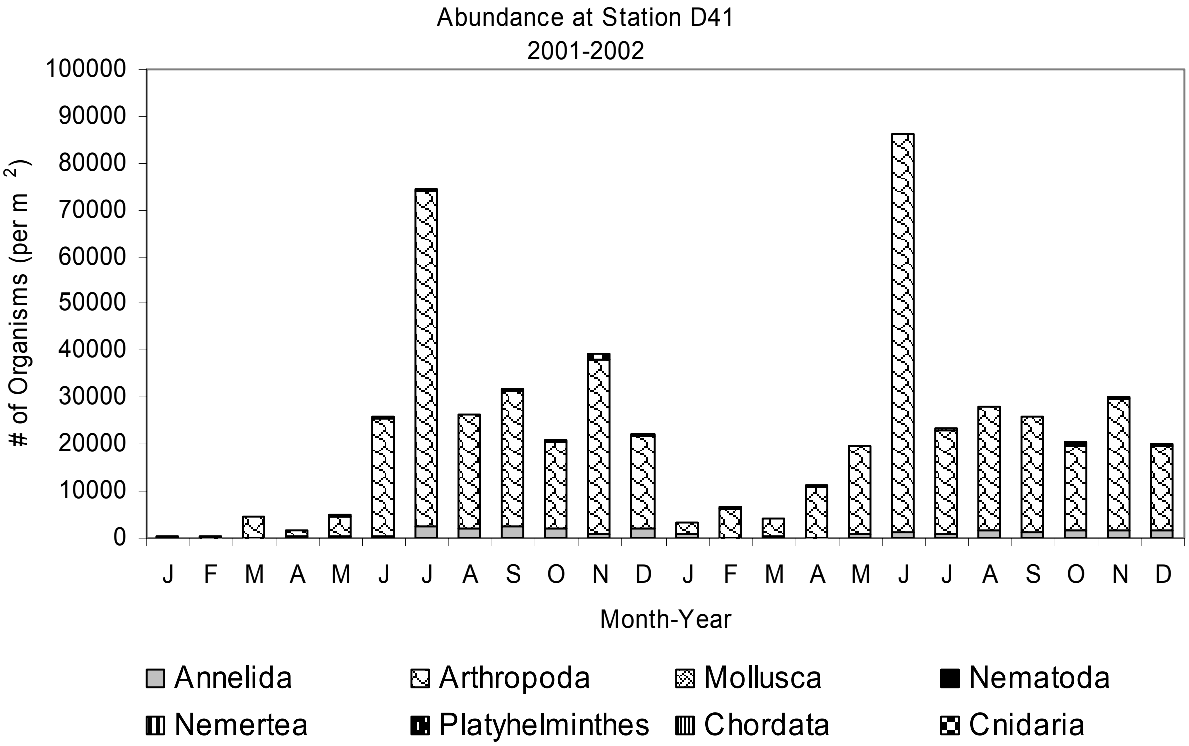


Figure 6-7 Benthic abundance at stations D41 and D41A, 2001-2002



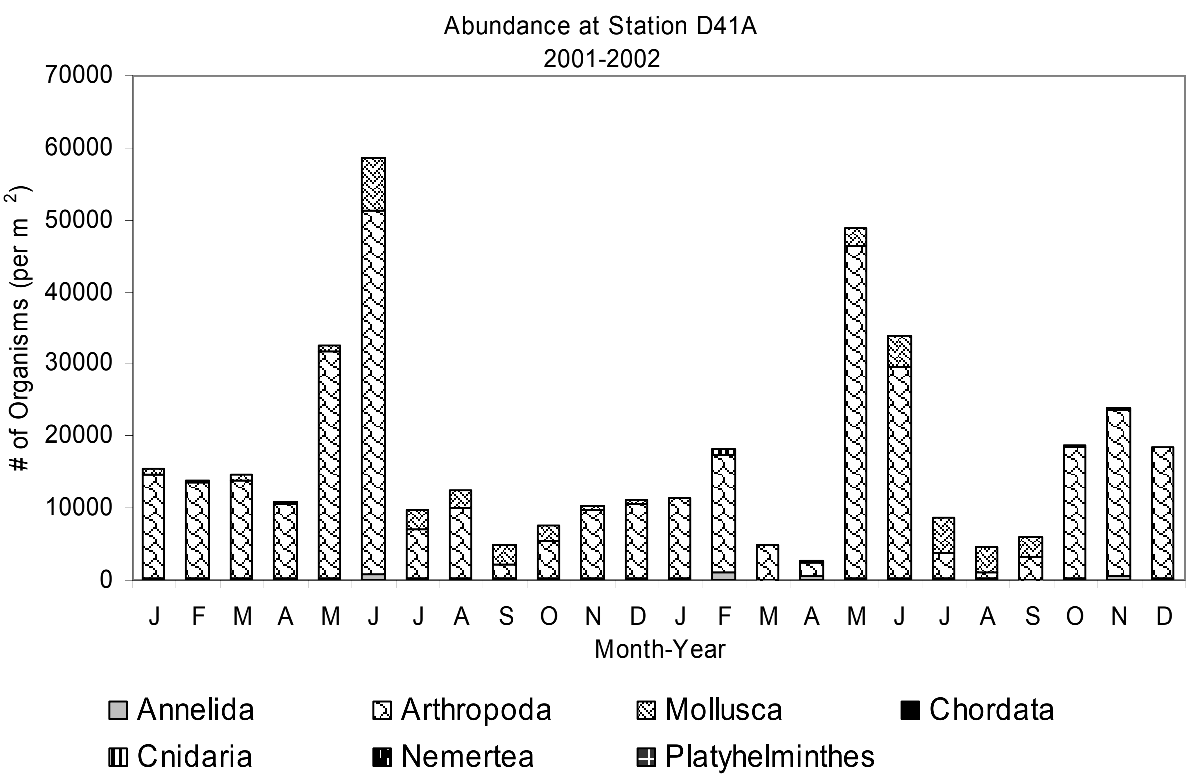
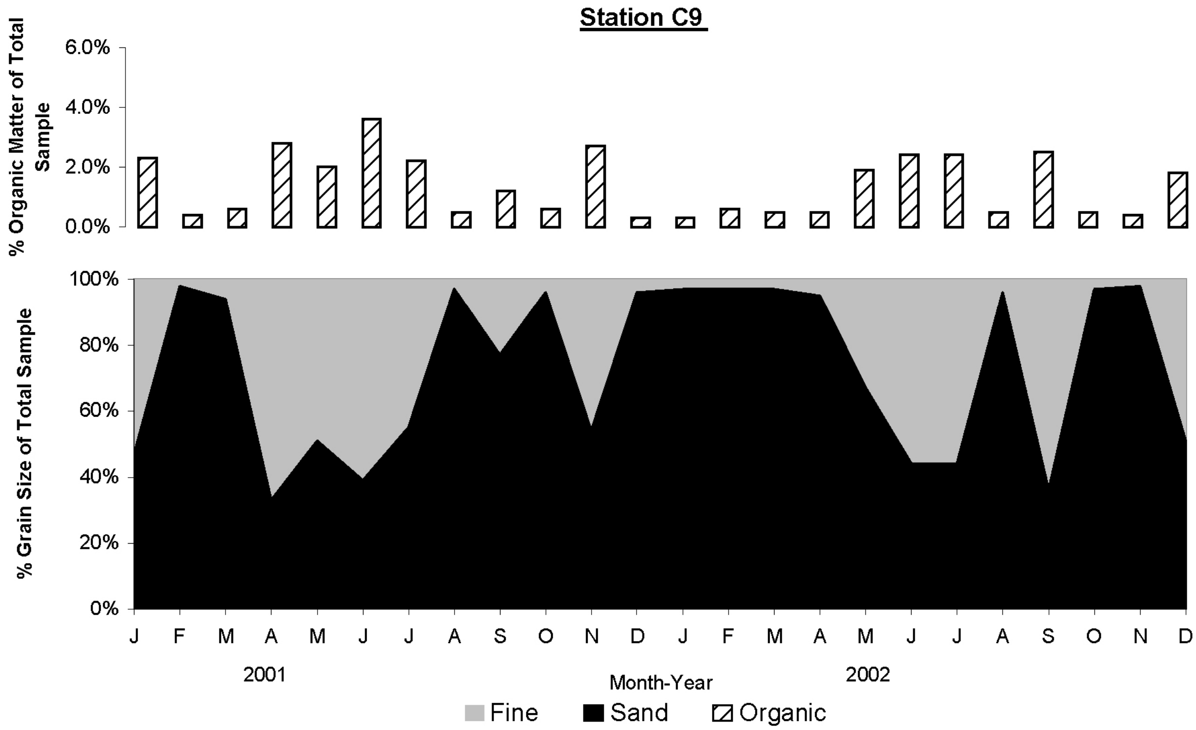


Figure 6-8 Percent sediment composition at sampling stations C9 and P8, 2001-2002



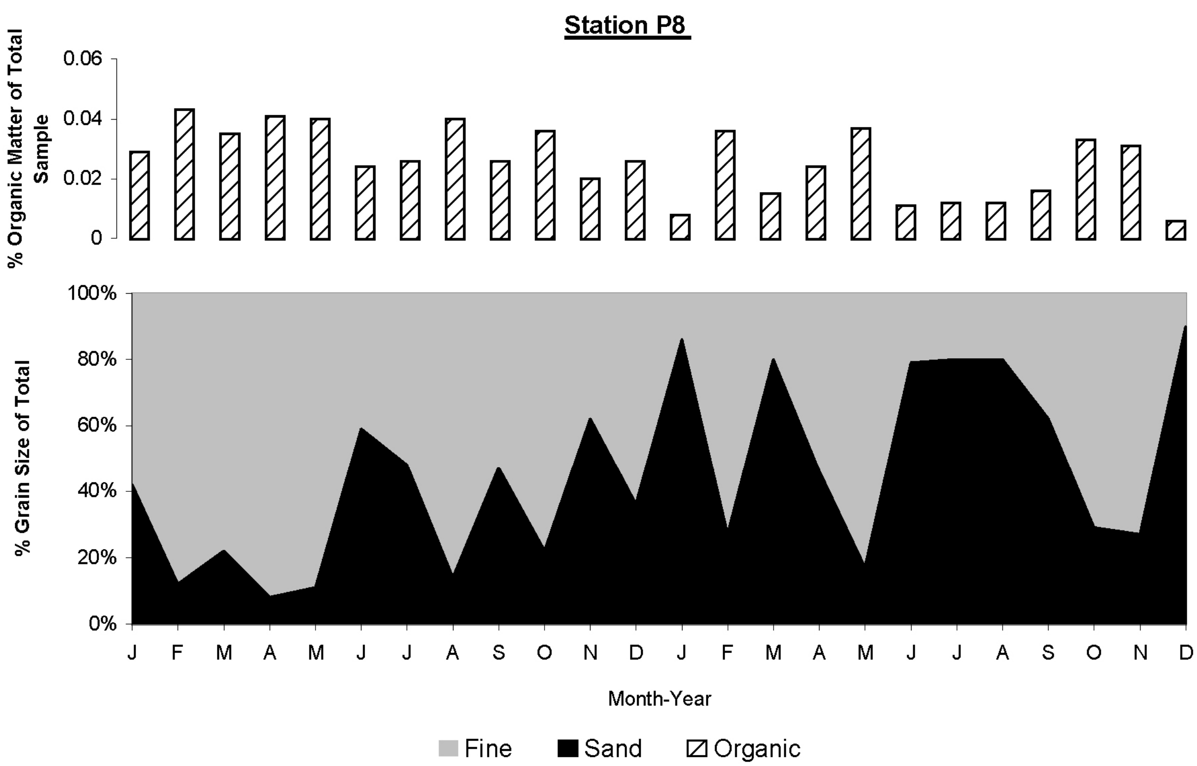


Figure 6-9 Percent sediment composition at sampling stations D16 and D28A, 2001-2002

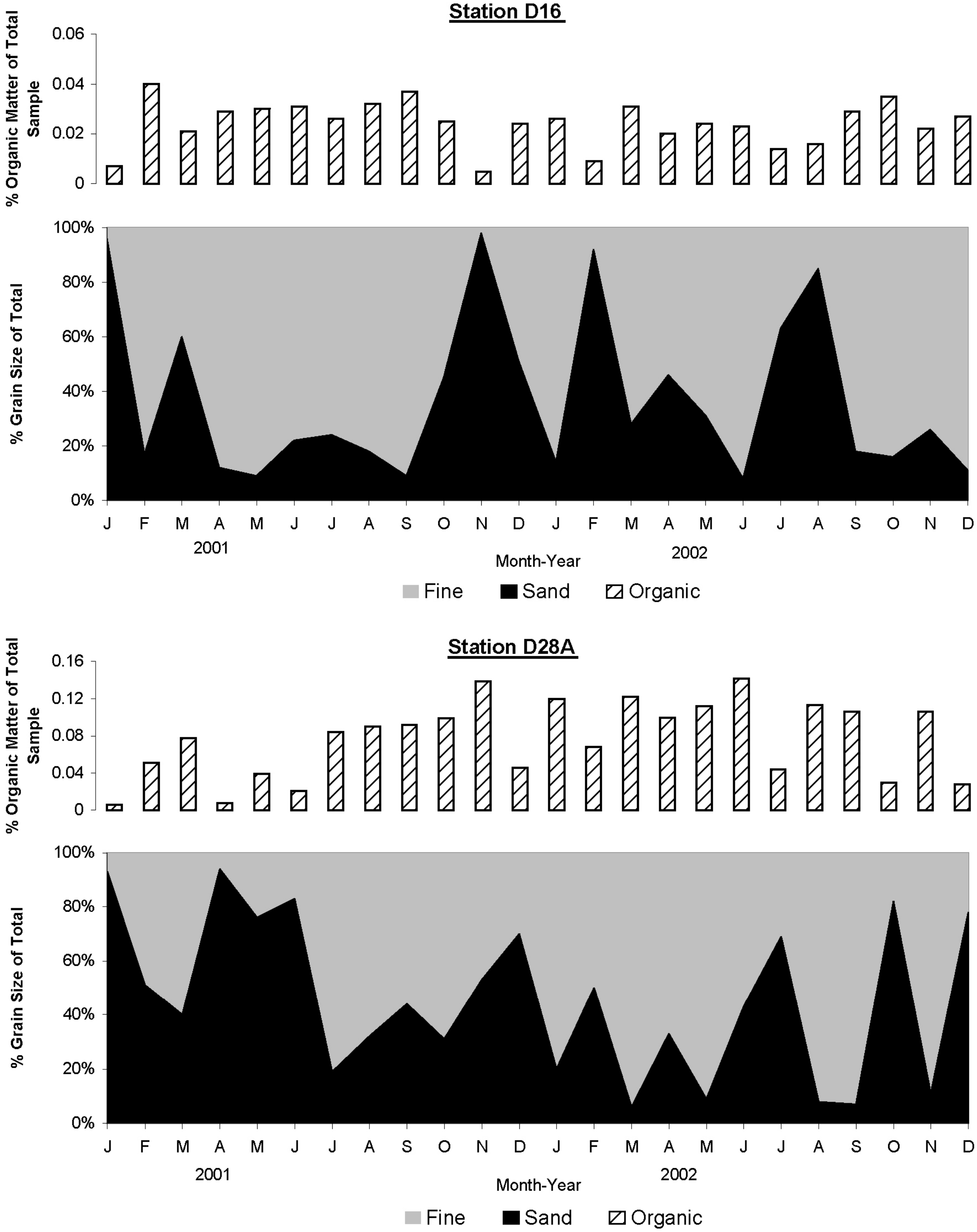


Figure 6-10 Percent sediment composition at sampling stations D24 and D4, 2001-2002

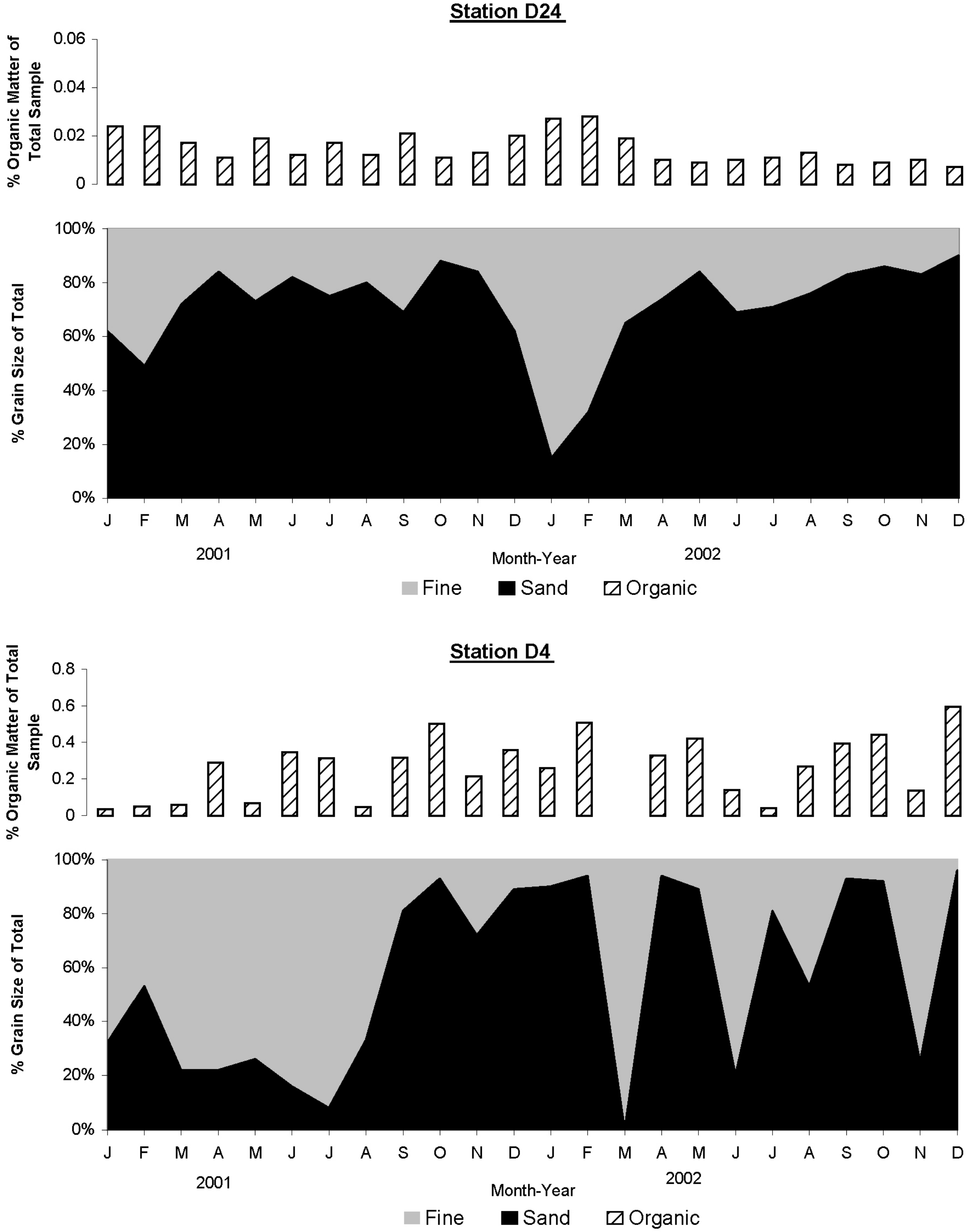
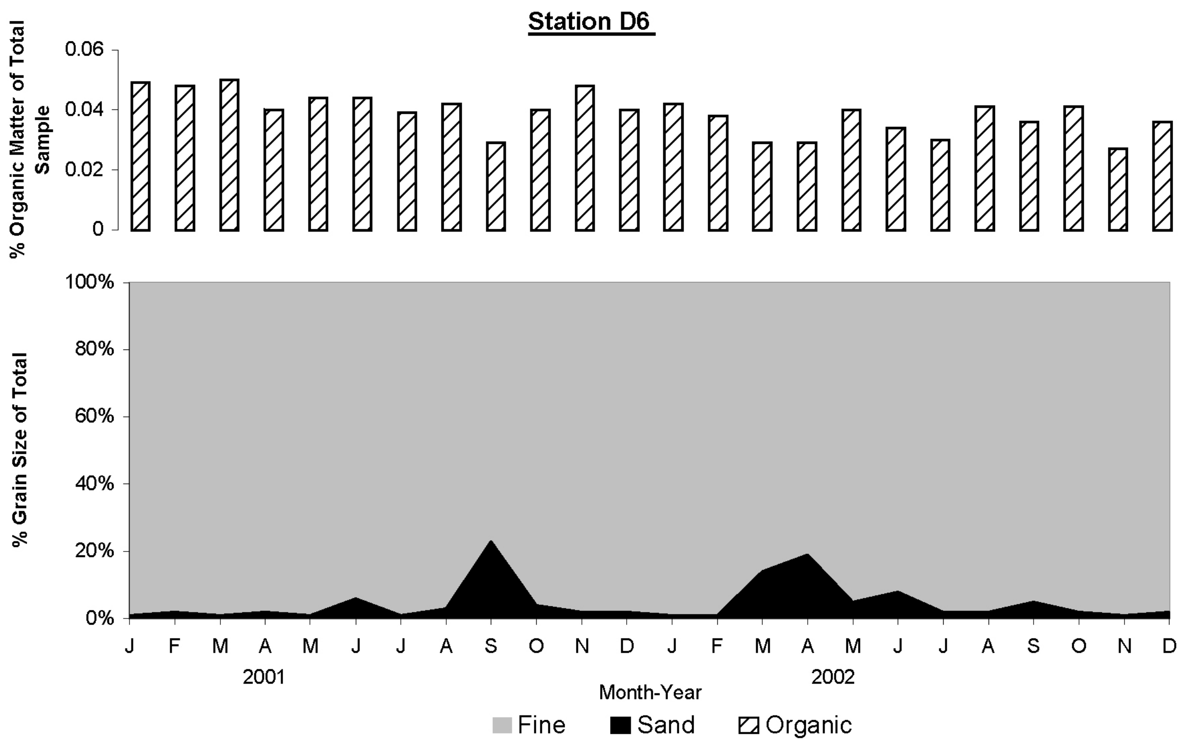


Figure 6-11 Percent sediment composition at sampling stations D6 and D7, 2001-2002



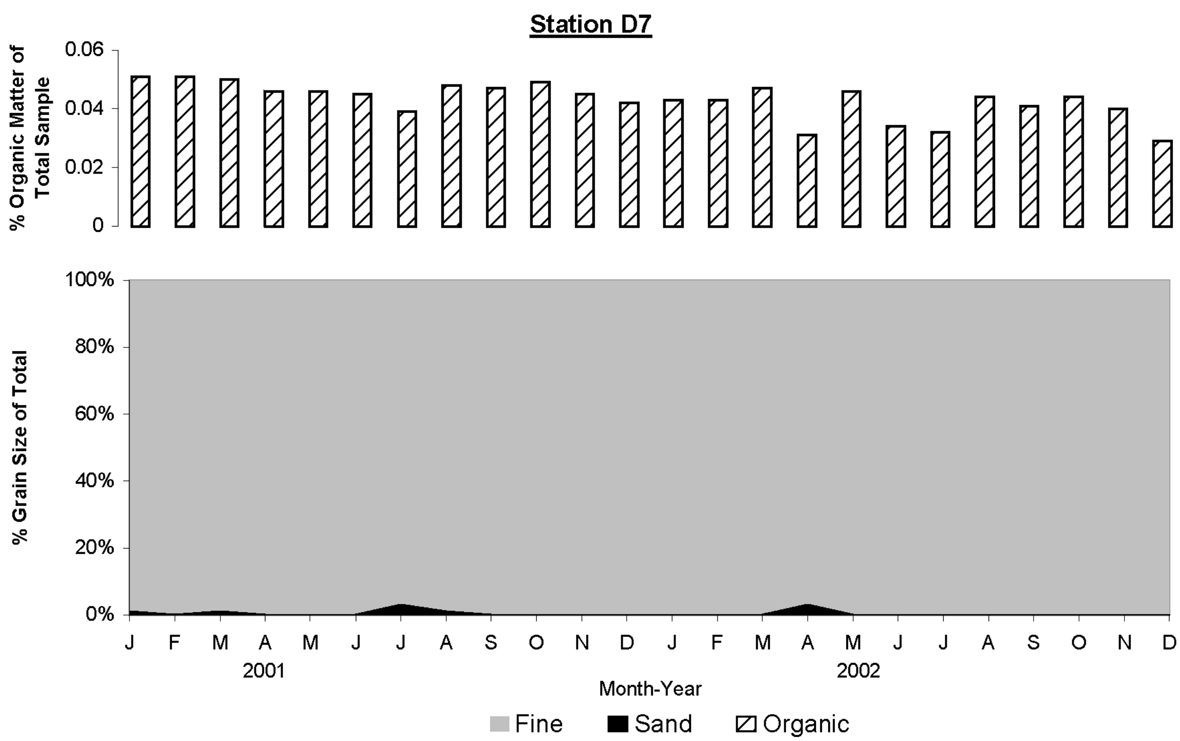
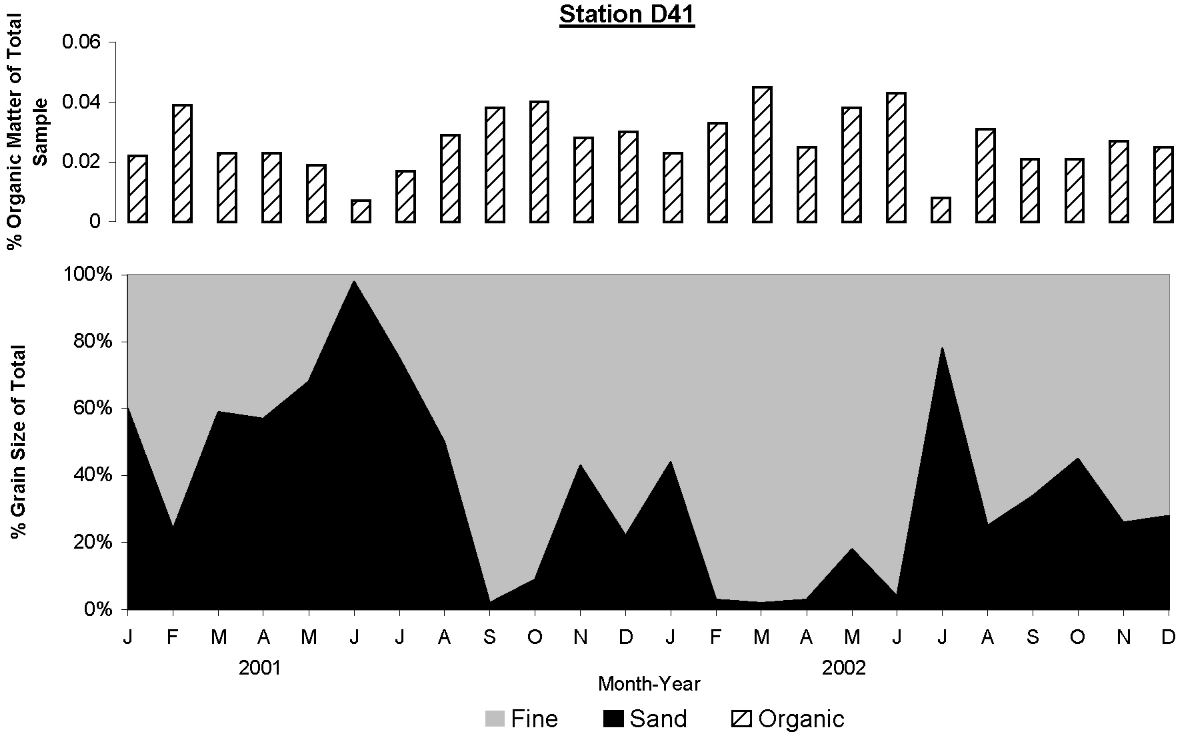
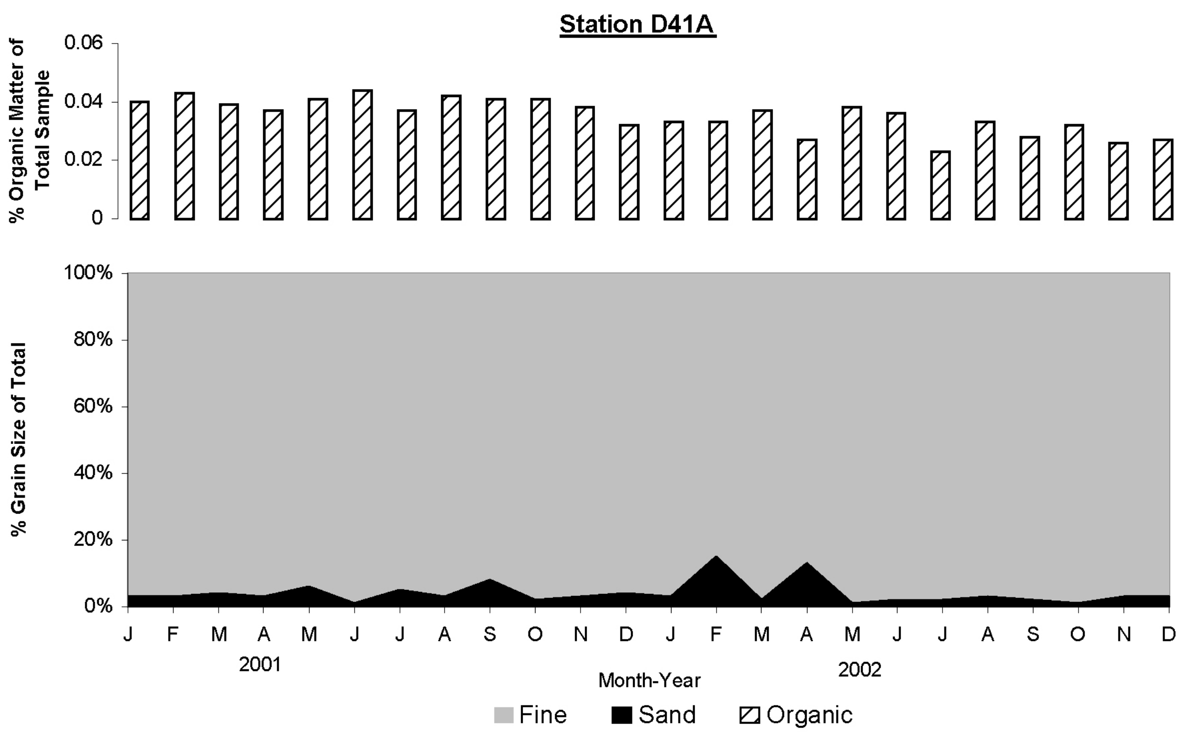


Figure 6-12 Percent sediment composition at sampling stations D41 and D41A, 2001-2002





Chapter 7
Dissolved Oxygen Monitoring in the Stockton Ship Channel, 2001-2002

Introduction

Dissolved oxygen levels in the Stockton Ship Channel have been monitored by the Department of Water Resources (DWR) during the late summer and fall of each year since 1968. Due to a variety of factors, dissolved oxygen levels have historically dropped to 5.0 mg/L or less in the central and eastern portions of the channel. These factors include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flows in the San Joaquin River past Stockton.

Because low dissolved oxygen levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, California has established specific water quality objectives to protect these uses. Within the channel, two separate dissolved oxygen objectives have been established. The most recent basin plan of the Central Valley Regional Water Quality Control Board (CVRWQCB 1998) establishes a baseline objective of 5.0 mg/L for the entire Delta, including the Stockton Ship Channel. However, due to the special concerns in the Stockton Ship Channel, a dissolved oxygen objective of 6.0 mg/L has been established in the channel for September through November by the State Water Resources Control Board (SWRCB 1995). This objective was established to protect fall-run Chinook salmon, and applies to the San Joaquin River between Stockton and the Turner Cut, which includes the eastern channel. Because a significant portion of the study area is within the designated 6.0 mg/L objective area and the majority of the study occurs within the September through November time frame, this report evaluates the data using the 6.0 mg/L objective.

As part of a 1969 Memorandum of Understanding between DWR, the US Fish and Wildlife Service (USFWS), the US Bureau of Reclamation (USBR), and the Department of Fish and Game (DFG), DWR has installed a rock barrier across the upstream end of Old River in the fall when San Joaquin River outflows are low. This Head of Old River Barrier (Barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can help increase dissolved oxygen concentrations within the channel. Because of bank erosion and barrier overtopping concerns, the Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cfs or less.

DWR installed the Barrier on October 6, 2001, and October 4, 2002, because late summer San Joaquin River flows past Vernalis were low (average September daily San Joaquin River flows past Vernalis were 1,390 cfs in 2001 and 1,160 cfs in 2002), and early fall flows were not projected to be sufficient to alleviate dissolved oxygen concerns in the eastern channel. The Barrier was removed in 2001 on November 30, and in 2002 on November 15, due to a sustained improvement in dissolved oxygen conditions, and concern for potential bank erosion and barrier overtopping due to projected high, late fall flows. This report summarizes monitoring results during fall 2001 and 2002 when the Barrier was in place.

Methods

Monitoring of dissolved oxygen concentrations in the Stockton Ship Channel was conducted by vessel seven times between August 1 and December 5, 2001, and nine monitoring runs were conducted from July 23 to December 18, 2002. During each of the monitoring runs, fourteen 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 ship channel (Station 14). For geographic reference and simplifying reporting, the sampling stations are keyed to channel light markers[1] as shown in Figure 7-1.

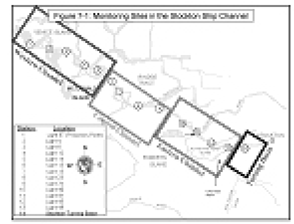


Figure 7-1 Monitoring sites in the Stockton Ship Channel

Because monitoring results differ along the channel[2], sampling stations are grouped into western, central, and eastern regions within the channel, and these regions are highlighted in Figure 7-1. The western channel begins at Prisoners Point (Station 1) and ends at Light 14 (Station 5). The central channel begins at Light 18 (Station 6) and ends at Light 34 (Station 9). Finally, the eastern channel begins at Light 40 (Station 10) and ends at Light 48 (Station 13). The Turning Basin (Station 14) is unique within the channel because it is east of the entry point of the San Joaquin River into the channel and therefore forms a backwater relatively isolated from river flow. Because of the unique hydro-morphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each station at low water slack tide, and analyzed for dissolved oxygen concentrations and temperature. Top dissolved oxygen samples were analyzed with the modified Winkler titration method (APHA 1998). Bottom dissolved oxygen samples were measured using either a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger, or with a YSI 6600 sonde equipped with a Model #6562 dissolved oxygen sensor. The multiple methods used to measure surface and bottom dissolved oxygen levels provided a means to compare various instruments and their accuracy. Surface and bottom water temperatures were measured using a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe or a Seabird SBE3 temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data at Vernalis, which was compiled by DWR[3]. Average daily flows past Vernalis were obtained by averaging 15-minute data for a daily average flow

---

[1] Channel light markers are ship navigational aids placed in navigable waters. Although they are not spaced at fixed intervals, they provide convenient landmarks for identifying sample locations.

[2] The findings of previous fall studies have shown that fall dissolved oxygen levels are typically robust and high (7.0-9.0 mg/L) in the western channel; transitional, variable (4.0-7.0 mg/L), and stratified in the central channel; and low (3.0-5.0 mg/L) and stratified in the eastern channel.

[3] Station information: DWR Station SJR at Vernalis, RSAN112

rate. Tidal cycles of ebb and flood are not significant in flows at Vernalis, and flow is always downstream (positive). Flows of the San Joaquin River past Stockton used in this report were obtained from data recorded by the US Geological Survey flow-monitoring station southeast of Rough and Ready Island [4].

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[5] to yield net daily flow. Due to low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes reverse direction, which results in a net upstream flow. Net daily reverse flows at Stockton were seen briefly in December 2001, but not seen during the fall 2002 study period.

In this report, we refer to dissolved oxygen “sags” and “depressions”. We define a dissolved oxygen “sag” as a region within the channel where dissolved oxygen levels are < 5.0 mg/L. These levels do not meet the CVRWQCB objectives described in the introduction to this chapter. A dissolved oxygen “depression” is defined as a region within the channel where dissolved oxygen levels are ≥ 5.0 mg/L but < 6.0 mg/L. These levels also do not meet the SWRCB objective for September through November.

Results

During summer and fall 2001 and 2002, dissolved oxygen levels varied considerably between regions within the channel. In both years, dissolved oxygen concentrations in the western channel were relatively high and stable and ranged from 6.6 to 10.0 mg/L through July and December. The robustness of dissolved oxygen concentrations in the western channel is apparently due to the greater tidal mixing, the absence of conditions creating BOD, and shorter hydrological residence time than in other sections of the channel. In the central portion of the channel, dissolved oxygen concentrations dropped from the consistently high concentrations in the western channel to concentrations below 5.0 mg/L through much of August, September, and October in 2001 and September through October in 2002. In the eastern channel, the dissolved oxygen levels were low from August through October 2001 and August through September 2002. The eastern channel dissolved oxygen levels tended to be stratified and were more variable in October. In 2001, dissolved oxygen levels in the eastern channel ranged from a low of 3.7 mg/L to a high of 10.5 mg/L. In 2002 levels ranged from 3.3 mg/L to 10.8 mg/L. Changing inflows into the eastern channel may partially account for the variability in dissolved oxygen levels observed here.

---

[4] Station information: USGS 304810 SJR at Stockton, RSAN063.

[5] The USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15-minute flow data, that occur during less than a 30-hour period. The resulting 15-minute time-series is then averaged to provide a single daily value that represents net river flow exclusive of tidal cycles.

Dissolved Oxygen Levels in 2001

On August 1, a surface dissolved oxygen depression and a bottom dissolved oxygen sag were observed in the central and eastern channels (Figure 7-2). Bottom dissolved oxygen levels dropped to a low of 3.7 mg/L at Station 10. In the eastern channel and part of the central channel (Stations 8 through 12), marked vertical dissolved oxygen stratification occurred, with bottom dissolved oxygen levels approximately 2.0 to 3.0 mg/L less than surface levels. Dissolved oxygen levels remained low on August 20 as the bottom dissolved oxygen sag within the central channel and the stratification within the eastern channel continued. Relatively warm late summer water temperatures (22.1-26.3 °C) (Figure 7-3) and low San Joaquin River inflows into the channel east of Rough and Ready Island appear to have contributed to the low dissolved oxygen concentrations observed. Average net daily flows in the San Joaquin River past Vernalis in August ranged from 1,253 to 1,531 cfs (Figure 7-4). USGS flow data were not available for San Joaquin flows past Stockton for this period.

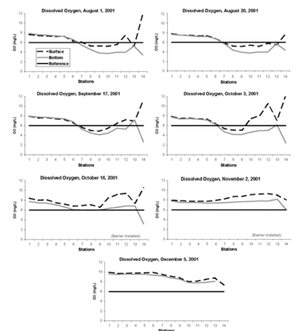


Figure 7-2 Dissolved oxygen levels, Aug 1–Dec 5, 2001

The extent of the surface depression and the bottom sag present in the channel in August decreased slightly in September. On September 17, eastern and central channels showed depressed surface dissolved oxygen concentrations ranging from 4.9 to 5.7 mg/L (Figure 7-2). At the bottom, low dissolved oxygen levels continued, with levels ranging from 4.1 to 4.5 mg/L. The stratification between surface and bottom values decreased to 0.5 to 1.0 mg/L. Average September water temperatures of 21 to 24 °C within the channel were significantly cooler (3 °C) than August water temperatures (Figure 7-3). September flow conditions within the San Joaquin River past Vernalis did not improve, and ranged from 1,255 to 1,580 cfs. USGS flow data for San Joaquin River at Stockton in September showed flows ranged from 1,037 to 735 cfs (Figure 7-4).

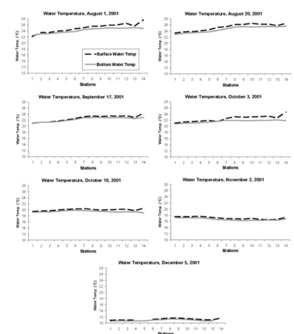


Figure 7-3 Surface and bottom water temperatures, Aug 1–Dec 5, 2001

A gradual but sustained improvement of dissolved oxygen conditions within the channel occurred in October. Initial sampling on October 3 showed continuation of the dissolved oxygen sag within the central and eastern channel with bottom levels ranging from 4.2 to 5.0 mg/L (Figure 7-2). A dissolved oxygen depression of 5.1 to 5.4 mg/L persisted at the surface of the central channel. These low dissolved oxygen levels can be attributed in part to sustained warm water temperatures (21-24 °C) (Figure 7-3) and relatively low flow conditions past Stockton in early October. Incomplete flow data recorded by USGS shows average daily flows past Stockton ranged from 1,370 to 1,589 cfs through October 15. During this period, the average net daily San Joaquin River flow past Vernalis ranged from 1,300 to 1,641 cfs (Figure 7-4).

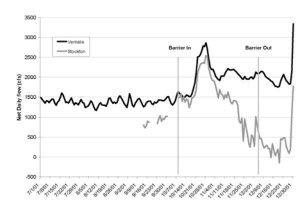


Figure 7-4 Average net daily flows in the San Joaquin River at Stockton and Vernalis, Jul 1–Dec 30, 2001

By October 16, dissolved oxygen conditions throughout the channel had improved significantly. Surface dissolved oxygen concentrations throughout the channel were all greater than 6.0 mg/L (Figure 7-2). However, a slight bottom dissolved oxygen depression, at 5.9 mg/L, persisted in the central channel. The general increase in dissolved oxygen levels throughout the channel may be attributed to significantly decreased water temperatures and improved inflows. Water temperatures (19-20 °C) were approximately 2 to 3 degrees cooler than temperatures recorded on October 3 (Figure 7-3). Flow conditions past Stockton from October 16 through 31 ranged from 1,234 to

2,541 cfs. This improvement was due, in part, to the placement of the Barrier on October 6, 2002. Average daily San Joaquin River flows past Vernalis from October 16 through October 31 ranged from 1,509 to 2,861 cfs (Figure 7-4).

Monitoring on November 2 confirmed a sustained improvement of dissolved oxygen levels throughout the channel. Surface dissolved oxygen levels ranged from 7.8 to 9.3 mg/L and bottom levels ranged from 7.5 to 8.1 mg/L (Figure 7-2). Water temperatures (16-17 °C) were 2 to 3 degrees cooler than those measured in mid-October (Figure 7-3). The relatively high San Joaquin River flows past Vernalis were sustained in November, as average daily flows ranged from 1,917 to 2,216 cfs. However, flow rates past Stockton dropped dramatically, ranging from 1,964 cfs at the beginning of the month to 245 cfs at the end of November (Figure 7-4).

Although the Barrier was removed on November 30, high dissolved oxygen concentrations persisted in early December; all surface concentrations were above 8.0 mg/L and all bottom concentrations were above 7.0 mg/L (Figure 7-2). Water temperatures continued to drop from the levels measured in November, and ranged from 10 to 11 °C (Figure 7-3). Average daily flows past Stockton remained below 480 cfs for most of the month except for a large spike in flow during the last three days of December, after sampling was completed. Average net flow rates at Stockton reversed several times in December with the lowest flow rate recorded as -172 cfs on December 20. Average net daily flows past Vernalis were relatively constant and ranged from 1,956 to 2,082 cfs during this period (Figure 7-4). The cooler water temperatures, maintenance of relatively high San Joaquin River inflows, and the elimination of reverse flow conditions past Stockton apparently maintained the improved dissolved oxygen concentrations detected previously throughout the channel. Because of the sustained improvement, no further special studies were conducted for dissolved oxygen in 2001.

Highly stratified dissolved oxygen conditions were detected in the Stockton Turning Basin (Station 14) throughout much of fall 2001. Sampling on August 1, August 20, September 17, October 3, and October 16 showed surface dissolved oxygen concentrations ranging from 7.6 to 12.2 mg/L, and bottom dissolved oxygen concentrations ranging from 2.4 to 4.3 mg/L (Figure 7-2). Sampling on November 2 and December 5 showed that marked dissolved oxygen stratification had subsided, with surface and bottom dissolved oxygen concentrations ranging from 6.0 to 8.0 mg/L.

Dissolved Oxygen Levels in 2002

Monitoring on July 23 showed that dissolved oxygen levels in the western channel were robust at ≥ 7.5 mg/L from Stations 1 to 5, with tidal mixing resulting on little stratification between surface and bottom measurements (Figure 7-5). Although dissolved oxygen levels remained largely unstratified in the central channel, dissolved oxygen levels decreased eastward. Dissolved oxygen levels ranged from a high of 7.5 mg/L at the bottom at Station 6 to a low of 5.7 mg/L at the surface at Station 9. Dissolved oxygen stratification was found in the eastern channel, with bottom levels at approximately 0.5 to 1.0 mg/L less than surface levels. As a result, a dissolved oxygen sag was present along the bottom at Stations 10 through 12

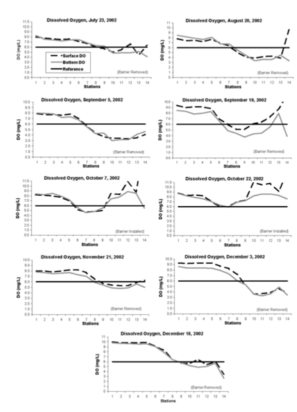


Figure 7-5 Surface and bottom dissolved oxygen, Jul 23–Dec 18, 2002

with a minimum dissolved oxygen value of 4.8 mg/L measured at Station 10. Surface measurements within the eastern channel were variable and ranged from 4.5 mg/L at Station 13 to 6.6 mg/L at Station 12. Thus, a surface dissolved oxygen depression was also present within the eastern channel. Relatively warm late summer water temperatures (22-27 °C) and low San Joaquin River inflows into the channel east of Rough and Ready Island appear to have contributed to the low dissolved oxygen concentrations in the eastern channel (Figure 7-6). Average daily flows in the San Joaquin River past Vernalis in July ranged from 1,186 to 1,426 cfs. Net flow in the San Joaquin River past Stockton ranged from 177 to 781 cfs (Figure 7-7).

The surface depression and the bottom sag detected in the eastern channel in July intensified in August, and the dissolved oxygen sag extended into portions of the central channel (Figure 7-5). On August 20, Stations 8 and 9 in the central channel showed surface sag concentrations of 5.0 and 4.1 mg/L respectively. Stations 10 through 13 within the eastern channel also had low surface concentrations ranging from 3.9 to 5.0 mg/L. At the bottom of the channel, the dissolved oxygen sag persisted and included Station 9 (4.4 mg/L) in the central channel along with Stations 10 through 13 in the eastern channel (3.3-4.5 mg/L). The stratification between surface and bottom values remained low at approximately 0.5 to 1.0 mg/L. August water temperatures (22-26 °C) decreased slightly from July water temperatures within the channel (Figure 7-6). August flows in the San Joaquin River at Vernalis were similar to those of July, and ranged from 1,026 to 1,313 cfs. Net flow conditions past Stockton ranged from 114 to 849 cfs (Figure 7-7).

The dissolved oxygen sag detected previously within the channel intensified at both the surface and the bottom in early September as the area expanded westward on September 5 to Station 8 in the central channel and eastward to Station 14 (Turning Basin) (Figure 7-5). Within this extended sag area, a minimum surface measurement of 3.0 mg/L was detected at Station 10, and a minimum bottom measurement of 3.3 mg/L was detected at Station 12. In addition, a surface and bottom depression extended to Station 7 in the central channel where surface and bottom concentrations of 5.6 mg/L and 5.5 mg/L respectively were measured.

By September 19, stratified dissolved oxygen conditions became well established within the central and eastern portions of the channel, as bottom dissolved oxygen levels were generally 2.0 mg/L less than surface levels within these regions. In addition, the dissolved oxygen sag area that had originated within the eastern portion of the channel moved westward into the central channel. There, bottom dissolved oxygen concentrations ranged from 3.7 to 4.9 mg/L between Stations 7 and 9 and surface dissolved oxygen levels at these stations ranged from 5.1 to 6.0 mg/L. In contrast, surface dissolved oxygen conditions at all stations within the eastern channel improved significantly to greater than 6.0 mg/L. Bottom dissolved oxygen levels in the eastern channel were variable and ranged from a high of 7.9 mg/L at Station 13 to a low of 4.3 mg/L at Station 10. The slight improvement in dissolved oxygen conditions was possibly due, in part, to slightly cooler water temperatures and improved flow conditions within the channel. Late September water temperatures ranged from 21 to 24 °C, and were slightly cooler than August water temperatures in the channel (Figure 7-6). The

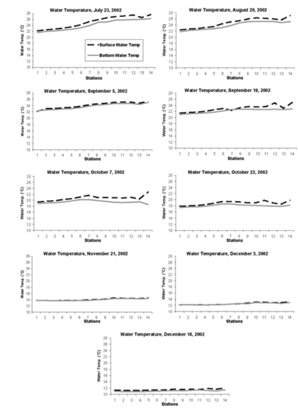


Figure 7-6 Surface and bottom water temperatures, Jul 23–Dec 18, 2002

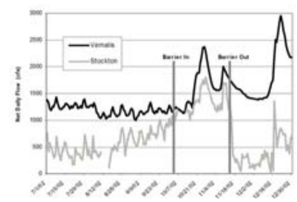


Figure 7-7 Net daily flow on Average daily flows in the San Joaquin River at Vernalis and Stockton, Jul 1–Dec 30, 2002

average daily San Joaquin River flows at Vernalis in September were similar to those of July and August, and ranged from 1,000 to 1,326 cfs (Figure 7-7). However, net daily flows past Stockton in September increased steadily and ranged from 512 to 1,017 cfs.

Dissolved oxygen levels in the eastern channel improved significantly in October as surface levels at all stations were ≥ 8.3 mg/L on October 7 and ≥ 9.0 mg/L on October 22 (Figure 7-5). Bottom dissolved oxygen levels within the eastern channel were also high at ≥ 7.4 mg/L on October 7 and ≥ 8.6 mg/L on October 22. This improvement coincided with the placement of the Barrier on October 4, and an early fall storm that increased average daily San Joaquin River flows past Vernalis from 1,200 cfs in early October to 2,400 cfs by late October. Cooler water temperatures (19-20 °C) may have also contributed to improved dissolved oxygen concentrations within the eastern channel (Figure 7-6).

Increased inflows to the channel may have contributed to the relocation of the sag area westward from the eastern channel into the central channel in early October. Sampling on October 7 showed that surface and bottom dissolved oxygen levels within the central channel at Stations 7 and 8 ranged from 4.6 to 4.8 mg/L. By October 22, sag conditions had disappeared from the channel, as daily San Joaquin River flows past Vernalis in the latter half of the month averaged 1,900 cfs and cooler water temperatures (18-19 °C) prevailed. Net daily flows past Stockton in October ranged from 904 to 1,788 cfs (Figure 7-7).

Due to the increased dissolved oxygen levels in late October the Barrier was removed on November 15. This removal coincided with a return of dissolved oxygen sag conditions in the eastern channel from Stations 10 to 12 and bottom dissolved oxygen levels ranged from 4.8 to 4.9 mg/L (Figure 7-5). A surface depression was present throughout the eastern channel with values ranging from a low at Station 10 of 5.4 mg/L and a high at Station 13 of 5.9 mg/L. The central portion of the channel showed sustained improvement as only Station 9 had slight surface and bottom dissolved oxygen depressions of 5.7 and 5.4 mg/L, respectively.

Decreased inflows to the channel may have contributed to the return of sag conditions within the eastern channel in November. Net flows past Stockton were high in early November one week prior to removal of the Barrier, but dropped dramatically from a high of 1,687 cfs to a low of 49 cfs one week after the Barrier was removed. Although flows at Vernalis remained between 1,400 and 3,000 cfs for the remainder of the year, net flows past Stockton remained below 500 cfs with the exception of a brief pulse flow and moderate increase in mid-December (Figure 7-7). Cooler water temperatures (13.7-14.6 °C) in late November were apparently insufficient to compensate for reduced inflows to the channel (Figure 7-6).

The relatively low inflow conditions to the eastern channel continued as the net daily San Joaquin River flow past Stockton through December generally ranged from 9 to 836 cfs, with a one-day pulse flow of 1,340 cfs on December 17, 1002 (Figure 7-4). On December 3, dissolved oxygen values in the eastern channel were exceptionally low, ranging from 3.6 mg/L at

Station 10 to 4.6 mg/L at Station 13 at the surface, and 3.3 mg/L at Station 11 to 4.9 mg/L at Station 13 at the bottom (Figure 7-5). This sag occurred in spite of relatively cool water temperatures of 12.9 to 13.0 °C within this region (Figure 7-6). Dissolved oxygen conditions in the central channel were similar to those measured in late November, with a surface and bottom dissolved oxygen depression present only at Station 9.

Improved net San Joaquin River inflows past Stockton in late December and cooler water temperatures (11.3-12.8 °C) may have contributed to the slightly improved dissolved oxygen conditions detected within the eastern channel on December 18. Dissolved oxygen levels in the eastern channel stations increased by an average of 2.0 mg/L over surface and bottom dissolved oxygen concentrations measured in early December. However, a bottom dissolved oxygen sag of 4.9 mg/L was detected at Station 11 and depressed dissolved oxygen conditions were present at the surface and bottom of the remaining stations, with the exception of the surface measurement of 6.5 mg/L at Station 11. The gradual improvement coincided with cooler water temperatures (11.1-11.6 °C) in the eastern channel. Dissolved oxygen conditions in the central and western portions of the channel were well mixed (unstratified) and were exceptionally high (≥ 9.6 mg/L) throughout the western channel. Because of the improving conditions, the 2002 dissolved oxygen special studies were terminated on December 18.

Highly stratified dissolved oxygen conditions were detected in the Stockton Turning Basin (Station 14) throughout much of fall 2002 (Figure 7-5). Sampling on August 20, September 19, October 7, and October 22 showed surface dissolved oxygen concentrations ranging from 9.6 to 18.1 mg/L, and bottom dissolved oxygen concentrations ranging from 3.4 to 7.6 mg/L. Sampling on September 5 indicated that the marked vertical stratification (9.6 mg/L at the surface and 3.4 mg/L at the bottom) detected on August 22 had subsided, as surface and bottom dissolved oxygen concentrations, at 4.1 and 4.6 mg/L, respectively, were similar. Sampling on November 21 indicated that a second and more sustained (late September through October) period of vertical stratification had subsided, with surface and bottom dissolved oxygen concentrations of 6.3 and 5.0 mg/L respectively. Sampling on December 3rd and 18 showed that dissolved oxygen stratification had subsided as all surface and bottom dissolved oxygen measurements were < 4.0 mg/L and were within 1.0 mg/L of each other.

The periodic dissolved oxygen stratification appears to be the result of localized biological and water quality conditions occurring in the Turning Basin. The Basin is at the eastern dead-end terminus of the Stockton Ship Channel and is subject to reduced tidal activity, restricted water circulation, and increased residence times when compared to the remainder of the channel. As a result, water quality and biological conditions within the Basin have historically differed from those within the main downstream channel, and have led to extensive late summer and fall algal blooms and die-offs. The late summer and early fall of 2002 were no exception, as intense algal blooms composed primarily of green algae, flagellates, diatoms, and Cryptomonads were detected.

Stratified dissolved oxygen conditions often occur in the water column as a result of these blooms. At the surface, these blooms are highly productive and can produce markedly high surface dissolved oxygen levels. However, dead or dying bloom algae can sink to the bottom to contribute to high biochemical oxygen demand and low bottom dissolved oxygen levels. Bottom dissolved oxygen levels in the basin are further degraded by additional biochemical oxygen demand loadings in the area from sources such as regulated discharges into the San Joaquin River and non-point pollution adjacent to the basin. When bloom activity subsides, the dissolved oxygen stratification is reduced, and basin surface and bottom dissolved oxygen levels become less stratified.

Summary

Dissolved oxygen concentrations in the eastern Stockton Ship Channel consistently fell below both the 5.0 mg/L and 6.0 mg/L objectives in both 2001 and 2002 due, in part, to relatively low net flows in the San Joaquin River past Stockton and to warm water temperatures. To alleviate low dissolved oxygen levels, a temporary Barrier across the head of Old River was installed in October of both years to increase flows down the main channel of the San Joaquin River into the channel.

In 2001, dissolved oxygen levels throughout the channel remained at greater than 6.0 mg/L after mid-October due to cooler water temperatures and improved inflows. However, in 2002, dissolved oxygen levels dropped below 6.0 mg/L in the eastern channel on November 21, and dropped further, to less than 4.0 mg/L in much of the eastern channel, on December 3. The removal of the Barrier on November 15, 2002, contributed to reduced net flows past Stockton, and likely contributed to low dissolved oxygen levels in late fall 2002 .

Dissolved oxygen conditions improved slightly on December 18, 2002, with surface dissolved oxygen levels greater than 6.0 mg/L in much of the eastern channel, and bottom dissolved oxygen values in the eastern channel greater than 5.0 mg/L. Significantly cooler water temperatures (11.3-12.8 °C) along with a moderate increase in net daily San Joaquin River flows past Stockton in December appear to have ultimately contributed to sustained improvement of dissolved oxygen conditions.

References

[APHA] American Public Health Association. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th Edition. Washington, D.C.

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

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

Figure 7-1 Monitoring sites in the Stockton Ship Channel

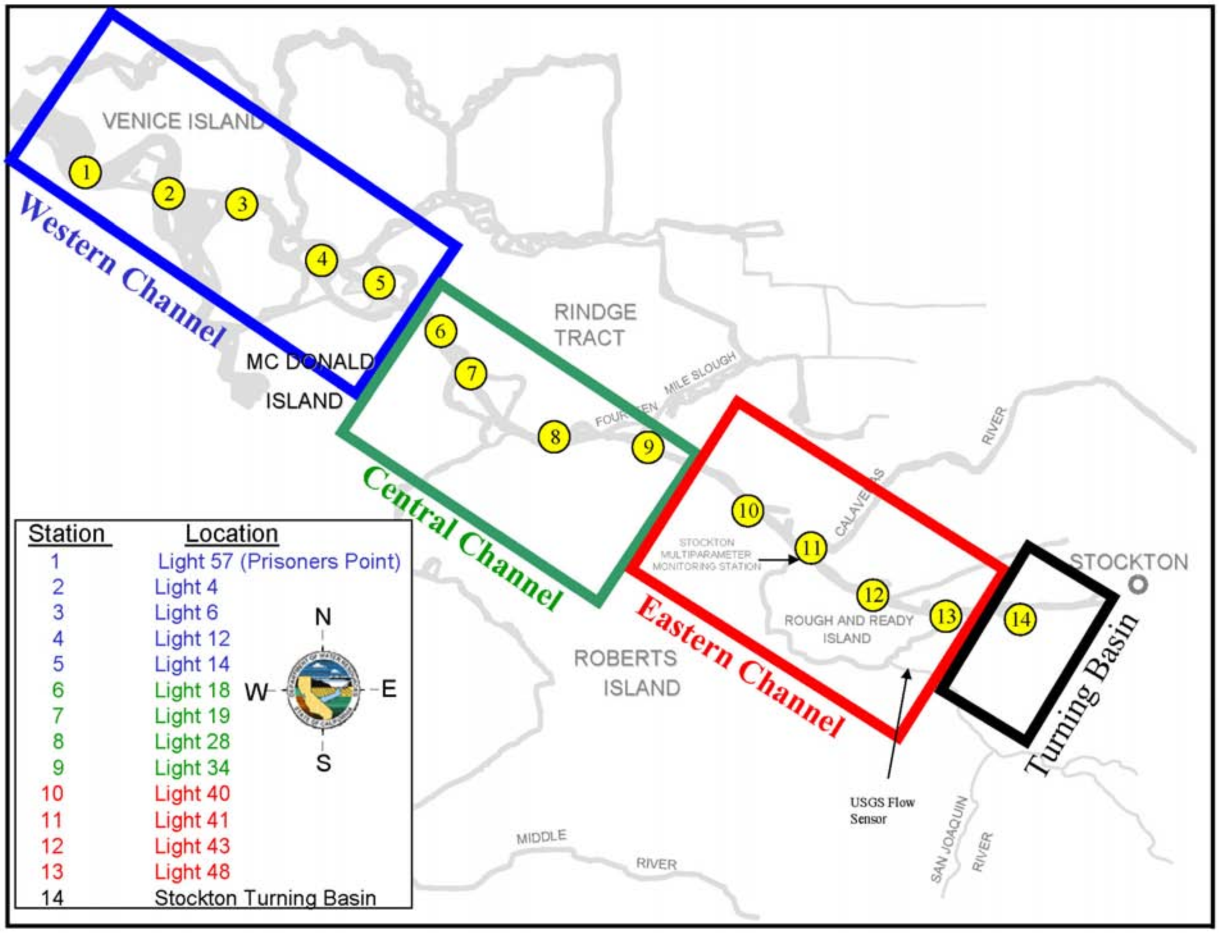


Figure 7-2 Dissolved oxygen levels, Aug 1–Dec 5, 2001

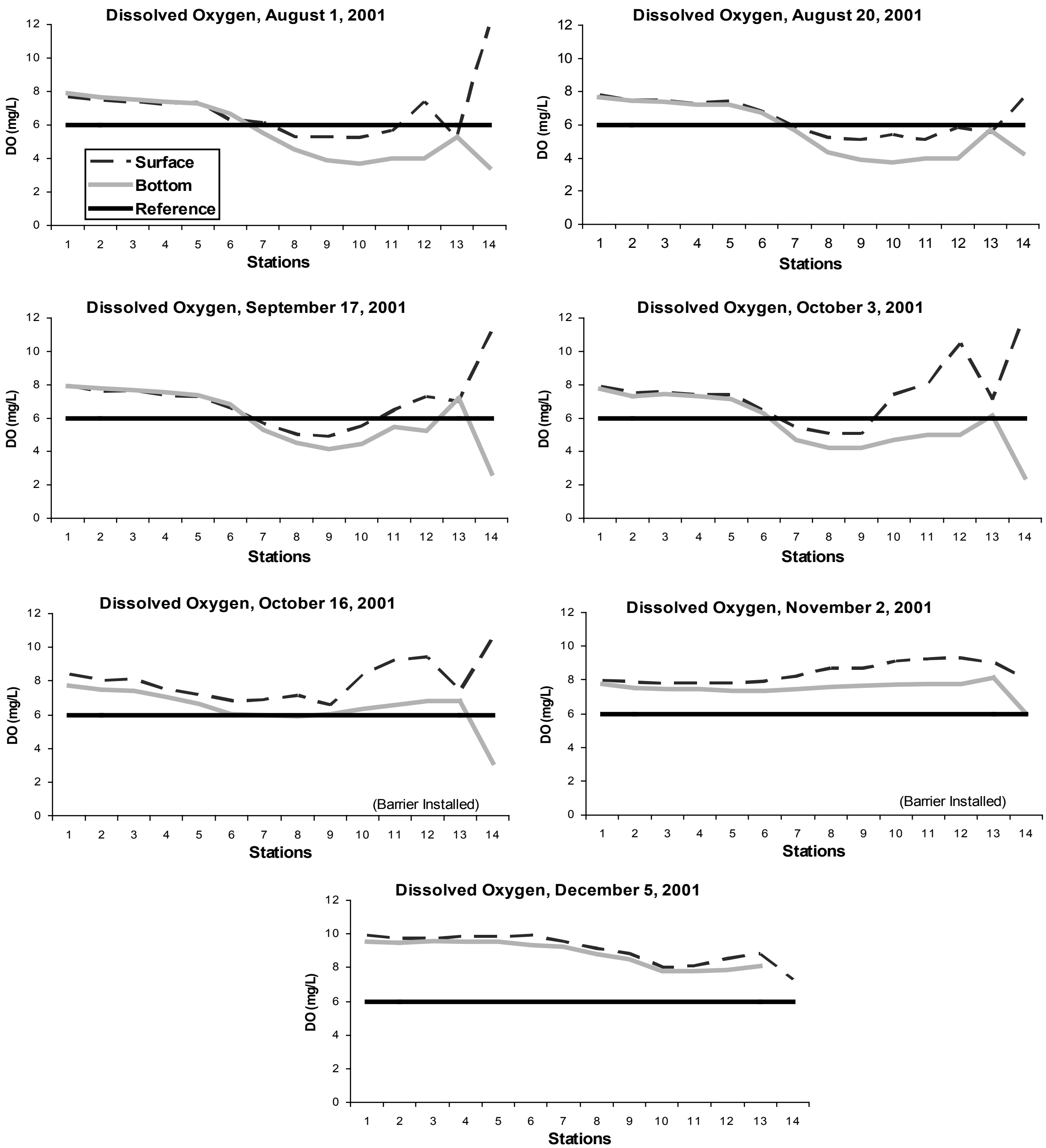


Figure 7-3 Surface and bottom water temperatures, Aug 1–Dec 5, 2001

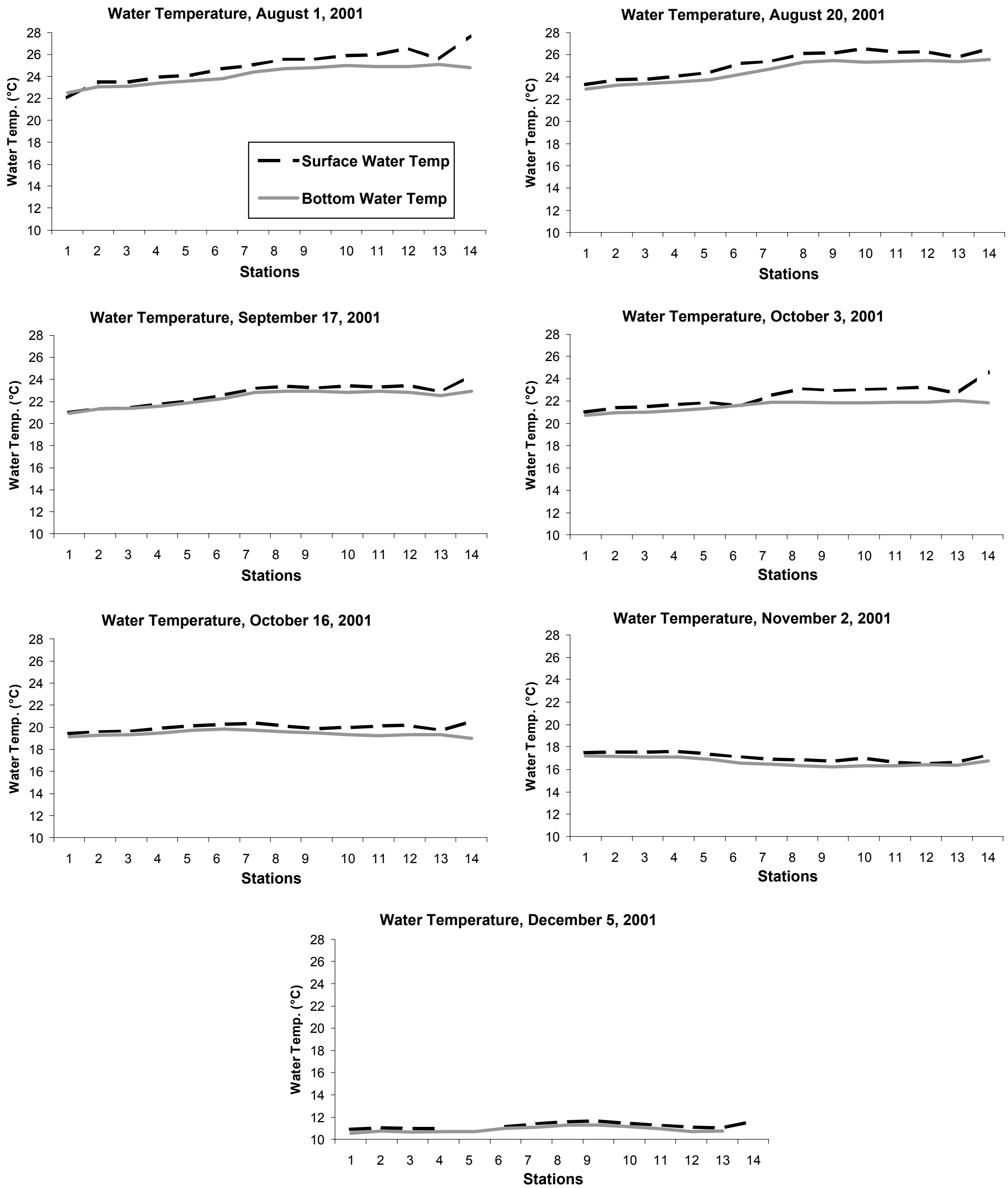


Figure 7-4 Average net daily flows in the San Joaquin River at Stockton and Vernalis, Jul 1–Dec 30, 2001

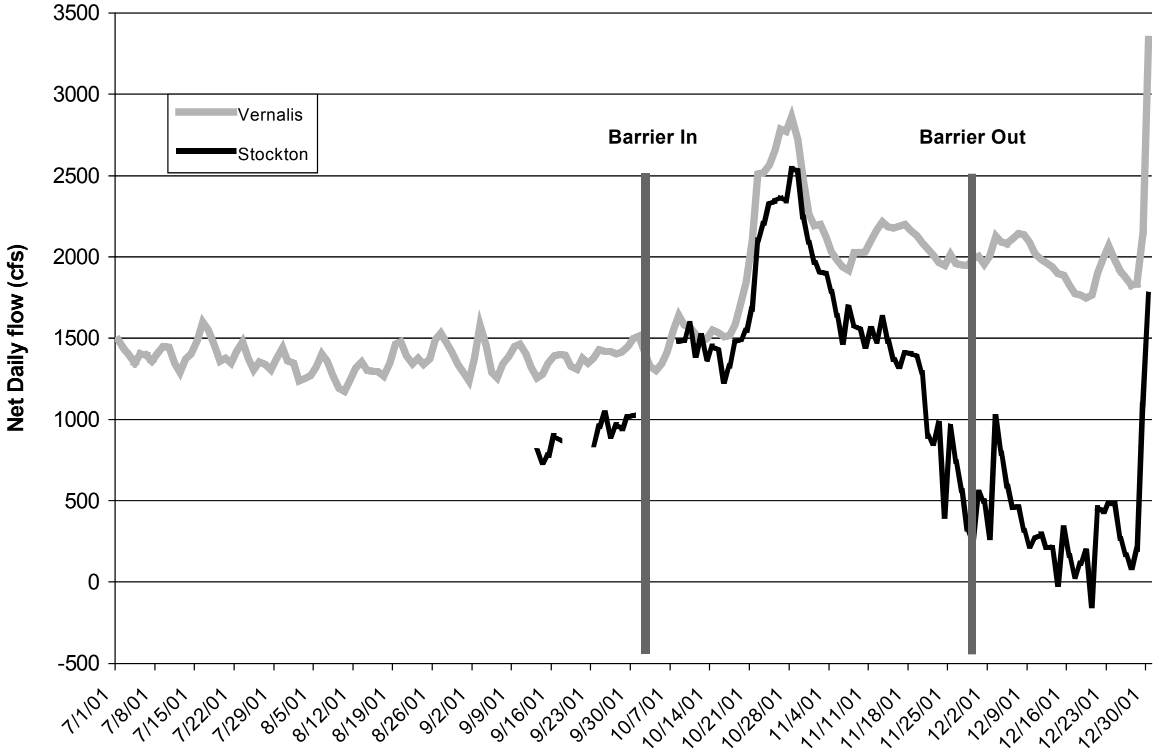


Figure 7-5 Surface and bottom dissolved oxygen, Jul 23–Dec 18, 2002

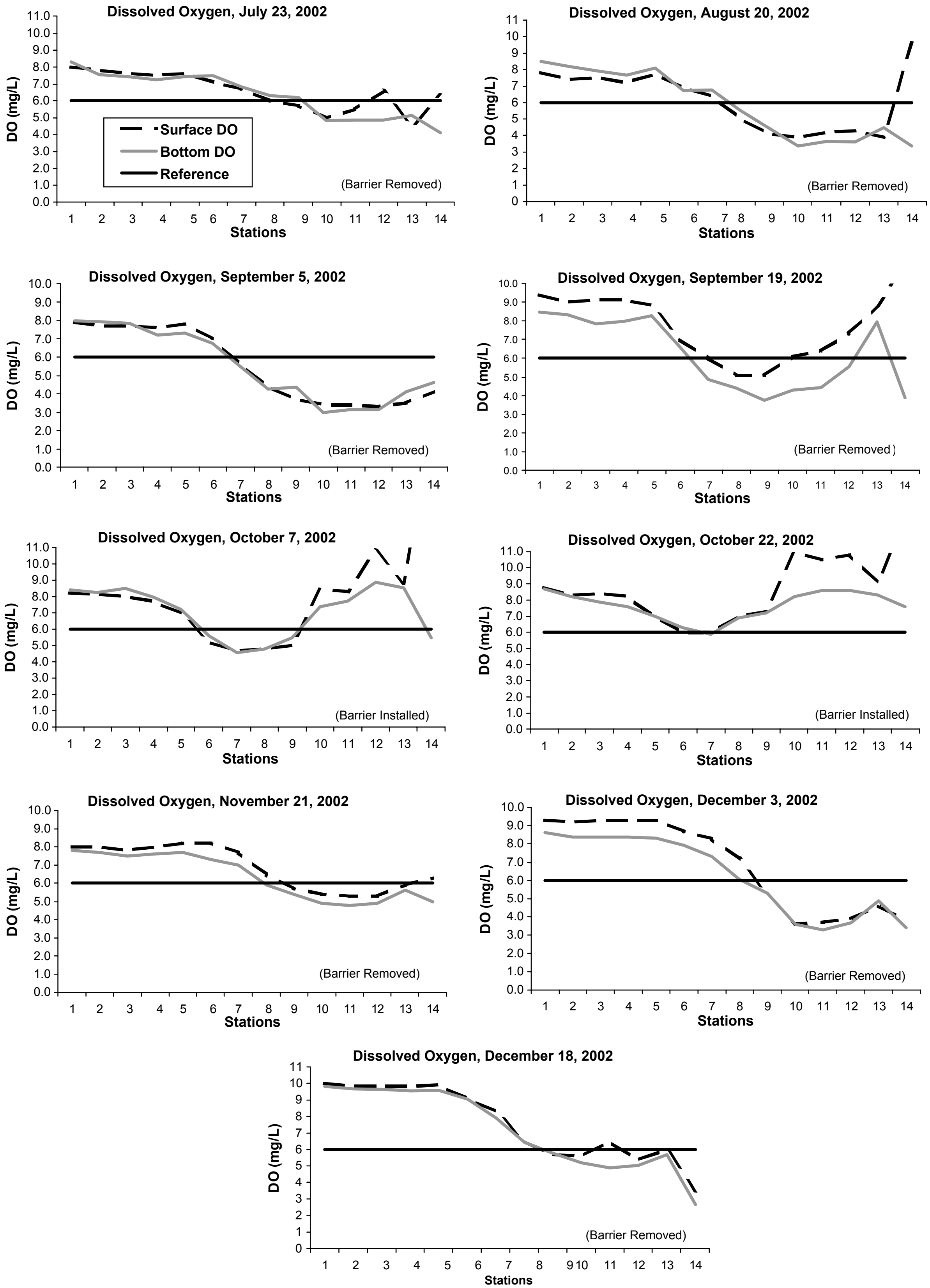


Figure 7-6 Surface and bottom water temperatures, Jul 23–Dec 18, 2002

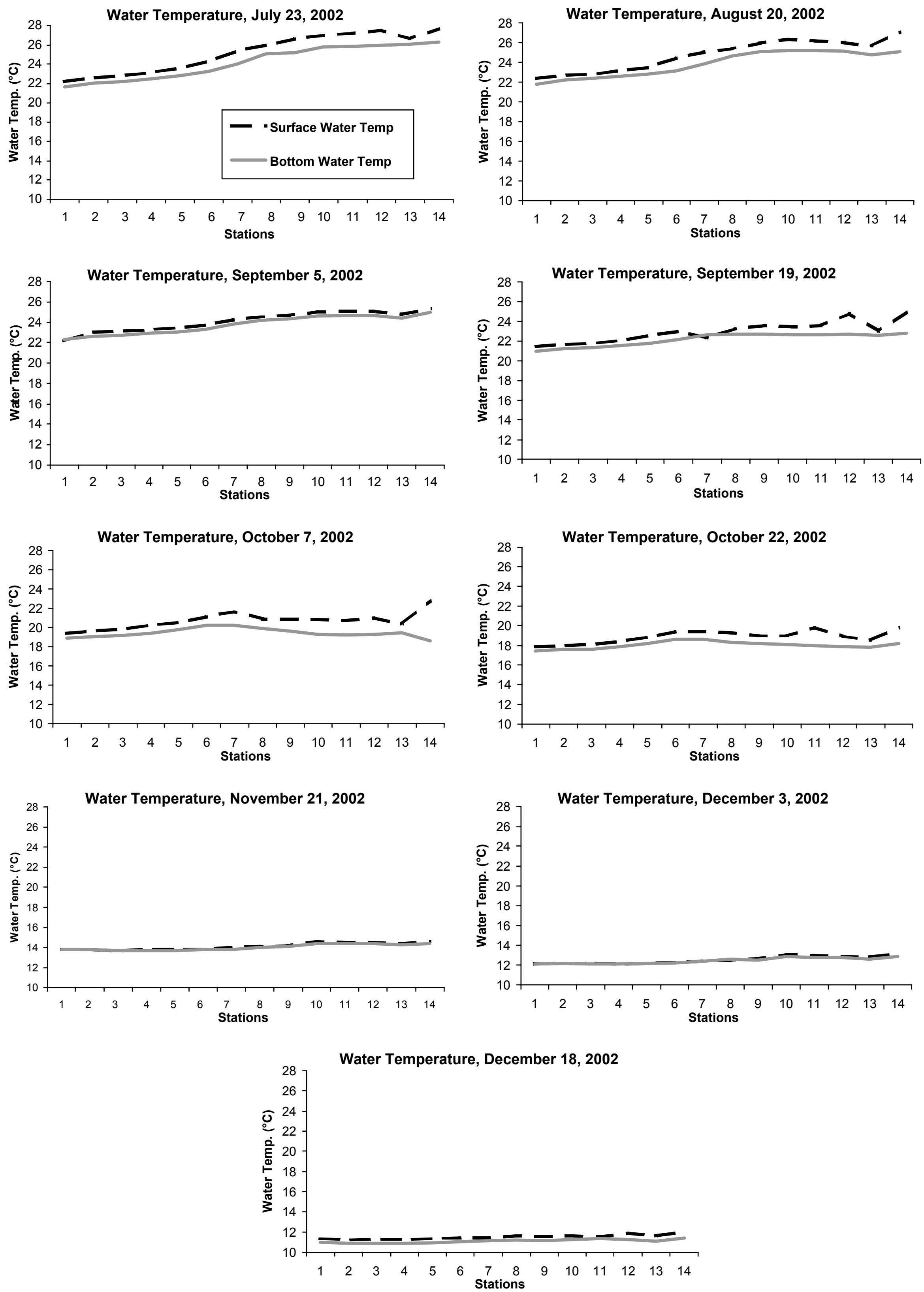
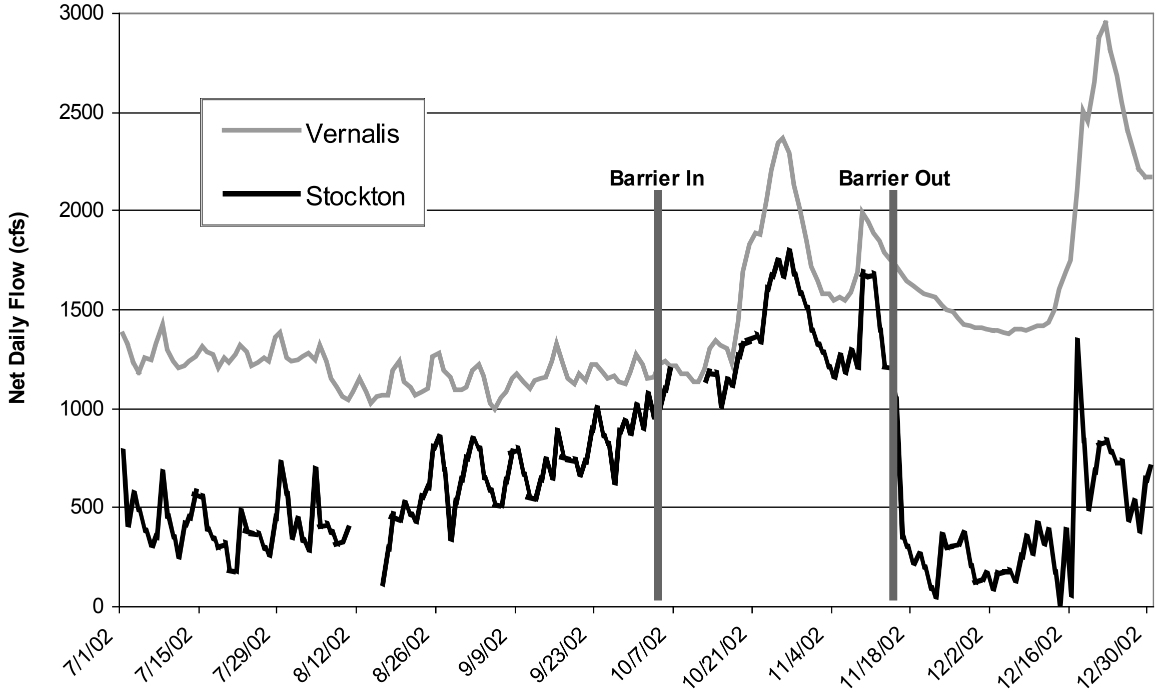


Figure 7-7 Average net daily flow in the San Joaquin River at Vernalis and Stockton, Jul 1–Dec 30, 2002



Chapter 8
Data Management, 2001-2002

Introduction

All data collected by the Environmental Monitoring Program (EMP) are stored in digital format for data management and dissemination. Each monitoring element (discrete and continuous water quality, benthic, phytoplankton, and zooplankton) has a particular method of data entry, quality control, management, and dissemination. All data, except zooplankton and sediment composition, can be downloaded via the World Wide Web, either from the Bay Delta and Tributaries database (BDAT) or from the Interagency Ecological Program's Data Storage System (IEP-DSS).

BDAT consolidates and provides public access to environmental data contributed by more than fifty organizations. The database includes water quality, biological, and meteorological data from throughout the Sacramento-San Joaquin Estuary's watershed. The EMP's discrete water quality, benthic and phytoplankton data stored in this database are available over the Internet at: http://baydelta.water.ca.gov.

IEP is a joint effort by state and federal agencies to gather and provide information on the factors that affect ecological resources in the Sacramento-San Joaquin Estuary. IEP compiles extensive hydrodynamic and water quality data collected by different agencies at more than 120 sampling stations in the Delta and its tributaries. These data are stored in a Data Storage System (DSS) developed by the US Army Corps of Engineer's Hydrologic Engineering Center. In the future these time-series data will be integrated into the BDAT database. The EMP's continuous water quality data are now available through the IEP-DSS at: http://www.iep.water.ca.gov/dss/

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

Metadata information—describing, in detail, sampling site locations, sampling methodology, and field and laboratory processing for all the data variables—is available on the IEP website at:
http://www.iep.water.ca.gov/emp/Metadata/metadata_index.html

Complete metadata files are available for the benthic and phytoplankton monitoring elements of this program. Metadata files are being developed for continuous water quality and the zooplankton monitoring elements. These files also provide contact information for staff responsible of each monitoring element.

Data Management Procedures

The procedures for handling each type of EMP data are described below. The description includes where the data are stored, how the data are checked for quality, what data are available, how to obtain these data, and who is responsible for managing the data for each monitoring element. Water quality is monitored with both discrete and continuous sampling. The discrete monitoring sites are surveyed monthly, primarily by vessel. The continuous monitoring stations are equipped with automated probes and data recorders that log data every 10 minutes to 1 hour depending on the water quality variable.

Discrete Water Quality Data

During monthly sampling runs, field measurements are recorded on paper datasheets and entered into the field module of DWR's Field and Laboratory Information Management System (FLIMS) using a portable computer. Later, laboratory analyses are performed at DWR's Bryte Laboratory, and the results are entered by laboratory staff into the lab module of the FLIMS database. Data are then loaded electronically into the EMP's Discrete Water Quality database, which is implemented using Microsoft Access. This Access database is the reference database for this program element. EMP staff periodically review the data for accuracy, completeness, and consistency against paper datasheets records. Data are then exported electronically to BDAT each month.

Discrete water quality data from 1975 to present are available for download through the BDAT web interface at http://baydelta.water.ca.gov/index.html.

For more information regarding management of and access to discrete water quality data, contact Scott Waller at swaller@water.ca.gov.

Continuous Water Quality Data

Data from automated continuous water quality monitoring stations are downloaded from each station's data recorders onto a handheld "pocket PC". Upon return to the office, data are loaded in a Microsoft Excel spreadsheet. EMP staff review these data for accuracy, completeness, and consistency using probe verification and calibration records. Data that are determined to be the result of a measuring instrument that was operating out of proper calibration are flagged as "bad", and are retained in the spreadsheet file. The collection of Excel spreadsheets constitutes the reference database for this program element. Selected data (temperature, dissolved oxygen, electroconductivity, pH, and river stage) are uploaded electronically into the IEP-DSS. However, data flagged as "bad" are not transferred.

Continuous water quality data from 1983 to present are available for download at the IEP DSS database at: http://iep.water.ca.gov/dss/

EMP staff members are currently developing a comprehensive continuous water quality database that will become the reference database and will be available for export data to BDAT.

For more information regarding management of and access to continuous water quality data, please contact Mike Dempsey at: mdempsey@water.ca.gov.

Benthic Data

Benthic sampling sites are surveyed monthly by vessel. Laboratory identification and enumeration of macrobenthic organisms in each sample is performed by Hydrozoology, a private laboratory under contract with DWR. The results are reported to DWR on standard paper datasheets. Laboratory analysis of sediment samples is performed by DWR's Soils and Concrete Laboratory. The results of the sediment analyses are provided to EMP staff in a written report.

Both sediment and benthic organism data are entered into the EMP Benthic database, which was implemented using Microsoft Access database software. This Access database is the reference database for this program element. EMP staff periodically reviews the data for accuracy, completeness and consistency. Data are exported electronically to BDAT each month.

Benthic data from 1975 to present are available for download through BDAT's Web interface at: http://baydelta.water.ca.gov/index.html.

Sediment composition data gathered by the benthic monitoring element have been exported to BDAT, but are not yet available for download via the Internet.

For more information regarding benthic or sediment data, please contact Karen Gehrts at: kagehrts@water.ca.gov.

Phytoplankton Data

Phytoplankton sampling sites are surveyed monthly, primarily by vessel. DWR's Bryte Laboratory identifies, enumerates, and measures the size of the phytoplankton from these samples. These data are entered into the EMP Phytoplankton database using Microsoft Access software. This Access database is the reference database for the phytoplankton monitoring element. EMP staff periodically reviews the data for accuracy, completeness, and consistency. Data are exported electronically to BDAT each month.

Phytoplankton data from 1975 to present are available for download through the BDAT web interface at: http://baydelta.water.ca.gov/index.html.

For more information regarding phytoplankton data, please contact Shaun Philippart at: sphilipp@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 Department of Fish and Game's Central Valley Bay-Delta Branch Laboratory. The results are entered into a computer at the DFG office and stored electronically in a SAS statistical package format. Data are periodically reviewed for accuracy and completeness by DFG staff. Currently zooplankton data are only available through DFG; however, construction is under way for a zooplankton database that is able to export data to BDAT.

Data are available upon request from Lee Mecum at: lmecum@delta.dfg.ca.gov.

Chapter 9
Continuous Monitoring, 2001-2002

Introduction

The Continuous Monitoring Program supplements the Department of Water Resources' monthly discrete Compliance Monitoring Program by providing real-time hourly and quarter hourly water quality and environmental data from seven shore-based automated sampling stations located in the upper San Francisco Estuary (Figure 9-1). These stations provide continuous measurements of seven water quality parameters and four environmental parameters, which 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 report summarizes the results of continuous water quality monitoring at seven sites for calendar years 2001 and 2002.

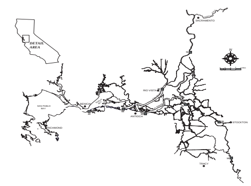


Figure 9-1 Monitoring station locations

Methods

Continuous data are collected for the water quality and environmental parameters shown in Table 9-1. Each of the seven monitoring stations collects continuous data for water temperature, pH, dissolved oxygen, and surface specific conductance. In addition, chlorophyll fluorescence data is recorded at four locations: two on the Sacramento River (Rio Vista and Mallard Island stations) and two on the San Joaquin River (Antioch and Stockton stations). Additional sensors at the Antioch, Mallard Island, and Martinez stations monitor bottom specific conductance at 1.5 meters above the channel bottom. These measurements, along with river stage data measured at the Mallard and Martinez stations, are needed to determine compliance with the salinity standard (also known as X2) mandated by the Bay-Delta Plan (SWRCB 1995). Environmental data (such as air temperature, solar radiation, wind speed, and direction) are measured at all stations, with the exception of Mossdale (only air temperature) and Hood stations (no environmental data recorded).

Except for bottom specific conductance, all water samples are collected at one meter below the water surface using a float-mounted pump and then distributed to the water quality sensors. A data acquisition, control, and telemetry system (Ocean Data Equipment model DACTS-80-26) scans the output from the sensors once per second and records the hourly average of these approximately 3,600 readings on the hour. Bottom specific conductance and environmental data (such as solar radiation, wind speed and wind direction data) are recorded at 15-minute intervals.

Complete hourly or quarter-hourly data for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, and river stage are available from the Interagency Ecological Program database http://wwwiep.water.ca.gov/dss/all/. Data for all other measured parameters are available by request to the Chief of the Real Time Monitoring and Support Section[1].

Table 9-1 Parameters Measured by the Continuous Monitoring Program

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

Results

The monthly averages of the continuous 15-minute or hourly data collected for air and water temperature, pH, dissolved oxygen, surface and bottom specific conductance, and chlorophyll fluorescence for calendar years 2001 through 2002 are shown in Figures 9-2 to 9-8.

Water Temperature

Water temperature was measured in degrees Centigrade (°C) using a Schneider Instruments RM25C-031 Temperature Parametric System.

Monthly average water temperatures in the Estuary for the two-year period ranged from 8.4 °C in January 2001 at the Rio Vista station on the Sacramento River to 26.5 °C in July 2002 at the Stockton station on the San Joaquin River (Figure 9-2).

Average monthly water temperatures at Hood and Rio Vista stations on the Sacramento River were 1º to 2º C lower than the same average temperatures at the inland stations of Stockton and Mossdale on San Joaquin River.

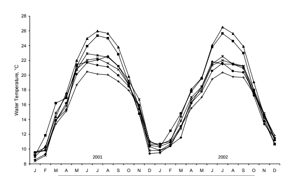


Figure 9-2 Average monthly water temperature at Seven Stations, 2001- 2002

Dissolved Oxygen

Dissolved oxygen was measured using a Schneider Instruments RM25C-033 utilizing a Clark polarographic probe.

[1] Send written request to: Chief, Real-Time Monitoring and Support Section, Division of Environmental Services, Office of Water Quality, Environmental Water Quality and Estuarine Studies Branch, 3251 S Street, Sacramento CA 95816

Average monthly dissolved oxygen values for the seven monitoring stations ranged from 3.1 mg/L to 13.6 mg/L (Figure 9-3). The greatest degree of variability was seen at the San Joaquin River stations of Stockton and Mossdale. A low monthly average of 3.1 mg/L was calculated for the Stockton station in August 2002, and a high monthly value of 13.6 mg/L was calculated for the Mossdale station for July 2002. All other stations showed monthly averages between 7.7 mg/L and 10.6 mg/L. All compliance monitoring stations, except the Stockton station, recorded values above the standard of 5.0 mg/L set by the Central Valley Regional Water Quality Control Board in the Basin Plan (CVRWQCB 1998). Average monthly dissolved oxygen values at the Stockton station were highly variable, and ranged from 3.1 mg/L to 8.5 mg/L.

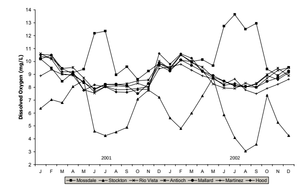


Figure 9-3 Average monthly dissolved oxygen at seven stations, 2001-2002

During the summer and fall of both study years, monthly average dissolved oxygen values at the Mossdale station were exceptionally high. Dissolved oxygen during the months of June and July 2001 ranged from 12.3 mg/L to 12.5 mg/L. Average monthly dissolved oxygen values in 2002 showed a similar pattern from June to September, ranging from 12.5 mg/L to 13.6 mg/L. The high average summer DO levels seen at the Mossdale station coincided with high chlorophyll fluorescence during the same period.

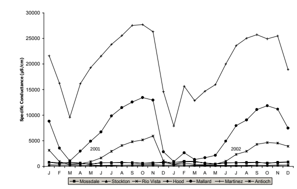


Figure 9-4a Average monthly surface specific conductance at seven stations, 2001-2002

Specific Conductance

Specific conductance was measured using a Schneider Instruments RM25C-032 measuring system.

Average monthly surface specific conductance for the Estuary for the two-year period ranged from 168 µS/cm to 31,000 µS/cm, with the lower values in the Sacramento River at Hood and the higher values at the more tidally influenced Martinez station (Figure 9-4a). Data taken from the Mossdale and Stockton stations on the San Joaquin River show a higher average specific conductance than the stations of Hood and Rio Vista on the Sacramento River (Figure 9-4b). For clarity, these data are shown separately in Figure 9-4b.

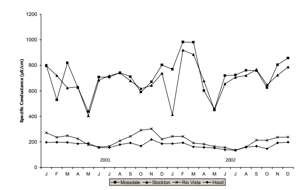


Figure 9-4b Average monthly surface specific conductance at four stations, 2001-2002

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

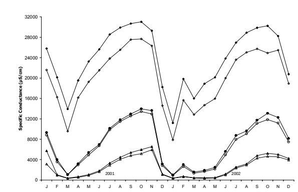


Figure 9-5 Average monthly surface and bottom specific conductance at three stations, 2001-2002

pH

A Schneider Instruments RM25C-035 measuring system was used to measure pH.

Monthly average pH levels for the Estuary for the two-year period at all stations ranged from 7.3 to 8 pH units, with the exception of Mossdale where pH values in June, July, August, and September ranged from 8.3 to 8.9 pH units (Figure 9-6). This increased pH coincided with high chlorophyll fluorescence observed at Mossdale during the same period.

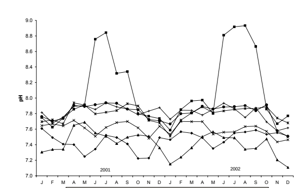


Figure 9-6 Average monthly pH at seven stations, 2001-2002

Air Temperature

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

Monthly average air temperatures in the Estuary for the two-year period ranged from 6.7 °C in January 2001 at the Stockton station on the San Joaquin River, to 24.4 °C at the Mossdale station on the San Joaquin River (Figure 9-7). A 1°C average temperature drop occurred from March to April 2001 at all stations except Martinez.

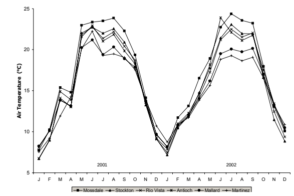


Figure 9-7 Average monthly air temperature at six stations, 2001-2002

Chlorophyll Fluorescence

Chlorophyll fluorescence was measured using a Turner Designs Model 10 Fluorometer set-up with a continuous flow system using chlorophyll *a* filters.

Monthly average chlorophyll fluorescence was recorded at four continuous monitoring stations in the Estuary: one station on the Sacramento River at Rio Vista, and three on the San Joaquin River at Mossdale, Stockton, and Antioch (Figure 9-8). The recorded values ranged from 8.5 fluorescence units (FU) on November 2001 at the Rio Vista station on the Sacramento River, to 229 FU on August 2002 at the Mossdale station on the San Joaquin River.

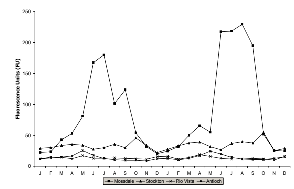


Figure 9-8 Average monthly chlorophyll fluorescence at four stations, 2001-2002

Stockton Ship Channel Dissolved Oxygen

As part of DWR's mandate for monitoring water quality in the Delta, a special monitoring study is focused on dissolved oxygen 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 #20) supplements monthly discrete sampling, and alerts DWR personnel when dissolved oxygen levels become critical.

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

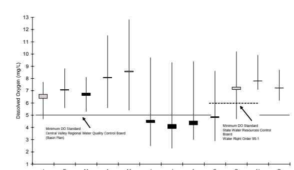


Figure 9-9 Hourly and average monthly dissolved oxygen. San Joaquin river at Stockton, 2001

For the year 2001, average monthly DO values at the Stockton station remained above the 6.0 mg/L objective during October and November, but fell below 6.0 mg/L in September (Figure 9-9). In 2002, average monthly DO levels were above the 6.0 mg/L standard in October, but were below the objectives in both September and November (Figure 9-10).

Hourly DO values ranged from 2.3 to 12.8 mg/L in 2001. The lowest DO values occurred from June through September, with values well below the State objectives. Monthly average DO values were also well below the standards during these months. In 2002, hourly values ranged from 1.2 to 11.9 mg/L. The minimum value of 1.2 mg/L recorded in July 2002 was the lowest value recorded in the last five years. Similar to 2001, the lowest DO levels in 2002 also occurred during the summer months of July, August, and

September; however, DO levels were much more variable, and low monthly and hourly DO levels occurred in winter months as well. The pattern of falling in DO levels in the winter was seen to a lesser degree in the 2001 data, and continues a trend that was first observed in 2000.

The box plots (Figure 9-9 and 9-10) show the maximum and minimum range of average hourly DO values for the month, along with monthly medians and averages. Horizontal "whiskers" indicate the range of hourly DO values for each month. Boxes represent monthly medians and averages. Open boxes indicate that the monthly median is greater than the monthly average, with the top of the box indicating the median, and the bottom of the box indicating the average. Filled boxes indicate that the monthly average is greater than the median, with the top of the box indicating the average and the bottom of the box indicating the median. A horizontal dashed line indicates that the median and the average are equal.

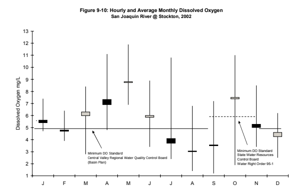


Figure 9-10 Hourly and average monthly dissolved oxygen. San Joaquin River at Stockton, 2002

Summary

Water quality conditions in the upper San Francisco Estuary for the calendar years 2001 and 2002 were in the expected range of values for water temperature, dissolved oxygen, specific conductance, pH, air temperature, and chlorophyll *a* fluorescence at the Sacramento River stations. The exceptions were found on the San Joaquin River.

The San Joaquin River station at Mossdale showed higher dissolved oxygen, pH, and chlorophyll *a* fluorescence values during the months of June, July August, and September, as compared with other stations in the Estuary. Dissolved oxygen levels ranged from 12.3 to 13.6 mg/L. The pH values ranged from 8.3 to 8.9 pH units, and chlorophyll *a* fluorescence values ranged from 101 to 229 FU.

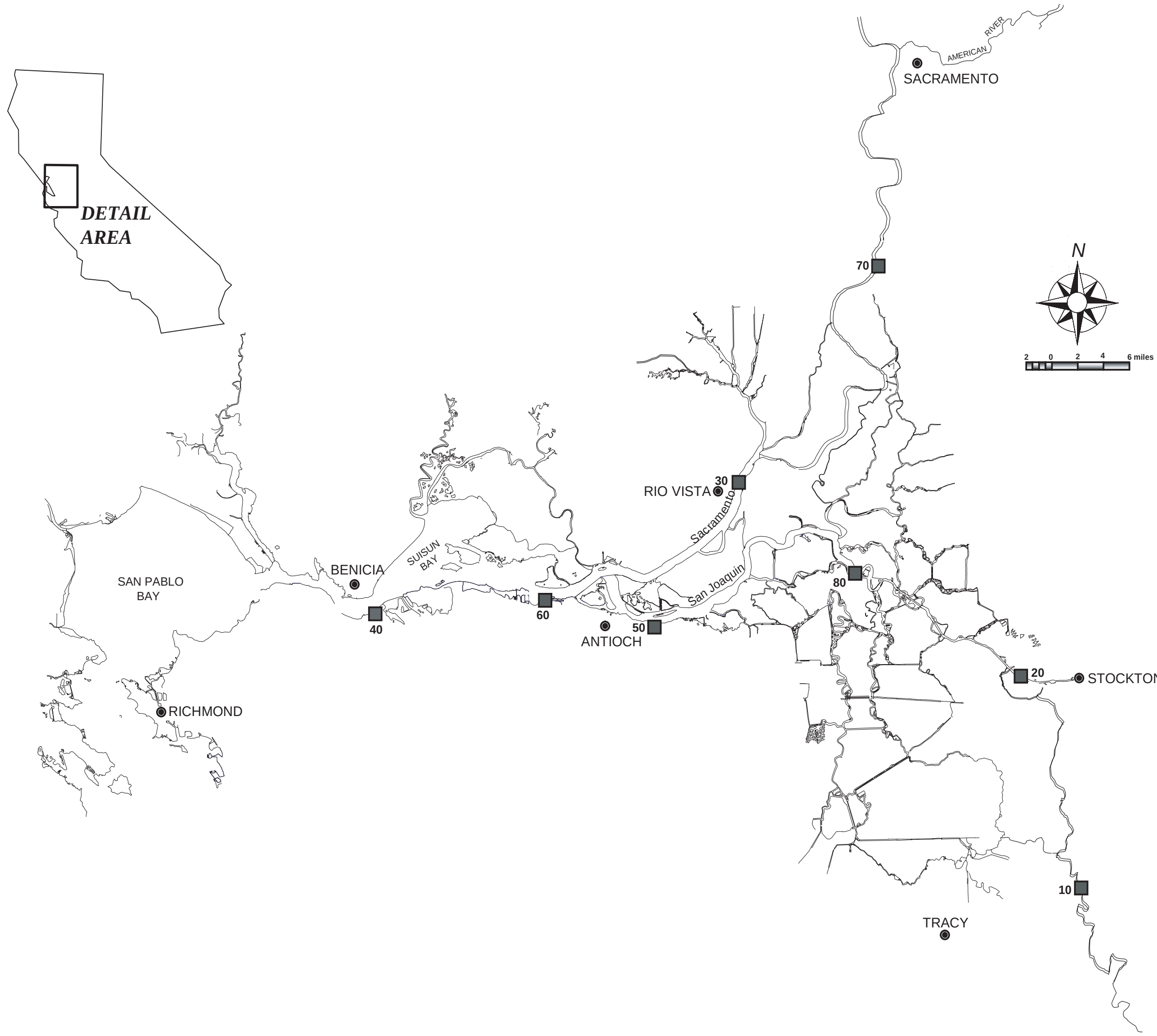
The San Joaquin River station at Stockton, unlike other stations in the Estuary, showed a dissolved oxygen sag below the 5.0 mg/L state objective (CVRWQCB 1998) for the months of June, July, and August 2001 and 2002, as well as a second sag below 5.0 mg/L in November and December 2002.

References

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

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

Figure 9-1 Monitoring Station Locations



Station #	Location	IEP HEC-DSS database ID
10	San Joaquin River at Mossdale	RSAN087
20	San Joaquin River at Stockton	RSAN058
30	Sacramento River at Rio Vista	RSAC101
40	Sacramento River at Martinez	RSAC054
50	San Joaquin River at Antioch	RSAN007
60	Sacramento River at Mallard Island	RSAC075
70	Sacramento River at Hood	RSAC142
80	San Joaquin River at Prisoners Point (seasonal station)	RSAN037

Figure 9-2 Average monthly water temperature at seven stations, 2001-2002

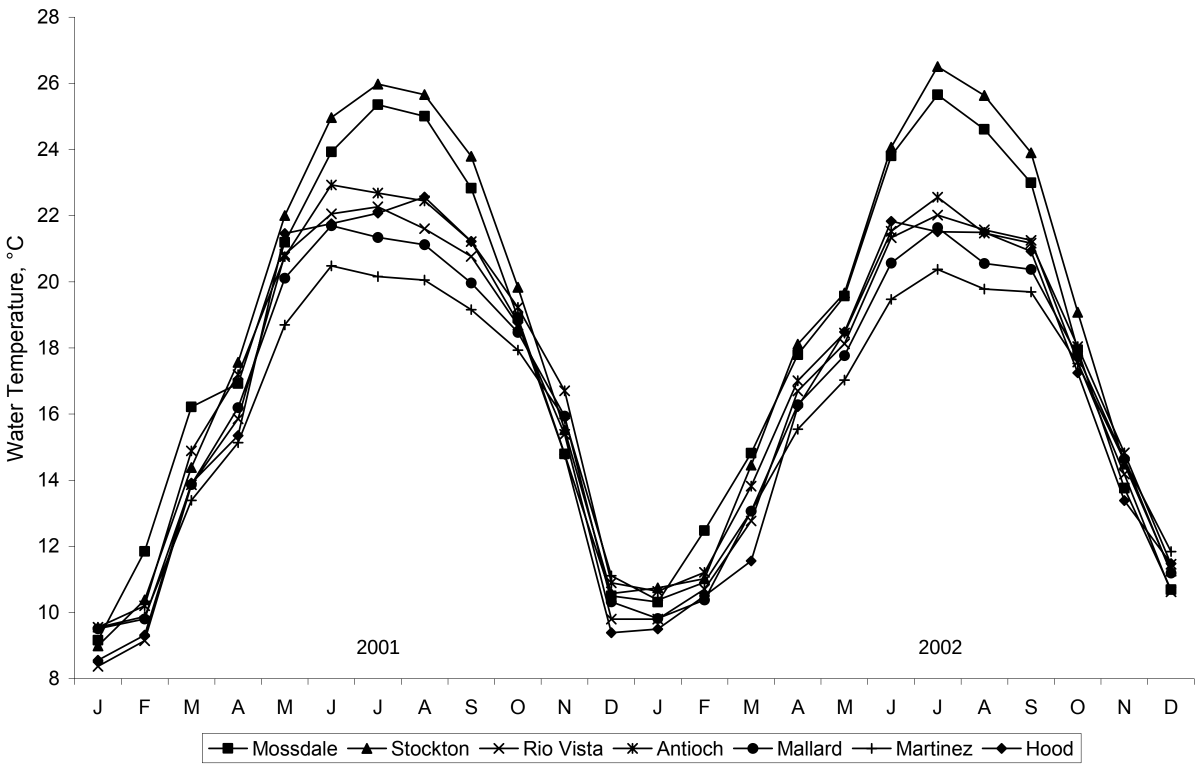


Figure 9-3 Average monthly dissolved oxygen at seven stations, 2001-2002

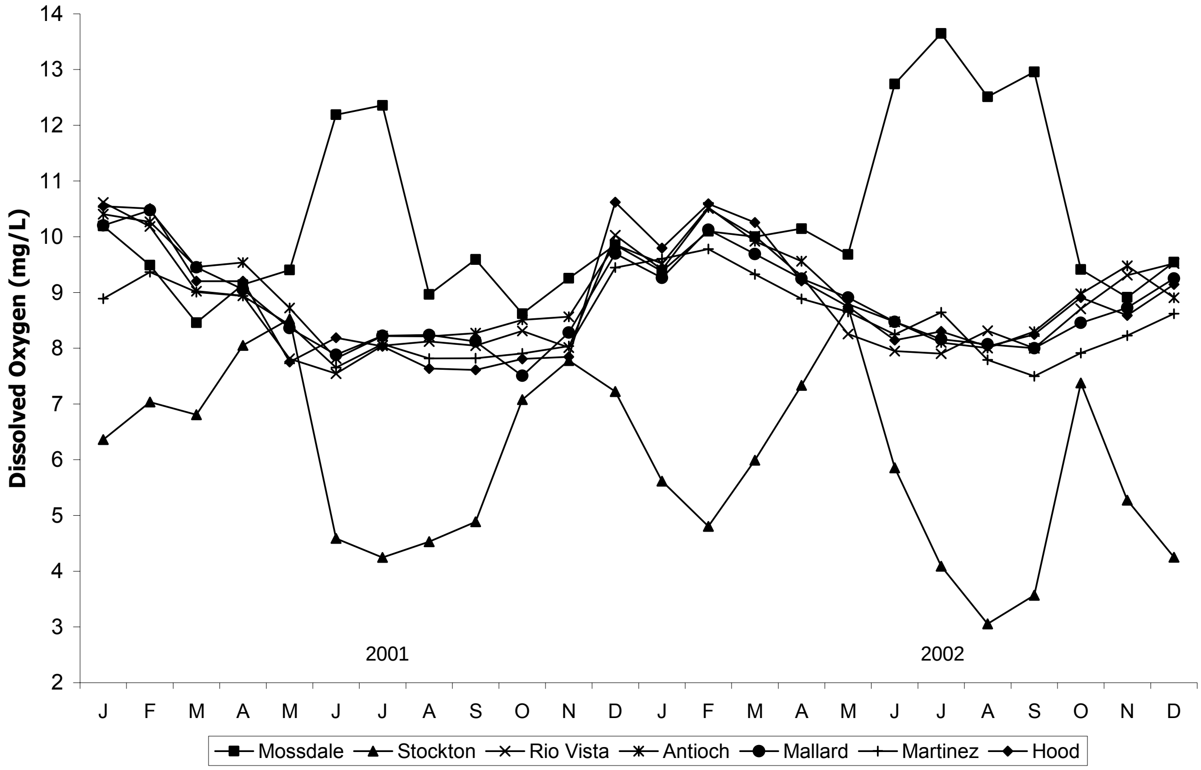


Figure 9-4a Average monthly surface specific conductance at seven stations, 2001-2002

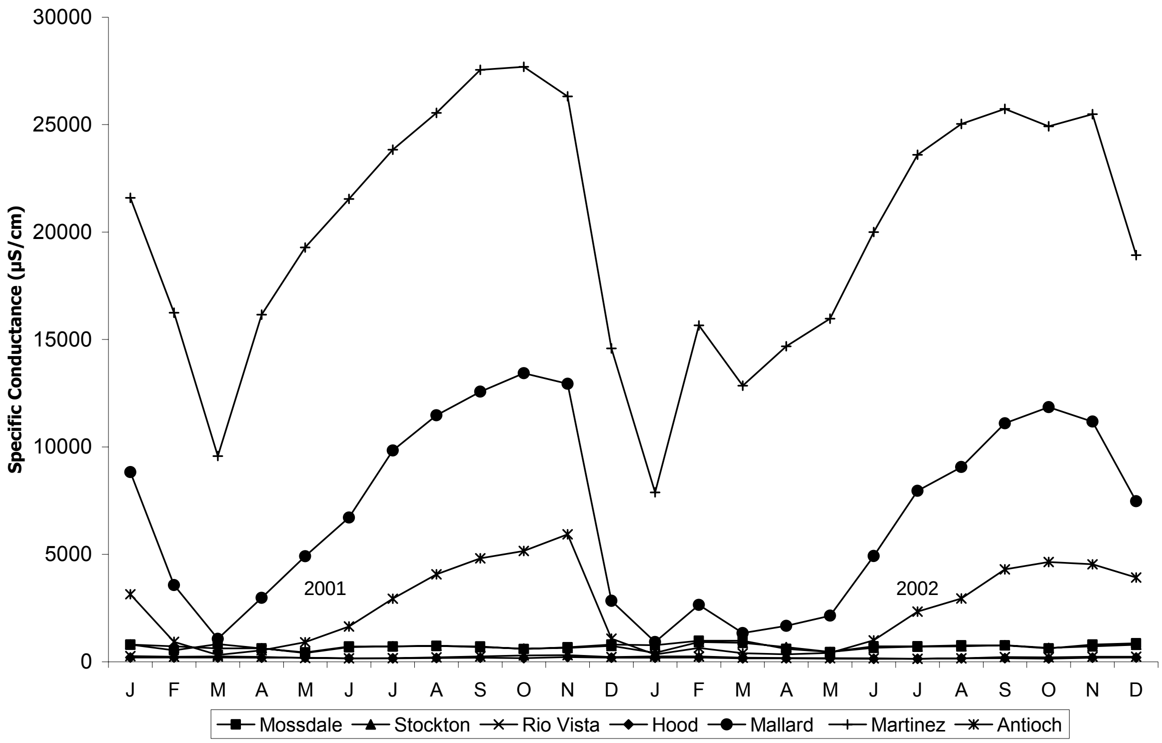


Figure 9-4b Average monthly surface specific conductance at four stations, 2001-2002

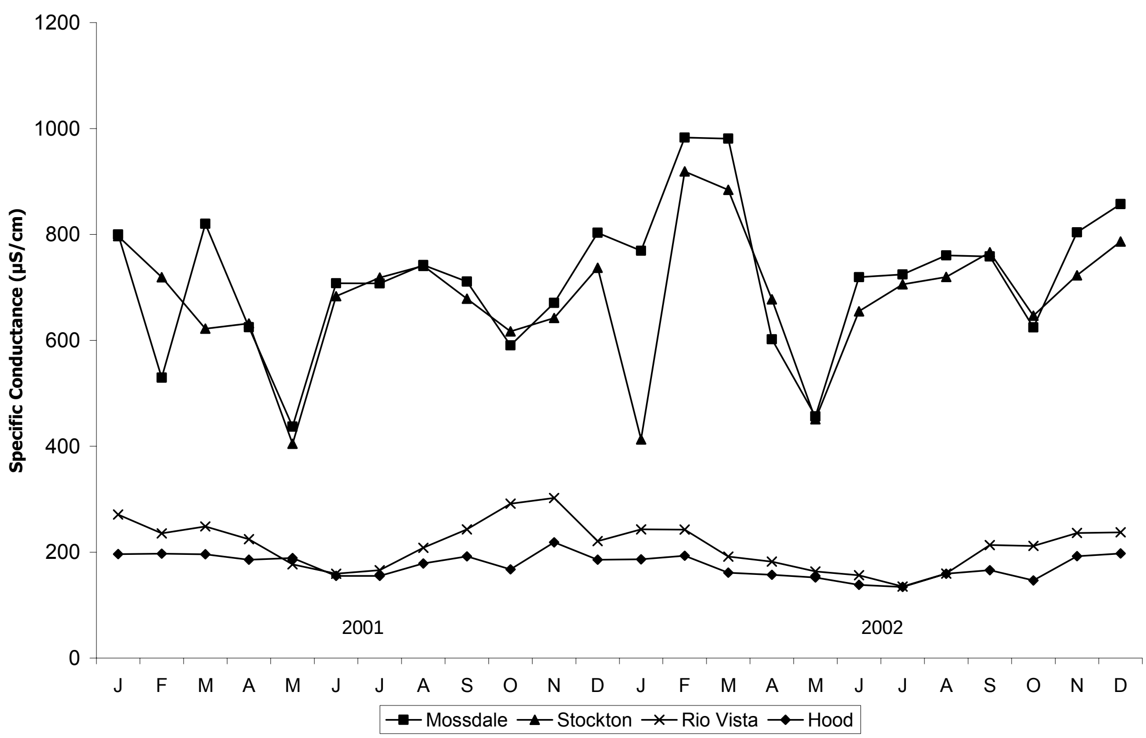


Figure 9-5 Average monthly surface and bottom specific conductance at three stations, 2001-2002

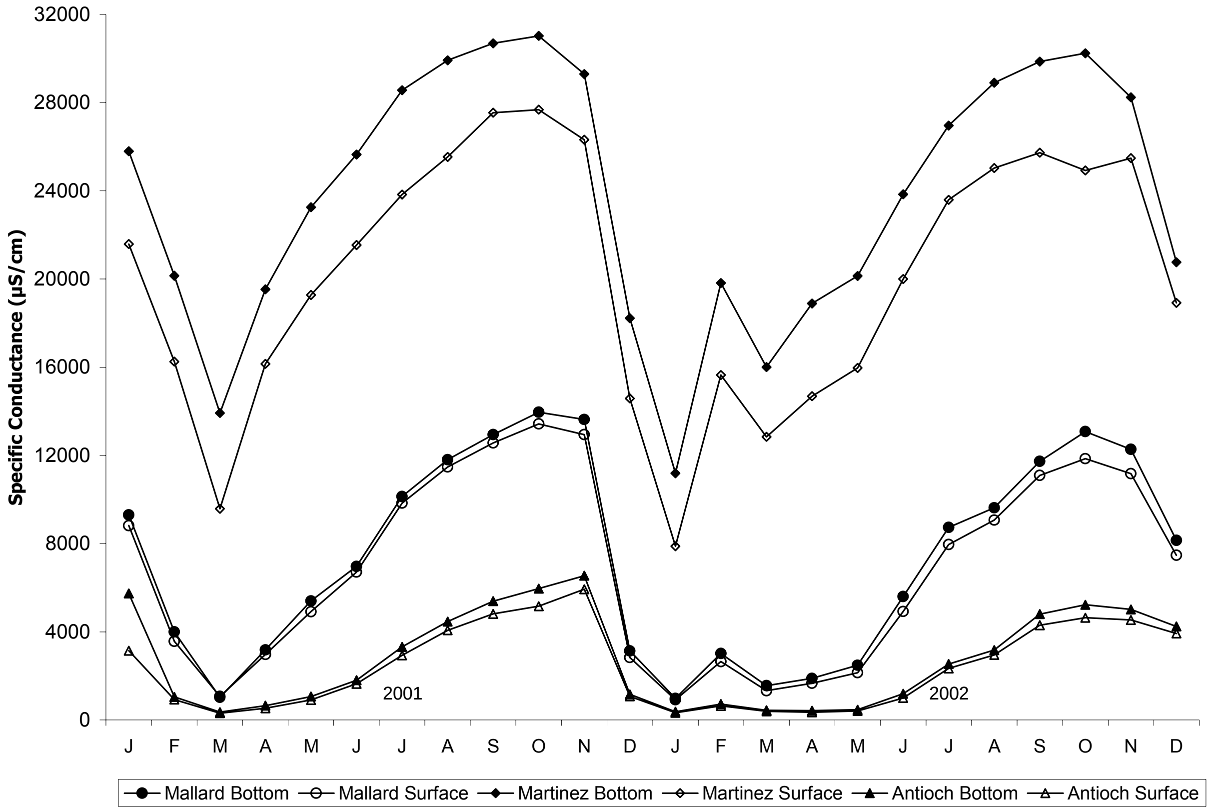


Figure 9-6 Average monthly pH at seven stations, 2001-2002

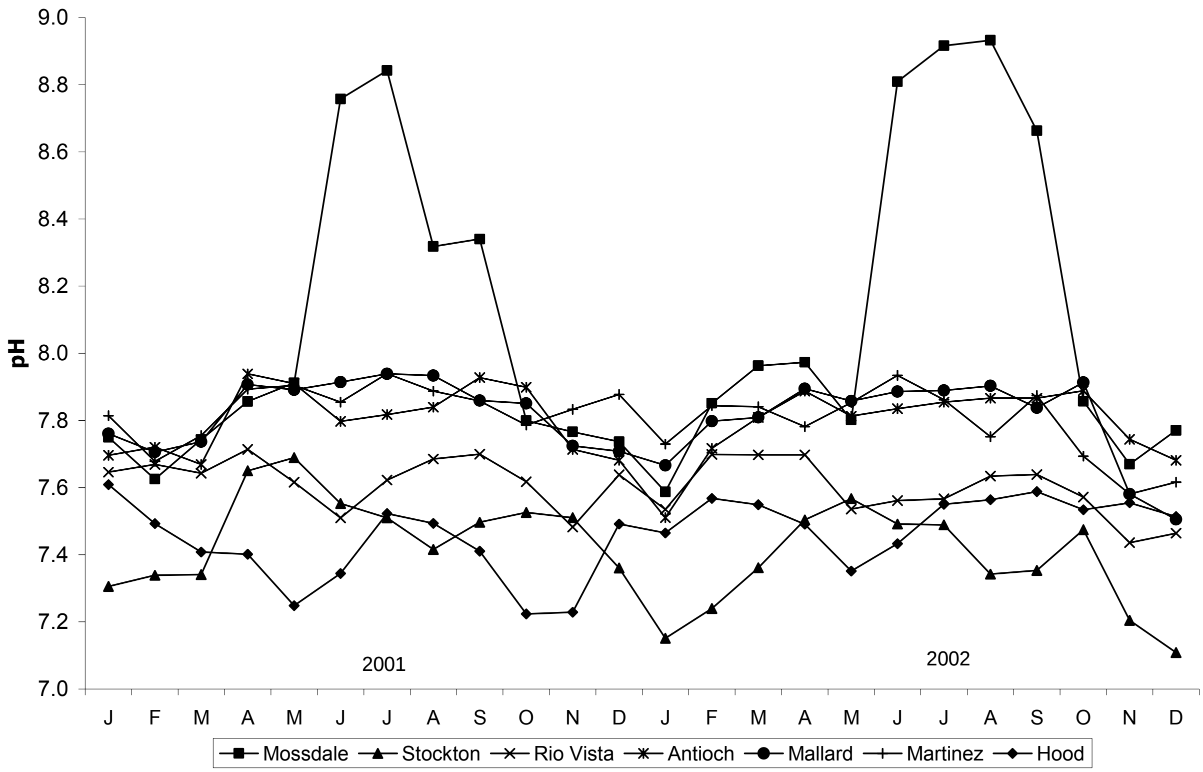


Figure 9-7 Average monthly air temperature at six stations, 2001-2002

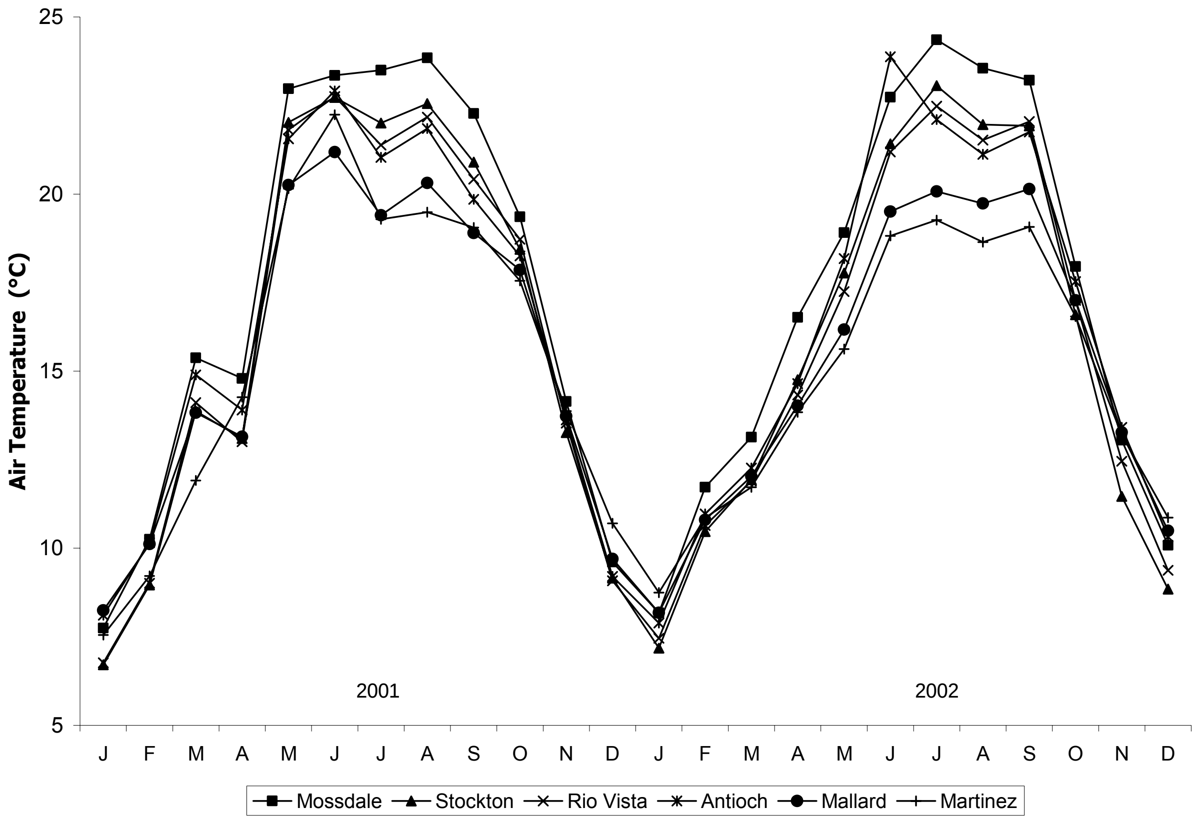


Figure 9-8 Average monthly chlorophyll fluorescence at four stations, 2001-2002

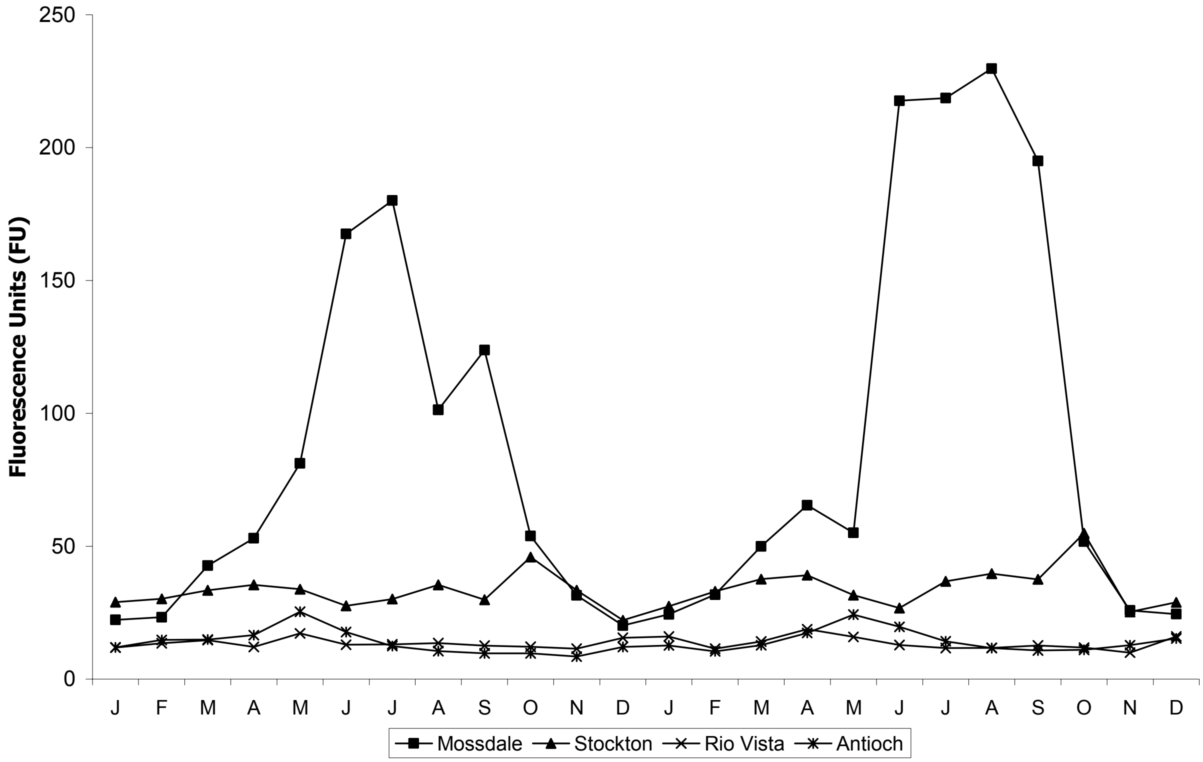


**Figure 9-9 Hourly and average monthly dissolved oxygen.
San Joaquin River at Stockton, 2001**

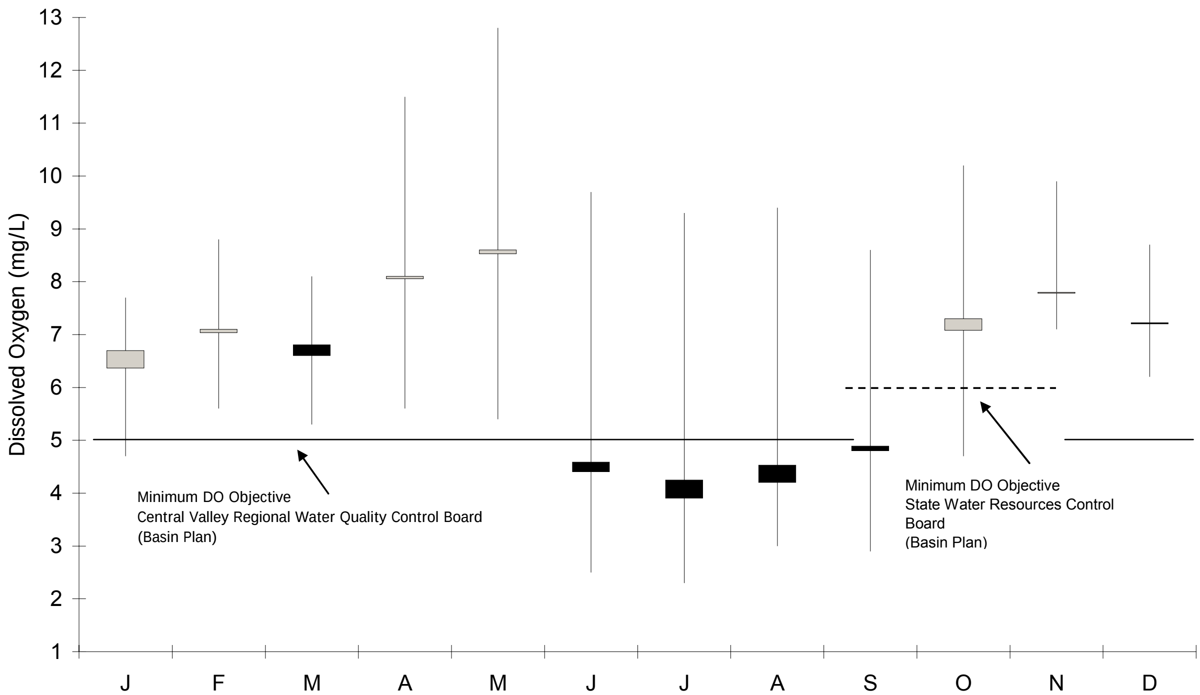


Figure 9-10 Hourly and average monthly dissolved oxygen.
San Joaquin River at Stockton, 2002