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Sediment organic matter composition and dynamics in San Francisco Bay, California, USA: Seasonal variation and interactions between water column chlorophyll and the benthos

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Abstract

Sediment and water column data from four sites in North, Central and South San Francisco Bays were collected monthly from November 1999 through November 2001 to investigate the seasonal variation of benthic organic matter and chlorophyll in channel sediments, the composition and quality of sediment organic matter (SOM), and the relationship between seasonal patterns in benthic organic matter and patterns in water column chlorophyll. Water column chlorophyll peaked in the spring of 2000 and 2001, characteristic of other studies of San Francisco Bay phytoplankton dynamics, however an unusual chlorophyll peak occurred in fall 2000. Cross-correlation analysis revealed that water column chlorophyll at these four channel sites lead sediment parameters by an average of 2 to 3 months. Sediment organic matter levels in the San Francisco Bay channel showed seasonal cycles that followed patterns of water column production: peaks in water column chlorophyll were followed by later peaks in sediment chlorophyll and organic matter. Cyclical, seasonal variations also occurred in sediment organic matter parameters with sediment total organic carbon (TOC) and total nitrogen (TN) being highest in spring and lowest in winter, and sediment amino acids being highest in spring and summer and lowest in winter. Sediment chlorophyll, total organic carbon, and nitrogen were generally positively correlated with each other. Sediment organic matter levels were lowest in North Bay, intermediate in Central Bay, and highest in South Bay. C:N ratio and the ratio of enzyme hydrolyzable amino acids to TOC (EHAA:TOC) data suggest that SOM quality is more labile in Central and northern South Bay, and more refractory in North Bay and southern South Bay.

Keywords: organic matter composition; organic matter dynamics; seasonal variation; chlorophyll; benthos; water column

1. Introduction

The sources and dynamics of organic matter in estuaries and coastal systems are important ecological problems that have occupied researchers for many years (Tietjen, 1968; Bryan, 1979; Spiker, 1981; Odum, 1984; Smith et al., 1989; Jassby et al., 1993; Deegan and Garritt, 1997; Zimmerman and Canuel, 2001). Some particular sources of interest have been the relative contributions of the water column and benthos, and the interactions between pelagic and benthic components of estuarine systems (''benthic-pelagic coupling'') (Asmus et al., 1992; Noji et al., 1993; Hopkinson et al., 1998; Vidal and Morgui, 2000). Organic matter and primary production originating in the water column have been documented to have major bearing on many benthic characteristics in estuaries including organic matter levels in sediment, benthic metabolism and flux, and the ecology and life histories of benthic organisms (Thompson and Nichols, 1988; Schlacher and Wooldridge, 1996; Sagan and Thouzeau, 1998; Zimmerman and Canuel, 2001). Similarly, researchers have shown that physical, chemical, and biological processes in the benthos can have key impacts on a wealth of pelagic qualities such as nutrient levels, phytoplankton

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biomass and water column chlorophyll concentration, and microbial loop activity (Cloern, 1982; Middelboe et al., 1998; Hopkinson et al., 1999). Considerable spatial and seasonal variation in the composition and sources of suspended particulate organic matter (SPM) as well as sediment organic matter (SOM) has been documented in estuaries globally (Canuel and Martens, 1993, 1996; Middelburg and Nieuwenhuize, 1998; Canuel and Zimmerman, 1999; Hedges and Keil, 1999; Zimmerman and Canuel, 2001; Schafer et al., 2002). Canuel and Zimmerman (1999) and Zimmerman and Canuel (2001) related SOM composition to water column parameters and SPM composition in Chesapeake Bay, USA. Canuel and Martens (1993, 1996) examined seasonal changes in SOM composition in response to delivery and diagenesis. Harvey and Johnston (1995) compared the lipid biomarker composition of sinking and size-fractionated particulate organic matter (POM). These studies have given us valuable information about organic matter cycling in estuaries, however, more research into seasonal variations in benthic organic matter and benthic-pelagic relationships are needed to complete the picture.

San Francisco Bay is a large, shallow, temperate estuary and is one of many such systems worldwide characterized by light-limitation, high nutrients, and low chlorophyll (Monbet, 1991; Jassby et al., 2002). San Francisco Bay has a substantial historical oceanographic data set and some well documented benthic-pelagic interactions (Cloern, 1996). The history of ecological research and availability of long-term data in San Francisco Bay thus make it an ideal system in which to further explore outstanding questions about sediment organic matter cycling in light-limited, low chlorophyll estuaries.

Seasonal cycles in sediment chlorophyll have been documented in the San Francisco Bay system, (Nichols and Thompson, 1985; Grenz et al., 2000), as have differences in microphytobenthos photosynthetic production between different regions of the bay (Guarini et al., 2002). Existing data on seasonal cycles in sediment chlorophyll-*a* in San Francisco Bay do not differentiate between water column and benthic sources of primary production, therefore quantitative knowledge of the relative importance of settling phytoplankton and in-situ production in the channel versus the shoals, and at different times of year, is limited (Nichols and Thompson, 1985; Grenz et al., 2000). Thus, while many aspects of primary production and organic carbon cycling have been studied, questions remain concerning the sources of benthic organic matter, the quantitative nature of benthic primary production, and the dynamics and composition of sediment organic matter (Nichols and Thompson, 1985; Guarini et al., 2002).

In this study, 2 years of sediment and water column data from four sites in North, Central and South San Francisco Bays are used to investigate the seasonal variation of organic matter and chlorophyll in channel sediments, between-site differences in sediment organic matter, and the relationship between seasonal patterns in benthic organic matter and patterns in water column chlorophyll.

2. Materials and methods

2.1. Environmental setting and study sites

San Francisco Bay is a shallow, turbid embayment with an average depth of only 6 m at mean lower low water. The bathymetry of the bay is largely characterized by extensive shallow areas that are cut by deeper channels of 10–20 m (Conomos et al., 1985). San Francisco Bay consists of two hydrologically distinct (but connected) subsystems (Conomos, 1979) (Fig. 1): North San Francisco Bay and South San Francisco Bay. North San Francisco Bay (referred to hereafter as "North Bay") is hydrodynamically and biologically characteristic of partially mixed estuaries, and is dominated by the influence of the San Joaquin and Sacramento Rivers. North Bay consists of two major sub-embayments: Suisun Bay, which is closest to the mouths of the San Joaquin and Sacramento Rivers and has the most riverine influence, and San Pablo Bay, which is downstream from Suisun Bay and experiences a combination of riverine and oceanic influence. South San Francisco Bay (hereafter "South Bay") is a tidally influenced, partly enclosed lagoon-type estuary which has nearly oceanic salinity in the dry summers that decreases during the high flow winter and spring season. Central San Francisco Bay (hereafter "Central Bay"), where North and South Bay meet, is closest to the site of ocean exchange and experiences the most oceanic influence of any part of the bay. San Francisco Bay is the largest estuary on the Pacific Coast of the Americas, with a surface area of 1240 km^2. San Francisco Bay is a highly seasonal system and experiences pronounced cyclic fluctuations in primary production. South Bay is characterized by marked spring phytoplankton blooms (Cloern, 1996), and North Bay has historically experienced spring and summer blooms (Cloern et al., 1985). These blooms are amongst the most ecologically important characteristics of seasonal cycles in the bay, and have a major effect on the chemical and biological processes in San Francisco Bay (Cloern et al., 1985).

This study focuses on four sites in San Francisco Bay: one site in North Bay, (USGS station 12.5); one site in Central Bay (USGS station 17.5); and two stations in South Bay (USGS stations 25 and 28) (Fig. 1). Station 12.5 in the North Bay is the most influenced by freshwater inflow (Table 1) (USGS, 2003). Station 25 is close to the San Bruno Shoal, an important bathymetric feature of South Bay that affects exchange between Central Bay and the southern part of South Bay.

2.2. Sampling

Sampling was carried out on monthly cruises for a 2-year period from November 1999 through November 2001 in cooperation with the United States Geological Survey (USGS) on the R/V Polaris (Table 2).

Water column chlorophyll data were collected on each cruise by USGS scientists using a CTD with sensors for measuring chlorophyll (Sea-Tech in vivo fluorometer) (USGS, 2003). CTD chlorophyll data were calibrated on each