Continuous Monitoring of Dissolved Oxygen in San Francisco Bay

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Abstract

Since passage of the 1972 Federal Clean Water Act, reported dissolved oxygen (DO) concentrations in San Francisco Bay (Bay) are routinely above the 5mg/L standard important for supporting biota, with few reported episodes below this concentration. However, long-term monitoring efforts have measured DO only in the main channel of the estuary by research vessel, and only at weekly to monthly sampling intervals. For this study we conducted a high temporal resolution deployment of dissolved oxygen sensors in both the main channel and the perimeter of the Bay. Four optical DO sensors were deployed near bottom and sampled every 15 minutes for a year: two in the main channel (depth>12m) and two in the estuary perimeter (depth<5m). Main channel sites included one in the upper estuary near the primary freshwater inflow and one in the lower estuary near the ocean boundary; estuary perimeter sites included one at the mouth of a tidal creek in Central Bay and one in a tidal slough in South Bay. The resulting time series for main channel sites showed DO concentrations which always exceeded 5mg/L, whereas during spring, summer, and fall the tidal slough exhibited sustained hypoxic conditions (<3mg/L) and the tidal creek daily minima dropped below 5mg/L. Compared to sites in the main channel, those along the estuary perimeter demonstrated greater variability in DO concentrations at seasonal, tidal, and especially diurnal time scales. At the tidal slough site, DO concentrations varied at the spring-neap time scale, with consistently lower concentrations during neap tides indicating tidally varying transport and system metabolism. These time series are the first to concurrently document the contrasting DO patterns in the main channel versus the shallow periphery of the Bay, with results highlighting the value of high temporal resolution sampling and the importance of measurements in the shallow habitats.

Background

- DO is a fundamental ecological parameter and is an important habitat variable to inform program managers who oversee restoration projects.
- Most of the DO monitoring in the Bay has been conducted along the main channel of the estuary at low temporal resolution.
- Relatively little is known about the variability of DO along the estuary perimeter, although it is important because this is where restoration projects occur and where nursery habitats are found.

Acknowledgements

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Methods

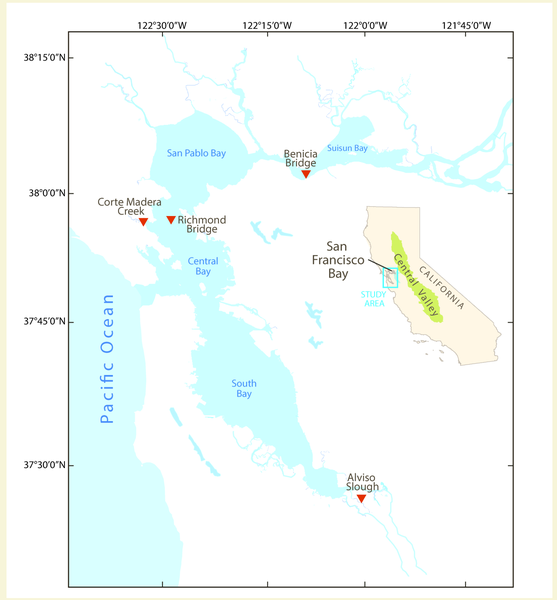

Figure 1. Map of San Francisco Bay with sampling locations. Two stations were located in the main channel of the estuary: Benicia Bridge (11455780) and Richmond Bridge (375607122264701). The two other stations were located along the perimeter of the estuary: Corte Madera Creek (11460090) and Alviso Slough (11169750).

Instrumentation

- Multiparameter water quality sondes (Model 6920 V2, YSI, Inc.) were equipped with sensors for specific conductance, temperature, depth, turbidity, and DO (Figure 2)
- DO concentration and percent saturation were measured using optical technology every 15 minutes
- DO sensors were calibrated on site to 100% saturation using water-saturated air

Figure 2. YSI Sonde, shown with sensor guard (top); close up of DO, turbidity, temperature, and specific conductance sensors (bottom).

Station	Sensor height above bed (ft)	Water depth at MLLW (ft)	Sensor depth at MLLW (ft)
Alviso Slough (AVS)	1.5	3	1.5
Benicia Bridge (BEN)	19	80	61
Corte Madera Creek (CM)	4	4	0
Richmond Bridge (RIC)	5	45	40

Table 1. Sensor and water depths at each station, relative to mean lower low water (MLLW). Station abbreviation used in subsequent figure legends.

Results

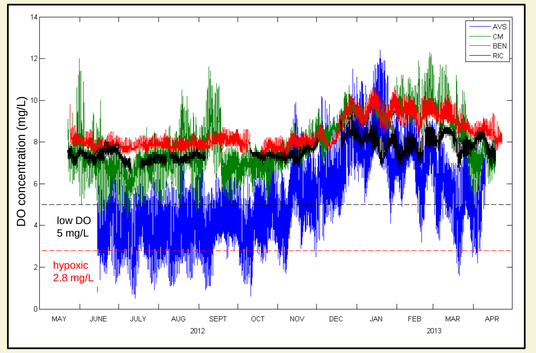

Figure 3. Time series of DO concentration at four sites in the Bay. In general, DO concentration increases at all sites during the winter period, likely due to decreased water temperatures and increased watershed runoff. Main channel sites (Benicia, BEN and Richmond, RIC) have less variation in DO concentration than perimeter sites (Corte Madera, CM and Alviso, AVS). Comparing main channel sites, BEN, located near the head of the estuary, has higher DO concentrations than RIC, possibly caused by either the greater proximity of BEN to freshwater inflow or differences in productivity or respiration between these sites. Comparing perimeter sites, AVS has much lower DO concentrations and much greater variability over short time scales than CM. Comparing observed concentrations to two benchmark standards, AVS had low-DO conditions (<5 mg/L, dark dashed line) 45% of the time and hypoxic conditions (<2.8 mg/L, dashed red line) 7.6% of the time. CM had low-DO conditions 0.3% of the time. BEN and RIC always exceeded the low-DO condition. Statistical testing (Kruskal-Wallis test) showed all sites had significantly different distributions, and multiple comparisons (Tukey-Kramer honestly significant difference test) produced the following similarity ranking:
RIC-CM > BEN-CM > BEN-RIC > RIC-ALV > CM-ALV > BEN-ALV

Table 2. Summary statistics of DO concentrations at all four sites. Daily averaged minimum was computed by finding the minimum concentration for each day and then calculating the average. Mean diel variation was computed by finding the range for each day and then calculating the average. Sites along the estuary perimeter have lower minimum concentrations and higher diel variations than those in the main channel. DO concentration varied the least at RIC, the main channel site nearest the ocean boundary.

	DO concentration (mg/L)			
Station	Mean	Standard deviation	Daily avg. minimum	Mean diel variation
Main channel sites				
Benicia (BEN)	8.4	0.7	8.1	0.8
Richmond (RIC)	7.6	0.5	7.3	0.7
Estuary perimeter sites				
Alviso (AVS)	5.4	1.9	3.5	4.0
Corte Madera (CM)	8.0	1.3	6.9	2.0

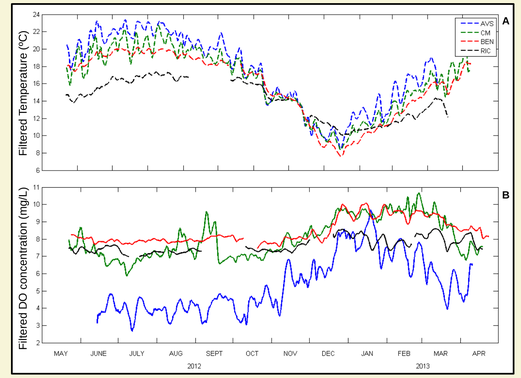

Figure 4. Filtered time series of A) water temperature and B) DO concentration at all sites. Filtering, used here to remove high-frequency variations associated with the tides, was accomplished using a Butterworth filter with stop and pass periods of 30 and 40 hours, respectively. At all sites, DO concentrations increased during winter months, as expected due to decreased temperatures during this time. Temperatures were generally higher at the estuary perimeter sites (AVS and CM), particularly during the summer months. At CM, we observed greater DO concentrations at similar temperatures as AVS. Filtered temperature and DO concentration varied more at perimeter sites, attributed to greater influence of the spring-neap tidal cycle along the shallower estuary perimeter.

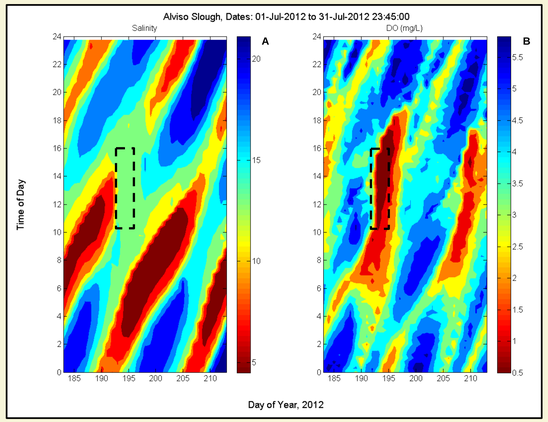

Figure 5. Contour plots of A) salinity and B) DO concentration at Alviso during July 2012. Hour of day (0 and 24 being midnight) is plotted on vertical axis and day of year is plotted on horizontal axis. The variations in salinity and DO concentration are periodic and correspond mostly to spring-neap and diurnal cycles. The lowest and highest salinities are observed during spring tides, when tidal excursion is greatest. The lowest DO concentrations are observed on neap tides at moderate salinity, during the afternoon hours (e.g., on Day 193 between hours 10 and 16, denoted by dashed box in both panels, salinity is constant at 13 and DO is 0.5 mg/L). We believe that hydrodynamics controls the occurrence of the low DO shown here. Early in ebb during summer neap tides, low DO is coincident with periods of near-constant salinity (A) and low suspended-sediment concentrations (SSC, not shown) that likely result from suppressed turbulent mixing due to density stratification of the water column. The water mass isolated near the bed during stratification experiences continued ecosystem respiration from ambient oxygen demands without oxygen input from the atmosphere or substantial photosynthesis. The stratification appears to be driven by vertical salinity gradients, and its control on DO and SSC has dramatic implications on the direction of net flux for these variables. During July, DO concentration is highest on flood tides following stratification episodes and at highest and lowest salinities (coincident with highest and lowest stage, respectively, not shown).

Summary

- DO concentration varies greatly between the main channel and estuary perimeter, with lower values and greater variability observed at the estuary perimeter sites.
- DO concentration varies at many time scales, including tidal, diurnal, spring-neap, and seasonal. At perimeter sites, these variations are magnified.
- Mean concentration at Alviso was near the low-DO benchmark of 5 mg/L, but daily averaged minimum was well below this level. This suggests further study to determine critical levels for ecosystem impairment.

Further Work

- Extend analysis through water year 2013
- Analyze data from 2 other stations in the Bay: Dumbarton Bridge and San Mateo Bridge
- Compare dominant time scales affecting DO concentrations among sites to develop mechanistic understanding of factors causing low DO conditions