■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

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Quarterly highlights

Ryan Mayfield and Mike Dege (both DFG) relate 2004 results for the NBA larval survey and the 20 mm survey. There were no NBA pumping restrictions attributable to delta smelt concerns in 2004. Annualized mean delta smelt "density" in the 20 mm survey ranked near the bottom of values obtained since the survey's inception in 1995. Mayfield and Dege show that several other years have also been very low; however, there have been no years with index values above 20 since 2000. Four of six years before 2001 yielded indexes larger than 20.

Geir Aasen, Jerry Morinaka, and Virginia Afentoulis (all DFG) report progress made in 2004 on elements of the CHTR (Capture, Handling, Trucking, Release) studies of delta smelt at the salvage facilities. The fish predation element has concluded pilot trials used to define the experimental design to be used in the study. The acute mortality investigation was still in preparation in 2004 pending completion of test facilities and experimental procedures. The diagnostic indicators element was beginning preparation for full study implementation in late 2004.

Mike Marshall (USFWS) summarizes the activities of the Delta Juvenile Fish Monitoring Project for March through December 2004. The station panel included 55 seine sites and three trawl locations in 2004. In all, 253,964 fishes representing 63 species were identified during the reporting period.

Robert Vincik (DFG) reports on progress in telemetry studies of salmon movement at the Suisun Marsh Salinity Control Gates in Montezuma Slough. This was the fourth year of a planned three-year study. A total of 197 adult Chinook salmon were tagged and monitored in 2004. As in previous years, the more restrictive operation scenarios impeded the progress of migrating salmon, reducing passage rate and increasing the time required to transit the study area.

Contributed Papers

Nicole Jones, Stephen Monismith, and Janet Thompson (page 7) contribute preliminary results of a study of the effects of hydrodynamic conditions on the grazing rates of the introduced bivalve *Corbicula fluminea*. The paper describes a field investigation in which the deployment of flow and concentration sampling equipment and analysis of data were informed by a "control volume" approach to quantifying the scalar exchange of phytoplankton between the benthos and the water column above it. Preliminary results indicate that at certain times phytoplankton was being lost from the water column at the study site in Frank's Tract during the two-week duration of the study. Owing to variability in hydrodynamic conditions during the experiment (and others like it), the authors expect to derive a better understanding of the relationship between benthic grazing and hydrodynamic conditions.

Philip Giovannini (page 14) reports on the monitoring of dissolved oxygen (DO) in the Stockton Deepwater Ship Channel from August through December 2003. DO concentrations in the eastern portion of the channel fell below both state objectives during August and September, a period featuring low San Joaquin River discharge into the Ship Channel and warm temperatures. A temporary barrier installed between September 15 and September 22 to increase flow in the Ship Channel caused some improvement, with all stations showing DO levels above the minimum standard by October 8. Although the temporary barrier was removed by November 13, causing a reduction in flow through the Ship Channel, DO levels remained above minimums through the end of the study on December 10.

Alan Jassby, Anke Mueller-Solger, and Marc Vayssieres (page 21) provide a detailed analysis of short-term variability in chlorophyll *a* fluorescence in the tidal San Joaquin River that is designed to evaluate the efficacy of current sampling methods. The data under study were collected at two of the "multiparameter" shore stations operated by the IEP Environmental Monitoring Program. The analysis draws several specific conclusions regarding instrument calibration, data interpretation, and efficient sample frequency and timing.

Other Items of Interest

Ted Sommer (DWR, page 29) provides citations for fifteen new articles that have been published in the peer-reviewed literature.

The San Francisco Estuary Institute (SFEI, page 30) has released a report entitled "Monitoring Trace Organic Contamination in Central Valley fish: Current Data and Future Steps." The report reviews existing information on organic contaminants in Delta fish and makes recommendations for future study to fill information gaps.

Kate Le (DWR, page 30) summarizes summer 2004 water project operations.

IEP Quarterly Highlights

July-December 2004

North Bay Aqueduct and 20-mm Surveys

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Sampling for the North Bay Aqueduct (NBA) larval fish survey typically begins on February 15 and finishes on July 15. Because of boat problems, the 2004 season ended on June 30. A total of 32,712 fish were collected, ranking ninth for the past 10 years (the beginning of this survey) of NBA; however, that ranking may be attributed to ending the season approximately two weeks early. This year's catch was dominated by prickly sculpin (46.4%), threadfin shad (24.0%), and striped bass (19.8%), which is typical of this survey. Longfin smelt comprised a small (1.1%) proportion of the catch, ranking fifth when comparing longfin catch percentages for the past 10 years. Similarly, the delta smelt catch percentage was moderate (0.5%) for this year and ranked fifth over the past 10 years.

NBA pumping is restricted to a five-day running average of 65 cfs when the weighted average of delta smelt catch from Barker Slough is equal to or greater than 1.0. There were no pumping restrictions for the North Bay Aqueduct Pumping Facility for 2004. For online information about the NBA Survey, see http://www.delta.dfg.ca.gov/data/NBA/.

20-mm Survey

The 20-mm Survey for 2004 began on March 29 and finished on July 10, with 8 surveys running every other week. This year's catch was dominated by threadfin shad (22.4%), longfin smelt (19.7%), and pacific herring (16.8%). Threadfin shad and longfin smelt commonly rank high in catch percentages; however, until recent years pacific herring has never exceeded 2% of the catch. The young-of-the-year (YOY) delta smelt catch percentage (total catch = 630) for 2004 was similar to the previous two years; it made up 1.2% of the total catch and ranked seventh. Although longfin smelt catch for 2004 was markedly lower than the previous year, its percentage of the total catch increased from 15.1% to 19.7%. The total overall catch (52,201) for the season ranked ninth.

Moderate catches of YOY delta smelt first appeared at the confluence area and the central and south Delta on the San Joaquin River. Throughout the sampling season, the majority of delta smelt caught in the surveys shifted towards the central Delta and then shifted back to the lower Sacramento River, never going downstream of Grizzly Bay. None of the surveys had a strong showing of delta smelt. The mean annual catch-per-unit effor for Delta smelt for 2004 ranks ninth (Figure 1) out of the 10 years of this survey. Moderate catches of YOY longfin smelt persisted throughout the season.

The 2004 water year was below normal, which can typically cause the larval delta smelt distribution to shift landward toward the Delta; this shift can increase the likelihood of salvage at the state and federal pumping facilities. Take levels at the SWP and CVP never reached a "red light" level of concern, but a "yellow light" was reached from early to mid-June. For online information about the 20-mm Survey, see http://www.delta.dfg.ca.gov/data/20mm/.

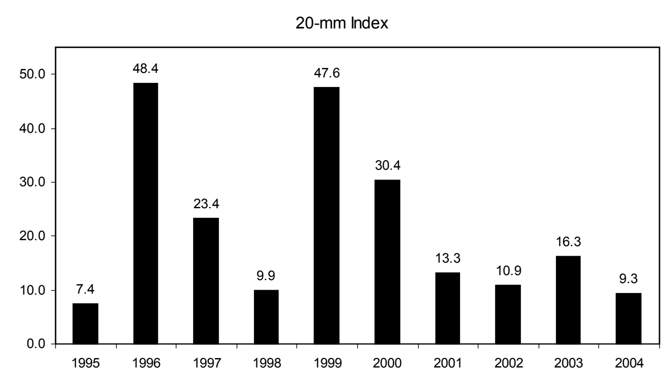

Figure 1 Annual mean density for delta smelt covering all years of the 20-mm Survey.

Fish Predation in the Collection, Handling, Transport, and Release Phase of the State Water Project's John E. Skinner Delta Fish Protective Facility Fish Salvage Operation

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Preliminary data analysis was completed for pilot studies conducted in late 2003 and early 2004. Comprising 94% of the predator population, juvenile striped bass was the most numerous predator in the Collection, Handling, Transport, and Release (CHTR) phase at the John E. Skinner Delta Fish Protective Facility from September through August 2003. Preliminary stomach content results indicate that predation by juvenile striped bass was significant in the CHTR phase. The most numerous prey fish digested were unidentified juvenile fishes (78%) followed by threadfin shad (8%) and American shad (6%). Digestion indices developed from timed feeding experiments showed limited promise for determining gross digestion rates and back-calculating when feeding occurred. Percent of body digested may be the best indicator to determine if prey fish were consumed during the CHTR phase. Other study variables such as percent fish scale loss, body color fading, and digestion of fins showed a high degree of variation.

The pilot study results are currently being used to validate the statistical design of the formal study scheduled to begin in January 2005. I am currently working with Phil Law, a DFG statistician, to set the number of replicate trials. Draft quality assurance program plan and standard operating procedures have been completed and are undergoing internal review. This study is expected to complete field trials in early July 2005.

Acute Mortality and Injury of Delta Smelt Associated with Collection, Handling, Transport, and Release at the State Water Project and Central Valley Project Fish Salvage Facilities

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This project will evaluate the effects of the Collection, Handling, Transport, and Release (CHTR) phase of the fish salvage process on injected groups of cultured adult delta smelt, as well as on wild adult delta smelt that are salvaged at the South Delta export facilities. During the last quarter of 2004, project staff concentrated on preparations to fully implement each CHTR study element. I led work on modifying the water supply system and refining facilities at the fish testing building at the Skinner Fish Facility in Byron. DFG staff was trained on fish facility loading and transport procedures. Staff performed test fish recovery experiments and initiated preparations of quality assurance documents during this period. Formal testing using adult delta smelt is scheduled to start at the John E. Skinner Delta Fish Protective Facility in January 2005. Rapid completion of the test facilities and refinement of the details of the test procedures and schedule will determine the exact starting date for this (and other) CHTR study element.

In late 2004, DFG and US Bureau of Reclamation staff evaluated a new method for mass marking delta smelt. A fluorochrome called calcein was used to mark groups of cultured adult delta smelt at the Tracy Fish Collection Facility in Byron. Live delta smelt were marked through an immersion bath; the chemical left a residue on the fish that was detectable using a special light. Preliminary results indicate that calcein may be a useful compound for mass marking adult delta smelt. The evaluations will continue in 2005 using juvenile delta smelt and also using alizarin compounds as another potential marking compound.

Diagnostic Indicators Developed to Predict Acute or Chronic Adverse Effects to Salvaged Delta Smelt

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Blood plasma collection methods were tested in a pilot study at the Tracy Fish Collection Facility from April 2004 to June 2004. I also examined the plasma cortisol response for fish groups exposed to (1) the salvage collection and handling (CH) phase, (2) an experimental control treatment, and (3) holding periods in black and white containers. One-hundred twenty-nine plasma samples were collected from cultured, post-spawned, adult delta smelt. These samples were analyzed by UC Davis's Clinical Endocrinology Laboratory using ELISA procedures (enzyme linked immunoassay) in August 2004. The plasma cortisol results were entered in a database and their statistical properties will be examined. This evaluation will help determine the appropriate sample size (number of plasma samples needed to produce statistically valid results) and the efficacy of plasma cortisol as a measure of fish stress at current and future fish facilities.

Preparation for full study implementation was begun in late 2004. Field sampling for wild delta smelt began in mid-November 2004. Due to low catches and initial holding facilities problems, we are extending field collections to obtain the number of wild test fish needed. We are hiring and training technicians and preparing quality assurance documents. Formal study implementation is scheduled to begin in January 2005. Planned experiments will explore acute stress during the collection, handling, transport, and release process, as well as the CH and TR portions, on wild and hatchery-raised delta smelt.

Delta Juvenile Fish Monitoring Project

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Historically, the US Fish and Wildlife Service (USFWS), Stockton Office, has monitored the relative abundance and distribution of juvenile Chinook salmon (*Onchorynchus tshawytscha*) in the lower Sacramento and San Joaquin rivers and in the Delta for the Interagency Ecological Program. In the early 1990s, the program expanded to monitor other juvenile fish species in the Delta.

All Species

For the reporting period (March 2004 through December 2004), sampling consisted of beach seining at more than 55 seine sites and trawling at three locations. Seine sites were distributed throughout the lower Sacramento River (upstream of river mile [RM] 60), the San Joaquin River (upstream of RM 41), and the Delta, with limited sites in the San Pablo and San Francisco bays. Trawling was conducted at Mossdale (San Joaquin River, RM 54), Sherwood Harbor (Sacramento River, RM 55), and Chipps Island (Suisun Bay, RM 18). Typically, seine sites were sampled once per week and trawls were conducted three days per week. We collected 556 seine samples on the Sacramento River, 191 on the San Joaquin River, 809 on the Delta, and 172 on San Pablo and San Francisco bays combined. We conducted 505 trawls at Chipps Island, 118 at Sherwood Harbor, and 149 at Mossdale. In all, we captured 253,964 fish comprised of 63 species.

During beach seining, 132,867 fish were captured: 28,452 from the Sacramento River, 49,245 from the San Joaquin River, 49,163 from the Delta and 6,007 from San Pablo and San Francisco bays. Inland silversides (*Menidia beryllina*; n = 64,150), red shiners (*Cyprinella lutrensis*; n = 24,772), threadfin shad (*Dorosoma petenense*; n = 9,067), splittail (*Pogonichthys macrolepidotus*; n = 6,229), and Chinook salmon (n = 6,028) dominated the catch in the Sacramento and San Joaquin rivers and the Delta, while top smelt (*Atherinops affinis*; n = 3,558) and Pacific herring (*Clupea harengus*; n = 1,377) dominated the catch in the bays. In addition, we captured 5 rainbow trout (*O. mykiss)*, and 60 Delta smelt (*Hypomesus transpacificus)*.

We captured 121,097 fish while trawling: 78,895 from Mossdale, 7,635 from Sherwood Harbor, and 34,567 from Chipps Island. At Mossdale, inland silversides (n = 55,822) and threadfin shad (n = 16,047) were the most commonly captured species. Chinook salmon (n = 6,020), and threadfin shad (n = 1,032) dominated the catch on the Sacramento River. At Chipps Island, American shad (*Alosa sapidissima*; n = 15,730), Chinook salmon (n = 13,369), and threadfin shad (n = 1,142) dominated the catch. In addition, we captured 3,664 splittail at Mossdale (March 1 through July 31);

2 unmarked rainbow trout and 1 splittail at Sherwood Harbor; and 222 splittail and 33 unmarked rainbow trout at Chipps Island.

Juvenile Chinook Salmon

A total of 6,028 unmarked Chinook salmon were captured while beach seining. Most of these were captured in the Sacramento River (n = 4,013) and the Delta (n = 2,015). Fifty-six were captured in the San Joaquin River and 86 were captured in the bay. We captured Chinook salmon throughout the reporting period, with the peak occurring mid-March through early April and decreasing through May, with few salmon seen after May. Few unmarked Chinook salmon were captured throughout the summer and fall months; however, the number of unmarked Chinook salmon captured increased in December. The first winter-run-sized juvenile Chinook salmon captured seining for the 2005 sampling period occurred on October 27, 2004, at Miller Park (Sacramento River, RM 57). Juvenile Chinook race designations are based on the Greene modification of the Fisher size criteria.

The majority (n = 21,530) of unmarked Chinook salmon were captured while trawling; 13,369 were captured at Chipps Island; 6,020 in the Sacramento River at Sherwood Harbor; and 2,141 in the San Joaquin River at Mossdale. We captured Chinook salmon throughout the sampling period, from early March through May. The catch of Chinook salmon peaked in late April to early May, with few fish seen after May. Catches of unmarked Chinook salmon increased in December. The first winter-run sized juvenile Chinook salmon captured trawling for the 2005 sampling period occurred on November 1, 2004, at Sherwood Harbor.

A relatively small number (n = 615) of marked (adipose fin-clipped) Chinook salmon were recovered during the sampling period; 555 were recovered trawling and 60 were recovered while beach seining. Of the 555 marked Chinook salmon recovered while trawling, 463 were recovered at Chipps Island and 92 at Sherwood Harbor. Of the 60 marked Chinook salmon recovered while beach seining, 34 were recovered on the Sacramento River, 20 from the Delta, and 6 from the San Joaquin River. There were also 1,129 marked fish recovered as part of the California Department of Fish and Game's (DFG) Region 4, Real-Time Monitoring (RTM) experiments, conducted on the San Joaquin River at Mossdale; all were recovered while Kodiak trawling.

Other Activities

In addition to our IEP sampling obligations, a number of other projects were conducted during the sampling period. Beginning in April, we provided field personnel to Region 4 to assist with Kodiak trawling at Mossdale, as part of the RTM. In December, we released approximately 292,000 late-fall Chinook salmon (obtained from Coleman National Fish Hatchery) as part of the Delta Action 8 experiments. Also in December, sampling effort was increased at Chipps Island from three days per week to seven days per week during the Delta Action 8 experiments.

Suisun Marsh Salinity Control Gates

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The 2004 adult salmon telemetry study at the Suisun Marsh Salinity Control Gates (SMSCG) in Montezuma Slough finished November 8. This was the fourth year of a planned 3-year study of fish passage which began to study the feasibility of using the structures existing boat lock as an alternate means of fish passage in fall 2001. A total of 197 adult Chinook salmon (*Oncorhynchus tshawytscha)* were implanted with ultrasonic tags and monitored for passage time and passage rate through three operational phases of the Salinity Control Gates. During the first portion of each phase, 65 to 66 adult salmon were tagged and released downstream from the gates. In addition to six fixed receivers used to record fish passage at the SMSCG, additional monitors were placed downstream near the Carquinez Strait and in Grizzly Bay; upstream at Chain Island, in the Sacramento River at Rio Vista and Hood, and in the San Joaquin River at Mossdale.

During Phase I of the control phase, gates were held open, flashboards were removed, and the boat lock was closed. Of the 66 fish released in this phase, 58% passed the gates with a mean passage time of 37 hours. After passing the gates, 11 tagged salmon moved back downstream and 28 (42%) moved downstream without passing the gates.

Phase II evaluated the proposed mitigation strategy of providing fish passage through an open boat lock when gates were tidally operated and flashboards were installed. During this period, 55% out of 66 fish passed the gates with a mean passage time of 27.9 hours. After passing the gates, 11 tagged salmon moved back downstream and 30 (45%) moved downstream without passing the gates.

Phase III tested normal operational schedule where gates were tidally operated, flashboards were installed, and the boat lock was closed. Out of the 65 fish released, 35% of the adult Chinook salmon passed the gates with a mean passage time of 60.6 hours. After passing the gates, two tagged salmon moved back downstream and 42 (65%) moved downstream without passing the gates.

Similar to previous years, "full open" configuration had the highest percentage of passage (58%), and the "full operation, boat lock closed" configuration had the lowest percentage of passage (35%). Percent passage of the mitigated operations was similar to performance in the full operation phase (55%).

CONTRIBUTED PAPERS

Preliminary Results from a Shallow Water Benthic Grazing Study

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Introduction

The nutrient-rich, shallow waters of San Francisco Bay support high rates of primary production, limited not by nutrients but by light availability and benthic grazing (Alpine and others 1992; Cloern 1982). Phytoplankton blooms are an important food source for upper trophic levels. Consequently animal populations, such as fish, may suffer under conditions of high benthic bivalve grazing. It has been hypothesized that several species of fish are suffering as a result of severe decreases in available phytoplankton since the introduction of *Potamocorbula amurensis* into San Francisco Bay (Feyrer 2003).

The extent of reduction in phytoplankton biomass by benthic bivalves is dependent on both physical and biological factors in addition to their spatial and temporal variability. Physical factors identified as important include: (1) vertical mixing rates, which are a function of wind velocity, currents, and bottom roughness; (2) suspended sediment concentrations; and (3) phytoplankton settling rates. The biological factors controlling the extent of phytoplankton grazing include animal density and organism size, pumping rate, food type and concentration, metabolic demands, assimilation efficiency, and behaviour (Wildish and Kristmanson 1997).

Several laboratory studies involving model and live clams have shown that benthic grazers can deplete phytoplankton in the water column (for example, Cole and others 1992). Initially, these studies assumed that the water column remained well mixed above benthic suspension feeders; therefore, parameters measured in the bulk water column were believed to be representative of available particle concentration. For this reason many relationships describing the influence of the bulk flow and bulk seston concentration on benthic grazers physiological processes exist (for example, Levinton 1991).

Laboratory measurements using live animals have shown that filtration rates vary with free stream velocity (for example, Levinton 1991). Increases in current speed lead to an increase in filtration rate; however, several studies have shown that filtration may cease at some critical current speed. It has been suggested that resuspension, occurring as a result of high current speeds, may be a factor that negatively affects uptake (Cloern 1987; Levinton 1991). Several mechanisms have been invoked to explain the effects of low speed on growth rates of active suspension feeders. These mechanisms include the formation of a concentration boundary layer and the limiting horizontal flux of seston. It is now accepted that a combination of these factors dictates the growth success of benthic grazers in a particular area.

Several field studies have shown that concentration boundary layers can form over benthic ecosystems (for example, Frechette and others 1989, Dolmer 2000); however, many of these studies have failed to measure the hydrodynamics needed to calculate benthic grazing rates. Furthermore, calculating benthic grazing rates with vertical measurements at a single point is problematic due to lack of knowledge of the horizontal gradients in seston (Thompson and others, forthcoming).

Despite great improvements in our knowledge on the effects of benthic grazers on seston concentrations in water columns, the effects of different hydrodynamic conditions on grazing rates has not been formulated. This makes it difficult to assess the system-wide effect of the benthic ecosystem on phytoplankton concentrations. Furthermore, it affects our ability to predict the potential success of a benthic species, such as the invasive clams *Corbicula fluminea* and *Potamocorbula amurensis*. This paper presents the preliminary results of a control volume approach to elucidate the effect of different hydrodynamic conditions on the grazing rates of *Corbicula fluminea*.

Methods

The Control Volume approach

The exchange of phytoplankton between the benthos and the water column was measured in a 10 x 20 m region. To quantify this exchange, the flux of the scalar to/from the benthos was calculated using a Control Volume approach (Genin and others 2002). In this method an imaginary box (the "Control Volume" = CV) is first chosen to enclose the region of interest (Figure 1). Mass balances for each scalar are then written, including fluxes through the faces of the CV (the "Control Surface" = CS), unsteady changes in quantities inside the CV, and any non-conservative processes that add or remove material from the CV. Mathematically this is expressed by the integral form of the mass conservation relation:

$$\frac{d}{dt}\iiint_{CV} C dV \quad + \quad \oiint_{CS} C\vec{u}.d\vec{A} \;=\; J.A_b \qquad (1)$$

where C is the concentration of the scalar, $\vec{u}$ is the local transport velocity, $d\vec{A}$ is the local directed surface area element (the direction normal to the surface), J is the mass flux per area of the benthos and A_b is the area of the rectangle A-B-C-D. Assuming that any losses are due to benthic grazing, the mass flux is related to the benthic grazing as:

$$J = \alpha C_B A_b \qquad (2)$$

where α is the benthic grazing rate and C_b is the scalor concentration close to the bed.

As an exact expression, Equation 1 requires that C and $\vec{u}$ be known everywhere in the control volume. However, in practice, each of the required integrals can be found approximately from limited pointwise velocity and concentration measurements. Phytoplankton was sampled at each corner of a 10 x 20 m control volume (Figure 1). Due to the likely vertical variation in phytoplankton concentration, samples were collected at 8 heights spaced approximately logarithmically from the sediment-water interface to the water surface. In terms of this sampling arrangement and substituting in Equation 2 we can then approximate Equation 1 as:

$$WHL\frac{\Delta\overline{C}}{\Delta t} + W\left[-\int_0^H C_{AB}(z)u(z)dz + \int_0^H C_{CD}(z)u(z)dz\right] + L\left[-\int_0^H C_{BC}(z)v(z)dz + \int_0^H C_{AD}(z)v(z)dz\right]$$
$$= \alpha C_B WL$$

where W is the width, L is the length and H is the height of the control volume; u is the lengthwise orientated velocity and v is the width-wise orientated velocity; C_{AB}, C_{CD}, C_{BC} and C_{AD} are the representative vertical distribution of chlorophyll *a* concentration for each face, averaged from the measurements at each corner; and $\overline{C}$ is the volume averaged concentration.

Experimental setup

The first of two major field studies was carried out in Franks Tract from April 27 to May 10, 2004. The control volume study was situated in the main channel of Franks Tract, which extends from the westward False River opening to the openings on the east shore (Figure 2). To enable the collection and processing of water samples and the real-time collection of hydrodynamic data, the experiment was staged from a houseboat (Figure 3). Control volume water sampling was undertaken during two 30-hour experiments conducted during spring and neap conditions.

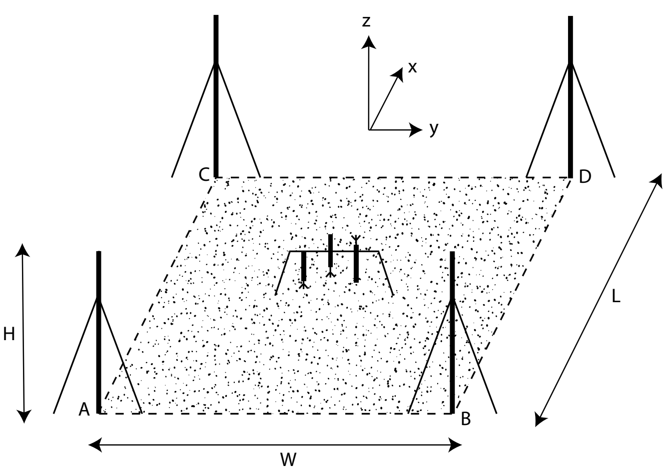

Figure 1 A schematic drawing of the control volume. The four water-sampling frames are shown at the corners of the control volume. The instruments in the center of the control volume measure hydrodynamics and sediment concentrations. The dominant flow is in the x-direction.

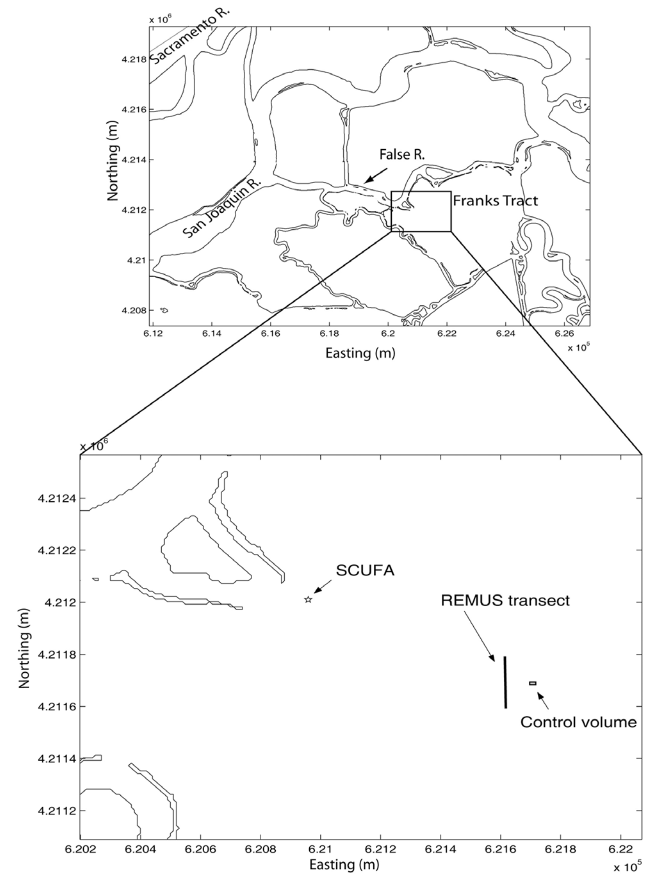

Figure 2 The location of the control volume experiment. The control volume is marked by a rectangle.

Figure 3 The experiment was staged from an anchored houseboat to enable continuous water sampling and filtering.

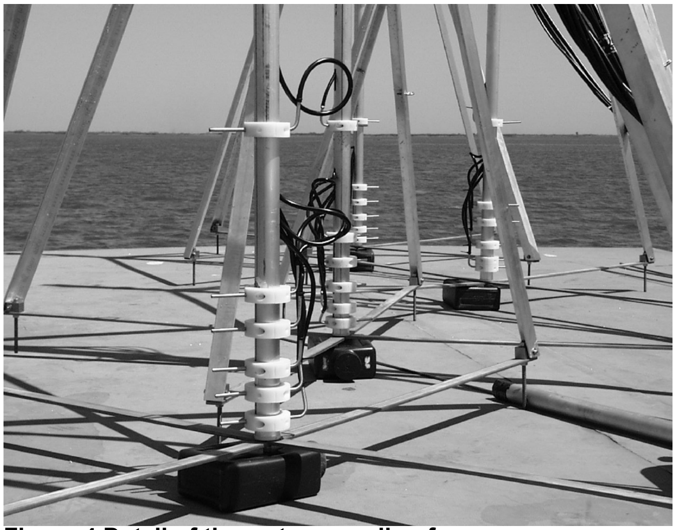

Figure 4 Detail of the water sampling frames.

The water sampling frames were constructed to measure samples at discrete heights beginning 3 cm above the sediment (Figure 4). The intake tubes were extended away from the central support to prevent potential mixing of the water by the obstruction of the frame. Furthermore, the water sampling frames were manually reoriented into the direction of the mean flow at each slack tide for the same reason. The 10-minute integrated water samples were collected via 30-m lengths of tube and peristaltic pumps operating at 90 mL/min, every hour for each 30-hour experiment. The 10-minute sampling time was chosen to ensure the water column was overturning a few times over the sampling period and to ensure the intake velocity was not excessive. Phytoplankton biomass was estimated by measuring extracted fluorescence. Water samples were immediately filtered through Whatman GF/F filters on board and then the filters were stored at -80 °C. The filters were then extracted in 90% acetone overnight, centrifuged, and the extract measured on a Model 10 fluorometer (Turner Designs, Inc). In addition to the water sample measurements, a continuous 2-week time series of in situ chlorophyll *a* fluorescence was obtained by a set of nine SCUFAs[1] (Turner Designs, Inc). Eight SCUFAs were positioned at the corners of the control volume at heights of 0.3 and 2 m and one was located at the False River inlet to Franks Tract.

Throughout the two 30-hour experiments zooplankton tows were performed every 6 hours. These samples were analysed for species composition, abundance, and length, enabling zooplankton grazing rates to be estimated. Water samples were also preserved every six hours for phytoplankton abundance, species composition, and mean cell biovolume analysis.

The lengthwise and widthwise currents were measured using instruments located in the centre of the control volume. Instruments included an upward looking 1,200 kHz Acoustic Doppler Profiler (RD Instruments) with 7-cm bins, with the first bin approximately 50 cm above the sediment-water interface. The currents close to the bed was measured using an array of three acoustic Doppler velocimeters (ADVs, Nortek) at heights of 0.11, 0.22, and 0.38 m. The ADVs sampled synchronously at 25 Hz to enable the removal of waves from the record such that turbulence conditions and bed stresses can be inferred. Each ADV also sampled pressure at 25 Hz and this data was used to calculate wave height and period via linear wave theory.

Three optical backscatter sensors (D&A Instruments) measured "sediment concentrations" at approximately 6 Hz at heights of 0.8, 0.26, and 0.39 m above the bed. Vertical temperature structure was measured by an array of thermistors (Seabird Electronics), positioned every half meter, sampling at 2-minute intervals. A wind station (RM Young) was mounted above the houseboat, 4.7 m above the water, to provide 10-minute averaged wind speed and direction data.

A REMUS (Hydroid) autonomous underwater vehicle carried out three periods of continuous 200-m transects perpendicular to the direction of the dominant current (Figure 2). Sensors on board the vehicle included temperature and conductivity sensors (Ocean Sensors), chlorophyll *a* fluorescence and optical backscatter sensors (Turner Designs), and sidescan sonar (Marine Sonic Technology, Ltd).

At the conclusion of the experiment the control volumes' benthos was systematically sampled and the areas surrounding it were randomly sampled in order to gauge spatial variability. A 0.05 m^2 van Veen grab was used for sampling.

Preliminary Results and Discussion

The experiment lasted approximately two weeks from April 27 to May 10, 2004.

Electronic data was collected over the two-week period to capture spring and neap tidal conditions (Figure 5). The velocities shown are depth-averaged records of the ADCP

1. Self-Contained Underwater Fluorescence Apparatus

rotated into streamwise (Figure 5B) and cross-stream (Figure 5C) coordinates. The asymmetry between the magnitude of flooding and ebbing tides is due to the jet that is formed as the water passes from the narrow false river inlet into Franks Tract on flood tide. The larger fluctuating components seen in the cross-stream current during flooding is most likely due to the largest eddies of the turbulent jet. A range of wind and hence wave conditions were also captured during the experiment (Figure 6). Two 30-hour grazing experiments were undertaken: one during neap tide conditions and one during spring tide conditions. These periods are indicated by the vertical lines on Figures 5 and 6.

Analysis of the benthic grab samples determined that the average abundance of *Corbicula fluminea* in the control volume was 600 ± 280 clams/m^2 and the calculated biomass was 66 ± 30 g dry tissue weight/m^2. This indicates that grazing rates in the control volume should be significant.

Preliminary results indicate that vertical profiles of chlorophyll *a* can be complicated by the energetic flows in the Franks Tract channel. Furthermore, advected horizontal gradients can be large enough that they could distort the calculation of grazing rates by the methods described above. The evolution in time of the horizontal variation in chlorophyll *a* across the channel was captured by the REMUS transects. REMUS completed the 200-m transect every 2 minutes, offering a near synoptic view of temperature, conductivity, fluorescence, and turbidity. Figure 7 illustrates the horizontal variation that was present throughout an 8-hour period of the spring condition 30-hour experiment. The spatial and temporal variations in chlorophyll *a* are due to a combination of two processes: (1) the spatial and temporal variability in the sources and sinks of phytoplankton, and (2) the transport of phytoplankton (Lucas 2002). Net production of phytoplankton is affected by factors such as turbidity, surface irradiance, water column height, grazers, and water temperature making certain locations and times suitable for bloom development. The complex network of channels and water bodies of the Delta enhances patchiness by allowing water from different locations to mix.

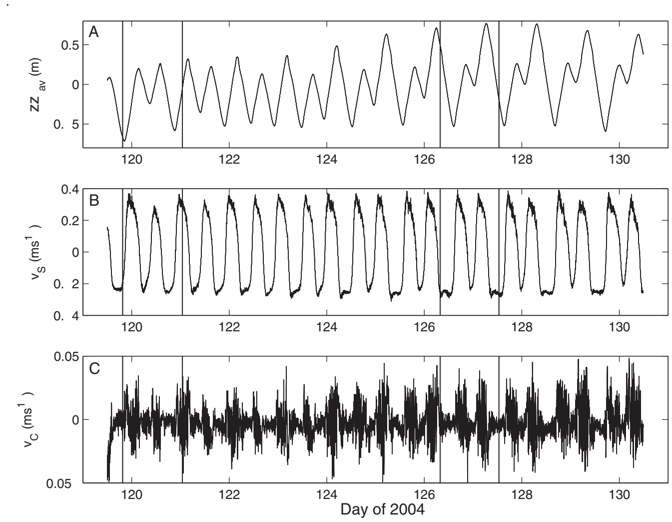

Figure 5 Tidal elevation (m; A) and depth averaged streamwise (B) and cross-stream (C) velocities (m/s) during the two-week experiment.

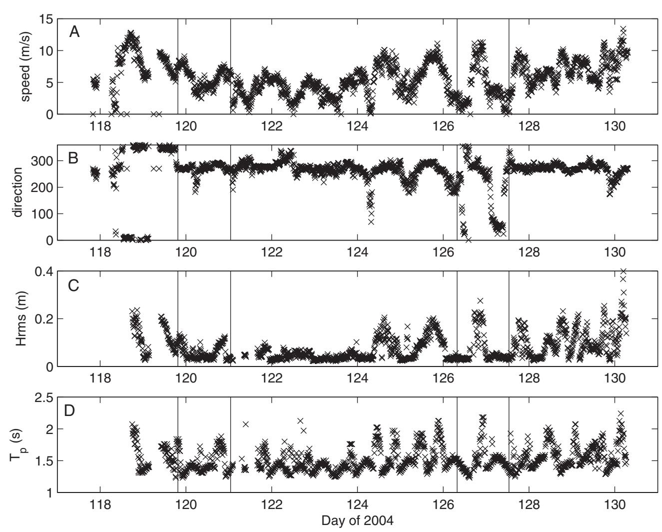

Figure 6 Wind speed (m/s; A), direction (degrees, B), the root mean square wave height (m; C), and peak wave period (s; D) throughout the two-week experiment

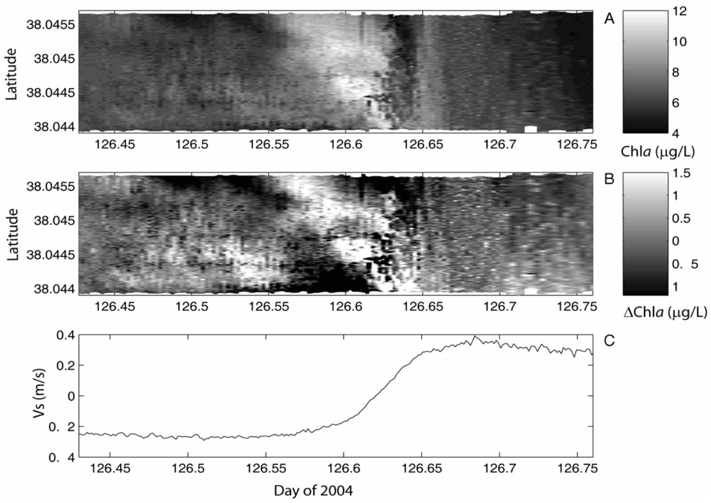

Figure 7 Chlorophyll *a* distribution across a 200-m section across the channel as a function of time (µg/L; A), the difference between the discrete chlorophyll a measurement and the mean chlorophyll a at that time step (µg/L; B), and the streamwise depth averaged velocity (m/s; C) for an 8-hour period during the spring 30-hour grazing experiment.

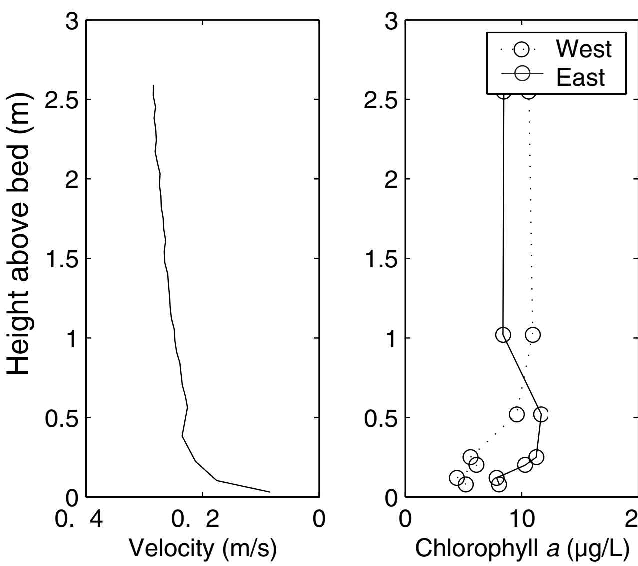

Figure 8 Profiles of east-west current and concentration of chlorophyll *a* during a single run of the control volume experiment (6 May 2004, 08:45). Negative velocities indicate an ebbing of westward flow. The chlorophyll *a* profiles have the shape of a concentration boundary layer below 0.5 m. A decrease in concentration is seen in the direction of flow below 0.5 m.

The REMUS transect displayed (Figure 7) begins during an ebbing tide (negative velocity). Over the 8-hour period, the range in chlorophyll *a* concentration measured in the transect is 4 to 12 µg/L (Figure 7A) with the peak concentration occurring at the end of the ebbing tide. In order to highlight the patchiness in the signal, Figure 7B displays the deviation of the chlorophyll concentration from the mean concentration at that time step. The smallest gradients are seen during the flood tide. This may be due to the efficiency of mixing as the False River water enters Franks Tract as a turbulent jet. During ebb tide the gradients are stronger and this may be due to the water moving from the shallows to towards the channel as well as along the main channel. These profiles will be used to understand the horizontal variability across the control volume in order to make necessary adjustments in calculating the grazing rate.

Figures 8 and 9 are examples of chlorophyll *a* concentration profiles at the east and west sides of the control volume displayed with the corresponding eastward velocity profiles. In Figure 8B the concentrations close to the bed (<0.5 m) are lower than those above. This is an example of a draw-down profile or concentration boundary layer, which is created when the pumping of the clams exceeds the rate at which water above, with higher concentrations of phytoplankton, can be mixed down to the bed. Below 0.5 m the concentrations decrease from east to west during an ebbing tide (westward) indicating a loss due to grazing. The data points above 1 m have the reverse sequence, which is likely due to the complicated horizontal patchiness.

The high velocities in the channel cause the bed stress to be high; this stress can be further enhanced by the presence of wind waves. Resuspension of the substrate, including settled phytoplankton, can occur when the bed stress reaches a critical level. Figure 9B shows an increase in chlorophyll *a* concentration that decreases further away from the bed. This is indicative of a resuspension profile. Occurring during a flooding tide (eastward), the profiles indicate that there was a net loss of phytoplankton from the control volume at this time, most likely due to benthic grazing.

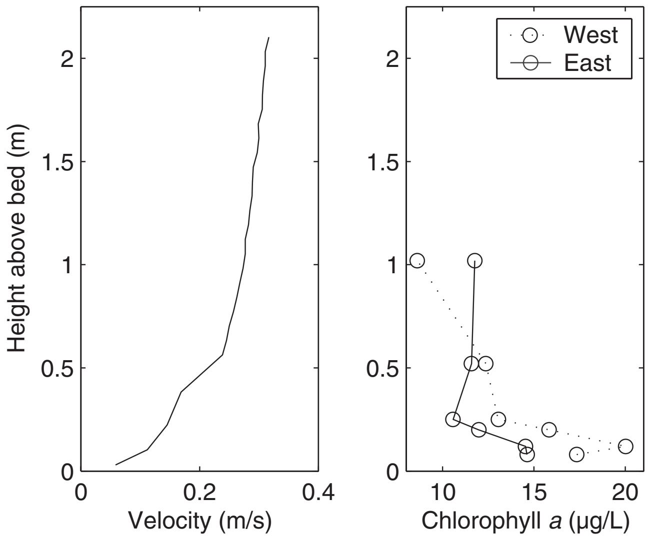

Figure 9 Profiles of east-west current and concentration of chlorophyll *a* during a single run of the control volume experiment (6 May 2004, 15:45). Positive velocities indicate a flooding or eastward flow. The chlorophyll *a* profiles have the shape of a resuspension boundary layer below 0.5 m. A decrease in concentration is seen in the direction of flow below 0.5 m.

Conclusions

This study has employed a control volume approach to study phytoplankton grazing by *Corbicula fluminea* in Franks Tract. Preliminary results indicate that phytoplankton is being lost from the control volume at a number of sampling times during the experiment. Owing to the variability in hydrodynamic conditions during the experiments this data set should produce an understanding of the relationship between benthic grazing and hydrodynamic conditions. The REMUS data will be used to understand the horizontal patchiness that is advected through the control volume.

Acknowledgements

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- USGS Menlo Park sampling and operations team: Francis Parchaso, Byron Richards, and Michelle Shouse

References

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

Cloern JE. 1982. Does the benthos control the phytoplankton biomass in South San Francisco Bay? Mar Ecol Prog Ser. 9:191-202.

Cloern JE. 1987. Turbidity as a control on phytoplankton biomass and productivity in estuaries. Cont Shelf Res. 7:1367-1381.

Cole BE, Thompson JK and Cloern JE. 1992. Measurements of filtration rates by infaunal bivalves in a recirculating flume. Mar Biol. 113:219-225

Dolmer P. 2000. Algal concentration profiles above mussel beds. J of Sea Res. 43:113-119.

Feyrer F, Herbold B, Matern SA, and Moyle PB. 2003. Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco Estuary. Environmental Biology of Fishes. 67(3):277-288

Fréchette M, Butman CA and Geyer WR. 1989. The importance of boundary-layer flows in supplying phytoplankton to the benthic suspension feeder, *Mytilus edulis*. Limnol Oceanogr 34:19-36.

Genin A, Yahel G, Reidenbach MA, Monismith SG, and Koseff JR. 2002. Intense benthic grazing on phytoplankton in coral reefs revealed using the control volume approach. Oceanography, 15(2): 90-96.

Levinton JJ. 1991. Variable feeding behavior in three species of Macoma (Bivalva: Tellinacea) as a response to water flow and sediment transport. Mar Biol. 110:375-383.

Lucas LV, Schraga TS, Lopez CB, Burau JR and Jassby AD. 2002. Pulsey, patchy water quality in the Delta: implications for meaningful monitoring. IEP Newsletter, 15(3): 21-27

Thompson JK, Koseff JR, and Monismith SG. (in review). Temporal variability in concentration boundary layer development over infauna; bivalves: a synthesis of laboratory and field experiments. Limnol. Oceanogr.

Wildish D and Kristmanson D. 1997. Benthic Suspension Feeders and Flow. Cambridge (UK): Cambridge University Press. 409 p.

Dissolved Oxygen and Flow in the Stockton Ship Channel in Fall 2003

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Dissolved oxygen (DO) levels in the Stockton Ship Channel were monitored by Bay-Delta Monitoring and Analysis Section staff during late summer and fall 2003 to document compliance with state water quality objectives. Due to a variety of factors, DO levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River past Stockton.

Because low DO 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 DO objectives have been established. The most recent basin plan from the Central Valley Regional Water Quality Control Board (CVRWQCB 1998) establishes a baseline objective of 5.0 mg/L for the entire Delta region (including the Stockton Ship Channel) throughout the year. This objective was modified to 6.0 mg/L from September through November by the State Water Resources Control Board (SWRCB) in their latest Bay-Delta Plan (SWRCB 1995). This objective has been established to protect fall-run Chinook salmon, and it applies to the lower San Joaquin River between Stockton and 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, we evaluate the data in this report using the 6.0 mg/L objective.

As part of a 1969 Memorandum of Understanding between the Department of Water Resources (DWR), the US Fish and Wildlife Service, the US Bureau of Reclamation, and the Department of Fish and Game (DFG), DWR has installed a rock barrier across the mouth of Old River during periods of projected low fall San Joaquin River outflow. This Head of Old River Barrier (barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving DO 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 finished installing the barrier on September 15, 2003 (the closure was fully operational by September 22) because late summer San Joaquin River flows past Vernalis were low (average September daily San Joaquin River flow past Vernalis was 1,383 cfs), and early fall flows were not projected to be sufficient to alleviate DO concerns in the eastern channel. Removal of the barrier began on November 3, 2003, and was completed by November 13.

Methods

Monitoring of DO concentrations in the Stockton Ship Channel was conducted by vessel on eight monitoring runs between August 11 and December 10, 2003. During each of the monitoring runs, fourteen sites were sampled at low water slack, beginning at Prisoner's Point (Station 1) in the central Delta and ending at the Port of Stockton Turning Basin (Turning Basin) at the terminus of the ship channel (Station 14). An exception to this standard protocol occurred during the November 14 sampling run, when Stations 1 through 9 were sampled at high water slack, due to a miscalculation of the vessel departure schedule. The sampling stations are keyed to channel light markers (Figure 1) to provide a geographic reference and to make reporting simpler.

Because monitoring results typically differ along the channel, sampling stations within the channel are grouped into western, central, and eastern regions. These regions are highlighted in Figure 1. The western channel begins at Prisoner's 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 isolated from down-channel flow. Because of the unique hydromorphology of Station 14, the findings for this station are discussed separately from those of the other channel stations.

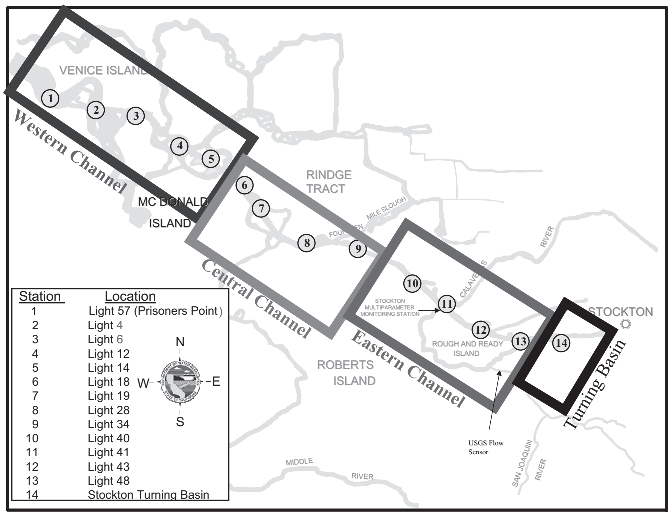

Figure 1 Monitoring stations in the Stockton Ship Channel

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, and analyzed for DO concentrations and temperature. Top DO samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were obtained using a Seabird submersible sampler and measured using a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ data logger. Surface and bottom water temperatures were measured using a 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 compiled by DWR[1]. Average daily flows past Vernalis were obtained by averaging 15-minute data. Tidal cycles of ebb and flood are not seen in flows at Vernalis and the flow proceeds downstream (positive flow) throughout the year. The San Joaquin River flows past Stockton used in this report were obtained from data recorded by the US Geological Survey (USGS) flow monitoring station southeast of Rough and Ready Island[2].

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[3] 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. Although net flows at Stockton frequently approached zero during this study period, net daily reverse flows were seen only during the end of fall 2003.

In this report, we define a DO "sag" as a region within the channel where DO levels are < 5.0 mg/L. These levels do not meet the CVRWQCB objectives described previously. A DO "depression" is defined as a region within the channel where DO levels are = 5.0 mg/L, but < 6.0 mg/L. These levels would not violate the CVRWQCB objective, but could, at times, violate the SWRCB objective.

Results

From August 11 to December 10 (the period of this study), DO levels varied considerably between regions within the channel, from a low of 3.0 mg/L to a high of 10.7 mg/L. In the western channel, DO concentrations were relatively high and stable, ranging from 6.9 to 9.4 mg/L. The robustness of DO concentrations in this portion of the channel is apparently due to the greater tidal mixing, the absence of conditions creating BOD, and shorter hydrological residence time. In the central portion of the channel, DO concentrations were more variable than the concentrations observed in the western channel, ranging from 4.1 to 9.3 mg/L. In the eastern channel, the DO levels were the most variable and stratified, ranging from a low of 3.0 mg/L to a high of 10.7 mg/L. Changing inflows from the San Joaquin River into the eastern channel may partially account for the variability of the DO levels within the eastern channel.

The findings for late summer and fall 2003 are briefly summarized by month as follows.

August

Monitoring on August 11 showed surface DO levels ranging from 4.7 mg/L at Stations 9 and 10 in the central and east channels, respectively, to 8.5 mg/L at Station 1 in

1. Station information: DWR Station SJR at Vernalis, RSAN112.

2. Station information: USGS 304810 SJR at Stockton, RSAN063.

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

the west channel (Figure 2). Bottom DO levels ranged from 3.8 mg/L at Station 12 in the east channel to 8.9 mg/L at Station 2 in the west channel. Both a DO sag and a depression were observed at the surface and bottom in the central and eastern channels. The depression extended from Stations 8 to 13, while the sag occurred from Stations 9 to 12 in the eastern channel. The western channel exhibited the highest DO and all stations maintained DO levels above 7.5 mg/L.

August 11 water temperature values ranged from surface values of 21.8 °C in the west channel to 26.1 °C in the east channel, and bottom values of 21.6 °C in the east to 25.3 °C in the west channel (Figure 3).

On August 29, monitoring showed surface DO levels ranging from 4.5 mg/L in the east channel to 7.8 mg/L in the west. Bottom DO levels ranged from 3.1 mg/L in the east channel to 7.4 mg/L in the west. A DO sag occurred at both the surface and bottom of the water column from Stations 10 to 12 in the eastern channel. The western channel exhibited the highest DO concentrations and all stations maintained surface DO levels above 7.3 mg/L.

On August 29, water temperature values ranged from surface values of 22.6 °C in the west channel to 26.2 °C in the east. Bottom values ranged from 22.5 °C in the west to 25.4 °C in the east channel (Figure 3).

Average daily flows in the San Joaquin River past Vernalis in August ranged from 1,265 to 1,655 cfs. Net flow in the San Joaquin River past Stockton ranged from 124 to 626 cfs when the flow meter was in operation (August 1 through 26) (Figure 4).

September

September 11 surface DO levels ranged from 4.4 mg/L at Station 9 in the central channel to 8.2 mg/L at Station 1 in the west channel. Bottom DO levels ranged from 3.0 mg/L at Station 10 in the east channel to 7.6 mg/L at Station 1 in the west channel. A DO sag occurred at both the surface and bottom, extending from Stations 8 to 13 in the eastern channel. The western channel exhibited the highest DO and all stations there maintained surface DO levels above 7.2 mg/L (Figure 2).

September 11 surface water temperatures ranged from 21.4 °C at Station 1 in the west channel to 24.9 °C at Station 11 in the east channel. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.8 °C at Station 9 in the central channel (Figure 3).

September 24 surface DO levels ranged from 4.7 mg/L at Station 8 in the central channel to 8.4 mg/L at Station 1. Bottom DO levels ranged from 4.4 mg/L at Station 8 in the central channel to 8.0 mg/L at Station 1. DO sags occurred at the surface in the central channel at Stations 7 and 8, at the bottom in the central channel from Stations 7 to 9, and in the eastern channel at Station 12. The western channel exhibited the highest DO and all stations there maintained surface DO levels above 7.6 mg/L (Figure 2).

September 24 surface water temperature ranged from 21.3 °C at Station 1 to 23.7 °C at Stations 12 and 13 in the eastern channel. Bottom temperatures ranged from 21.2 °C at Station 1 to 23.5 °C at Station 13 (Figure 3).

September flows in the San Joaquin River at Vernalis were similar to those in August, and remained fairly steady, ranging from 1,233 to 1,535 cfs. DWR began installation of the barrier at the head of Old River on September 2. The closure was completed on September 15 and all culverts were closed on September 22. Coincident with the barrier placement, net flow past Stockton increased steadily during the month, which resulted in an increase in flow rates from 406 cfs in early September to 1,206 cfs at the end of the month[1] (Figure 4).

1. USGS flow data for the San Joaquin River at Stockton was not available for the first four days in September (9/1/03-9/4/03).

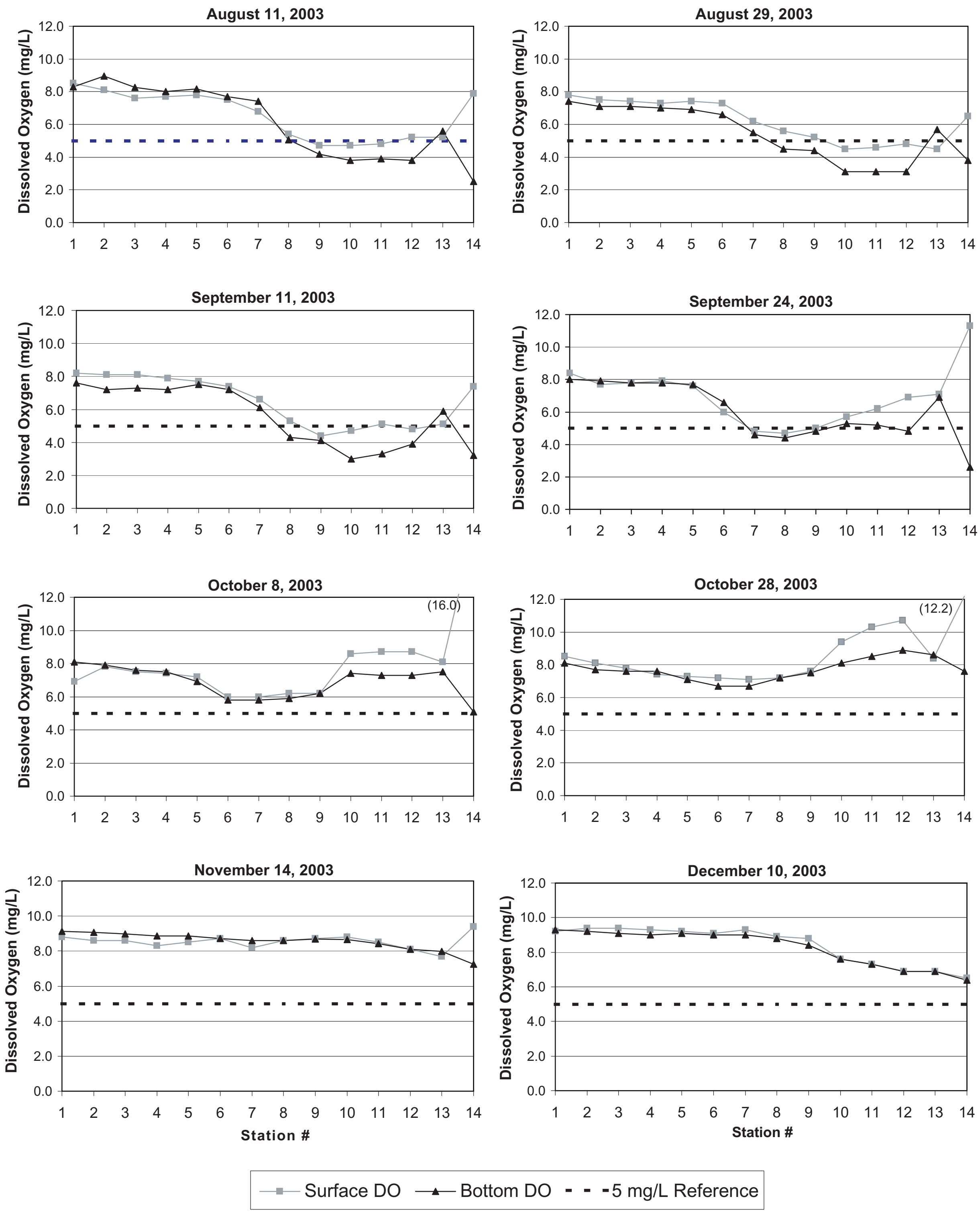

Figure 2 Dissolved oxygen concentrations in the Stockton Ship Channel, fall 2003

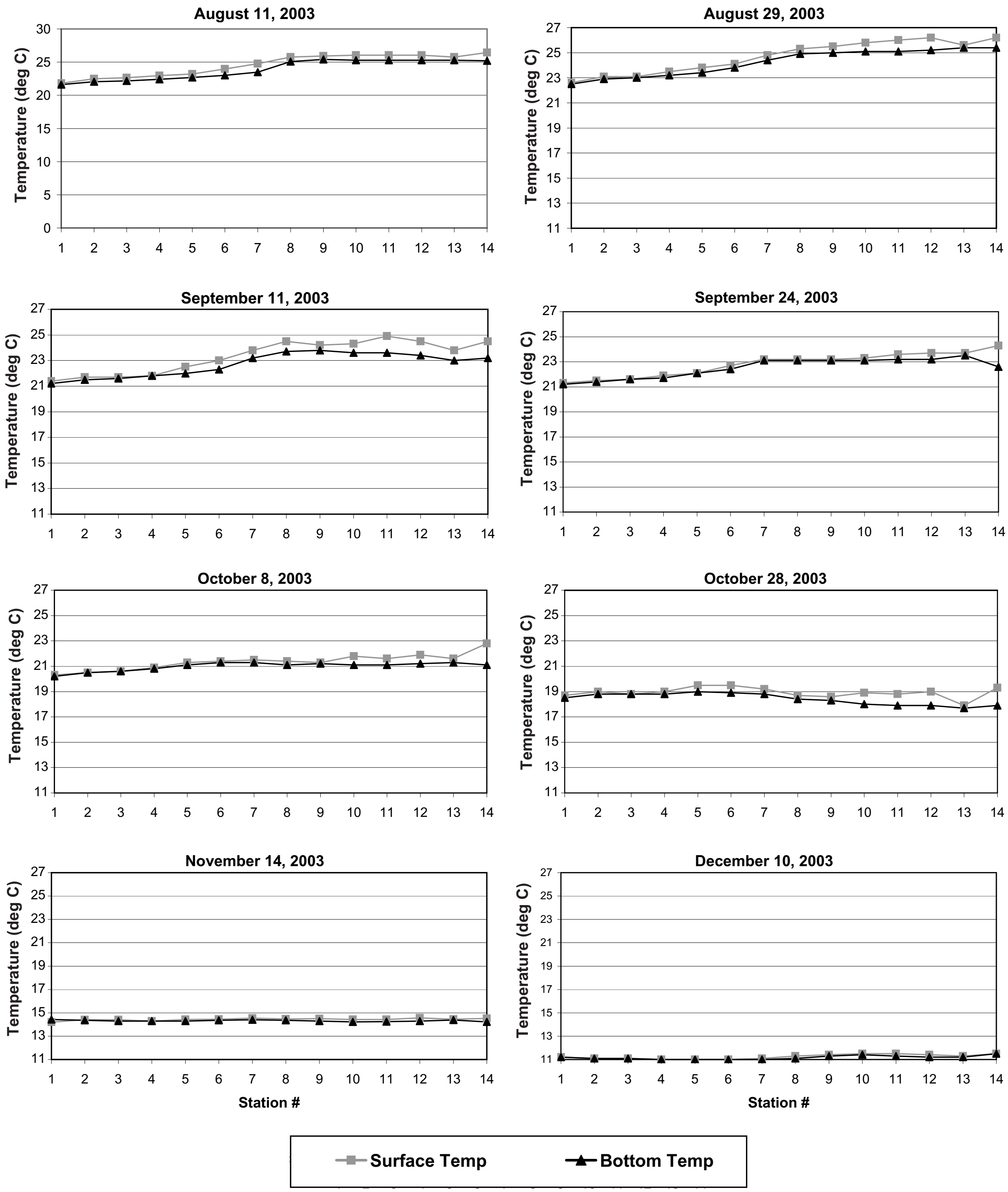

Figure 3 Water temperatures in the Stockton Ship Channel, fall 2003

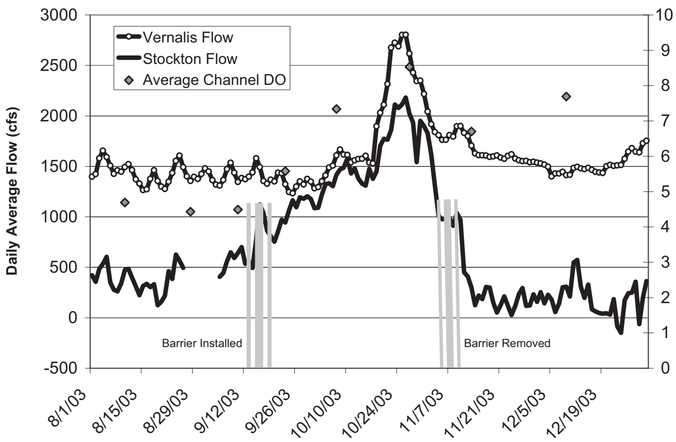

Figure 4 Flow conditions and average east and east-central channel DO levels, fall 2003

October

October 8 surface DO levels ranged from 6.0 mg/L at Stations 6 and 7 in the central channel to 8.7 mg/L at Stations 11 and 12 in the east channel. Bottom DO levels ranged from 5.9 mg/L in the central channel at Stations 6, 7, and 8, to 8.1 mg/L at Station 1. A DO sag was not observed within the channel; however, a very slight DO depression (below the 6.0 mg/L objective by a tenth of a mg/L) occurred on the bottom at Stations 6, 7, and 8 in the central channel.

On October 8, surface water temperatures ranged from 20.3 °C at Station 1 in the west channel to 21.9 °C at Station 12 in the east channel. Bottom temperatures ranged from 20.2 °C at Station 1 to 21.3 °C at Stations 6, 7, and 13.

On October 28, surface DO levels ranged from 7.1 mg/L at Station 7 in the central channel to 10.7 mg/L at Station 12 in the east channel. Bottom DO levels ranged from 6.7 mg/L at Stations 6 and 7 to 8.9 mg/L at Station 12. A DO sag was not observed within the channel during this sampling run. The eastern channel exhibited the highest DO and all stations maintained surface DO levels above 7.1 mg/L.

On October 28, surface water temperatures ranged from 17.9 °C in the east channel at Station 13 to 19.5 °C in the west channel at Stations 4 and 5. Bottom temperatures ranged from 17.7 °C at Station 13 to 19.0 °C at Station 5.

Average daily flows for the San Joaquin River at Stockton ranged from 1,085 to 2,182 cfs, increasing steadily throughout the month (Figure 4). Flows recorded at Stockton were very similar to those measured at Vernalis for much of the month, indicating that little upstream diversion was occurring. The barrier at Old River was in place with all culverts closed for the entire month of October. Flow rates at Vernalis ranged from 1,283 to 2,804 cfs, and also increased steadily throughout the month.

November

DO readings throughout the channel remained well above state objectives in November, and the barrier was removed in early November. On November 14 surface DO levels ranged from 7.7 mg/L at Station 13 to 8.8 mg/L at Stations 1 and 10. Bottom DO levels ranged from 8.0 mg/L at Stations 13 to 9.1 mg/L at Stations 1 and 2 (Figure 2). Although DO readings were fairly consistent throughout the channel, DO levels in the east were slightly lower than those seen in the central and western channels, and bottom DO levels were slightly higher than surface readings in the western channel.

Water temperatures on November 14 were consistent throughout the channel within a half a degree, with surface temperatures ranging from 14.2 °C at Station 1 to 14.6 °C at Station 12. Bottom temperatures ranged from 14.2 °C at Station 10 to 14.4 °C at Stations 1, 2, 6, 7, and 8 (Figure 3).

Flow rates past Vernalis continued to decline from 2,043 cfs on November 1 to 1,546 cfs by November 30. Net daily flows past Stockton also fell markedly from 1,828 cfs on November 1 to 233 cfs by November 30 (Figure 4). The reduced flows seen at Stockton coincided with the removal of the barrier, which allowed a diversion of flow from the San Joaquin River to the Old River.

December

DO readings remained steady in the west and central channels, but declined slightly in the eastern channel during December; however, all levels were well above state objectives. December 10 surface DO levels ranged from 6.9 mg/L at Stations 12 and 13 to 9.4 mg/L at Stations 2 and 3. Bottom DO levels ranged from 6.9 mg/L at Stations 12 and 13 to 9.3 mg/L at Station 1 (Figure 2). The western channel exhibited the highest DO and all stations maintained surface DO levels above 6.9 mg/L.

Water temperatures throughout the channel declined further from November, and were consistent throughout the channel, within a half a degree Celsius. December 10 surface temperatures ranged from 11.0 °C at Stations 4, 5, and 6 to

11.5 °C at Stations 10 and 11. Bottom temperatures ranged from 11.0 °C at Stations 4, 5, 6, and 7 to 11.4 °C at Station 10 (Figure 3).

Flow rates past Vernalis in December ranged from 1,400 to 1,753 cfs, with an increase of flow occurring towards the end of the month. Net daily flows past Stockton continued to decline, with negative flows and flows approaching zero recorded on several occasions. December net daily flows at Stockton ranged from 573 to -150 cfs.

Stockton Turning Basin

Stratified DO conditions were recorded in the Stockton Turning Basin (Station 14) throughout much of fall 2003 (Figure 2). Surface DO levels in late September and October were supersaturated, while bottom levels were at or below state objectives. The highest stratification was observed on October 8 when sampling showed surface DO concentrations of 16.0 mg/L, with a bottom concentration of 5.1 mg/L. Vertical DO stratification at Station 14 was observed on all sampling runs except the final run of December 10.

The periodic DO 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 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 2003 were no exception, as intense algal blooms composed primarily of green algae, flagellates, diatoms, and Cryptomonads were detected.

Stratified DO 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 DO levels. However, dead or dying bloom algae can sink to the bottom to contribute to high BOD and low bottom DO levels as they decompose. Bottom DO levels in the basin are further degraded by additional BOD loadings in the area from sources, such as regulated discharges into the San Joaquin River and nonpoint source pollution adjacent to the basin. When bloom activity subsides, the DO stratification is reduced, and basin surface and bottom DO levels become less stratified.

Summary

DO concentrations in the eastern Stockton Ship Channel fell below both the state's 5.0 mg/L and 6.0 mg/L objectives in August and September 2003, a period which coincided with relatively low net flows in the San Joaquin River past Stockton and warm water temperatures. A temporary barrier across the head of Old River was installed on September 15, 2003, to increase flows down the San Joaquin River into the channel. The barrier became fully operational on September 22 when all culverts were closed. Subsequent sampling on October 8 showed an improvement of DO conditions, with all stations showing levels above the 5.0 mg/L objective, and only the central channel with levels slightly below the 6.0 mg/L objective. By October 28, DO levels had improved to 6.0 mg/L or greater throughout the channel, and remained above state objectives for the remainder of the sampling program. The barrier was fully removed by November 13, and although flows past Stockton were subsequently reduced, DO levels remained within compliance. The fall sampling program was suspended after sampling on December 10.

References

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

[CVRWCB] 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.

Short-term Variability of Chlorophyll and Implications for Sampling Frequency in the San Joaquin River

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Introduction

Phytoplankton chlorophyll *a* can undergo striking changes over the day. In estuaries, short-term variability due to tidal forcing is often present (Cloern 1991), but there are also strictly diel cycles not related to tides. Diel changes are a potential source of bias and variability when using in situ measurements of optical properties to infer phytoplankton biomass or primary productivity (Claustre and others 2002). Diel chlorophyll *a* variability has been reported in the Sacramento-San Joaquin Delta and immediately upstream (Lucas and others 2002), but there is still much to be known about its magnitude, site differences, seasonal and interannual variability, and effects on determining phytoplankton trends.

In this study, we use the continuous chlorophyll *a* fluorescence record to examine short-term variability in the tidal San Joaquin River. Implications for sampling rather than underlying mechanisms are the focus. Three specific areas are covered. First, calibration procedures and issues are reported. Next, the data are described in terms of magnitude, differences between stations, and long-term variability in the diel cycle. Finally, the implications of the data patterns and magnitudes for sampling are considered. Only data from the continuous monitoring stations are considered, and only two of these stations have been analyzed to date. These two stations, however, avoid certain complications of interpretation, as discussed below. At a later stage, similar data from the other stations as well as other programs in the Delta will be included. It is also anticipated that some of the calibration issues mentioned here will have been resolved.

We gratefully acknowledge support for this research from the California Bay-Delta Authority (ERP-02-P33).

Methods

Data Collection and Conversion

The chlorophyll fluorescence data used in this study were collected by the IEP Environmental Monitoring Program at two of its "multiparameter" shore stations, located along the San Joaquin River on Rough and Ready Island near Stockton and on the Manthey Road bridge at Mossdale (Figure 1). At these sites, sample water is continuously pumped from a depth of one meter below the water surface and delivered to several continuously-recording instruments. (The intake is enclosed and protected by a vertical perforated pipe extending from 1 to 5 m, approximately, so the sample actually comes from a wider upper stratum of the water column.) We used hourly fluorescence averages recorded from March 1997 to December 2002 at the Stockton station and from April 2000 to April 2003 at the Mossdale station. Chlorophyll fluorescence was measured with Turner 10 fluorometers equipped with a red sensitive photomultiplier tube, Blue Mercury vapor lamp, Corning color specification 5-60 excitation filter, Corning color specification 2-64 emission filter, Corning color specification 3-66 reference filter, a continuous-flow sample chamber, and automatic temperature compensation. The instruments were set to measure fluorescence every second. At the end of each hour, the average and the highest and lowest values of the approximately 3,600 measurements were recorded. To assure measurement quality and consistency, the fluorometers were frequently inspected with 0.5 and 0.25 mg/L rhodamine B standard solutions and adjusted as necessary. Instrument and measurement problems were noted, and data associated with noted problems was marked. These problematic data were excluded from our analyses, leaving a total number of 25,852 hourly fluorescence records for Stockton and 22,767 records for Mossdale. On an approximately monthly basis, grab samples were taken for chlorophyll *a* analysis following Standard Method 10200 H (Clesceri and others 1998) at the California Dept. of Water Resources' Bryte Chemical Laboratory.

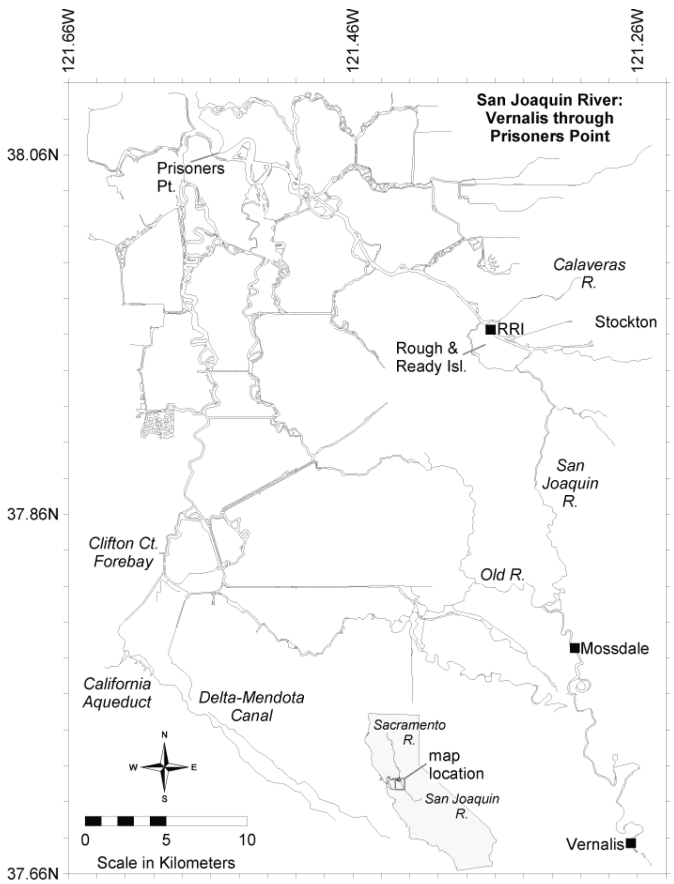

Figure 1 The tidal San Joaquin River from Vernalis through Prisoners Point. Fluorescence data used in this study were collected at the Mossdale and Stockton (RRI) stations.

Grab sample chlorophyll *a* data were paired with the nearest recorded fluorescence data to convert fluorescence values into chlorophyll *a* concentrations. All replicated chlorophyll and fluorescence measurements were averaged. Two of the Mossdale pairs and four of the Stockton pairs were identified as suspicious outliers and removed from the analysis. The remaining data, consisting of 36 pairs of chlorophyll and fluorescence values for Mossdale and 53 pairs for Stockton, were used to fit two linear calibration models:

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i \qquad (1)$$

where y_i is the ith chlorophyll *a* value, x_i is the corresponding fluorescence value, β_0 and β_1 are constant coefficients, and ϵ_i are the within-station errors.

The parameters were first determined for each station using ordinary least squares, under the assumption that within-station errors are independent and identically distributed as a normal zero-mean distribution, that is:

$$\mathrm{var}(\epsilon_i) = \sigma^2 \qquad (2)$$

but with a different σ for each station. Heteroscedasticity, that is changing variance of residuals with fitted values, was detected. In particular, the variance increased with fluorescence, which has the effect of biasing fitted values for smaller values of chlorophyll *a*. To address this problem, we next used generalized least squares to fit the linear model of Equation 1, allowing the ϵ_i to have variances proportional to fluorescence, that is:

$$\mathrm{var}(\epsilon_i) = \sigma^2 x_i \qquad (3)$$

Although the relative variance of fluorescence measurements is constant, Equation 3 implies that the relative variance of estimated chlorophyll *a* increases as chlorophyll *a* decreases:

$$\frac{\mathrm{var}(\varepsilon_i)}{y_i} = \frac{\sigma^2 x_i}{y_i} = \frac{\sigma^2}{\beta_1}\left(1 - \frac{\beta_0}{y_i}\right) \qquad (4)$$

We ignored estimates less than or equal to zero. Models were compared on the basis of their Akaike Information Criterion (AIC); a lower AIC denotes a superior model. All theory and calculations are described in detail by Pinheiro and Bates (2000).

Data Analysis

A *cumulative periodogram* was estimated for each time series of hourly chlorophyll *a*. The cumulative periodogram for any given frequency (or corresponding time period) can be interpreted as the proportion of variance in the series accounted for by all frequencies lower than or equal to the given frequency (equivalently, all time periods longer than or equal to the given period). Note that one must examine a small frequency range surrounding the frequency of interest to understand the latter's importance because of a mathematical phenomenon known as spectral *leakage*, which increases as the length of the observed series decreases. Periodic components in the series were first sharpened by *tapering*, i.e., the first and last 10% of the data were tapered to zero with a bell curve. Theory and calculations are described by Venables and Ripley (1994).

We compared simulated discrete near-monthly sampling to the hourly data to determine how well the former captures seasonal patterns, as well as monthly and annual averages. First, the hourly data were averaged for each day to remove any effects of the diel cycle, enabling us to focus on variability at time scales of one day and longer. Near-monthly sampling was then simulated by alternating between spring and neap tides to reduce tidal biases, which is the recommended plan for the IEP Environmental Monitoring Program. We also simulated sampling on the first day of every month without regard to spring-neap tidal cycles. In both cases, near-monthly samples were linearly interpolated to provide monthly averages, which were then compared to actual monthly averages determined from the hourly data. Percentage deviations of simulated averages x_{sim} from actual averages x_{obs} were calculated as $100\left|x_{\text{sim}} - x_{\text{obs}}\right| / x_{\text{obs}}$.

Results

According to the AIC, the proportional-variance model (Equation 3) was superior to the constant-variance model (Equation 2; Table 1). Assuming a nonconstant variance had the effect of decreasing slopes and increasing intercepts for both stations, especially Stockton, as well as removing heteroscedasticity in the resulting residuals. Parameter values, however, were actually not significantly different from those obtained using ordinary least squares. In fact, the parameter values for the two stations were not significantly different. In any case, we used the less biased results of the generalized least squares estimates to convert the fluorescence data here. R^2 values were 0.97 for Mossdale and 0.81 for Stockton (Figure 2). The negative constants are a result of background (non-chlorophyll *a*) fluorescence. The converted time series are plotted in Figure 3.

Table 1 Parameter values (± standard errors) for the linear calibration of chlorophyll *a* versus fluorescence, assuming that variance of within-station errors is either constant or proportional to fluorescence.

Model	β_0	β_1	*aic*
Constant variance:			
Mossdale	–10 ± 2	0.61 ± 0.01	250
Stockton	–8 ± 1	0.55 ± 0.06	289
Proportional variance:			
Mossdale	–9 ± 1	0.60 ± 0.02	241
Stockton	–6 ± 1	0.51 ± 0.04	281

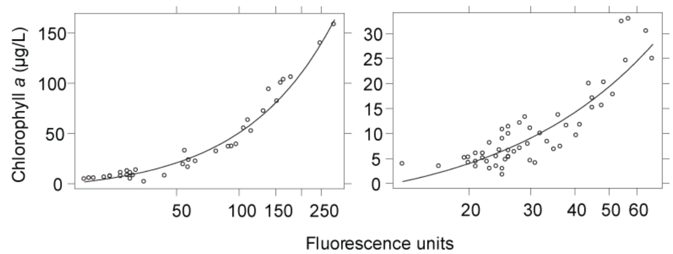

Figure 2 Linear calibration plots for chlorophyll *a* versus fluorescence at Mossdale and Stockton. The x-axes are log-transformed to display the fit at lower values more clearly.

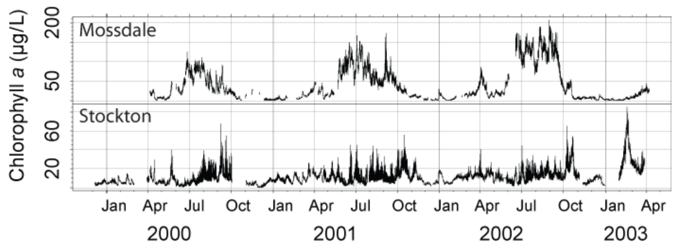

Figure 3 Hourly time series of chlorophyll *a* at Mossdale and Stockton, based on calibrations of Figure 2.

At Mossdale, chlorophyll *a* reaches a maximum in mid-afternoon, typically between 16:00 and 17:00 (Figure 4). It then begins to decline and, in some months at least (for example, April), continues to decline until dawn. The daytime change, however, is much larger than the night-time change. A secondary maximum occurs in the morning during some months (for example, September). At Stockton, chlorophyll *a* also reaches a daily maximum between 16:00 and 17:00, and exhibits a nocturnal decline and a morning minimum during late spring and early summer. A secondary morning maximum in autumn months is barely observable. Overall, the diel cycle is stronger at Stockton than at Mossdale.

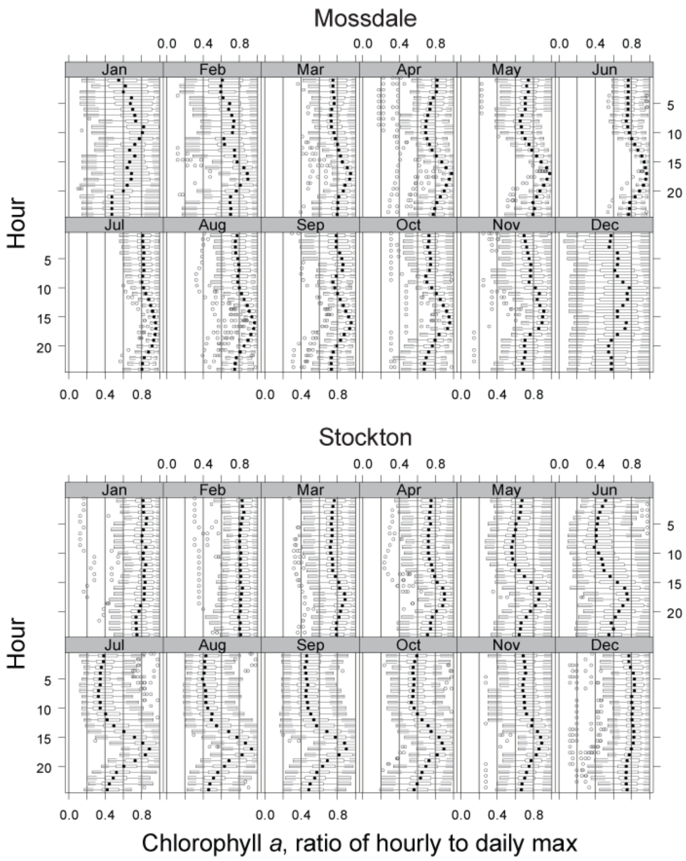

Figure 4 Diel patterns of chlorophyll *a* by month at Mossdale for 2000-2003 and at Stockton for 1999-2003. On the y-axis, hour 10 (for example) refers to the period 09:00-10:00. Values are scaled by the maximum value for the same day. The data are summarized by hour and month with a traditional box-and-whiskers plot: the box spans the middle two quartiles of the data, the whiskers span all data within 1.5 times the box width from the median (filled circles), and the hollow circles are outlying data.

A clear seasonal cycle in the diel pattern can be observed at Stockton (Figure 5). The chlorophyll *a* daily minimum can be less than half the maximum during summer, but typically only about 30% less in winter. The seasonal pattern is quite consistent from year to year. In contrast, the diel pattern does not appear to have a consistent seasonal cycle at Mossdale. The chlorophyll *a* daily minimum is typically about 70% of the maximum, ranging from about 40% to 80%. Note that we ignored estimates less than 2 µg/L in order to avoid artifacts associated with dividing by low chlorophyll *a* values: recall that uncertainty rises rapidly as estimated chlorophyll *a* approaches zero (Equation 4). This made little difference for Stockton but had a large effect on winter values for Mossdale when chlorophyll *a* was particularly low.

We calculated the absolute percentage deviation of each hourly value from the daily mean. At Mossdale, the median deviation ranges from 7.0% during 10:00-11:00 hours to 15% during 16:00-17:00, although the range is large and there are individual cases where the deviation exceeds 50% (Figure 6). Similar comments apply to Stockton, although the median deviations are even larger.

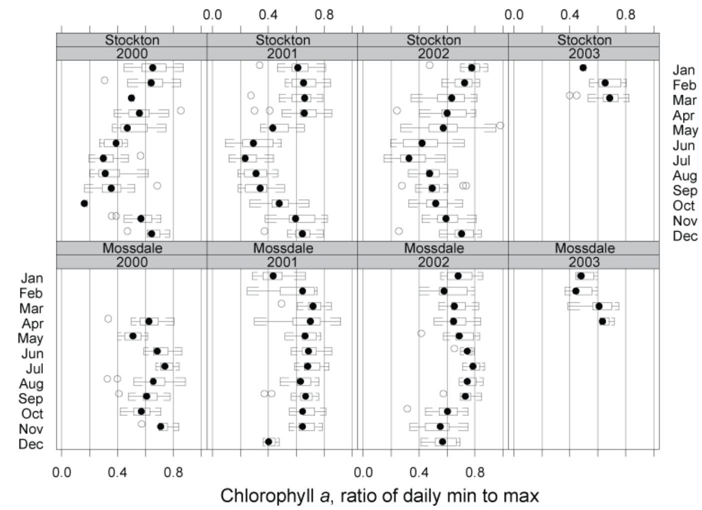

Figure 5 Seasonal patterns of the daily chlorophyll *a* range by year at Mossdale and Stockton for 2000–2003. Values are the ratio of minimum to maximum chlorophyll *a* for the same day. Chlorophyll *a* values less than 2 µg/L were excluded. The data are summarized by month and year with a traditional box-and-whiskers plot. The dark circles are medians.

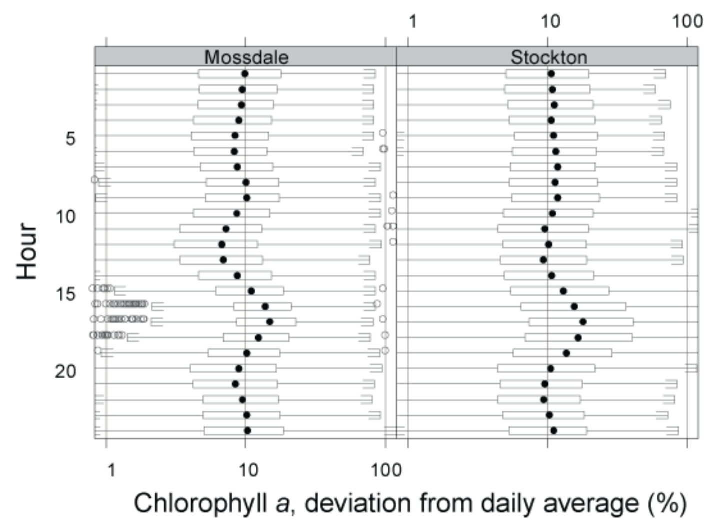

Figure 6 Absolute percent deviations of hourly average from the daily average chlorophyll *a* at Mossdale and Stockton.

Cumulative periodograms were quite different for the two stations (Figure 7, which plots cumulative variance versus period, i.e., inverse frequency). The annual cycle contributes most of the total variance at Mossdale; whereas the daily cycle and higher frequencies (smaller periods) contribute only a few percent. In contrast, the daily cycle at Stockton is the largest contributor of any single frequency and variability associated with the annual cycle is barely detectable. In fact, an approximately semi-annual frequency component centered at 0.0057 d^{-1} (174 d) plays a much larger role than the annual cycle. The fortnightly spring-neap tidal cycle is perceptible at Stockton, but not at Mossdale. Other frequencies also account for much more of the variability at Stockton, reflecting its more irregular annual chlorophyll *a* patterns (Figure 3).

There was little difference between simulated tidal and calendar sampling results at these two stations (Table 2). Both sampling schemes provided monthly estimates that were highly correlated with monthly averages at Mossdale and, somewhat less so, at Stockton (tidal sampling results are illustrated in Figure 8). Estimated monthly averages differed from actual averages typically by about 30%, whereas annual averages differed typically by about 10%.

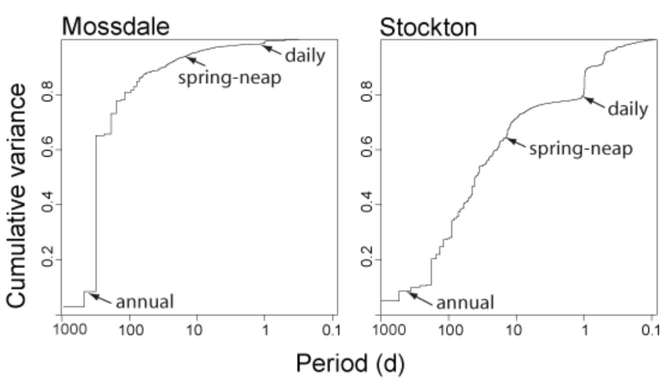

Figure 7 Cumulative periodogram of hourly chlorophyll *a* at Mossdale and Stockton stations. The y-axis indicates the cumulative variance (as a proportion of total variance) for all periods larger than or equal to the corresponding period on the x-axis.

Table 2 Comparison of monthly averages (± standard errors) based on spring-neap tidal or first-day-of-the-month calendar sampling with monthly averages calculated from hourly observations.

	Tidal		*Calendar*	
	Mossdale	*Stockton*	*Mossdale*	*Stockton*
Correlation	0.97	0.75	0.96	0.69
Monthly deviation, %	32 ± 6	25 ± 4	29 ± 5	27 ± 4
Annual deviation, %	4 ± 2	15 ± 4	9 ± 2	11 ± 4

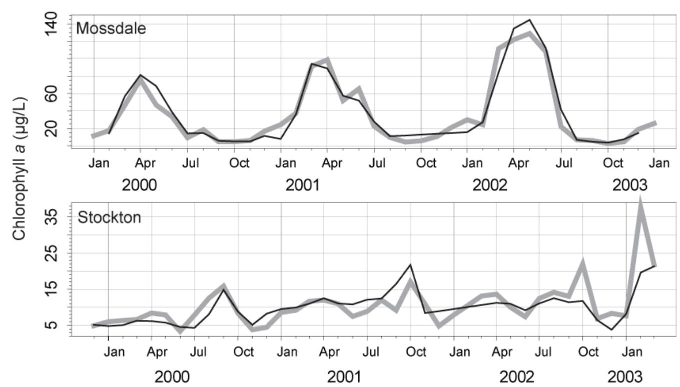

Figure 8 Monthly time series of chlorophyll *a* based on hourly data (thick gray line) and on simulated near-monthly tidal sampling (thin black line).

Discussion

A number of factors could contribute to calibration uncertainty, which was considerably higher at Stockton than at Mossdale. Pheophytin, a breakdown product of chlorophyll *a*, fluoresces weakly and could introduce variability into the conversion if it is high enough and variable enough. At Stockton, the ratio of pheophytin to chlorophyll *a* in conversion grab samples was 0.95 ± 0.55 (standard deviation); at Mossdale, this ratio was only 0.40 ± 0.20. In other words, pheophytin was a more important and a more variable contributor to fluorescence at Stockton than Mossdale. The partial correlation between fluorescence and pheophytin after correcting for chlorophyll *a* is 0.31 ($p = 0.024$) at Stockton, whereas it is only 0.096 ($p = 0.58$) at Mossdale. Thus, the effect of pheophytin on fluorescence is indeed detectable at Stockton, but not at Mossdale. Dissolved organic matter may also be a source of fluorescence.

Other factors also can contribute in principle, but we did not have the appropriate data in hand to consider them. We mention in passing that turbidity is high in the Delta and could interfere with fluorescence detection. If that is the case, then data from continuous turbidity sensors should be incorporated into the conversion (the recent installation of new sensors now makes this possible). A further possible factor is the pigment makeup of phytoplankton cells. Fluorescence per unit chlorophyll *a* depends on an array of accessory pigments as well as chlorophyll *a*, which are different for different phytoplankton taxa. Phytoplankton community composition at Stockton reflects that at Mossdale (namely, small centric diatoms characteristic of turbid rivers) when discharge is high enough, but a more local flora in which cryptophytes dominate develops at lower discharge. Thus, a more variable species composition at Stockton could result in higher calibration uncertainty. Finally, we note that Stockton chlorophyll *a* also has a higher relative variance for smaller time periods (< 1 d: Figure 7), perhaps because the water is not as well-mixed as at Mossdale. This implies that extra care should be taken to match calibration grab samples with fluorescence measurements as closely as possible in time and space.

We also examined calibrations that included more complicated variance models and corrections for serial correlation, as well as a variety of mixed-effects models in which the parameters were dependent on station or sampling hour. None of these refinements provided a superior description of the data and so are not detailed here. Perhaps this is due to the relatively small number of calibration data currently available for these two stations. Even with these few data, however, we were able to identify heteroscedasticity and improve the fit for lower values of fluorescence. As more calibration data become available for these and other stations, we expect that mixed-effects models incorporating nonconstant variance and serial correlation could very well become suitable as calibration models.

It was not surprising to find that inclusion of sampling hour did not improve the calibration. Non-photochemical fluorescence quenching results in lower fluorescence per unit chlorophyll *a* at higher light, sometimes causing a depression of fluorescence at midday. But the effect is negligible when solar radiation is less than 200 µE m^{-2} s^{-1} (Kinkade and others 1999). The average water column light at Mossdale is lower than this even around the summer solstice (Jassby 2005). Average water column light at Stockton is probably lower still because of the far greater optical depth (depth × vertical attenuation coefficient for light). Quenching could happen only in a thin quiescent surface layer, an unlikely event considering the absence of any obvious midday depression in the spring-summer data (Figure 4). Non-photochemical fluorescence quenching could be a more important issue at other shallow, more transparent locations in the Delta.

It is possible that the higher values of fluorescence at Mossdale were outside the linear response range of the fluorometer, resulting in underestimates of chlorophyll *a* (a phenomenon known as *concentration quenching*). Fluorescence readings for the 0.5 mg/L rhodamine standard ranged from 57.6 at 40 °C to 125 at 8 °C, which is well below the highest fluorometer readings of 360 at Mossdale. The calibration data indicate linearity up to 158 µg/L (Figure 2), but maximum chlorophyll *a* was considerably larger at 207 µg/L. Assuming minimum daily values were within the linear response range, an artifactual dampening of the diel cycle could result at times of high phytoplankton concentration (late spring and summer). In contrast, the maximum chlorophyll *a* at Stockton was only 86 µg/L. This may account in part for the more intense diel cycles observed at Stockton, although these differences extend to months with lower phytoplankton and must therefore involve other factors as well.

These diel cycles imply that the sampling hour is important for estimating daily or longer-term average values. At these two stations, midday (11:00–13:00) is the best time to sample for a daily average whereas late afternoon (16:00–17:00) is the worst. The difference is considerable and makes it worthwhile to choose midday when estimating daily averages. A closer look at the data, which we do not undertake here, may reveal that the sampling time can be optimized even further according to season. Diel cycles, however, may be especially prominent at Mossdale and Stockton because of relatively low tidal variability. The regularity of the diel patterns shows that semidiurnal tidal cycles are having little impact at these stations, and the cumulative periodograms show that the fortnightly spring-neap tidal cycles are also relatively unimportant (Figure 7). The Environmental Monitoring Program in fact aims to sample stations within an hour of high slack tide to reduce noise due to semidiurnal tidal effects, reflecting that tidal is more important than diel variability for most stations and water quality variables. Sampling at a given phase of the semidiurnal tidal cycle is the best strategy when tidal effects are dominant and the aim is detection of long-term pattern.

The continuous fluorescence record also enables us to examine how well the discrete near-monthly sampling program captures long-term patterns in chlorophyll *a*. Chlorophyll *a* at Mossdale varies strongly on an annual scale, whereas chlorophyll *a* at Stockton varies predominantly on shorter time scales. Thus, the discrete sampling program does a better job of capturing the monthly averages at Mossdale, with a correlation of 0.97 for the tidal sampling scheme (Table 2, Figure 8; recall that within-day variability has been eliminated for this analysis). Even at Stockton, however, discrete sampling captures much of the month-to-month variability. There is little difference between tidal and calendar sampling schemes, presumably because tidal influences at these stations are relatively small compared to variability at the monthly and longer scales.

One might expect that, although strong interannual variability makes it easier to determine the annual pattern with discrete near-monthly samples, it also makes it harder to determine the mean for a specific month. The uncertainties in means for specific months are in fact somewhat higher at Mossdale than Stockton, but only by a small amount. The deviations of about 30% from true values imply that mass balances for specific months of specific years, when based on near-monthly discrete sampling, are unreliable at either station. It is important to note, however, that averaging over many years decreases the uncertainties, as it does for other sources of uncertainty such as the conversion from fluorescence to chlorophyll *a*, and makes mass balances feasible at monthly time scales. For example, even for just the three to four years analyzed here, the deviation for a long-term monthly mean decreases to 24 ± 7% for Mossdale and 13 ± 3% for Stockton. Construction of mass balances based on long-term monthly data are therefore a reasonable undertaking. Even without long-term averaging, the deviations in means at the annual scale is only about 10% and therefore useful for a number of purposes, including mass balances and "ecosystem health" indicators (Table 2).

Although it is not our purpose here to investigate mechanisms underlying diel cycles in chlorophyll *a* concentrations, we close by mentioning some possibilities. The phenomenon is best known from open ocean studies (Binder and DuRand 2002), but similar evidence is available from other estuarine systems (Brunet and Lizon 2003) and rivers (Kiss 1996). The 1996 study by Kiss on the River Danube is particularly interesting because of many similarities to the reach of the San Joaquin River under consideration: dominance by small centric diatoms; eutrophy; and community biomass control by discharge rate and transparency (Jassby 2005). Kiss observed, as we did, late afternoon maxima of chlorophyll *a* and sometimes a second peak in the morning. Fluctuations in cell number exhibited similar patterns, so chlorophyll *a* reflected real changes in population density. Microscopic examination showed diel cycles of dividing cells and average cell volumes. The evidence implied that the driving force behind the daily increases was synchronous cell division; sometimes two divisions occurred each day. But the study did not explain what held the community in check, creating a cycle rather than a prolonged increase. Grazing could be responsible, as is the case elsewhere (Litaker and others 1988). Perhaps vertical movement due to buoyancy changes or migration also plays a role (Brunet and Lizon 2003). Finally, based only on the data presented here, we cannot rule out that factors other than varying cell concentration, including intracellular rhythms in pigment content, may be important (Vaulot and Marie 1999).

Conclusions

- Uncertainty in converting fluorescence measurements to chlorophyll *a* concentrations may be reduced by incorporating continuous turbidity data and by pairing calibration grab samples with continuous readings more exactly in space and time; some known uncertainty sources such as the variable ratio of pheophytin to chlorophyll *a* will remain.

- Calibration models need to account for heteroscedasticity and possibly serial correlation in residuals in order to avoid bias.

- Non-photochemical fluorescence quenching is probably not occurring at Mossdale and Stockton. There is also no statistical evidence that the calibration curve changes over the day at these stations, but the relatively small calibration data set makes this a tentative conclusion.

- The linear response range of fluorometers needs to be established over a larger range of fluorescence to ensure that concentration quenching is not occurring at the highest phytoplankton concentrations.

- Sampling at midday is the best time and late afternoon is the worst for estimating a daily chlorophyll *a* average at Mossdale and Stockton, although this is not necessarily the case at more downstream stations where tidal forces are stronger.

- Discrete monthly sampling does an excellent job of capturing seasonal and longer-term patterns at stations like Mossdale with a strong annual cycle, and an adequate job at stations like Stockton that have relatively more variability at shorter time scales.

- Discrete monthly sampling cannot provide reliable means for specific months in specific years, but it can provide reliable long-term means for specific months. It also can provide useful estimates of means for specific years.

- Other studies of similar environments suggest that the diel cycles in chlorophyll *a* represent real changes in cell number and are the result of one or two synchronous cell divisions per day paired with cell losses due to grazing or other factors.

References

Binder BJ, DuRand MD. 2002. Diel cycles in surface waters of the equatorial Pacific. Deep-Sea Research Part II-Topical Studies in Oceanography 49:2601-2617.

Brunet C, Lizon F. 2003. Tidal and diel periodicities of size-fractionated phytoplankton pigment signatures at an off-shore station in the southeastern English Channel. Estuarine Coastal and Shelf Science 56:833-843.

Claustre H, Bricaud A, Babin M, Bruyant F, Guillou L, Le Gall F, Marie D, Partensky F. 2002. Diel variations in *Prochlorococcus* optical properties. Limnology and Oceanography 47:1637-1647.

Clesceri LS, Greenberg AE, Eaton AD, editors. 1998. Standard methods for the examination of water and wastewater. 20th ed. Washington: American Public Health Association, American Water Works Association, and Water Environment Federation.

Cloern JE. 1991. Tidal stirring and phytoplankton bloom dynamics in an estuary. Journal of Marine Research 49:203-221.

Jassby AD. 2005. Phytoplankton regulation in a eutrophic tidal river (San Joaquin River, California). San Francisco Estuary and Watershed Science 3(1 [March 2005]):Article 3. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art3.

Kinkade CS, Marra J, Dickey TD, Langdon C, Sigurdson DE, Weller R. 1999. Diel bio-optical variability observed from moored sensors in the Arabian Sea. Deep-Sea Research Part II-Topical Studies in Oceanography 46:1813-1831.

Kiss KT. 1996. Diurnal changes of planktonic diatoms in the River Danube near Budapest (Hungary). Algological Studies 80:113-122.

Litaker W, Duke CS, Kenney BE, Ramus J. 1988. Diel Chl-a and phaeopigment cycles in a shallow tidal estuary - potential role of microzooplankton grazing. Marine Ecology-Progress Series 47:259-270.

Lucas LV, Schraga T, Lopez CB, Burau JR, Jassby AD. 2002. Pulsey, patchy water quality in the Delta: implications for meaningful monitoring. IEP [Interagency Ecological Program for the Sacramento-San Joaquin Estuary] Newsletter 15(3):21-27.

Pinheiro JC, Bates DM. 2000. Mixed-Effects models in S and S-PLUS. New York: Springer.

Vaulot D, Marie D. 1999. Diel variability of photosynthetic picoplankton in the equatorial Pacific. Journal of Geophysical Research-Oceans 104(C2):3297-3310.

Venables WN, Ripley BD. 1994. Modern applied statistics with S-Plus. New York, NY, USA: Springer-Verlag.

7th Biennial State of the San Francisco Estuary Conference

The San Francisco Estuary Project announces the 7th Biennial State of the San Francisco Estuary Conference: "Celebrating Science and Stewardship" is set for October 4-6, 2005, at the Henry J. Kaiser Convention Center, 10 Tenth Street, Oakland.

The conference will include plenary sessions with over 60 invited speakers addressing topics, including wetland habitat restoration and the North and South Bay Salt Pond projects; ecosystem and water planning in the Delta, including the status of the pelagic organism crash research efforts; the challenges of the San Joaquin River; and important changes in the state of the Estuary.

Cost for the conference is $100 per day ($40 per day for students) or an early bird rate of $225 for all 3 days until September 16 or $250 after. Scholarships are also available. Contact Karen McDowell at 510-622-2398 or Paula Trigueros at 510-622-2499.

For additional information, the complete program and registration details go to

http://www.abag.ca.gov/abag/events/estuary

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Journals

Baerwald M.R. and B. May. 2004. Characterization of microsatellite loci for five members of the minnow family Cyprinidae found in the Sacramento-San Joaquin Delta and its tributaries. Molecular Ecology Notes 4 (3): 385-390.

Dahlgren R., E. Van Nieuwenhuyse, and G. Litton. 2004. Transparency tube provides reliable water-quality measurements. California Agriculture 58(3): 149-153.

Feyrer F., T.R. Sommer, S.C. Zeug, G. O'Leary, and W. Harrell. 2004. Fish assemblages of perennial floodplain ponds of the Sacramento River, California (USA), with implications for the conservation of native fishes. Fisheries Management and Ecology 11:335-344.

Greenfield B.K., J.A. Davis, R. Fairey, C. Roberts, D. Crane, and G. Ichikawa. 2005. Seasonal, interannual, and long-term variation in sport fish contamination, San Francisco Bay. Science of the Total Environment 336: 25-43.

Gregory J.A., J.B. Graham, J.J. Cech, Jr., N. Dalton, J. Michaels, and N.C. Lai. 2004. Pericardial and pericardioperitoneal canal relationships to cardiac function in the white sturgeon (*Acipenser transmontanus*) Comp. Biochem. Physiol. 138A:203-213.

Hooff R.C. and S.M. Bollens. 2004. Functional response and potential predatory impact of *Tortanus dextrilobatus*, a recently introduced carnivorous copepod in the San Francisco Estuary. Mar. Ecol. Prog. Ser. 277: 167-179.

Houck A. and J.J. Cech, Jr. 2004. Effects of dietary methylmercury on juvenile Sacramento blackfish bioenergetics. Aquat. Toxicol. 69:107-123.

Israel J.A., J.F. Cordes, M.A. Blumberg, and B. May. 2004. Geographic patterns of genetic differentiation among collections of green sturgeon. North American Journal of Fisheries Management: 24 (3): 922–931.

Mayfield R. and J.J. Cech, Jr. 2004. Temperature effects on green sturgeon bioenergetics. Trans. Amer. Fish. Soc. 133:961-970.

Merz J.E. and J.D. Setka. 2004: Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California river. North American Journal of Fisheries Management: Vol. 24, No. 2, pp. 397–407.

Stewart A.R., S.N. Luoma, C.E. Schlekat, M.A. Doblin and K.A. Hieb. 2004. Food web pathway determines how selenium affects aquatic ecosystems: A San Francisco Bay case study. Environmental Science and Technology 38(17): 4519-4526.

Swanson C., P.S. Young, and J.J. Cech, Jr. 2004. Swimming in two-vector flows: performance and behavior of juvenile Chinook salmon near a simulated screened water diversion. Trans. Amer. Fish. Soc. 133:265-278.

Thompson B. and S. Lowe, 2004. Assessment of macrobenthos response to sediment contamination in the San Francisco Estuary, California, USA. Environ. Toxicol., Chem. 23: 2178-2187.

Warren D.E., S. Matsumoto , J.M. Roessig, and J.J. Cech, Jr. 2004. Cortisol response of green sturgeon to acid-infusion stress. Comp. Biochem. Physiol. A137:611-618.

Young P.S., C. Swanson, and J.J. Cech, Jr. 2004. Photophase and illumination effects on the swimming performance and behavior of five California estuarine fishes. Copeia 2004(3):479-487.

New San Francisco Estuary Institute Report Available

The San Francisco Estuary Institute (SFEI) has publicly released a report entitled, "Monitoring trace organic contamination in Central Valley fish: Current data and future steps." The report was prepared by SFEI with funding from the Central Valley Regional Board. The report reviews existing information on organic contaminants in fish from the Delta region and makes recommendations on future work to fill information gaps. In particular, the report makes recommendations for the analysis of archived fish samples. These analyses will be conducted by the California Department of Fish and Game over the next year.

Free copies of the report may be downloaded from the SFEI website:

http://www.sfei.org

http://www.sfei.org/rmp/reports/delta_organics/delta_organics_report.pdf

Errata

IEP Newsletter, Spring 2004 (Volume 17, Number 2)

In "Length-Weight Relationships for 18 Fish Species Common to the San Francisco Estuary", by Russ Gartz.

Page 50. In the Methods section, the sentence "For specimens that exceeded the limits of the balance..." should read "For specimens that exceeded the limits of the balance (**210g**)..."

Page 55. In Figure 15, the vertical axis should read "Weight (**gm**)" not "Weight (mm)".

Delta Water Project Operations

Kate Le (DWR), kle@water.ca.gov

From July through September 2004, San Joaquin River flow ranged between 27 and 38 cubic meters per second (m^3/s) (950 cfs and 1,354 cfs), Sacramento River flow ranged between 350 and 618 m^3/s (12,358 cfs to 21,814 cfs), and the Net Delta Outflow Index (NDOI) ranged between 73 and 217 m^3/s (2,588 cfs and 7,662 cfs) (Figure 1). Compared to last year's flow levels, San Joaquin River, Sacramento River, and NDOI flows were lower from July through September 2004. NDOI from July through September was no higher than 226 m^3/s (8,000 cfs). The short increase in NDOI on September 9 and 10, 2004, was the result of reduced exports to meet south Delta water level concerns, whereas the short increase in Sacramento River flows at the end of August was used to meet outflow standards.

Export action during the July through September 2004 at both the State Water Project (SWP) and the Central Valley Project (CVP) were similar to last year's pumping during this time period. The significant changes in SWP pumping from July through September 2004 were made to meet either outflow or water level concerns (Figure 2). However, in July the SWP pumped an extra 500 cfs for the Environmental Water Account (EWA) because the standard for export-to-inflow ratio was 65%. CVP pumping was stable from July through September.

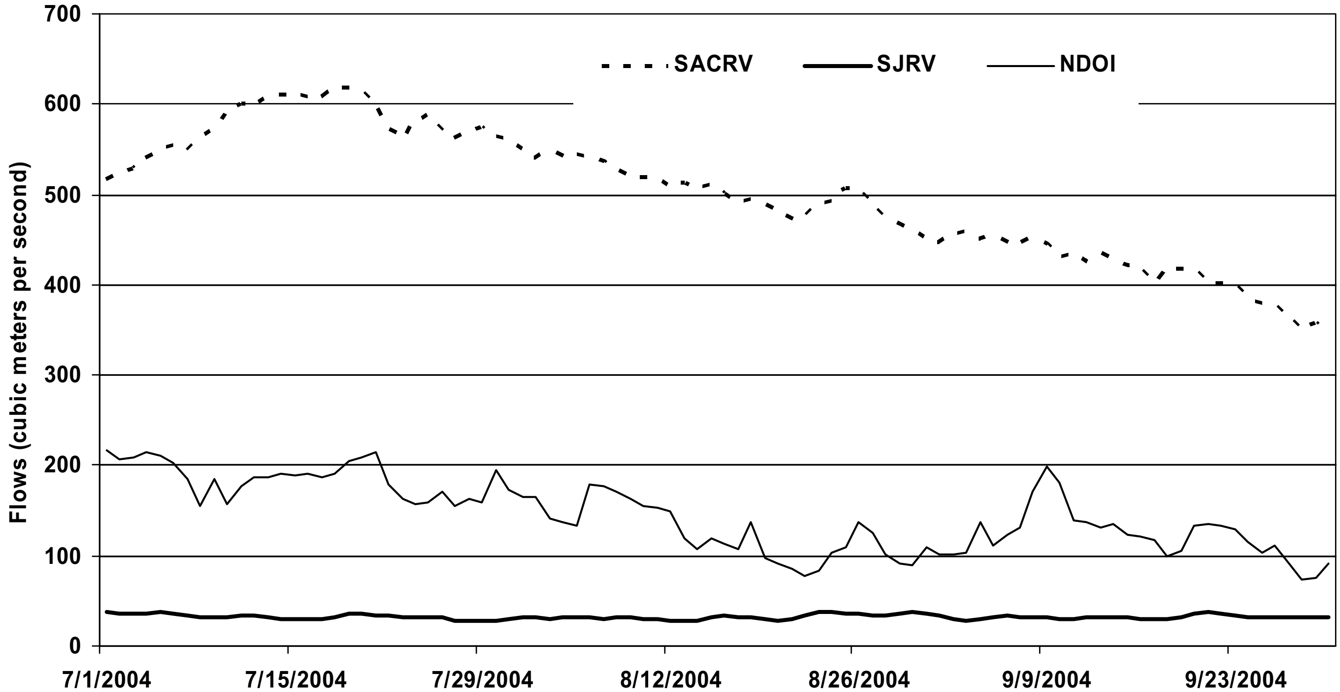

Figure 1 Sacramento River, San Joaquin River, and Net Delta Outflow Index, July through September 2004

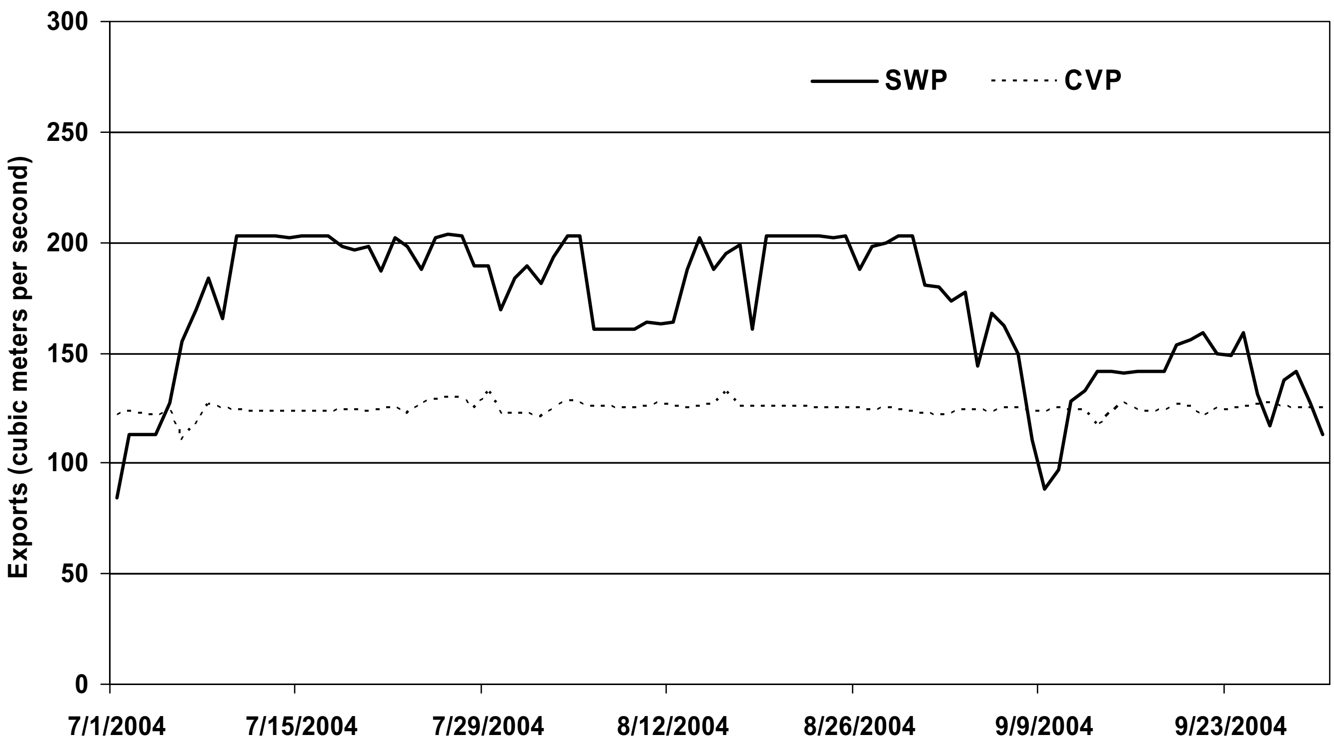

Figure 2 State Water Project and Central Valley Project pumping, July through September 2004

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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For information about the Interagency Ecological Program, log on to our website at http://www.iep.water.ca.gov. Readers are encouraged to submit brief articles or ideas for articles. Correspondence—including submissions for publication, requests for copies, and mailing list changes—should be addressed to Nikki Blomquist, California Department of Water Resources, P.O. Box 942836, Sacramento, CA, 94236-0001. Questions and submissions can also be sent by e-mail to: nikkib@water.ca.gov.

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

The Interagency Ecological Program for the San Francisco Estuary
is a cooperative effort of the following agencies:

California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Environmental Protection Agency

National Marine Fisheries Service

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