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A sediment budget for the southern reach in San Francisco Bay, CA: Implications for habitat restoration

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ABSTRACT

The South Bay Salt Pond Restoration Project is overseeing the restoration of about 6000 ha of former commercial salt-evaporation ponds to tidal marsh and managed wetlands in the southern reach of San Francisco Bay (SFB). As a result of regional groundwater overdrafts prior to the 1970s, parts of the project area have subsided below sea-level and will require between 29 and 45 million m^3 of sediment to raise the surface of the subsided areas to elevations appropriate for tidal marsh colonization and development. Therefore, a sufficient sediment supply to the far south SFB subembayment is a critical variable for achieving restoration goals. Although both major tributaries to far south SFB have been seasonally gaged for sediment since 2004, the sediment flux at the Dumbarton Narrows, the bayward boundary of far south SFB, has not been quantified until recently. Using daily suspended-sediment flux data from the gages on Guadalupe River and Coyote Creek, combined with continuous suspended-sediment flux data at Dumbarton Narrows, we computed a sediment budget for far south SFB during Water Years 2009–2011. A Monte Carlo approach was used to quantify the uncertainty of the flux estimates. The sediment flux past Dumbarton Narrows from the north dominates the input to the subembayment. However, environmental conditions in the spring can dramatically influence the direction of springtime flux, which appears to be a dominant influence on the net annual flux. It is estimated that up to several millennia may be required for natural tributary sediments to fill the accommodation space of the subsided former salt ponds, whereas supply from the rest of the bay could fill the space in several centuries. Uncertainty in the measurement of sediment flux is large, in part because small suspended-sediment concentration differences between flood and ebb tides can lead to large differences in total mass exchange. Using Monte Carlo simulations to estimate the random error associated with this uncertainty provides a more statistically rigorous method of quantifying this uncertainty than the more typical "sum of errors" approach. The results of this study reinforce the need for measurement of estuarine sediment fluxes over multiple years (multiple hydrologic conditions) to adequately detail the variability in flux. Additionally, the timing of breaching events for the restoration project could be tied to annual hydrologic conditions to capitalize on increased regional sediment supply.

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1. Introduction

There has been increased focus on coastal margin habitat restoration over the last several decades. These habitats serve as a valuable wildlife resource, attenuators of storm waves and flooding, sites for recreation, and opportunities for education. However, there have been large declines in these habitats around the world, generally due to factors such as resource overuse, development, and pollution (Boesch et al., 2001; Jackson et al., 2001). More than 65% of worldwide seagrass and wetland habitats, including tidal marsh, have been lost over roughly the last 300 years (Lotze et al., 2006). Given that more than half of the world's population lives within 100 km of the coast and the rate of population growth is increasing in coastal regions (Martínez et al., 2007), it is safe to assume that coastal habitats will be under increased pressure in the future.

San Francisco Bay (SFB) is a large estuary in Northern California, USA, which is surrounded by a major urban area with a population density of about 8200 people km^{-2} (Lotze et al., 2006). This region has lost nearly 80% of its historic tidal marsh habitat over the last 150 years (Goals Project, 1999), representing a loss of about 60,000 ha. Major restoration activities are underway in the SFB area, where over 10,000 ha of former commercial evaporative salt production ponds have been acquired by federal, state, local, and private interests in an attempt to regain some of the lost wetland habitats that historically surrounded the estuary.

The salt ponds around SFB were created over the last 150 years from tidal marsh by constructing levees to isolate the wetlands from the bay and create ponds (Goals Project, 1999). The South Bay Salt Pond Restoration Project (http://www.southbayrestoration.org/), the largest urban wetland restoration project in the US, plans to reclaim about 6000 ha of former salt ponds in south SFB to create a blend of tidal marsh and managed wetland habitats. A major goal of

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the restoration project is to create habitat that can support endangered species and over-wintering and migrating birds that travel along the Pacific Flyway. However, because of groundwater overdrafts in previous decades, parts of the project area have subsided below mean tide level (MTL) — the elevation at which salt marsh plants typically begin to colonize. It is estimated that between 29 and 45 million m^3 of sediment would be required to raise all of the subsided project areas to MTL (U.S. Fish and Wildlife Service and California Department of Fish and Game, 2007). If tidal marsh habitat is desired for these ponds, sediment will be required for the project. The question arises: is there enough sediment naturally available for the successful tidal marsh restoration of these lands?

The far southern reach of SFB has only a few potential sources of natural sediment. The tributaries to this reach provide sediments during the wet season, while there are only minimal inflows during the dry summer season. Three waste-water treatment plants discharge to this area of SFB. There are no definitive plans to import dredge material into the reach or project area. There will be limited dredging in the project area, primarily to breach or lower existing levees and direct water flow into relic marsh channels in the ponds. The only other main potential allochthonous sediment source in this reach would be tidal transport from the rest of the bay through the Dumbarton Narrows. The objectives of this study are to: 1) compare the sediment fluxes from the two main local tributaries to the tidal sediment flux measured at the bayward margin of the reach (Dumbarton), 2) compute a sediment budget for this reach of SFB, and 3) determine if this reach serves as a source or sink of sediment to greater SFB. In addition, the results of the sediment budget are compared to the subsided accommodation space in the restoration project area to determine the feasibility of using the natural supply of sediment for the project needs.

2. Regional setting

San Francisco Bay is the largest estuary on the Pacific coast of the United States. Freshwater enters the head of the estuary primarily via the Sacramento and San Joaquin River Delta on the east side of the bay area, and salt water enters the mouth of the estuary through the narrow Golden Gate on the west end (Conomos et al., 1985). Numerous local tributaries enter on the margins of SFB, the largest in terms of flow being the Napa River, Alameda Creek, and the Guadalupe River (Webster et al., 2005). SFB has a channel-shoal morphology, with narrow, deep channels surrounded by extensive areas of shallow water and mudflats (Fig. 1, Conomos et al., 1985). Far south SFB is the southernmost reach of SFB. The reach is bounded on the bayward side by the Dumbarton Narrows, across which spans the Dumbarton Bridge (Figs. 1 and 2). The two major tributaries Guadalupe River and Coyote Creek enter at the southern end of the reach. The average water depth in this reach of the bay is 2.6 m and the surface area is 34 km^2, both at mean tide level (Hager and Schemel, 1996), maximum depth is about 20 m, and the mixed, semi-diurnal tide range is roughly 3 m. Three municipal waste-water treatment plants (WWTP) discharge to this reach. This region of California experiences a Mediterranean climate, with cool, wet winters and warm summers with strong diurnal winds. Most rainfall occurs between October and April, and hydrologic 'Water Years' are defined locally as 1 October through 30 September, with the spring/summertime year as the Water Year (WY; e.g., WY2011 runs from 1 October 2010 through 30 September 2011).

3. Material and methods

3.1. Tributaries, precipitation, and wastewater

Sampling locations are depicted in Fig. 1. The two main tributaries are gaged with existing USGS stream and suspended-sediment gaging stations on the Guadalupe River (station 11169025) and Coyote Creek (station 11172175). Both stations are located just upstream of tidal influence. A daily record of stream discharge is available from each location, and a daily flux of suspended sediment is available between October 1 and April 30 of a given Water Year (during the wet season). Details on these two sites can be found on the USGS National Water Information System website (http://waterdata.usgs.gov/nwis). Published data were available for Guadalupe River from 23 May 2002–30 September 2011 (discharge) and 1 November 2002–30 April 2011 (suspended sediment), while Coyote Creek data included 1 October 2003–30 September 2011 (discharge) and 1 October 2003–30 April 2011 (suspended sediment, no data were collected during winter 2008).

Several additional tributaries enter this reach of SFB. Individually, they have substantially smaller discharge than Guadalupe River and Coyote Creek and tend not to be reliably gaged for flow or suspended sediment. In order to estimate the contribution of these watersheds to the water and sediment budget, we estimated the watershed areas for the gaged and ungaged watersheds and scaled the Coyote Creek and Guadalupe data by the ungaged watershed area. The majority of the tributaries are in Santa Clara County along the west and south side of far south SFB. Tributary watershed areas, including Coyote Creek and the Guadalupe River, were obtained from Santa Clara Basin Watershed Management Initiative (2000). The area of the ungaged watersheds on the east side of the reach was estimated using the USGS StreamStats web-based tool (streamstats.usgs.gov). Combined, the Coyote Creek and Guadalupe River watersheds cover about 55% of the total drainage area of far south SFB, while the remaining 45% of the drainage area is ungaged. Therefore, the fraction of the sediment contributed by the ungaged tributaries was estimated as 0.82 of the combined Coyote Creek and Guadalupe River fluxes.

Local precipitation data were obtained from the Union City location (station 171) on the California Irrigation Management Information System website (http://wwwcimis.water.ca.gov/). Data from both sources have been quality assessed and controlled and are considered to be of high quality. The three WWTP that discharge to this reach are for the cities of Palo Alto, Sunnyvale and San Jose/Santa Clara. Estimates of this discharge and the average total suspended solids in the wastewater were obtained from the City of San Jose (2012).

3.2. Dumbarton Bridge

A continuous time series of suspended-sediment flux (SSF) at the Dumbarton Bridge was computed for the study period (12 November 2008–30 September 2011) using a combination of high frequency measurements (15-minute intervals) of index quantities (Ruhl and Simpson, 2005; Levesque and Oberg, 2012) and periodic measurements (monthly to quarterly) of water discharge and cross-sectionally averaged suspended-sediment concentration (SSC). Calibrations of the index quantities to cross-section-averaged quantities were used to develop time series of water discharge, SSC, and SSF through the cross-section. Uncertainty was estimated based on a Monte Carlo simulation approach parameterized using the regression residuals from the instrument calibrations.

3.2.1. Data collection

An acoustic Doppler current profiler (ADCP, Nortek Aquadopp 1000 kHz, NortekUSA, Boston, MA, USA) was used to collect water velocity, pressure, and acoustic backscatter data at 15-minute intervals. The instrument was installed in November 2008 and mounted on a pier of the Dumbarton Bridge (Fig. 2), oriented to profile at an angle of ~18° downward toward the bed (Fig. 3). Velocity profiles were collected in fifty 50 cm bins with a blanking distance of 50 cm. Pressure data were corrected for changes in barometric pressure, as measured on the bridge pier. Velocity data were corrected for changes in salinity using data collected during ~weekly–monthly cruises of San Francisco Bay (http://sfbay.wr.usgs.gov/access/wqdata/). Turbidity was measured with an optical sensor (DTS-12, FTS, Victoria, BC, Canada; 15-minute interval) attached to a cable extended alongside the bridge pier (Fig. 3). Instrument