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Cover photo: Preparing to deploy a porewater profiler from a kayak at Pond A16 on August 27, 2008

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Conversion Factors

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
micromolar (µM)	molecular weight	micrograms per liter ($\mu g\text{-}L^{-1}$)
micrograms per liter ($\mu g\text{-}L^{-1}$)	0.001	milligrams 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
SRP	Dissolved (soluble) reactive phosphate
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Executive Summary

Sampling trips were coordinated in the second half of 2008 to examine the interstitial water in the sediment and the overlying bottom waters of three shallow (average depth <1 meter) ponds adjacent to the southern reach of San Francisco Bay (herein referred to as South Bay), which were previously used in commercial salt production. In recent years, the ponds were modified for wetland restoration and management as part of the South Bay Salt Pond Restoration Project. A pore-water profiler, modified for dissolved-oxygen sampling, was used to obtain the first centimeter-scale estimates of the vertical concentration gradients for diffusive-flux determinations. This study, a collaboration between scientists from two disciplines within the U.S. Geological Survey (Water Resources and Biological Resources), provides information necessary for developing and refining pond-management strategies and supports efforts to monitor changes in fish and wildlife assemblages associated with the habitat-restoration program.

Between August 27 and September 30, 2008, pore-water profilers were successfully deployed in the South Bay salt ponds A16, A14, and A3W (fig. 1; fig. 2; table 1), measuring the concentration gradient of dissolved oxygen near the sediment-water interface. In each pond, profilers were deployed in triplicate at two sites: a shallow site (< 1 meter) and a deep site (> 2 meters). The water column at all deployment sites was monitored with dataloggers for ancillary water-quality parameters (including dissolved oxygen, salinity, specific conductance, temperature, and pH) to facilitate the interpretation of benthic-flux results.

Calculated diffusive benthic flux of dissolved (0.2-micron filtered) oxygen was consistently negative (that is, drawn from the water column into the sediment) and ranged between -0.5×10^{-6} and -37×10^{-6} micromoles per square centimeter per second (site averages depicted in table 2).

Assuming pond areas of 1.0, 1.4, and 2.3 square kilometers for ponds A16, A14, and A3W, respectively, this converts to an oxygen mass flux into the ponds' sediment ranging from -1 to -72 kilograms per day. Diffusive oxygen flux into the benthos (listed as negative) was lowest in pond A14 (-0.5×10^{-6} to -1.8×10^{-6} micromoles per square centimeter per second) compared with diffusive flux estimates for ponds A16 and A3W (site averages -26×10^{-6} to -35×10^{-6} and -34×10^{-6} to -37×10^{-6} micromoles per square centimeter per second, respectively). These initial diffusive-flux estimates are of the order of magnitude of those measured in the South Bay using core-incubation experiments (Topping and others, 2004), which include bioturbation and bioirrigation effects. Estimates of benthic oxygen demand reported herein, based on molecular diffusion, serve as conservative estimates of benthic flux because solute transport across the sediment-water interface can be enhanced by multidisciplinary processes including bioturbation, bioirrigation, ground-water advection, and wind resuspension (Kuwabara and others, 2009).

Potential Management Implications

Evaluation and refinement of management efforts to restore the South Bay salt ponds involves physical habitat construction that reestablishes hydrologic communication between the estuary and ponds. Such hydrodynamic changes can affect the water quality and hence, through trophic transfer, the composition and abundance of fish and wildlife assemblages in both the ponds and the estuary. Aside from the transport of major cations and anions associated with salt ponds, concentration gradients for both macro- and micronutrients between the ponds and estuary may also affect the rate of primary production and the associated biomass and composition of primary producers at the base of the food web in these ponds. This work provides: (1) initial measurements of benthic demand of dissolved oxygen in three of the salt ponds involved in the restoration program and (2) a research approach to effectively screen areas where benthic/sediment oxygen demand may be of concern. Results presented herein indicate significant oxygen demand by the pond benthos that depletes water-column oxygen levels in interior, shallow regions that dominate the ponds relative to deeper areas at the entrances and discharge areas with lower hydrologic residence times. Application of the pore-water profilers, modified for this dissolved-oxygen study, can help locate areas ("hot spots") of particular concern and subsequent emphasis for restoration or management activities in the ponds and adjacent areas of the estuaries.

Background

Commercial solar evaporation salt production began in the mid-1850s in San Francisco Bay (Goals Project, 1999). Production at a massive scale (more than 1,000,000 annual tons, including North and South Bay ponds) was occurring by 1959, and continued through the end of the century. In 2003, the ponds were purchased for restoration using Federal and California State funds. An Initial Stewardship Plan was implemented beginning in 2004 for controlled circulation of ponds with estuarine waters to maintain low salinity concentrations during the restoration planning phase (Life Science Inc., 2003). Ponds remain under active management until actions are taken to restore them to tidal salt marsh, but some ponds will be maintained as ponds and managed long-term for waterbird habitat. This study occurred in three ponds that are slated to be retained as open-water pond systems. More information can be found at the South Bay Salt Pond Restoration Project website: http://southbayrestoration.org.

Oxygen demand estimates are necessary to determine the viability of managed ponds as habitat for wildlife, including birds and fishes. Anoxic waters are unsuitable for fish survival and can lead to massive die-offs. Hypoxic and anoxic conditions similarly limit the biomass and diversity of estuarine benthic invertebrates (Diaz and Rosenberg, 1995). Low dissolved oxygen conditions can thus limit foraging resources for waterbirds that feed on these taxa. The thick benthic algal mats observed in these former salt ponds act as an organic source of energy for bacteria, which deplete the supply of oxygen through respiration.

In order to quantify the porewater concentrations of dissolved oxygen, an existing porewater profiler was modified to accommodate gas-tight glass syringes instead of the gas-permeable polypropylene syringes used for macronutrient and trace-metal sampling. However, each profiler operated as detailed in Kuwabara and others (2007 and 2009).

Objectives

To facilitate science-based management decisions related to water and ecosystem quality in South Bay Salt Ponds undergoing restoration activities, this study provided the first in-place (in-situ) measurements of the benthic fluxes of dissolved oxygen between the bed material and water column of three salt ponds. The sampling occurred during late summer or early fall, when benthic algal biomass would be expected to be at its peak. Benthic-chlorophyll-*a* measurements at each pond site were made to help place results from this study in proper context. Because dissolved oxygen in the water column near the entrances to these ponds is consistently higher than at sites within these ponds, it is hypothesized that the benthos contributes to the water-column depletion. The apparent level of depletion is surprising. Usually in cases of predominantly shallow aquatic systems (average < 1 meter) there is expedited exchange of oxygen with the atmosphere and little benthic depletion. Conversely, the shallow depths also increase the surface/volume ratio, potentially increasing the importance of the benthos.

Results and Discussion:

Dissolved-Oxygen Flux Estimates Based on Diffusion:

As discussed in detail within the section on Methods below, pore-water profilers were deployed in South Bay Salt Ponds A16, A14, and A3W (fig. 1; fig. 2) in late summer to early fall 2008. The flux of dissolved oxygen as determined from pore-water concentration gradients was consistently negative (that is, into the sediment from the overlying water column) and ranged between -0.5×10^{-6} and -37×10^{-6} micromoles per square centimeter per second (table 2a).

Ponds A16 and A3W exhibited comparable diffusive flux estimates, while A14 dissolved-oxygen fluxes were, on average, more than an order of magnitude lower. Within A16 and A3W, replicate samples showed little variation, both between and within the ponds' shallow and deep locations (table 2b). However, the dissolved-oxygen fluxes at A14 were three times higher at the deep site relative to the shallow site.

All flux calculations are based on Fick's Law, which describes how differences in concentration drive diffusion. As discussed in Methods, the sampler used in these methods was designed to assess concentration changes over the first 10 centimeters of sediment, with the assumption that many solutes will exhibit a gradient between different sediment depths. However, at least in ponds A16 and A3W, the sediment oxygen demand was high enough to reduce even the shallowest porewater sample (1 centimeter deep) to zero milligrams per liter of oxygen (table 3). It is certainly possible that porewaters were oxygen depleted at depths less than 1 centimeter. As a result, diffusive flux estimates, particularly for A16 and A3W, are probably gross underestimates.

Extrapolated over the pond areas, our observed range is 1 to 72 kilograms of oxygen per day. By comparison, the calculated atmospheric diffusion of oxygen to the pond water column based on Fick's Law estimates is orders of magnitude higher (656, 657, and 1,365 kilograms oxygen per day for ponds A16, A14, and A3W, respectively; appendix A) Although a direct comparison would seem to indicate that diffusive flux of oxygen is insignificant compared to atmospheric supply, an observation of the diel oxygen levels indicates otherwise. Figures 3, 4, and 5 show that dissolved-oxygen concentrations in the water column become suboxic, and sometimes anoxic, in the absence of photosynthetic oxygen production. There is a drawdown of oxygen during the dark hours, due to factors such as algal and detrital decomposition and respiration by living algae, which is occurring at a faster rate than inputs of oxygen by atmospheric and other sources. Further study of total-oxygen demand in these systems would be warranted to provide greater spatial and temporal resolution for this process that so critically affects water quality in the ponds.

In ponds A14 and A3W, the sonde data indicate that water coming in through the intake is always more oxygenated than at any internal sites (Mruz and others, 2009). This demonstrates the depletion occurring within the ponds despite the well-mixed, shallow depths. Pond A16 is an outlier here, with low dissolved oxygen at the intake site most of the time. The hydrodynamics of A16 appear to be that only at the highest tidal cycles does oxygenated water enter the pond through the inlet. All other sites at all three ponds exhibit their highest dissolved oxygen concentrations during the most optimal photosynthetic conditions at midday. Although a complete understanding of the hydrodynamics of these ponds is beyond the scope of this report, figure 2 indicates the specific flow structures of each pond.

The benthic-chlorophyll-*a* and phaeophytin data presented below do not explain the lower oxygen diffusion to the sediment in pond A14 relative to ponds A16 and A3W. However, Mruz and other (2009) have published water-column chlorophyll-*a* concentrations, taken within 10 days of each of the profiler deployments at each pond, which indicate that A14 has the lowest water-column chlorophyll-*a* concentrations of the three ponds [A16 (on Aug. 27): 72 $\pm$ 90 micrograms/liter; A14 (on Sept. 18): 25 $\pm$ 8 micrograms/liter; A3W (on Oct. 9): 72 $\pm$ 17 micrograms/liter]. Additional sampling, detailed in Mruz and others (2009), occurring earlier in the summer and later in the fall indicated that A14 has significantly lower average chlorophyll-*a* concentrations in the water column compared to A16 and A3W. It should be noted that only phytoplanktonic, not macroalgal (which are significant in this system), chlorophyll-*a* is measured by this method.

The growth and subsequent settling of phytoplankton augment the benthic carbon source to microbial and macroinvertebrate assemblages near the pond beds. 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). Very little is known about the macroinvertebrate or microbial assemblages in the ponds that may alter nutrient cycling in ponds. Macroinvertebrates likely contribute significantly to benthic processes, given the elevated biomass of primary producers and dramatic dissolved-oxygen gradients observed near the sediment-water interface in these ponds.

Linkage to Dissolved Nutrients:

Autotrophic activity can generate biomass, reflected in elevated benthic-chlorophyll-*a* measurements, that upon degradation creates a benthic oxygen demand. This primary production assimilates macronutrients at a ratio referred to as the Redfield ratio (Wetzel, 2001). Specifically, dissolved-inorganic nitrogen (nitrate, nitrite, and ammonium combined; N) divided by dissolved phosphorus (P, most bioavailable as orthophosphate or soluble reactive phosphorus) often exists at the ratio of approximately 16:1 (in molar units) in systems without N or P limitation. Averaged over all dates and ponds, the molar N:P was about 2:1 (27 $\pm$ 24 micromolar N: 15 $\pm$ 6 micromolar P; Mruz and others, 2009), indicating that all three ponds are significantly depleted in nitrogen relative to phosphorous. However, the N concentration is too high to be considered limiting. Still, this imbalance suggests that nitrogen-fixing cyanobacteria (blue-green algae) might thrive in the ponds. The algal population of a nearby pond also under restoration, named A18, was shown to include *Anabaenopsis* sp. and *Anabaean* sp., both capable of nitrogen fixation (Thebault and others, 2008).

The original configuration of the profilers was designed for nutrient flux determination (Kuwabara and others, 2009). Estimates of the diffusive flux of nutrients into the water column of these salt ponds could be useful in the study of algal blooms and their effect on water quality.

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 and 2002) noted that spatial trends for certain dissolved trace metals (copper and zinc) in south San Francisco Bay and Lahontan Reservoir (mercury) were coincident with DOC.

DOC analysis, while not part of the study's focus, was completed for one profiler in pond A16 and for all profilers in pond A3W. The profiler data (table 4) exhibit DOC concentrations increasing with depth, in some cases by an order of magnitude. These DOC concentration gradients indicate that organics are diffusing out of the sediment. Both the nearby Alviso slough (Marvin-DiPasquale and Cox, 2007) and the upstream reservoirs (Kuwabara and others, 2005) are known to exhibit elevated mercury concentrations, and this mercury is likely to be bound to the organics diffusing out of the sediment. Future direct measurements of mercury and other trace metals in porewater would be required to investigate that possibility.

Water-column DOC concentrations were between 9 and 12 milligrams of carbon per liter (J.E. Cloern, written commun.; table 4), which is much higher that the typical South Bay concentrations of between 1 and 2 micrograms per liter (Topping and others, 2004).

Benthic Chlorophyll:

Benthic-chlorophyll-*a* measurements provide an indication of the settled carbon load, as well as benthic phytoplankton communities, on the lake bed as phytoplanktonic bloom conditions wax and wane. Measurements of benthic chlorophyll-*a* and its degradation by-product, phaeophytin, were taken for the three salt ponds associated with the profiler deployments. Benthic chlorophyll-*a*, averaged over all three ponds (table 5), appears marginally higher compared to results for nearby south San Francisco Bay, but the difference is not statistically significant (2.3 $\pm$

2.6 and 1.1 ± 1.5 micrograms per square centimeter, respectively; Topping and others, 2004). Benthic phaeophytin was significantly higher in the ponds relative to the Bay (averaging 58 ± 18 and 11 ± 4 micrograms per square centimeter, respectively). This high phaeophytin concentration at all sites is an indicator of the settled algal material now at senescence and available for consumption by bacteria—resulting in respiration and oxygen depletion. Note that these samples were collected in late summer to early fall, when algal communities are often maximal but tending toward senescence. Also, with no other known benthic-chlorophyll-*a* data from these ponds, there is no temporal context for within-site comparison. Compared to the highest annual average observed in salt ponds in Western Australia (~40 and ~10 micrograms per square centimeter of benthic chlorophyll-*a* and benthic phaeophytin, respectively; Segal and others, 2006), ponds A14, A16, and A3W averaged much lower benthic chlorophyll-*a* and much higher benthic phaeophytin.

Study Design and Methods

The protocol described in this section focuses on method applications in this sampling of porewater for dissolved oxygen in south San Francisco Bay salt ponds. A basic understanding of the hydrodynamics of these ponds can be inferred from the map in figure 2.

A nonmetallic pore-water profiler, originally designed for nutrient and trace-metal sampling (with a patent application submitted), was modified for this study. In addition to water just above (approximately 1 centimeter) the sediment-water interface, samplers collected interstitial water from five depths within the top 10 centimeters of the lakebed, with fritted polypropylene probes at 1, 2, 3.3, 5.5, and 10 centimeters, to characterize dissolved-solute vertical gradients (that is, six independent sampling circuits). Each sampling circuit collected filtered (0.2 micron) water into 25-milliliter glass syringes. After being lowered onto the pond bed, the device was tripped mechanically to begin sample collection and retrieved at least 8 hours later to ensure that sufficient volume had been collected at a slow rate. In designing the profiler, dye experiments indicated that this slower intake avoided short circuiting (in other words, the porewater at the 2-centimeter depth accidentally being collected by the 1-centimeter probe) of samples between depths and along device surfaces. After retrieval, the sample syringes were closed with a valve, placed in argon-filled bags, and refrigerated in darkness until chemical analysis.

Pore-water profilers were deployed in the South Bay salt ponds A16, A14, and A3W on August 27, September 10, and September 30, 2008, respectively (fig. 1; fig. 2; table 1),

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

At each profiler-deployment site, dataloggers monitored diel changes in the water column at 15-minute intervals. Samples for benthic chlorophyll-*a* were also obtained by subcoring replicate grab samples.

Sampling methods have been previously described (Kuwabara and others, 2003 and 2007), but details are provided below. At each site, the following samples were collected, unless otherwise noted.

Dissolved Oxygen (DO)

Within hours of recovering the samplers, each 25-millilter glass syringe was placed in a syringe pump, which dispensed the sample at a steady rate. Dissolved oxygen (0.2 micron) was measured as the sample passed through a 3.2 millimeter (1/8 inch) acrylic 0.9-milliliter flow-through cell fitted with a microelectrode (Microelectrodes, Inc., Bedford, New Hampshire). The microelectrode was calibrated initially with helium-sparged water and sloped with air-saturated water. Periodic calibration checks were performed using oxygen-free helium and air in place of water. Less than 1 milliliter of sample from the profiler syringe was required for a stable DO reading, significantly less than the volume requirement for the micro-Winkler method used in previous studies (approximately 7 milliliters, Kuwabara and others, 2000). Sample containment in the glass syringe was an additional advantage of this DO method.

Benthic Chlorophyll

At each pond site, the top 0.5 centimeter of lakebed 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 within 24 hours for benthic chlorophyll-*a.* The surficial sediment for each replicate was collected on a glass-fiber filter and buffered with 1 milliliter of magnesium carbonate. Water was removed from the buffered samples by vacuum at less than 5 pounds per square inch 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).

Dissolved Organic Carbon (DOC)

Aliquots of sample water from the glass syringes were dispensed directly into autosampler vials for dissolved organic carbon analysis by high-temperature combustion (Qian and Mopper, 1996; 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).

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Appendix A: Calculations of atmospheric flux of oxygen into the ponds

POND	Depth	Water Temperature (oC)[1]	Atmospheric Pressure (mm Hg)[2]	Vapor Pressure of Water (mm Hg)[3]	Salinity (PSU)[4]	$[Cl^-]$ ($g\text{-}L^{-1}$)	DO Saturation ($mg\text{-}L^{-1}$)[5]	Minimum Water Column DO ($mg\text{-}L^{-1}$)	Transfer Coefficient ($cm\text{-}hr^{-1}$ @ 25°C)	Transfer Coefficient ($cm\text{-}hr^{-1}$ @ pond temp)[6]	Average depth (cm)	Atm DO flux ($mg\text{-}L^{-1}\text{-}hr^{-1}$)[7]	Pond surface area (m^2)	Areally averaged Atm DO flux ($kg\text{-}d^{-1}$)
A16	Shallow#2	22.5	730	20.44	27.5	15.2	8.22	0.02	0.41	0.39	50	0.06	983,000	**764**
	Deep	22.4	730	20.32	29.1	16.1	8.24	0.03	0.41	0.39	210	0.02	983,000	**764**
A14	Shallow#1	21.1	730	18.76	36.8	20.4	8.46	1.09	0.41	0.39	53	0.05	1,380,000	**942**
	Inlet	21.2	730	18.88	35.7	19.8	8.44	2.50	0.41	0.39	120	0.02	1,380,000	**761**
A3W	Shallow#2	22.1	745	19.95	29.9	16.6	8.46	0.42	0.41	0.39	16	0.20	2,270,000	**1720**
	Inlet	21.7	745	19.47	28.0	15.5	8.53	1.31	0.41	0.39	97	0.03	2,270,000	**1534**

[1] Water temperature when logged DO is lowest.

[2] Atmospheric pressure from the San Jose airport meteorological data

[3] Vapor pressure of water from Physics Handbook or using Internet calculator at: http://antoine.frostburg.edu/chem/senese/javascript/water-properties.html

[4] Salinity from sonde data (in PSU), assumed proportional chlorinity from seawater

[5] Calculated from eq. 23-10 in Fair and others, 1958, p. 23-10.

DO saturation concentration (C_s) = ((0.680-(6E-4*D7))*(e7-F7)*(1-(9E-6*H7))/(D7+35)

[6] Calculated from eq. 23-5 in Fair and others, 1958, p. 23-7.

k_d = K7*(8.7/9.4)*POWER(1.016,D7-20)

[7] Calculated from eq. 23-11 in Fair and others, 1958, p. 23-11.

dc/dt = (L7/m7)*(I7-J7)

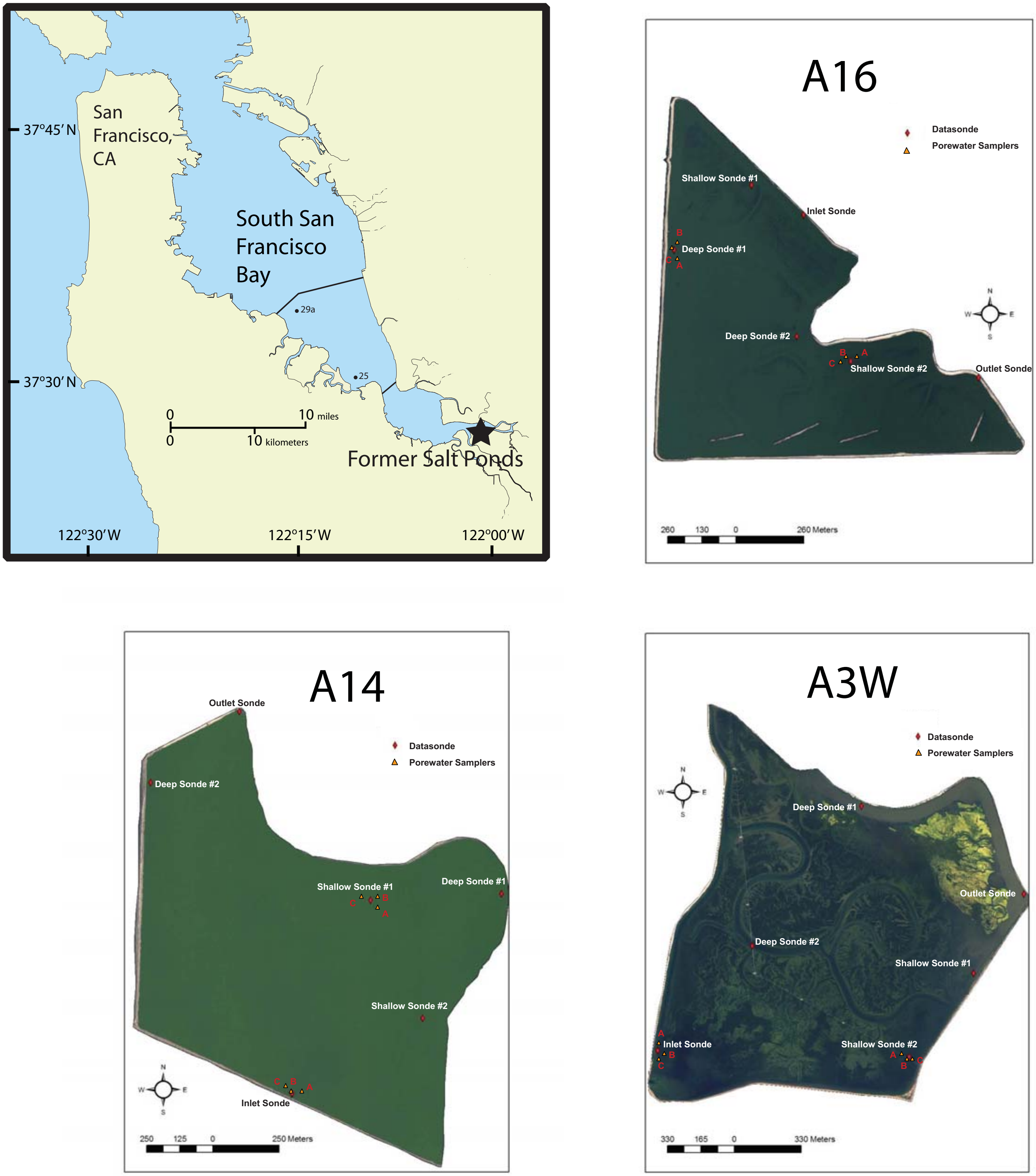

Figure 1. Maps of ponds A16, A14, and A3W, including sampling locations and datasonde locations

Figure 2. Map of former salt ponds near Alviso, California, including flow direction between ponds and specific flow structure information for ponds A16, A14, and A3W. Map and Information courtesy of Army Corps of Engineers by way of Eric Mruz, Don Edwards San Francisco Bay National Wildlife Refuge. Blue arrows represent typical flow direction through structures that are currently (as of summer 2009) or often in use. Two-way 48" gates at A3W and A14 are rarely used in the smaller arrow direction. At pond A16, purple gates are used to show typical winter flow, while red gates indicate typical summer flow. A16 is connected hydrodynamically with pond A17 to the North.

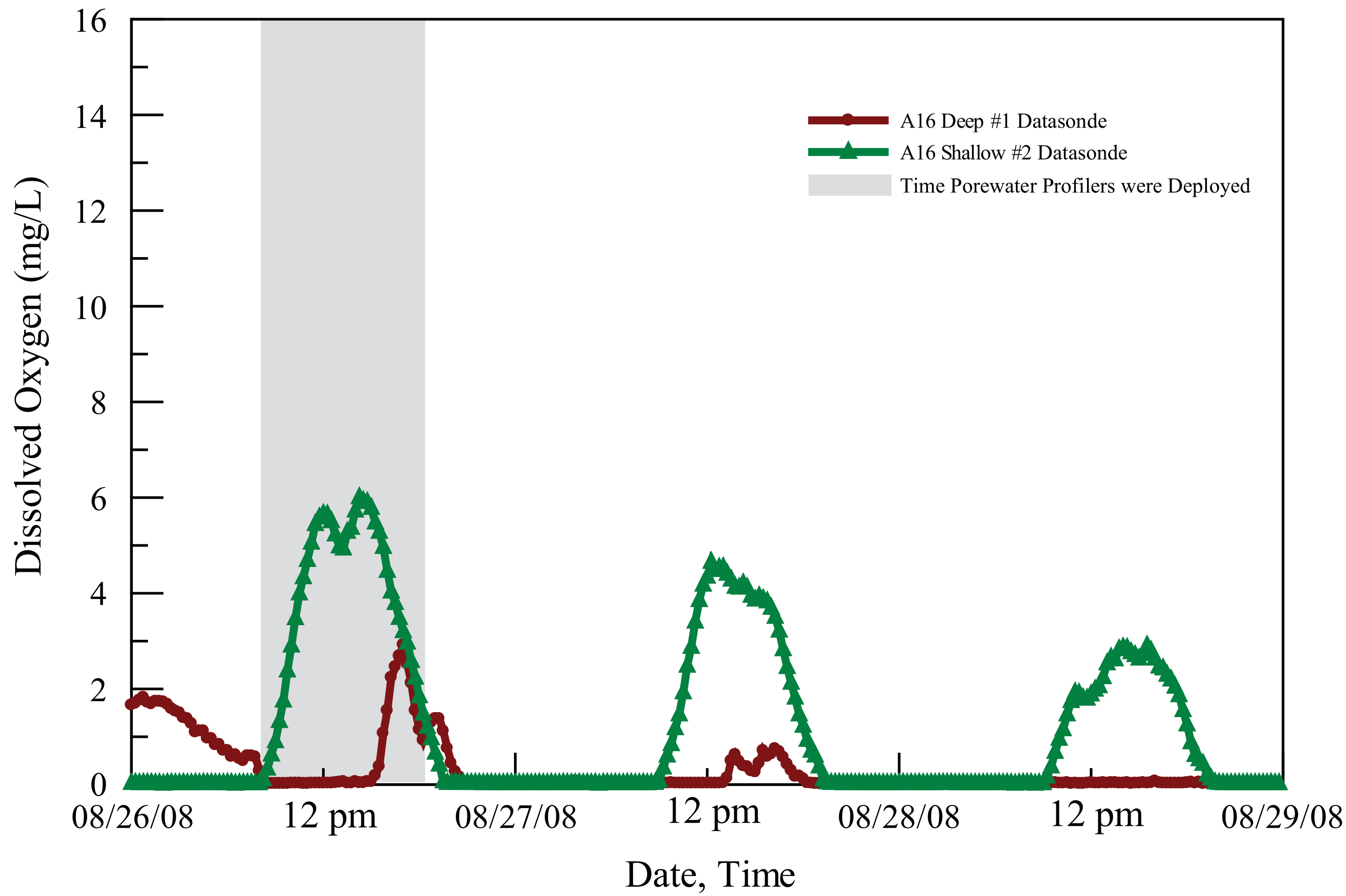

Figure 3. Plot of dissolved oxygen data in the water-column as monitored by dataloggers (Pond A16)

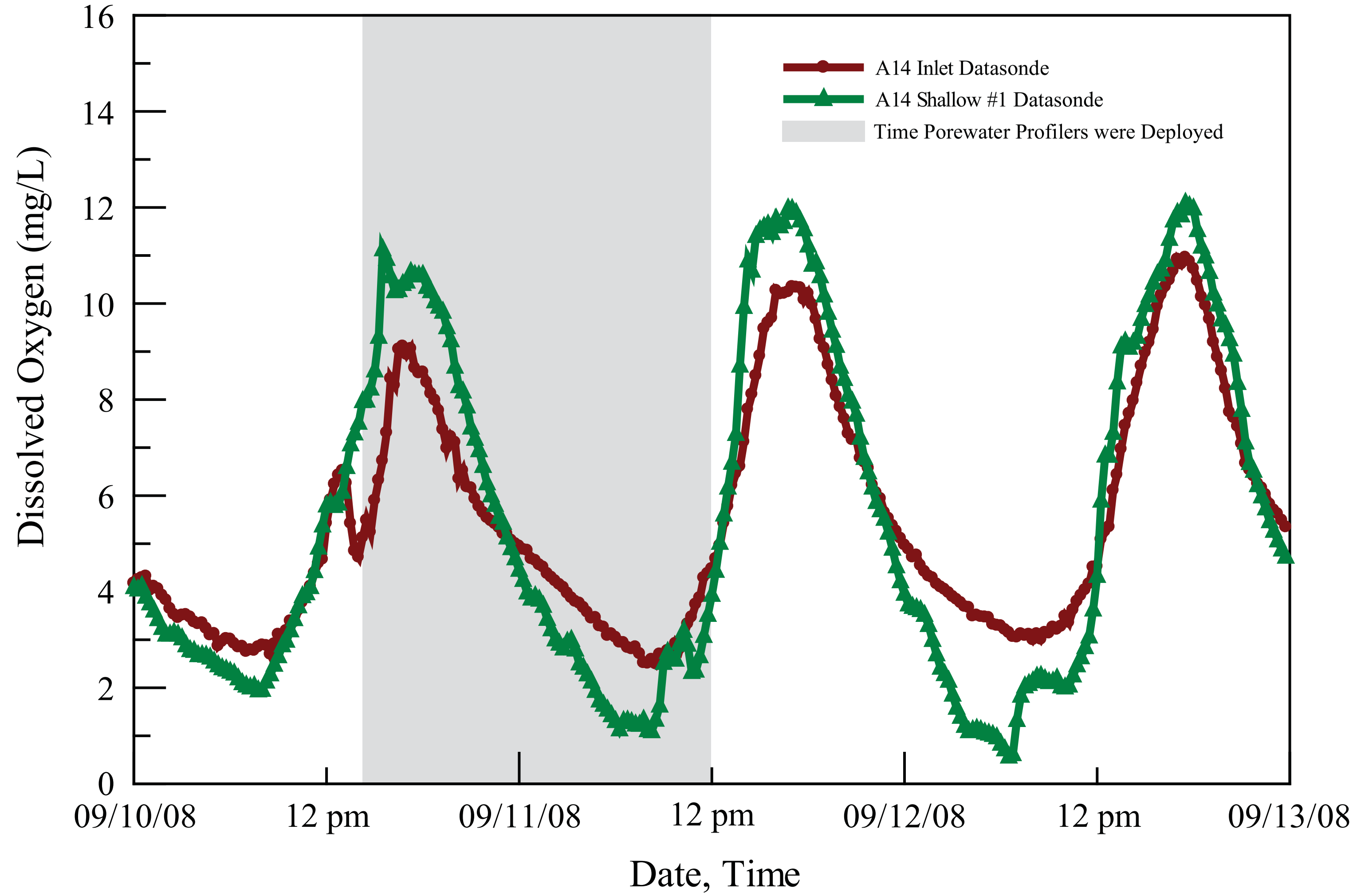

Figure 4. Plot of dissolved oxygen data in the water-column as monitored by dataloggers (Pond A14)

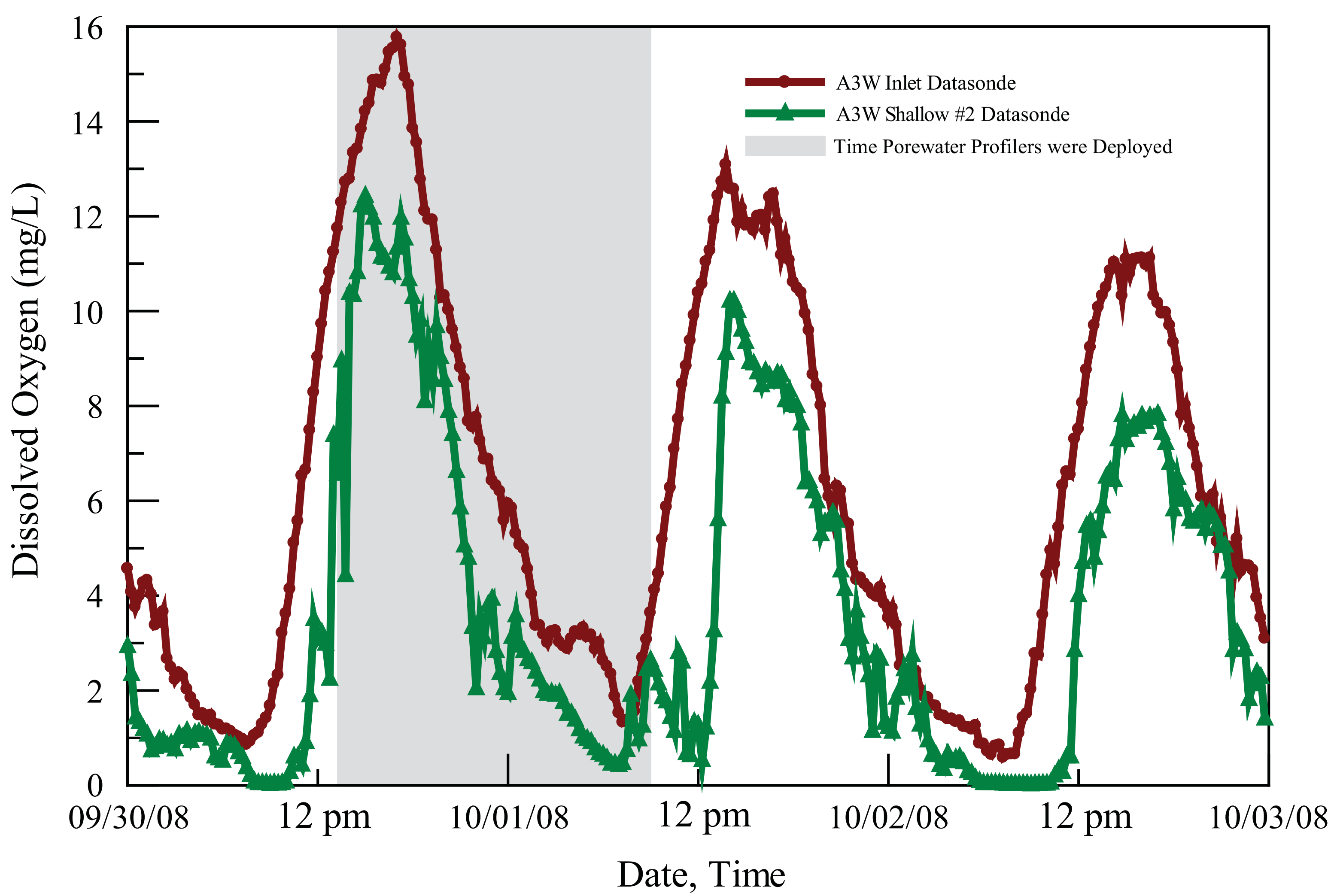

Figure 5. Plot of dissolved oxygen data in the water-column as monitored by dataloggers (Pond A3W)

Table 1. Water-quality sites, Alviso salt pond study, summer 2008

[NAD 27 CONUS datum (UTM Zone 10)]

[Ref: UTM Conversions at http://www.rcn.montana.edu/resources/tools/coordinates.aspx]

Full Site Names	Site Name Abbreviation	UTM Northing	UTM Easting	Latitude (North - min/sec)	Longitude (West - min/sec)	Latitude (North - decimal min)	Longitude (West- decimal min)	Full-Pool Measured Depth (cm)
A16 Shallow Sonde #2	A16-7	414461	591359	37° 26' 44.499"	121° 58' 1.916"	37°26.742'	121°58.032'	50
A16 Deep Sonde #1	A16-2	4145021	590671	37° 26' 57.980"	121° 58' 29.731"	37°26.966'	121°58.496'	210
A14 Shallow Sonde #1	A14-6	4145968	589185	37° 27' 29.226"	121° 59' 29.789"	37°27.487'	121°59.496'	53
A14 Inlet Sonde	A14-2	4146255	588688	37° 27' 38.710"	121° 59' 49.892"	37°27.645'	121°59.832'	120
A3W Shallow #2	A3W	4142866	585384	37° 25' 49.873"	122° 2' 5.779"	37°25.831'	122°2.096'	16
A3W Inlet Sonde	A3W	4142899	584122	37° 25' 51.360"	122° 2' 57.109"	37°25.856'	122°2.952'	97

Table 2. Summary of Dissolved-oxygen Diffusive Fluxes for ponds A16, A14, and A3W

Table 2a

Ponds A16, A14 and A3W

			Dissolved Oxygen		Dissolved Oxygen		Dissolved Oxygen	
Site	**Site name**	**Date**	**Site Average ($\mu mole/cm^2/s$)**	Site StDev ($\mu mole/cm^2/s$)	**Site Average ($g/m^2/day$)**	Site StDev ($g/m^2/day$)	**Site Average (kg/d)**	Site StDev (kg/d)
1	A16 Shallow #2	8/27/2008	**-2.6E-05**	7.8E-06	**-0.36**	0.11	**-23**	7
2	A16 Deep #1	8/27/2008	**-3.5E-05**	1.3E-05	**-0.48**	0.19	**-30**	11
3	A14 Shallow #1	9/11/2008	**-5.4E-07**	4.6E-07	**-0.01**	0.01	**-1**	1
4	A14 Inlet	9/11/2008	**-1.8E-06**	1.4E-06	**-0.03**	0.02	**-2**	2
5	A3W Shallow #2	9/30/2008	**-3.4E-05**	3.2E-06	**-0.48**	0.04	**-69**	6
6	A3W Inlet	9/30/2008	**-3.7E-05**	1.3E-05	**-0.51**	0.18	**-72**	25

By comparison, the oxygen demand from core incubations for 2 South Bay stations averaged 1.5 $g/m^2/day$ =

(Ref: Topping and others, 2004) **1.1E-04** +/- 1.4E-05 ($\mu mole/cm^2/s$)

Note: South Bay stations, named 29A and 25, are in the deep channel and western shallows, respectively.

Table 2b: Individual replicate DO estimates

			Dissolved Oxygen	
Site	**Site name**	**Replicate**	**($\mu mole/cm^2/s$)**	**($g/m^2/day$)**
1	A16 Shallow #2	A	**-3.38E-05**	**-0.5**
		B	**-1.82E-05**	**-0.3**
		C	**-2.73E-05**	**-0.4**
2	A16 Deep #1	A	**-3.26E-05**	**-0.5**
		B	**-4.87E-05**	**-0.7**
		C	**-2.27E-05**	**-0.3**
3	A14 Shallow #1	A	**-1.04E-06**	**-0.01**
		B	**-1.75E-07**	**0.00**
		C	**-3.91E-07**	**-0.01**
4	A14 Inlet	A	**-3.41E-06**	**-0.05**
		B	**-9.22E-07**	**-0.01**
		C	**-1.18E-06**	**-0.02**
5	A3W Shallow #2	A	**-3.88E-05**	**-0.5**
		B	**-3.44E-05**	**-0.5**
		C	**-3.25E-05**	**-0.4**
6	A3W Inlet	A	**-2.79E-05**	**-0.4**
		B	**-5.16E-05**	**-0.7**
		C	**-3.15E-05**	**-0.4**

Table 3. Dissolved-Oxygen (DO) profiles for ponds A16, A14, and A3W

Pond A16 - **8/27/2008**

Deployment: 08:00 - 18:00 PT
Shallow #2

Shallow A depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	9.2	8.4	111	
1	0.5	-0.3	0	
2	0.3	-0.5	0	
3.3	0.2	-0.6	0	
5.5	9.5	8.7	n/a	low volume
10	8.8	8.0	n/a	low volume

Shallow B depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	5.5	4.7	62	
1	n/a		n/a	no volume
2	8.6	7.8	n/a	low volume
3.3	1.5	0.7	9	
5.5	8.5	7.7	n/a	low volume
10	9.2	8.4	n/a	low volume

Shallow C depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	7.3	6.5	85	
1	8.1	7.3	96	
2	0.8	0.0	0	
3.3	10.6	9.8	n/a	low volume
5.5	5.8	5.0	66	
10	9.8	9.0	n/a	low volume

Avg. Temp (^oC) = **24.1** (3.0 degree range)

Deployment: 08:00 - 18:00 PT
Deep #1

Deep A depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	9.2	8.4	111
1	0	-0.8	0
2	0.6	-0.2	0
3.3	1.1	0.3	3
5.5	0	-0.8	0
10	0	-0.8	0

Deep B depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	12.9	12.1	160
1	0	-0.8	0
2	1.7	0.9	11
3.3	0.5	-0.3	0
5.5	0.2	-0.6	0
10	0.2	-0.6	0

Deep C depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	6.8	6.0	79
1	0.1	-0.7	0
2	0.1	-0.7	0
3.3	1.5	0.7	9
5.5	0.1	-0.7	0
10	0.1	-0.7	0

Avg. Temp (^oC) = **22.9** (1.1 degree range)

olw = overlying water

Dead space correction note: The syringes were filled with low-oxygen lab water prior to when the profilers were assembled. This water was pushed out through the tubing and the frit. It is assumed that the water within the tubing could becomes oxygenated in the time between prepping the profilers and deploying them. Thus, the assumption is that each syringe sample included 1 milliliter of oxygen-saturated water. This has been subtracted out of the final dissolved oxygen concentration for each syringe. If dead space correction lead to a negative DO concentration, zero was used instead. The assumption that the dead volume was entirely saturated may be incorrect in these cases. Regardless, the calculated DO flux is not influenced due to the order(s) of magnitude higher values found in the overlying water.

Pond A14 - **9/10/2008**

Deployment: 18:30 (9/10/08) - 13:00 (9/11/08) PT
Shallow #1

Shallow A depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	14.5	13.7	181	
1	11.2	10.4	137	
2	13.9	13.1	173	
3.3	14.5	13.7	181	
5.5	15.9	15.1	199	
10	n/a	n/a	n/a	no volume

Shallow B depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	2.9	2.1	27
1	2.4	1.6	21
2	2.2	1.4	18
3.3	2.6	1.8	23
5.5	4	3.2	42
10	2.6	1.8	23

Shallow C depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	3.3	2.5	33
1	2.4	1.6	21
2	3.9	3.1	40
3.3	2.9	2.1	27
5.5	2.2	1.4	18
10	3.1	2.3	30

Avg. Temp (^oC) = **21.7** (2.8 degree range)

Deployment: 14:30 (9/10/08) - 09:00 (9/11/08) PT
Inlet

Deep A depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	20.9	20.1	265
1	9.4	8.6	113
2	9.5	8.7	115
3.3	1.8	1.0	13
5.5	2.2	1.4	18
10	1.5	0.7	9

Deep B depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	15.6	14.8	195
1	16.7	15.9	210
2	7.2	6.4	84
3.3	7.3	6.5	85
5.5	1.9	1.1	14
10	1.8	1.0	13

Deep C depth (cm)	% DO vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	15.3	14.5	191	
1	20.3	19.5	257	
2	12	11.2	148	
3.3	2.8	2.0	26	
5.5	8.5	7.7	101	<- throw out (reset prior to deploy
10	11	10.2	134	so potentially air in line)

Avg. Temp (^oC) = **22.3** (3.0 degree range)

Pond A3W - **9/30/2008**

Deployment: 13:15 (9/30/08) - 09:00 (10/1/08) PT
Shallow #2

Shallow A depth (cm)	Ↄ vs. atmo.	Dead sp. correct.	**DO umoles/L**	
olw	10.9	10.1	133	
1	0.3	-0.5	0	
2	0.3	-0.5	0	
3.3	0.3	-0.5	0	
5.5	n/a	n/a	n/a	no volume
10	0.5	-0.3	0	

Shallow B depth (cm)		Dead sp. correct.	**DO umoles/L**
olw	9.8	9.0	119
1	0.1	-0.7	0
2	0.2	-0.6	0
3.3	0.5	-0.3	0
5.5	0.5	-0.3	0
10	0.7	-0.1	0

Shallow C depth (cm)		Dead sp. correct.	**DO umoles/L**	
olw	9.4	8.6	113	
1	0.2	-0.6	0	
2	0.1	-0.7	0	
3.3	1.6	0.8	10	
5.5	n/a	n/a	n/a	no volume
10	1.4	0.6	7	

Avg. Temp (^oC) = **22.1** (4.5 degree range)

Deployment: 13:15 (9/30/08) - 09:00 (10/1/08) PT
Inlet

Deep A depth (cm)	Ↄ vs. atmo.	Dead sp. correct.	**DO umoles/L**
olw	8.3	7.5	99
1	0.2	-0.6	0
2	0.3	-0.5	0
3.3	0.4	-0.4	0
5.5	0.2	-0.6	0
10	1	0.2	2

Deep B depth (cm)		Dead sp. correct.	**DO umoles/L**
olw	14	13.2	174
1	0.2	-0.6	0
2	0.2	-0.6	0
3.3	0.2	-0.6	0
5.5	0.2	-0.6	0
10	0.3	-0.5	0

Deep C depth (cm)		Dead sp. correct.	**DO umoles/L**
olw	9.2	8.4	111
1	0.6	-0.2	0
2	0.1	-0.7	0
3.3	0.3	-0.5	0
5.5	0.5	-0.3	0
10	0.2	-0.6	0

Avg. Temp (^oC) = **21.7** (4.8 degree range)

Table 4. DOC porewater profiles in ponds A3W and A16; water-column DOC

Station	Rep	depth (cm)	DOC in mg-C/L
A3W	A	olw	**12.5**
Shallow#2		1	**14.7**
		2	**15.0**
		3.3	**13.2**
		10	**18.9**
A3W	B	olw	**10.8**
Shallow#2		1	**22.8**
		2	**13.3**
		3.3	**103.5**
		5.5	**90.9**
		10	**183.7**
A3W	C	olw	**12.3**
Shallow#2		1	**17.2**
		2	**17.4**
		3.3	**15.2**
		10	**25.2**
A3W	A	olw	**12.0**
Inlet		1	**59.6**
		2	**14.9**
		3.3	**14.2**
		5.5	**21.9**
		10	**37.3**
A3W	B	olw	**23.9**
Inlet		1	**14.0**
		2	**16.6**
		3.3	**36.8**
		5.5	**161.9**
		10	**204.0**
A3W	C	olw	**11.8**
Inlet		1	**43.7**
		2	**27.6**
		3.3	**51.0**
		5.5	**79.5**
		10	**139.5**

			DOC in mg-C/L
A16	B	olw	**12.2**
Deep#1		1	**11.8**
		2	**12.0**
		3.3	**12.5**
		5.5	**15.0**
		10	**16.9**

[olw = overlying water]

Water-column DOC		DOC in mg-C/L	std err	notes
A16	Deep#2	**11.8**	0.1	- taken same day/ Deep #2 is close to Shallow #1
A14	Inlet	**9.1**	0.1	- taken 9/18/08 (one week after porewater samples)
A3W	Shallow#2	**10.8**	0.1	- taken 8/6/08 (two months before porewater samples)
	Inlet	**9.4**	0.2	

[Note: These water-column DOC data were taken at different time because they were performed by a separate project (James Cloern, project Chief) under its own schedule.]

Table 5. Benthic chlorophyll and phaeophytin concentrations

Pond	Site	Replicate	Benthic chl-a (ug/cm^2)	Phaeo-phtyin (ug/cm^2)
A16	Shallow#2	A	**4.8**	**55.9**
		B	**7.6**	**59.7**
		C	**7.9**	**46.3**
A16	Deep#1	A	**1.0**	**78.8**
		B	**-0.5**	**82.0**
		C	**-0.7**	**81.5**
A14	Shallow#1	A	**0.4**	**78.1**
		B	**0.8**	**76.1**
		C	**0.7**	**77.3**
A14	Inlet	A	**4.5**	**32.2**
		B	**2.5**	**29.1**
		C	**2.9**	**27.3**
A3W	Shallow#2	A	**-0.3**	**52.5**
		B	**-0.5**	**57.2**
		C	**1.8**	**55.2**
A3W	Inlet	A	**1.3**	**59.3**
		B	**4.0**	**58.5**
		C	**2.7**	**45.0**