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Benthic Flux of Nutrients and Trace Metals in the Northern Component of San Francisco Bay, California

By James S. Kuwabara, Brent R. Topping, Francis Parchaso, Anita C. Engelstad and Valerie E. Greene

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Conversion Factors

Multiply	By	To obtain
cubic foot per sec ($ft^3\ s^{-1}$)	35.31	cubic meter per sec ($m^3\ s^{-1}$)
degree Centigrade (°C)	1.8 and add 32	degree Fahrenheit (°F)
foot (ft)	0.3048	meter (m)
liter (L)	1000	milliliter (mL)
inch (in)	2.54	centimeter (cm)
millimole (mmole)	1000	micromole (µmole)
micromolar (µM)	molecular weight	microgram per liter ($\mu g\text{-}L^{-1}$)
microgram per liter ($\mu g\text{-}L^{-1}$)	0.001	milligram per liter ($mg\text{-}L^{-1}$)
micron (µm)	1,000,000	meter (m)
mile (mi)	1.609	kilometer (km)

Abbreviations and Acronyms

Abbreviations and Acronyms	Meaning
DO	Dissolved oxygen
%	percent
ORP	Oxidation-reduction potential
PSU	Practical Salinity Unit
SD	Standard deviation
SRP	Dissolved (soluble) reactive phosphate
USBR	U.S. Bureau of Reclamation
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

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Executive Summary

Two sets of sampling trips were coordinated in late summer 2008 (weeks of July 8 and August 6) to sample the interstitial and overlying bottom waters at 10 shallow locations (9 sites <3 meters in depth) within the northern component of the San Francisco Bay/Delta (herein referred to as North Bay). The work was performed to better understand sources of biologically reactive solutes (namely, dissolved macronutrients and trace metals) that may affect the base of the food web in this part of the estuary. A nonmetallic pore-water profiler was used to obtain the first centimeter-scale estimates of the vertical solute-concentration gradients for diffusive-flux determinations. This study, performed in collaboration with scientists from San Francisco State University's Romberg Tiburon Center for Environmental Studies, provides information to assist in developing and refining management strategies for the Bay/Delta system and supports efforts to monitor changes in food-web structure associated with regional habitat modifications directed by the California Bay-Delta Authority.

On July 7, 2008, and August 5, 2008, pore-water profilers were successfully deployed at six North Bay sites per trip (figure 1) to measure the concentration gradient of dissolved macronutrients and trace metals near the sediment-water interface. Only two of the sites (433 and SSB009 within Honker Bay) were sampled in both series of profiler deployments (table 1). At each sampling site, profilers were deployed in triplicate (figure 2), while discrete samples and dataloggers were used to collect ancillary data from both the water column and benthos to help interpret diffusive-flux measurements.

Benthic flux of dissolved (0.2-micron filtered) inorganic phosphate (that is, soluble reactive phosphorus (SRP)) ranged from negligible levels (-0.003±0.005 millimole per square meter per day (mmole $m^{-2}d^{-1}$) at Site 4.1 outside Honker Bay; table 2) to 0.060±0.006 mmole $m^{-2}d^{-1}$ near the northern coast of Brown's Island. Except for the elevated flux at Browns Island, the benthic flux of soluble reactive phosphorus (SRP) was consistently: (1) lower than previously reported for South Bay sites (Topping and others, 2004), (2) an order of magnitude lower than oligotrophic Coeur d'Alene Lake (Kuwabara and others, 2003), (3) two orders of magnitude lower than determined for eutrophic Upper Klamath Lake, and (4) an order of magnitude or more lower than the estimated summer riverine inputs for SRP (900 to 1,300 kilograms of phosphorous per day (kg-P d^{-1}); tables 3 and 4).

In contrast to fluxes reported for the South Bay (Topping and others, 2004), nitrate fluxes were consistently negative (that is, drawn from the water column into the sediment), except for one site with statistically insignificant nitrate fluxes (Site 409 within Suisun Bay; table 2). The most negative nitrate flux (-7.3±0.1 mmole $m^{-2}d^{-1}$) was observed within Grizzly Bay (Site 416). Observed nitrate fluxes bracketed the estimated summer fluvial flux of nitrate (3,500 to 5,000 kg-N d^{-1}; table 3). With the exception of the two Grizzly Bay sites (416 and 417), the consistently positive benthic flux of ammonia generally counteracted the negative flux of nitrate to yield a net balance of dissolved inorganic nitrogen (table 2). Ammonia benthic fluxes extrapolated for Suisun Bay ranged from 320 kg-N d^{-1} (Site SSB009 near the entrance to Honker Bay) to 1,900 kg-N d^{-1} (Montezuma Island). These values represent a significant ammonia source to the water column relative to summer riverine inputs (approximately 400 to 600 kg-N d^{-1}; table 3).

Dissolved silica also displayed a consistently positive benthic flux, except for Site 409 within Suisun Bay, which showed insignificant fluxes (also insignificant for nitrate and SRP). As with the nitrate fluxes, Grizzly Bay and Browns Island sites yielded the highest dissolved silica fluxes (1.3±1.2 to 2.5±0.6 mmole $m^{-2}d^{-1}$, respectively; table 2). These initial diffusive-flux estimates are greater than those measured in the South Bay using core-incubation experiments (Topping and others, 2004), which include bioturbation and bioirrigation effects, but they are nevertheless probably one to two orders of magnitude below summer riverine inputs (see section on Results and Discussion).

In summary, riverine sources of SRP and silicate appear to overwhelm diffusive benthic fluxes. This is not true for the nitrogen species. Internal cycling of nitrate and ammonia in the Delta and Suisun Bay should not be disregarded, because the magnitude and direction of benthic sources and sinks for nitrogen species represent significant transport processes for these solutes. This finding may have particular relevance in this region of the estuary, where water-column clarity is gradually increasing and nitrogen-to-phosphorus molar ratios were consistently lower than the Redfield Ratio of 16 (table 5).

Water-column concentrations for dissolved trace elements (for example, Cu, Ni, Co, Cd and Pb) were consistent with those reported by the San Francisco Estuarine Institute's (SFEI) Regional Monitoring Program (SFEI 2009) at nearby stations. Diffusive fluxes for all trace metals, extrapolated over the Suisun Bay area, were insignificant compared to fluvial-flux estimates (see Results and Discussion).

The diffusive-flux measurements reported herein serve as conservative (under-) estimates of benthic flux, because solute transport across the sediment-water interface can be enhanced by other processes, including bioturbation, bioirrigation, groundwater advection, and wind resuspension. They do, however, provide lower bounds to indicate the potential importance of this internal solute source.

Potential Management Implications

In support of the mission of the California Bay-Delta Authority (CALFED) "to improve California's water supply and the ecological health of the San Francisco Bay/Sacramento-San Joaquin River Delta," CALFED's Food Web Project is administered by San Francisco State University's Romberg Tiburon Center for Environmental Studies. They employ diverse yet complementary research approaches to quantitatively understand the processes that regulate pelagic and benthic food webs in the estuary. Availability of biologically reactive solutes (that is, both nutrients and toxic substances) may have pronounced effects at the base of the food web in structure and abundance. In North Bay, it is reasonable to initially assume that the major source of these biologically reactive solutes is advective transport from the Sacramento and San Joaquin Rivers. However, recent studies in freshwater, estuarine, and coastal environments indicate that the remobilization of particle-bound solutes, accumulated in bed material, may represent a significant water-column source relative to fluvial transport (Zheng and others, 2000; Topping and others, 2004, Kuwabara and others, 2009). This work provides: (1) initial determinations of the benthic flux of dissolved macronutrients and trace metals at hydrodynamically contrasting sites within North Bay, in the vicinity of ongoing and proposed CALFED restoration projects, and (2) a research approach to effectively screen areas where benthic sources of nutrients and toxic substances may be of concern. Results presented herein indicate the presence of significant benthic nutrient sources, particularly in Grizzly Bay and in the vicinity of Browns Island. Deployment of the pore-water profilers may serve as a cost-effective approach to help locate areas ("hot spots") of particular concern and subsequent emphasis for restoration activities within and adjacent to the estuary.

Background

The delta smelt (*Hypomesus transpacificus*), listed as an endangered species on March 4, 2009, by the California Fish and Game Commission, spend their late-larval and early-adult lives in low-salinity estuarine environments using copepods as a major food source. Food limitation for delta smelt has been linked to low primary productivity since the Asiatic clam *Corbula amurensis* invaded San Francisco Bay in 1987, because the latter voracious species has a broad diet of phytoplankton, bacteria, larval copepods, and other small zooplankton. A food-web study, supported by the California Bay-Delta Authority, assembled researchers of broad expertise to examine biological and environmental controls on phytoplankton and bacterial production and by extension, the implications of those controls on trophic and energy transfer within the Bay-Delta food-web. As part of this food-web study, our work attempts to fill an information gap about the internal cycling of nutrients that may affect primary production in the North Bay.

Various processes may induce internal loading of surface-reactive solutes (for example, phosphate): (1) wind-induced resuspension of bottom sediments, (2) desorption of anionic solutes from surface sediments by high-pH waters induced by algal production, (3) desorption of nutrients from sediments exposed to increasing salinity or reducing conditions during episodic thermal stratifications, and (4) degradation and remineralization of settled organic material. Our study provides initial estimates of internal loading by directly measuring concentration gradients of essential biological constituents across the sediment-water interface, determining diffusive benthic-flux rates, and testing additional hypotheses as to the possible biological, chemical, and physical interactions that influence those rates. Sampling sites represent locations monitored in an existing study of food-web dynamics in the North Bay.

Particle-reactive solutes like dissolved orthophosphate can form surface complexes on a variety of mineral and biotic surfaces (Sigg and Stumm, 1981; Goldberg, 1985; Kuwabara and others, 1986). As sorbed or surface-complexed solutes settle in depositional zones within the estuary, they accumulate in the bottom sediments. Various biogeochemical processes related to changes in acid-base and redox (oxidation-reduction) chemistry near the sediment-water interface then remobilize these solutes and generate a benthic, internal source that may far exceed external sources in magnitude (Topping and others, 2004; Kuwabara and others, 2009).

In many surface-water systems like the San Francisco Bay/Delta, it is often desirable to estimate the potential importance of solute flux from the benthos where long-term (decadal) sediment accumulation of nutrients and/or toxic substances is of concern. For example, water-quality managers and modelers require measurements of benthic flux to comprehensively and accurately represent the transport of toxic and nutritive substances in surface waters. Many methods have been used to measure this flux (for example, core incubations, pore-water extrusions, and lander deployments), all being labor, equipment, and resource intensive (Kuwabara and others, 1999; Kuwabara and others, 2000; Kuwabara and others, 2003). Each approach has its technical and resource-related advantages and limitations (Huettel and Gust, 1992; Berg and others, 2003; Tengberg and others, 2005). Where sediment is dominated by fine particles (less than 63 µm), conventional pore-water samplers can quickly clog and so yield inadequate sample volumes. The profiler approach used in this study provided a simple, cost-effective, reliable, remote sampling device for use in quantifying centimeter-scale pore-water concentration gradients where all wetted surfaces of the nonmetallic device were acid-washable—hence this is a device compatible for nutrient and trace-element studies that did not clog when sampling within fine or organic-rich sediments.

Objectives

In support of science-based restoration/management strategies for the San Francisco Bay/Delta ecosystem, this study provided the first in-place measurements of the benthic fluxes of dissolved macronutrients and trace elements between the bed material and overlying water column at 10 North-Bay sites during late summer, when elevated air and water-column temperatures would be expected to peak and foster microbial remobilization or diagenesis involving biologically reactive solutes. Benthic-chlorophyll and water-column solute measurements were made at each site to help place results from this study in proper context. Because some of the macronutrients (for example, SRP and ammonia) and many of the trace elements (for example, cadmium, copper, nickel and zinc) are surface reactive, we hypothesize that benthic nutrient sources could be significant relative to previously quantified fluvial sources within these predominantly shallow areas (< 3 m in depth) of the North Bay and delta.

Results and Discussion:

Ancillary water-column parameters (from datalogger profiles).—Measurement of ancillary parameters (for example, temperature, salinity, pH, oxidation-reduction potential, dissolved-oxygen saturation) at the 10 sampling sites provides a basic physical and chemical context that may help interpret benthic-flux results (table 1). Except for Site 409 (~8 m depth), the sites where profilers were deployed were shallow (<3 m depth), with minimal density or thermal stratification through the water column. Salinity values showed an unsurprising longitudinal gradient, with lowest values at Big Break (0.7 Practical Salinity Units (PSU) nearest the riverine source and highest values at Site 409 (9.2 to 12.8 PSU) in Suisun Bay. Temperature ranges during the July trip (20.4 to 23.5°C over all six sites) were similar to those observed in August (19.6 to 21.5°C overall), and both ranges were consistent with mid-summer water-column temperatures reported in the long-term U.S. Geological Survey (USGS) record at a nearby but downgradient Benicia site (table 6). For example, over the past decade, the near-surface temperature ranges in July and August at that Benicia site were 17.3 to 23.5 and 18.2 to 23.0°C, respectively (Schoellhamer and Buchanan, 2009). Similarly, the near-bottom temperature ranges reported for July and August were 17.3 to 24.0 and 18.2 to 21.7°C, respectively. The oxidizing water column was evidenced by dissolved-oxygen concentrations that were consistently near saturation (>90 percent; table 1), although the sonde was never closer than 0.5 m above the bottom sediment to avoid sediment resuspension and sensor fouling. As with temperature, pH did not exhibit major horizontal or vertical variations, with an overall range for the 10 sites on both sampling trips of 6.2 to 7.9, and the largest vertical pH gradient observed during the July trip was at the deepest Site 409. As one might expect of a well-oxygenated water column, the oxidation-reduction potentials (ORP) values were consistently >+100 mV.

Dissolved (0.2-µm filtered) nutrients in the water column.—Water-column nutrient concentrations were monitored by others beyond the period of our experiments in 2008 as a primary focus of the food-web study and will therefore be discussed in depth elsewhere. This discussion will be constrained to dissolved-nutrient distributions in the water-column observed during our profiler deployments (table 5). For soluble reactive phosphorus (SRP; primarily dissolved orthophosphate), the overlying water concentrations (collected approximately 1 cm above the sediment water interface by the porewater profiler, see section on Methods) compared favorably with surface-grab samples (collected approximately 1 m below the surface). In July, ranges were 2.78 to 3.90 µM in the overlying water and 2.67 to 3.92 µM near the surface. By comparison, in August the range of SRP concentrations in the overlying waters was contained within the surface-water range (2.26 to 3.06 µM and 1.90 to 3.25 µM, respectively). For comparison and verification, a surface-grab sample collected from upgradient USGS Station 3 on August 18, 2008, contained 2.07 µM SRP (Pittsburg, Calif.; C. Mioni, written commun., September 23, 2009).

Nitrate concentrations decreased in our August sampling relative to July. Two sites (SSB009 and 433) were sampled in both trips. The average nitrate concentrations from those two sites were 40.2±2.0 µM (n=8) and 31.4±2.4 µM (n=9) for July and August, respectively (table 5). In addition, the overall nitrate concentration ranges did not overlap for either the overlying water or surface-water samples: (1) overlying-water concentration ranges were 38.8 to 43.2 µM and 22.4 to 32.2 µM for July and August, respectively, and (2) surface-water concentration ranges were 38.2 to 44.0 µM and 24.8 to 35.0 µM for July and August, respectively.

Given the oxidizing water-column environment indicated by dissolved-oxygen concentrations and oxidation-reduction potential measurements described above, it is not surprising that dissolved-ammonia concentrations were consistently lower, by an order of magnitude, than nitrate concentrations. Even in overlying waters, concentrations were all below 6 µM (with an overall range of 0.40 to 5.32 µM for both sampling trips). As with nitrate concentrations, dissolved-ammonia concentrations were generally lower in August relative to July. The average ammonia concentrations from repeated sites SSB009 and 433 were 3.66 ±0.84 µM and 1.95±0.73 µM for July and August, respectively.

For both overlying-water samples and surface grabs, ranges in dissolved silicate concentrations during July and August deployments were similar (182 to 254 µM and 194 to 291 µM, respectively). Overlying-water concentrations were consistent with those near the surface. The highest silicate concentration in overlying waters for July and the lowest for August were observed at site 433 within Honker Bay (254 and 194 µM, respectively).

The Redfield Ratio (Redfield, 1934) represents a fairly constant molar ratio (that is, 106 to 16 to 1) of the essential elements carbon, nitrogen, and phosphorus in coastal or open-ocean phytoplankton. Deviations from this molar ratio in dissolved (that is, more readily bioavailable) macronutrient concentrations suggests a nutrient limitation or added environmental stressor for the food web. Observed nitrogen-to-phosphorus molar ratios for the water-column values were consistently below the 16-to-1 Redfield ratio (that is, 13.7±1.0 and 11.8±1.4 for the July and

August sampling trips, respectively; table 5). Such macronutrient distributions may favor phytoplankton species with lower nitrogen requirements or nitrogen-fixing capability. In contrast, the upgradient N:P molar ratio observed at Station 3 near Pittsburg was 18.8.

Dissolved trace metals in the water column.—For all dissolved metals, the overlying-water concentrations (collected approximately 1 cm above the sediment water interface by the porewater profilers, see Methods) compared favorably with surface-grab samples (collected approximately 1 m below the surface; table 7). In some cases, the limited volume of the overlying water sample available for analysis (see Methods) created higher uncertainty and poorer replication for those samples.

For the surface-grab samples, dissolved-metal concentrations compared between the two repeated sites (SSB009 and 433) reveal inconsistent temporal trends. Copper (Cu) concentrations decreased from July to August at both sites (table 7), while vanadium (V) concentration increased between the field trips. For nickel (Ni), cobalt (Co), and cadmium (Cd), concentrations increased from July to August at SSB009, but decreased at 433. Lead (Pb) showed no temporal trend, and all values for iron (Fe), manganese (Mn), and zinc (Zn) were below reported detection limits (5 $\mu g\text{-}L^{-1}$ for Fe and Mn; 2 $\mu g\text{-}L^{-1}$ for Zn).

For elements Cu, Ni, Co, Cd, and Pb, the range of values for the study generally fell within the range of values reported by the San Francisco Estuarine Institute's (SFEI) Regional Monitoring Program (SFEI, 2009) at nearby stations for the latest data available on their searchable database (August of 2006 and 2007).

Dissolved organic carbon (DOC) in the water column.—Dissolved organic matter, measured as DOC, is a ligand that can compete for trace-metal complexation in the water and hence affect the remobilization and bioavailability of biologically reactive trace metals (Kuwabara and others, 1986). For example, Kuwabara and others (1989, 2002) noted that spatial trends for certain dissolved trace metals (copper and zinc) in South San Francisco Bay, as well as in Lahontan Reservoir (mercury), were coincident with DOC.

The overlying-water DOC concentrations (collected approximately 1 cm above the sediment water interface by the porewater profiler, see Methods) compared favorably with surface-grab samples (collected approximately 1 m below the surface; table 8). For the repeated stations, DOC concentrations increased from July to August at SSB009, while they decreased at 433, mirroring the trend, discussed above, for Ni, Co, and Cd.

Benthic flux of macronutrients.—Initial benthic-flux calculations discussed herein are based on Fick's Law, which describes how concentration gradients near the sediment-water interface drive diffusive flux of solutes across that interface (see Methods). Benthic flux of dissolved (0.2-micron filtered) inorganic phosphate (that is, soluble reactive phosphorus, SRP) ranged from insignificant levels (-0.003 ± 0.005 mmole $m^{-2}d^{-1}$ at Site 4.1 outside Honker Bay; table 2) to 0.060 ± 0.006 mmole $m^{-2}d^{-1}$ near the northern coast of Brown's Island. Except for the elevated flux at Brown's Island, the SRP flux was consistently lower than previously reported for South Bay sites (Topping and others, 2004) an order of magnitude lower than oligotrophic Coeur d'Alene Lake (Kuwabara and others, 2003) and two orders of magnitude lower than determined for eutrophic Upper Klamath Lake, the site for which the profilers were developed (Kuwabara and others, 2009). Extrapolated over the area of Suisun Bay (1.4×10^8 m^2; Cappiella and others, 1999), our observed range of <10 (Site 409) to 260 (Browns Island) kg-P d^{-1} is an order of magnitude or more lower that the estimated summer fluvial flux of that solute (900 to 1,300 kg-P

d^{-1}; table 3). Fluvial fluxes were calculated using mean monthly Delta outflow values over the past decade (table 4)

In contrast to fluxes reported for the South Bay (Topping and others, 2004), nitrate fluxes were consistently negative (that is, drawn from the water column into the sediment), though the average of the triplicate measurements was not significant at Site 409 in Suisun Bay (-0.02 ± 0.03 mmole $m^{-2}d^{-1}$, table 2). We hypothesize from the consistently low macronutrient fluxes at Site 409 (table 2) and sediment accumulation in two to four of the six sampling-tower bases for each profiler that the profilers at Site 409 were pulled over in the tidal current, despite their attachment to a secured buoy. Discussion below of trace-metal fluxes supports this hypothesis. The most negative nitrate flux (-7.3±0.1 mmole $m^{-2}d^{-1}$) was observed within Grizzly Bay at Site 416. With nitrate fluxes varying over two orders of magnitude at our 10 sampling sites, areally averaged nitrate fluxes estimated for Suisun Bay ranged from -36 (Site 409) to -14,000 (Site 416) kg-N d^{-1}, bracketing the estimated summer fluvial flux of that solute (3,500 to 5,000 kg-N d^{-1}). That is, at least in parts of Suisun Bay and the Delta, the riverine flux of nitrate may be readily consumed by the benthos.

With the exception of the two Grizzly Bay sites, the benthic flux of ammonia (consistently positive) generally counteracted the negative flux of nitrate to yield a net balance of dissolved inorganic nitrogen transported across the sediment-water interface at sampling sites. Areally averaged ammonia fluxes estimated for Suisun Bay ranged from 320 (Site SSB009 near the entrance to Honker Bay) to 1,900 (Montezuma Island) kg-N d^{-1}, thus constituting a significant ammonia source to the water column relative to summer riverine inputs (approximately 400 to 600 kg-N d^{-1}).

Dissolved silica also displayed a consistently positive benthic flux, but as with nitrate and SRP, the dissolved silica flux at Site 409 in Suisun Bay was not significant (-0.02±0.04 mmole $m^{-2}d^{-1}$). As with the nitrate fluxes, Grizzly Bay and Browns Island sites yielded the highest dissolved-silica fluxes (1.4±1.2 to 2.5±0.6 mmole $m^{-2}d^{-1}$, respectively; table 2). These initial diffusive-flux estimates for silica bracket those measured in the South Bay using core-incubation experiments (Topping and others, 2004) and include bioturbation and bioirrigation effects. Extrapolated over the area of Suisun Bay, the silica benthic flux range is -76 (Site 409) to 9,900 (Browns Island) kg-Si d^{-1}. Unfortunately, silicate analysis was not performed on the Station 3 (Pittsburg, Calif.) surface sample collected on August 18, 2008. However, if we conservatively assume a silicate concentration of 182 µM (matching the lowest water-column concentration observed in our study), the estimated riverine flux for silicate would still be 72,000 to 104,000 kg-Si d^{-1}, far exceeding any benthic sources reported here.

In summary, riverine sources of SRP and silicate exceed diffusive fluxes for these solutes from the benthos. However, internal cycling of nitrogen species in the Delta and Suisun Bay should not be disregarded, because the magnitude and direction of nitrate and ammonia benthic sinks and sources represent significant transport processes for these solutes. This may have particular importance in this region of the estuary, where nitrogen-to-phosphorus molar ratios were consistently lower than the molar Redfield Ratio of 16 (table 5). However, concentrations of nutrients in the region are such that, regardless of the ratio, nutrient limitation has been extremely rare (Jassby and others, 2002). The Delta/Estuary is instead considered to be light limited (Cloern and Dufford, 2005).

Benthic flux of trace elements.—Using calculations based on Fick's law, as for nutrients above, benthic flux estimates were made for the metals Fe, Mn, Co, Cd, and Ni. Other metals discussed above (Cu, V, Pb, and Zn) did not exhibit statistically significant gradients, so fluxes were assumed to be negligible and were not included in flux calculations (table 9).

Both Fe and Mn exhibited dramatic concentration differences between overlying waters and porewaters, with the deepest porewater sample at 10 cm often being two or more orders of magnitude higher than the overlying sample. Calculations based on these gradients yielded flux estimates for Fe ranging from 1.1 ± 0.3 micromole per square meter per day (umole-m^{-2}-d^{-1}; Station 409) to 131 ± 112 umole-m^{-2}-d^{-1} (Sherman Lake). As mentioned in the prior section on macronutrient fluxes, consistently low macronutrient fluxes at Site 409 (table 2) is consistent with the low trace-metal flux estimates for this deployment site (table 9). The absence of concentration gradients for macronutrients and trace metals, along with the observation of sediment accumulation in two to four of the six sampling-tower bases for each profiler support our hypothesis that profilers at Site 409 were pulled over in the tidal current, despite their attachment to a secured buoy. The average of all Fe flux estimates is of the same order of magnitude as those reported for Upper Klamath Lake, Oregon, using the same porewater samplers (Kuwabara and others, 2007). In contrast, Fe flux estimates from Lake Coeur d'Alene, Idaho, were estimated to be an order of magnitude lower (Kuwabara and others, 2000), as estimated by core incubations. Iron fluxes reported here could be an underestimate for two major reasons. First, diffusive porewater flux estimates do not account for bioturbation or bioirrigation by macroinvertebrates, which are likely to increase flux due to advection. Second, because of the sample volume constraints discussed in detail in the section on Methods, the highly concentrated samples appeared to saturate the iminodiacetate chelating resin because they could not be diluted. As a result, these samples may have been even more concentrated, which could increase diffusive flux estimates. Conversely, diffusive iron fluxes could be an overestimate of the transport of bioavailable iron into the water column. The reduced iron species prevalent in the deeper samples could become more particle-reactive as they reach an oxidized water column. Elevated dissolved-iron concentration gradients at the Sherman Lake site may represent remobilized iron in dense, decomposing macrophyte stands, but trace-element analysis of bed sediment would be required to confirm this hypothesis.

Manganese flux estimates ranged from 1.2 ± 0.8 umole-m^{-2}-d^{-1} (Station 409) to 148 ± 23 umole-m^{-2}-d^{-1} (Station 417). The average of all Mn flux estimates is two orders of magnitude lower than those reported for Lake Coeur d'Alene, Idaho, an oligotrophic lake with surficial sediment deposits of iron and manganese oxyhydroxides (Kuwabara and others, 2000, 2003).

In summary, all trace-metal fluxes, extrapolated over the Suisun Bay area, are insignificant compared to fluvial fluxes assumed from delta outflow and an average of measured water-column concentrations (table 9).

Benthic chlorophyll.—Benthic-chlorophyll measurements provide an indication of the settled carbon load to the sediment bed as phytoplanktonic densities cycle through seasonal variations in productivity. This study includes measurements of benthic chlorophyll for the 10 estuary sites associated with profiler deployments.

During the July 8, 2008, sampling, site means for benthic-chlorophyll concentrations ranged from 0.37 ± 0.11 µg cm^{-2} at Site 4.1 outside Honker Bay to 1.14 ± 0.15 µg cm^{-2} at station 416 in central Grizzly Bay (table 10). Those concentrations significantly decreased during the second profiler deployment, with a site range from consistently nondetectable (<0.05 µg-cm^{-2}) at both the Sherman Lake site and SSB009 site at the entrance to Honker Bay to 0.34 ± 0.14 µg cm^{-2} at the Big Break. Mean benthic-chlorophyll concentrations from the repeated sites (433 and SSB009) were significantly higher in July relative to August (that is, 1.06 ± 0.10 and 0.15 ± 0.24

µg cm^{-2}, respectively, n = 6). Before the invasion of *C. amurensis,* Nichols and Thompson (1985) observed benthic-chlorophyll concentrations between 10 and 25 µg cm^{-2} in Suisun Bay, although lower values between 10 and 15 µg cm^{-2} were observed during the summer prior to the annual fall phytoplankton bloom, then characteristic of the North Bay. Consistent with a food-limited condition, values reported here are at least an order of magnitude lower (table 10). The concentration ratio of benthic chlorophyll to the sum of phaeophytin plus benthic chlorophyll represents a coarse indicator of the reproductive status of the benthic algal community. Because phaeopigments represent degradation products of chlorophyll, observed ratios consistently $\leq$0.2 (table 10) suggest the degradation or senescence of phytoplankton cells that settle to the sediment bed or an active benthic fauna (including *C. amurensis*) that consumes benthic algae to generate feces rich in phaeopigments (Thompson and others, 1981; Light and Beardall, 1998; U.S. Environmental Protection Agency, 2000).

Growth and subsequent settling of phytoplankton augment the benthic carbon source to microbial and macroinvertebrate assemblages near the sediment-water interface. It has been demonstrated that feeding and foraging mechanisms by certain macroinvertebrates may significantly enhance the benthic flux of solutes (Kuwabara and others, 1999; Boudreau and Jorgensen, 2001). As part of the food-web study, macroinvertebrate assemblages at these 10 and other sites within the North Bay have been quantitatively and taxonomically characterized by others. Details of this aspect of the study will therefore be provided in another publication.

Methods

The protocol described in this section focuses on method applications in the sampling of porewater for dissolved solutes in the northern component of San Francisco Bay.

A nonmetallic pore-water profiler, designed for nutrient and trace-metal sampling (patent application 12/107,331; Kuwabara and others, 2009), was used for this study. In addition to water just above (approximately 1 cm) the sediment-water interface, samplers collected interstitial water from five depths within the top 10 centimeters of the sediment, with fritted polypropylene probes at approximately 1, 2, 3.3, 5.5, and 10 cm depth, to characterize dissolved-solute vertical gradients (that is, six independent sampling circuits). Each sampling circuit collected filtered (0.2 µm) water into 50-milliliter acid-washed, all-plastic syringes. After being lowered onto the sediment, the device was tripped mechanically to begin sample collection and retrieved approximately 24 hours later. Dye experiments indicated that this extended sampling period avoided short-circuiting of samples between depths and along device surfaces. After retrieval, the sample syringes were closed with a valve, double-bagged in argon, and refrigerated in darkness for sample processing, splitting, and later chemical analyses.

Flux calculations, based on Fick's Law, assume that the process is diffusion controlled with solute-specific diffusion coefficients (Li and Gregory, 1974; Applin 1987; Rebreanu and others, 2008). Hence, the calculated benthic flux of dissolved solutes based on porewater profiles can be enhanced by bioturbation, bioirrigation, wind resuspension, and potential groundwater inflows (Kuwabara and others, 2009).

At each profiler-deployment site, dataloggers provided water-column profiles of ancillary parameters (pH, salinity, temperature, dissolved oxygen, and oxidation-reduction potential), monitored at 15-second intervals. Samples for determination of benthic chlorophyll were also obtained by subcoring replicate Ekman-grab samples.

Sampling methods have been previously described (Kuwabara and others, 2003, 2009), but details are provided below. At each site, the following samples were collected, unless otherwise noted:

Biological Parameters

1. **Benthic chlorophyll-*a*.** At each profiler-deployment site, surficial sediment (that is, the top centimeter of bed material) was collected from a fresh Ekman grab and stored refrigerated in a plastic Petri dish within a sealed plastic bag. Each dish was subsampled in triplicate for benthic chlorophyll-*a*. The surficial sediment for each replicate (0.785 cm^2) was collected on a glass-fiber filter and buffered with 1 milliliter of a supersaturated magnesium carbonate suspension (10 $g\ L^{-1}$). Water was removed from the buffered samples by vacuum at less than 5 pounds per square inch (psi) to avoid cell lysis. Samples were then frozen in darkness for preservation until spectrophotometrically analyzed by methods described in Thompson and others (1981) and Franson (1985).

Chemical Parameters

1. **Dissolved nutrients.** Nutrient samples were filtered (0.2-micron polycarbonate membranes) and immediately refrigerated in darkness. Unlike trace-metal samples, nutrient samples were not acidified. Concentrations for dissolved (0.2-micron filtered) nitrate, ammonia, orthophosphate (SRP), and silica were determined by automated spectrophotometry (Solorzano, 1969; Witledge and others, 1981; Bran Luebbe AutoAnalyzer Applications, 1999).
2. **Dissolved organic carbon (DOC).** Dissolved organic carbon samples were also collected in duplicate in baked 60-milliliter glass bottles with acid-washed fluoroethylene-polymer caps and filtered (0.7-micron baked glass-fiber filter) for analysis by high-temperature catalytic combustion (Vandenbruwane and others, 2007). Potassium phthalate was used as the standard. Low-DOC water (blanks less than 40 micrograms organic C per liter) was generated from a double-deionization unit with additional ultraviolet treatment (Milli-Q Gradient, Millipore Corporation).
3. **Dissolved trace elements.** Water-column samples were collected in duplicate in 250-mL acid-washed high-density polyethylene bottles, filtered (0.2-µm polycarbonate membrane), and acidified (pH 2) to provide dissolved trace-metal information for the saline waters by flow-injection (metals collected on an iminodiacetate chelating resin before analysis) inductively coupled plasma mass spectrometry (ICP-MS; Topping and Kuwabara, 1999; Topping and Kuwabara, 2003). Porewater samples were filtered in-line and acidified before analysis. The dissolved nutrient analyses, which were the focus of the study, required most of the volume from the porewater samplers, which can hold no more than 60 mL. After DOC analyses were completed as well, often less than 10 mL was available for ICP-MS analyses. Because each analytical replicate using the flow-injection method consumes at least 3 mL of sample, typically each porewater sample reported only two replicates before exhausting the volume. Dilution to increase volume was not an option because lower concentration elements (Cd, Co, Pb)

would have been rendered undetectable. These volume limitations required that the method detection limits (MDL's) were reported higher for the porewater samples than for the water-column samples.

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Figures

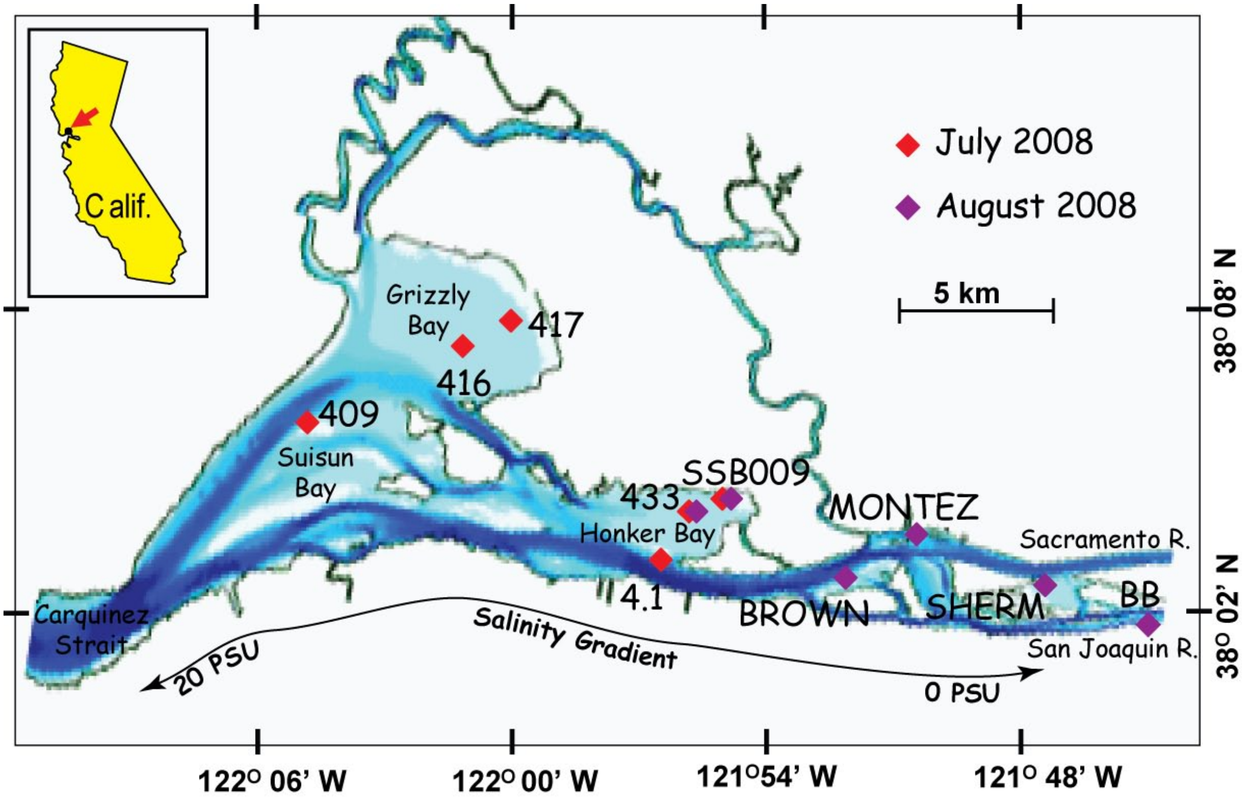

Figure 1. Map of Suisun Bay study area, showing sampling sites. Station numbers conform to established U.S. Geological Survey sampling locations. Acronyms BROWN, MONTEZ, SHERM, and BB designate Brown's Island, Montezuma Island, Sherman Lake, and Big Break, respectively. Shades of blue reflect relative water depth from dark blue (>20 meters) to light blue (<2 meters). Typical salinity gradient shown with end member concentrations in PSU (Practical Salinity Units).

Figure 2. Porewater profilers deployed in triplicate off Montezuma Island (MONTEZ)

Tables

Table 1. Water-quality sites for food-web, benthic-flux study (NAD 27 CONUS datum) including ranges for ancillary parameters [PSU, practical salinity units; ORP, oxidation reduction potential]

Site Description	Site Index	Profiler Deployment Date	Latitude (North - min/sec)	Longitude (West - min/sec)	Latitude (North - decimal min)	Longitude (West- decimal min)	Salinity Range (PSU)	Temperature Range (°C)	Dissolved-oxygen Saturation (%)	Dissolved-oxygen ($\mathrm{mg\ L^{-1}}$)	pH Range	ORP Range (mV)
Honker Bay entrance	SSB009	7-Jul-08	38° 4' 41.70"	121° 55' 10.80"	38° 4.695'	121° 55.180'	4.1 - 4.4	22.4 - 23.4	98 - 100	8.3 - 8.4	7.9 - 7.9	295 - 298
Mid-Grizzly Bay	416		38° 7' 3.00"	122° 2' 22.98"	38° 7.050'	122° 2.383'	8.3 - 8.7	20.6 - 21.3	97 - 102	8.2 - 8.8	7.8 - 7.9	318 - 329
Grizzly Bay east	417		38° 7' 4.56"	122° 0' 37.26"	38° 7.076'	122° 0.621'	7.1 - 7.2	21.7 - 21.9	100 - 102	8.4 - 8.6	7.9 - 7.9	298 - 300
Mid-Honker Bay	433		38° 4' 17.52"	121° 56' 1.68"	38° 4.292'	121° 56.028'	4.7 - 4.8	22.4 - 23.5	100 - 102	8.3 - 8.6	7.8 - 7.9	281 - 288
409 Suisun Bay	409		38° 5' 48.66"	122° 3' 29.46"	38° 5.811'	122° 3.491'	9.2 - 12.8	20.4 - 20.8	92 - 100	7.7 - 8.5	6.2 - 7.8	176 - 324
Outside Honker Bay	4.1		38° 3' 25.62"	121° 56' 41.46"	38° 3.427'	121° 56.691'	4.7 - 6.4	21.5 - 22.3	96 - 98	8.1 - 8.3	6.4 - 7.4	191 - 207
Big Break	BB	5-Aug-08	38° 1' 15.90"	121° 43' 24.66"	38° 1.265'	121° 43.411'	0.7 - 0.7	21.0 - 21.5	91 - 101	8.1 - 8.9	7.1 - 7.7	151 - 205
Browns Island	BROWN		38° 2' 44.58"	121° 52' 6.48"	38° 2.743'	121° 52.108'	5.0 - 5.6	20.5 - 20.6	97 - 100	8.5 - 8.8	7.6 - 7.8	139 - 151
Montezuma Island	MONTEZ		38° 4' 15.42"	121° 51' 4.14"	38° 4.257'	121° 51.069'	4.2 - 4.5	20.4 - 20.7	94 - 98	8.2 - 8.6	7.2 - 7.7	142 - 158
Sherman Lake	SHERM		38° 2' 49.68"	121° 47' 31.62"	38° 2.828'	121° 47.527'	2.1 - 3.0	20.5 - 20.8	96 - 98	8.4 - 8.7	7.2 - 7.7	114 - 123
Honker Bay entrance	SSB009		38° 4' 41.70"	121° 55' 10.80"	38° 4.695'	121° 55.180'	7.0 - 7.0	19.6 - 19.6	100 - 101	8.8 - 8.9	7.7 - 7.9	120 - 126
Mid-Honker Bay	433		38° 4' 17.52"	121° 56' 1.68"	38° 4.292'	121° 56.028'	6.3 - 6.3	20.4 - 20.5	100 - 101	8.7 - 8.8	7.2 - 7.8	120 - 129

Table 2. Summary of dissolved-macronutrient fluxes
[SD, standard deviation]

8-Jul-08 Bottom-water temperature = **20.4 to 22.4** degrees Centigrade

		Silicate			Ortho-P			Nitrate			AMMONIA			Dissolved Inorganic Nitrogen (DIN)		
Site Index	**n (replicate deployments)**	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Site Index**
SSB009	3	0.7	0.5	2.8E+03	0.007	0.010	3.2E+01	-0.1	0.0	-1.3E+02	0.16	0.04	3.2E+02	0.1	0.1	SSB009
416	3	1.4	1.2	5.5E+03	0.031	0.013	1.4E+02	-7.3	0.1	-1.4E+04	0.35	0.06	6.9E+02	-6.9	0.1	416
417	3	1.7	0.4	6.8E+03	0.018	0.006	7.7E+01	-2.1	1.3	-4.2E+03	0.37	0.13	7.2E+02	-1.8	1.5	417
433	3	0.7	0.1	2.9E+03	0.009	0.006	4.0E+01	-0.6	0.3	-1.1E+03	0.33	0.10	6.4E+02	-0.3	0.4	433
409	3	<0.1	<0.1	-7.6E+01	0.000	0.000	-5.0E-01	<0.1	<0.1	-3.6E+01	0.39	0.68	7.7E+02	0.4	0.7	409
4.1	2	0.1	0.0	4.8E+02	-0.003	0.005	-1.2E+01	<0.1	<0.1	-9.7E+01	0.58	0.22	1.1E+03	0.5	0.3	4.1
Estimated Riverine Flux**							1.3E+03			5.0E+03			5.8E+02			**Estimated Riverine Flux**

6-Aug-08 Bottom-water temperature = **19.6 TO 21.0** degrees Centigrade

		Silicate			Ortho-P			Nitrate			AMMONIA			Dissolved Inorganic Nitrogen (DIN)		
Site Index	**n (replicate deployments)**	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (mmole-m^{-2} d^{-1})**	**Site SD (mmole-m^{-2} d^{-1})**	**Site Index**
BB	3	0.0	0.0	1.6E+02	0.002	0.003	1.0E+01	-0.2	0.1	-3.2E+02	0.25	0.21	4.9E+02	0.1	0.3	BB
BROWN	3	2.5	0.6	9.9E+03	0.060	0.006	2.6E+02	-0.8	0.5	-1.6E+03	0.35	0.07	6.8E+02	-0.5	0.5	BROWN
MONTEZ	3	0.8	0.4	3.2E+03	0.013	0.003	5.7E+01	-0.5	0.4	-1.0E+03	0.95	0.29	1.9E+03	0.4	0.7	MONTEZ
SHERM	2	0.9	0.2	3.4E+03	0.001	0.002	5.0E+00	-0.2	0.0	-4.9E+02	0.27	0.08	5.3E+02	0.0	0.1	SHERM
SSB009	3	0.1	0.1	5.9E+02	0.001	0.002	6.2E+00	-0.1	0.0	-1.5E+02	0.17	0.03	3.4E+02	0.1	0.1	SSB009
433	2	0.8	0.4	3.3E+03	0.004	0.004	1.5E+01	-0.4	0.2	-7.3E+02	0.29	0.15	5.7E+02	-0.1	0.4	433
Estimated Riverine Flux							9.1E+02			3.5E+03			4.1E+02			**Estimated Riverine Flux**

* Extrapolated benthic fluxes assume Suisun Bay projected area of 1.7 million square meters (Smith and others, 2009)
Internet access at: http://sfbay.wr.usgs.gov/sediment/sfbay/geostat.html

** Refer to Table 3 calculations. Estimated riverine fluxes for dissolved solutes assume delta outflow of decadal monthly averages for July and August (1997-2007 excluding 1998)
Discharge from Dayflow estimates (Interagency Ecological Program, 2009).

Table 3. Riverine flux estimates for dissolved nutrients.
[SD, standard deviation; NA, not available]

			JULY**				AUGUST			
Solute	**Inflow Concentration* (µM)**	**(µg L^{-1})**	**Mean Discharge (m^3 s^{-1})**	**Discharge SD (m^3 s^{-1})**	**Estimated riverine flux (kg d^{-1})**	**Flux SD (kg d^{-1})**	**Mean Discharge (m^3 s^{-1})**	**Discharge SD (m^3 s^{-1})**	**Estimated riverine flux (kg d^{-1})**	**Flux SD (kg d^{-1})**
Silicate	NA	NA	235	69	NA	NA	164	56	NA	NA
Ortho-P	2.07	64	235	69	1300	382	164	56	907	309
Nitrate	17.53	245	235	69	4978	1460	164	56	3472	1181.102
Ammonia	2.05	29	235	69	582	171	164	56	406	138

* Concentrations from Station 3, Pittsburg, California on 19 August 2008 (C. Mioni, written communication, September 23, 2009)
Comparative water-column concentrations are tabulated in Table 5.

** Mean delta outflow values from table 4.

Table 4. Decadal summary of July and August daily delta outflow
[SD, standard deviation; NA, not available. Reference: Interagency Ecological Program, 2009; 1998 data not used in average due to anomolously high flows]

	JULY				**AUGUST**			
	(ft^3 s^{-1})		**(m^3 s^{-1})**		**(ft^3 s^{-1})**		**(m^3 s^{-1})**	
Year	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1997	9,286	1,230	263	35	8,639	2,203	245	62
1999	10,463	1,108	296	31	5,930	3,011	168	85
2000	9,123	1,875	258	53	6,024	2,095	171	59
2001	4,645	887	132	25	3,153	618	89	18
2002	5,662	619	160	18	3,768	784	107	22
2003	9,631	2,105	273	60	6,874	3,501	195	99
2004	7,317	596	207	17	5,204	1,159	147	33
2005	9,378	1,027	266	29	5,586	736	158	21
2006	12,044	3,100	341	88	8,914	1,369	252	39
2007	5,354	1,033	152	29	3,724	757	105	21
Decadal Mean&SD	**8,290**	**2,432**	**235**	**69**	**5,782**	**1,967**	**164**	**56**

Table 5. Dissolved nutrients in the water column at profiler deployment sites.
[Cells with a light-green background represent a concentration maximum or minimum for that sampling trip. NA, not available; SRP, soluble reactive phosphate; DIN, dissolved inorganic nitrogen]

Collection date: **7/8/2008**

Site Index	Sample Type	Ortho-P (SRP) (μM)	(ug-P L^{-1})	Nitrate+ Nitrite (NO$_3^-$ + NO$_2^-$) (μM)	(ug-N L^{-1})	Ammonia (NH$_3$) (μM)	(ug-N L^{-1})	Silicate Si(OH)$_4$ (μM)	(ug-Si L^{-1})	DIN (N0$_3$ + NH$_3$) (μM)	N:P Molar Ratio
SSB009	Overlying Water	3.15	98	38.8	544	4.50	63	210	5912	43.3	13.8
	Overlying Water	3.07	95	39.2	549	3.40	48	212	5966	42.6	13.9
	Surface grab	3.06	95	38.3	536	2.90	41	218	6119	41.2	13.5
416	Overlying Water	3.47	107	43.2	605	3.80	53	212	5966	47.0	13.6
	Overlying Water	3.90	121	43.2	605	2.90	41	222	6224	46.1	11.8
	Overlying Water	3.71	115	42.3	592	4.70	66	221	6193	47.0	12.7
	Surface grab	3.88	120	43.1	603	5.01	70	210	5902	48.1	12.4
	Surface grab	3.92	121	43.6	610	5.16	72	215	6051	48.7	12.4
417	Overlying Water	3.73	116	42.2	591	4.10	57	211	5927	46.3	12.4
	Overlying Water	3.64	113	41.8	585	3.70	52	216	6063	45.5	12.5
	Overlying Water	3.61	112	41.6	583	4.00	56	223	6264	45.6	12.6
	Surface grab	3.64	113	44.0	615	3.95	55	230	6458	47.9	13.2
	Surface grab	3.56	110	42.9	601	4.39	61	219	6159	47.3	13.3
433	Overlying Water	3.26	101	42.1	589	4.38	61	241	6770	46.4	14.2
	Overlying Water	3.34	103	42.9	601	4.85	68	254	7142	47.8	14.3
	Overlying Water	3.32	103	42.7	597	3.54	50	245	6880	46.2	13.9
	Surface grab	2.90	90	39.3	551	2.45	34	240	6728	41.8	14.4
	Surface grab	2.67	83	38.2	534	3.23	45	223	6249	41.4	15.5
409	Overlying Water	3.51	109	42.5	595	5.32	74	215	6032	47.8	13.6
	Overlying Water	3.37	104	41.4	579	4.74	66	215	6025	46.1	13.7
	Surface grab	3.50	108	40.8	571	6.67	93	182	5102	47.5	13.6
4.1	Overlying Water	2.99	93	41.0	574	4.05	57	247	6933	45.0	15.1
	Overlying Water	2.78	86	41.0	574	3.22	45	246	6905	44.2	15.9
	Surface grab	3.28	102	43.3	606	4.55	64	223	6256	47.9	14.6
	Surface grab (Replicate)	3.19	99	42.3	592	5.24	73	219	6143	47.5	14.9

Collection date: **8/6/2008**

Site Index	Sample Type	Ortho-P (SRP) (μM)	(ug-P L^{-1})	Nitrate+ Nitrite (NO$_3^-$ + NO$_2^-$) (μM)	(ug-N L^{-1})	Ammonia (NH$_3$) (μM)	(ug-N L^{-1})	Silicate Si(OH)$_4$ (μM)	(ug-Si L^{-1})	DIN (N0$_3$ + NH$_3$) (μM)	N:P Molar Ratio
BB	Overlying Water	2.43	75	22.9	320	0.40	6	283	7939	23.3	9.6
	Overlying Water	2.47	77	22.4	314	0.96	13	280	7857	23.4	9.5
	Overlying Water	2.60	81	23.1	323	1.39	19	286	8025	24.5	9.4
	Surface grab	2.73	85	25.4	355	2.18	31	291	8172	27.5	10.1
	Surface grab	2.70	84	25.4	355	2.20	31	288	8098	27.6	10.2
BROWN	Overlying Water	2.80	87	30.9	432	2.60	36	238	6689	33.5	12.0
	Overlying Water	3.09	96	31.5	441	3.10	43	239	6711	34.6	11.2
	Overlying Water	2.93	91	30.5	427	2.10	29	225	6316	32.6	11.1
	Surface grab	3.04	94	32.1	449	2.12	30	222	6226	34.2	11.2
	Surface grab	2.91	90	32.5	455	2.22	31	214	6017	34.7	11.9
MONTEZ	Overlying Water	2.89	90	30.6	428	1.68	24	252	7075	32.3	11.2
	Overlying Water	2.98	92	31.4	440	2.77	39	247	6931	34.2	11.5
	Overlying Water	2.80	87	30.1	421	1.80	25	252	7064	31.9	11.4
	Surface grab	3.04	94	32.5	455	2.98	42	254	7122	35.5	11.7
	Surface grab	2.97	92	32.6	457	1.80	25	224	6281	34.4	11.6
SHERM	Overlying Water	2.78	86	28.7	401	1.59	22	256	7192	30.3	10.9
	Overlying Water	2.79	86	29.5	413	1.96	27	246	6907	31.4	11.3
	Overlying Water	2.72	84	28.1	393	2.20	31	258	7241	30.3	11.1
	Surface grab	1.90	59	24.8	347	1.89	26	251	7044	26.7	14.1
	Surface grab	1.90	59	25.4	356	2.96	41	255	7159	28.4	14.9
SSB 009	Overlying Water	3.06	95	32.2	451	1.85	26	204	5718	34.1	11.1
	Overlying Water	3.04	94	30.9	433	1.04	15	207	5807	32.0	10.5
	Overlying Water	3.06	95	31.3	438	2.19	31	206	5782	33.5	10.9
	Surface grab	2.82	87	27.9	390	1.08	15	204	5724	28.9	10.3
	Surface grab	2.82	87	28.4	397	1.20	17	201	5655	29.6	10.5
433	Overlying Water	2.26	70	31.7	443	2.33	33	208	5849	34.0	15.0
	Overlying Water	2.31	72	31.0	434	2.87	40	194	5454	33.8	14.6
	Surface grab	3.20	99	34.5	483	2.00	28	211	5936	36.5	11.4
	Surface grab	3.25	101	35.0	490	3.00	42	218	6116	38.0	11.7
3*	Surface grab	2.07	64	17.5	245	2.05	29			39.0	18.8

* Comparative dissolved-nutrient concentrations for samples collected from USGS Station 3 (Pittsburg, California) on August 18, 2008 (C. Mioni, written communication, September 23, 2009).

Table 6. Summary of July and August water-column temperatures at a long-term monitoring site near Benicia, California (Schoellhamer and Buchanan, 2009).
[SD, standard deviation]

Bottom Water-column Temperature Summary by Month

	JULY (°C)					AUGUST (°C)				
Year	**Mean**	**SD**	**Min**	**Max**	**n***	**Mean**	**SD**	**Min**	**Max**	**n***
1998	19.8	0.9	17.3	22.5	2,878	August data not available				
2001	20.1	0.6	19.2	22.1	2,965	20.3	0.2	19.5	20.9	873
2002	20.3	0.5	19.4	21.6	2,962	19.8	0.6	18.2	21.0	2,381
2003	20.8	0.5	19.8	22.8	2,975	21.0	0.3	20.3	21.7	2,377
2004	20.3	0.7	19.1	21.7	2,964	20.6	0.4	19.6	21.6	2,068
2005	20.6	0.7	18.8	22.2	2,973	20.1	0.6	19.1	21.3	2,074
2006	22.0	0.8	19.9	24.0	1,187	20.1	0.7	18.9	21.6	3,068
2007	20.6	0.5	19.2	21.9	2,966	20.1	0.5	19.1	21.7	2,950
Decadal Mean =	**20.6**	**0.7**	**19.1**	**22.4**		**20.3**	**0.5**	**19.2**	**21.4**	
Decadal SD =	**0.7**	**0.2**	**0.8**	**0.8**		**0.4**	**0.2**	**0.7**	**0.3**	
Decadal minimum =	**19.8**	**0.5**	**17.3**	**21.6**		**19.8**	**0.2**	**18.2**	**20.9**	
Decadal maximum =	**22.0**	**0.9**	**19.9**	**24.0**		**21.0**	**0.7**	**20.3**	**21.7**	

Surface Water-column Temperature Summary by Month

	JULY (°C)					AUGUST (°C)				
Year	**Mean**	**SD**	**Min**	**Max**	**n***	**Mean**	**SD**	**Min**	**Max**	**n***
1998	20.6	1.0	17.3	22.5		August data not available				
2001	21.3	0.6	20.0	23.5	922	20.1	0.4	18.7	21.6	2871
2002	20.3	0.6	19.0	21.9	2752	19.8	0.7	18.2	21.5	2936
2003	20.7	0.5	19.6	21.9	970	21.0	0.4	19.8	22.9	2620
2004	20.4	0.7	19.1	22.2	2965	20.6	0.5	19.1	23.0	2968
2005	20.4	0.7	18.8	22.7	1637	August data not available				
2006	July/August data not available									
2007	July/August data not available									
Decadal Mean =	**20.6**	**0.7**	**19.0**	**22.5**		**20.4**	**0.5**	**19.0**	**22.3**	
Decadal SD =	**0.4**	**0.2**	**0.9**	**0.6**		**0.5**	**0.1**	**0.7**	**0.8**	
Decadal minimum =	**20.3**	**0.5**	**17.3**	**21.9**		**19.8**	**0.4**	**18.2**	**21.5**	
Decadal maximum =	**21.3**	**1.0**	**20.0**	**23.5**		**21.0**	**0.7**	**19.8**	**23.0**	

* Number (n) of water-column temperatures logged that month varied from year to year due to the number of unacceptable values or an absence of deployed and retrieved dataloggers.

Table 7. Dissolved organic carbon in the water column at profiler deployment sites.
[SD, standard deviation]

Collection date: 7/8/2008

Site	Sample Type	Copper (µg L^{-1})	SD (µg L^{-1})	Nickel (µg L^{-1})	SD (µg L^{-1})	Cobalt (ng L^{-1})	SD (ng L^{-1})	Lead (ng L^{-1})	SD (ng L^{-1})	Cadmium (ng L^{-1})	SD (ng L^{-1})	Vanadium (µg L^{-1})	SD (µg L^{-1})	Iron (µg L^{-1})	Zinc (µg L^{-1})	Manganese (µg L^{-1})
SSB009	Overlying Water A	1.5	0.1	1.3	0.1	20	2	35	2	35	0	3.9	0.1	<15	<5	<10
	Overlying Water B	3.1	0.7	1.6	0.1	28	4	<2		17	0	4.8	0.2	<15	<5	<10
	Surface grab A	2.4	0.1	1.0	0.1	<10		<0.5		6	7	2.1	0.8	<5	<2	<5
	Surface grab B	2.3	0.1	0.9	0.1	11	2	1.1	0.2	15	5	4.7	0.2	<5	<2	<5
416	Overlying Water A	3.4	0.6	1.6	0.1	17	7	23	1	44	2	4.9	0.1	<15	<5	<10
	Overlying Water B	2.4	0.3	1.5	0.1	17	1	6	1	34	3	5.1	0.1	<15	<5	<10
	Overlying Water C	2.0	0.1	1.4	0.1	31	26	4	1	41	5	4.6	0.1	<15	<5	<10
	Surface grab A	2.4	0.1	1.2	0.1	13	5	4.0	0.3	33	4	5.0	0.4	<5	<2	<5
	Surface grab B	2.3	0.2	1.3	0.1	16	2	0.9	0.3	47	6	5.1	0.1	<5	<2	<5
417	Overlying Water A	1.7	0.1	1.3	0.1	12	0	16	1	49	3	3.7	0.1	<15	<5	<10
	Overlying Water B	1.7	0.1	1.2	0.1	10	0	<2		48	2	3.7	0.1	<15	<5	<10
	Overlying Water C	1.7	0.1	1.3	0.1	17	5	54	1	46	1	3.6	0.1	<15	<5	<10
	Surface grab A	2.3	0.1	1.4	0.1	22	1	1.1	0.8	60	4	5.0	0.1	<5	<2	<5
	Surface grab B	2.3	0.1	1.4	0.1	27	3	1.6	0.4	63	7	4.9	0.1	<5	<2	<5
433	Overlying Water A	1.7	0.1	1.2	0.1	19	2	4	1	28	1	3.8	0.1	<15	<5	<10
	Overlying Water B	2.0	0.1	1.2	0.1	21	n=1	20	n=1	20	n=1	4.2	0.1	<15	<5	<10
	Overlying Water C	1.8	0.1	1.5	0.1	9	n=1	<2		21	n=1	5.1	0.1	<15	<5	<10
	Surface grab A	2.0	0.1	1.4	0.1	47	4	1.4	0.4	43	2	4.7	0.2	<5	<2	<5
	Surface grab B	2.2	0.1	1.5	0.1	33	3	2.6	0.2	47	0	4.8	0.2	<5	<2	<5
409	Overlying Water A	1.8	0.1	1.5	0.1	32	1	<2		44	1	5.0	0.1	<15	<5	<10
	Overlying Water B	1.9	0.1	1.5	0.1	35	n=1	8	n=1	39	n=1	5.0	0.1	<15	<5	<10
	Surface grab A	2.3	0.1	1.4	0.1	15	5	2.0	0.5	56	6	4.9	0.1	<5	<2	<5
	Surface grab B	2.3	0.1	1.4	0.1	11	2	1.2	0.3	69	9	4.9	0.1	<5	<2	<5
4.1	Overlying Water A	1.5	0.1	1.1	0.1	14	2	13	1	16	3	3.7	0.1	<15	<5	<10
	Overlying Water B	1.4	0.1	1.0	0.2	11	1	6	5	14	4	3.7	0.2	<15	<5	<10
	Surface grab A	2.0	0.1	1.4	0.1	11	2	1.2	0.1	46	4	4.9	0.2	<5	<2	<5
	Surface grab B	2.1	0.1	1.4	0.1	14	2	2.0	0.4	57	7	5.1	0.2	<5	<2	<5

Collection date: 8/6/2008

Site	Sample Type	Copper (µg L^{-1})	SD (µg L^{-1})	Nickel (µg L^{-1})	SD (µg L^{-1})	Cobalt (ng L^{-1})	SD (ng L^{-1})	Lead (ng L^{-1})	SD (ng L^{-1})	Cadmium (ng L^{-1})	SD (ng L^{-1})	Vanadium (µg L^{-1})	SD (µg L^{-1})	Iron (µg L^{-1})	Zinc (µg L^{-1})	Manganese (µg L^{-1})
BB	Overlying Water A	0.6	0.1	0.6	0.1	5	4	<2		<2		5.5	0.1	<15	<5	<10
	Overlying Water B	0.7	0.1	0.6	0.1	2	2	<2		<2		5.8	0.3	<15	<5	<10
	Overlying Water C	0.7	0.1	0.6	0.1	7	5	14	1	6	1	5.7	0.3	<15	<5	<10
	Surface grab A	1.0	0.1	0.8	0.1	<10		<0.5		3	1	5.9	0.1	<5	<2	<5
	Surface grab B	0.9	0.2	0.7	0.1	13	4	<0.5		<2		5.6	0.3	<5	<2	<5
BROWN	Overlying Water A	0.9	0.1	1.2	0.1	5	2	<2		20	1	5.1	0.1	<15	<5	<10
	Overlying Water B	1.0	0.1	0.8	0.1	8	2	<2		21	1	4.8	0.1	<15	<5	<10
	Overlying Water C	1.2	0.1	1.3	0.1	11	3	4	1	17	6	7.1	0.1	<15	<5	<10
	Surface grab A	1.3	0.1	1.1	0.2	20	2	<0.5		11	2	5.9	0.2	<5	<2	<5
	Surface grab B	1.3	0.2	1.2	0.1	18	2	<0.5		8	1	5.8	0.3	<5	<2	<5
MONTEZ	Overlying Water A	0.8	0.1	0.6	0.1	6	1	13	1	18	1	4.1	0.1	<15	<5	<10
	Overlying Water B	1.4	0.1	1.0	0.1	27	1	n/a		24	1	5.8	0.1	<15	<5	<10
	Overlying Water C	1.2	0.1	1.1	0.1	<10		4	1	20	2	5.5	0.1	<15	<5	<10
	Surface grab A	1.7	0.6	0.9	0.1	<10		<0.5		<2		3.6	0.5	<5	<2	<5
	Surface grab B	2.1	0.7	0.7	0.1	<10		<0.5		<2		4.0	0.9	<5	<2	<5
SHERM	Overlying Water A	0.8	0.1	0.6	0.1	9	6	4	1	14	2	4.5	0.1	<15	<5	<10
	Overlying Water B	0.9	0.1	0.7	0.1	10	5	8	2	16	4	4.7	0.2	<15	<5	<10
	Overlying Water C	0.8	0.1	0.6	0.1	7	4	3	1	13	1	4.9	0.2	<15	<5	<10
	Surface grab A	1.7	0.1	1.2	0.2	<10		2.2	1.2	14	3	8.2	1.4	<5	<2	<5
	Surface grab B	1.0	0.2	0.8	0.3	<10		<0.5		5	4	5.5	0.7	<5	<2	<5
SSB009	Overlying Water A	1.5	0.1	1.5	0.1	19	5	12	1	41	1	5.7	0.1	<15	<5	<10
	Overlying Water B	1.3	0.1	1.6	0.1	14	0	n/a		47	3	5.5	0.2	<15	<5	<10
	Overlying Water C	2.4	1.4	2.1	1.0	n/a		n/a		34	9	6.7	1.3	<15	<5	<10
	Surface grab A	1.6	0.1	1.3	0.1	16	2	<0.5		36	4	5.1	0.5	<5	<2	<5
	Surface grab B	1.7	0.1	1.3	0.1	18	2	1.4	0.8	45	4	5.1	0.4	<5	<2	<5
433	Overlying Water A	1.2	0.1	1.1	0.1	25	1	8	1	35	1	5.9	0.2	<15	<5	<10
	Overlying Water B	1.3	0.1	1.2	0.1	17	3	12	1	40	3	5.4	0.2	<15	<5	<10
	Surface grab A	1.4	0.1	1.3	0.2	15	3	2.2	0.2	14	3	6.0	0.3	<5	<2	<5
	Surface grab B	1.5	0.1	1.2	0.2	18	3	2.0	0.2	14	3	6.0	0.3	<5	<2	<5

Table 8. Dissolved organic carbon (DOC) in the water column at profiler deployment sites. [SD, standard deviation]

Collection date: 7/8/2008

Site Index	Sample Type	DOC (µM)	SD (µM)
SSB009	Overlying Water	264	3
	Overlying Water	272	0
	Overlying Water	287	8
	Surface grab	227	1
	Surface grab	225	1
416	Overlying Water	227	3
	Overlying Water	254	4
	Overlying Water	262	8
	Surface grab	217	2
	Surface grab	218	2
417	Overlying Water	240	0
	Overlying Water	243	2
	Overlying Water	247	2
	Surface grab	226	1
	Surface grab	220	1
433	Overlying Water	253	3
	Overlying Water	277	6
	Overlying Water	229	3
	Surface grab	240	2
	Surface grab	245	1
409	Overlying Water	234	1
	Overlying Water	233	2
	Overlying Water	235	0
	Surface grab	213	3
	Surface grab	227	1
4.1	Overlying Water	225	1
	Overlying Water	257	3
	Surface grab	220	1
	Surface grab	216	1

Collection date: 8/6/2008

Site Index	Sample Type	DOC (µM)	SD (µM)
BB	Overlying Water	200	2
	Overlying Water	184	4
	Overlying Water	179	2
	Surface grab	178	1
	Surface grab	176	2
BROWN	Overlying Water	215	3
	Overlying Water	202	3
	Overlying Water	196	2
	Surface grab	196	1
	Surface grab	197	1
MONTEZ	Overlying Water	207	1
	Overlying Water	205	2
	Overlying Water	193	2
	Surface grab	200	1
	Surface grab	195	1
SHERM	Overlying Water	201	5
	Overlying Water	192	3
	Overlying Water	212	4
	Surface grab	182	2
	Surface grab	201	2
SSB009	Overlying Water	229	1
	Overlying Water	234	3
	Overlying Water	223	1
	Surface grab	255	1
	Surface grab	251	2
433	Overlying Water	224	2
	Overlying Water	211	2
	Surface grab	211	1
	Surface grab	204	1

Table 9. Summary of dissolved trace-element fluxes.

8-Jul-08 Bottom-water temperature = **20.4 to 22.4** degrees Celsius

		Iron			Manganese			Cobalt			Cadmium			Nickel			
Site Index	**n (replicate deployments)**	**Site Average (µmole-m^{-2} d^{-1})**	**Site SD (µmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (µmole-m^{-2} d^{-1})**	**Site SD (µmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Index**
SSB009	3	**18**	9	1.7	**33**	11	3.1	**59**	16	5.9	**3.2**	0.8	0.6	**31**	19	6.0	SSB009
416	3	**n/a**	n/a	n/a	**41**	19	3.9	**80**	50	8.0	**17.4**	14.6	3.3	**116**	87	22.2	416
417	3	**33**	4	3.1	**148**	23	13.8	**180**	24	18.0	**19.6**	11.5	3.7	**350**	239	66.9	417
433	3	**55**	68	5.3	**58**	8	5.4	**125**	62	12.5	**8.2**	4.6	1.6	**69**	21	13.2	433
409	3	**1.1**	0.3	0.1	**1.2**	0.8	0.1	**22**	5	2.2	**1.2**	1.0	0.2	**12**	5	2.3	409
4.1	2	**16**	23	1.6	**7**	8	0.6	**41**	47	4.1	**0.2**	0.7	0.0	**52**	38	9.9	4.1
Estimated Riverine Flux**				100			100			400			770			26000	**Estimated Riverine Flux**
				assuming Fe conc of 5 ug/L			assuming Mn conc of 5 ug/L			assuming Co conc of 20 ng/L			assuming Cd conc of 38 ng/L			assuming Ni conc of 1.3 ug/L	

6-Aug-08 Bottom-water temperature = **19.6 TO 21.0** degrees Celsius

		Iron			Manganese			Cobalt			Cadmium			Nickel			
Site Index	**n (replicate deployments)**	**Site Average (µmole-m^{-2} d^{-1})**	**Site SD (µmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (µmole-m^{-2} d^{-1})**	**Site SD (µmole-m^{-2} d^{-1})**	**Extrapolated Flux (kg-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Average (nmole-m^{-2} d^{-1})**	**Site SD (nmole-m^{-2} d^{-1})**	**Extrapolated Flux (g-d^{-1})***	**Site Index**
BB	3	**4**	5	0.4	**18**	9	1.7	**33**	19	3.4	**0.8**	0.1	0.2	**56**	32	10.8	BB
BROWN	3	**49**	15	4.7	**37**	44	3.5	**91**	31	9.1	**10.2**	6.9	2.0	**149**	79	28.5	BROWN
MONTEZ	3	**39**	19	3.7	**63**	99	5.9	**78**	50	7.8	**3.4**	3.3	0.7	**215**	321	41.2	MONTEZ
SHERM	2	**131**	112	12.4	**13**	4	1.2	**56**	5	5.6	**7.5**	8.6	1.4	**38**	4	7.2	SHERM
SSB009	3	**81**	71	7.7	**10**	4	0.9	**44**	24	4.4	**1.7**	0.8	0.3	**25**	17	4.8	SSB009
433	2	**22**	7	2.1	**42**	31	3.9	**249**	230	25.0	**4.0**	1.6	0.8	**91**	43	17.3	433
Estimated Riverine Flux				70			70			200			280			14000	**Estimated Riverine Flux**
				assuming Fe conc of 5 ug/L			assuming Mn conc of 5 ug/L			assuming Co conc of 15 ng/L			assuming Co conc of 20 ng/L			assuming Ni conc of 1.0 ug/L	

* Extrapolated benthic fluxes assume Suisun Bay projected area of 1.7 million square meters (Smith and others, 2009)
Internet access at: http://sfbay.wr.usgs.gov/sediment/sfbay/geostat.html

Table 10. Benthic chlorophyll-a (Chl a) at profiler-deployment sites.
[SD, standard deviation. Capital letters following the site index represent replicate samples]

Collection date: 7/8/2008

Site Index	Location Description	Extraction vol (mL)	Dilution Factor[1]	Chl a (μg-cm^{-2})	Mean Chl a (μg-cm^{-2})	SD (μg-cm^{-2})	95% Confidence Interval	Pheophytin (μg-cm^{-2})	Mean Pheophytin (μg-cm^{-2})	SD (μg-cm^{-2})	95% Confidence Interval	Chl ÷ (Chl+ Phaeophytin) ratio
4.1-A	Outside Honker	8.0	1	0.25	0.37	0.11	0.47	1.22	1.45	0.22	0.95	0.20
4.1-B	Bay	7.0	1	0.39				1.47				
4.1-C		7.0	1	0.46				1.65				
409-A	Suisun Bay	7.0	0.125	0.78	0.67	0.21	0.94	4.06	3.65	1.20	5.28	0.16
409-B		7.0	0.125	0.81				4.60				
409-C		7.0	0.125	0.43				2.30				
416-A	Mid-Grizzly	7.0	0.125	1.11	1.14	0.15	0.66	7.13	7.34	0.96	4.22	0.13
416-B	Bay	7.0	0.125	1.00				6.50				
416-C		7.0	0.125	1.30				8.39				
417-A	Grizzly Bay	7.0	0.125	1.19	0.89	0.27	1.17	6.11	4.71	1.25	5.48	0.16
417-B	east	7.0	0.125	0.67				3.70				
417-C		7.0	0.125	0.81				4.33				
433-A	Mid-Honker Bay	7.0	0.125	1.11	1.07	0.04	0.16	5.01	5.03	0.13	0.59	0.18
433-B		7.0	0.125	1.07				5.18				
433-C		7.0	0.125	1.04				4.91				
SSB009-A	Honker Bay	7.0	0.125	1.00	1.05	0.15	0.68	4.38	4.76	0.65	2.84	0.18
SSB009-B	entrance	7.0	0.125	0.93				4.39				
SSB009-C		7.0	0.125	1.22				5.50				

0.86 = overall average
0.31 = overall SD
0.19 = 95% confidence interval
18 = n measurements

4.49 = overall average
1.94 = overall SD
1.16 = 95% confidence interval
18 = n measurements

Collection date: 8/6/2008

Site Index	Location Description	Extraction vol (mL)	Dilution Factor[1]	Chl a (μg-cm^{-2})	Mean Chl a (μg-cm^{-2})	SD (μg-cm^{-2})	95% Confidence Interval	Pheophytin (μg-cm^{-2})	Mean Pheophytin (μg-cm^{-2})	SD (μg-cm^{-2})	95% Confidence Interval	Chl ÷ (Chl+ Phaeophytin) ratio
433-A	Mid-Honker Bay	10.0	1	0.54	0.30	0.28	1.21	9.84	9.00	1.97	8.64	0.03
433-B		10.0	1	0.00				10.41				
433-C		10.0	1	0.34				6.75				
SHERMAN-A	Sherman Lake	10.0	1	0.00	0.00	0.00	0.00	17.10	13.32	3.30	14.50	0.00
SHERMAN-B		10.0	1	0.00				11.02				
SHERMAN-C		10.0	1	0.00				11.83				
SSB009-A	Honker Bay	10.0	1	0.00	0.00	0.00	0.00	4.80	4.36	0.61	2.68	0.00
SSB009-B	entrance	10.0	1	0.00				4.61				
SSB009-C		10.0	1	0.00				3.66				
MONTEZ-A	Montezuma	10.0	1	0.14	0.20	0.12	0.52	2.82	3.26	0.80	3.53	0.06
MONTEZ-B	Island	10.0	1	0.34				4.18				
MONTEZ-C		10.0	1	0.14				2.77				
BB-A	Big Break	10.0	1	0.48	0.34	0.14	0.60	24.29	19.75	3.93	17.26	0.02
BB-B		10.0	1	0.20				17.22				
BB-C		10.0	1	0.34				17.75				
BROWN-A	Browns Island	10.0	1	0.00	0.32	0.31	1.35	12.58	11.29	1.73	7.58	0.03
BROWN-B		10.0	1	0.61				11.96				
BROWN-C		10.0	1	0.34				9.33				

0.19 = overall average
0.21 = overall SD
0.13 = 95% confidence interval
18 = n measurements

10.16 = overall average
6.07 = overall SD
3.62 = 95% confidence interval
18 = n measurements

[1] Dilution factor for fluorometer readings where 0.1 represents a ten-fold dilution.