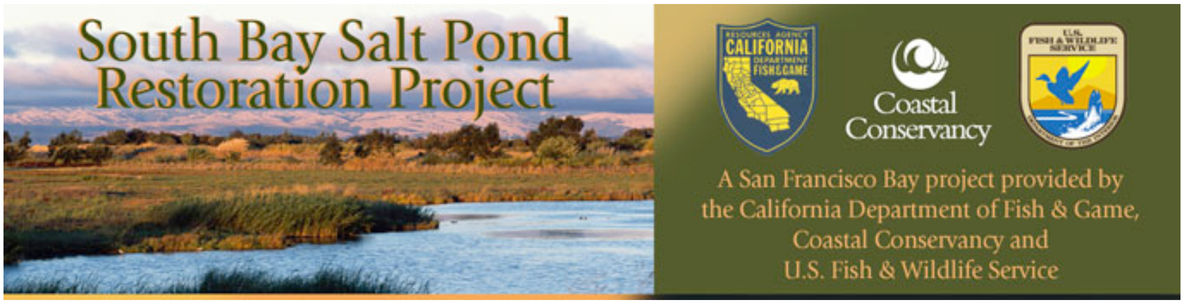

South Bay Science Symposium: South Bay Salt Ponds, Bay and Watershed Research

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Speaker Abstracts

Discharge of water and suspended sediments to the South Bay from Coyote Creek and Guadalupe River Watersheds: Water years 2003 – 2005

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Conceptually marshes on the edge of the Bay can receive sediment from both fluvial and tidal sediment sources. Managers concerned with the restoration and maintenance of marches are challenged with determining the magnitude and quality of sediment derived from each of these important sources. Alameda Creek, Coyote Creek, and Guadalupe River are the 1^{st}, 2^{nd} and 4^{th} largest tributaries that enter the Bay from the Coast Range and together comprise 82% of the South Bay drainage area south of Alameda Creek on the east and San Francisquito Creek on the west. The objective of this presentation is to discuss the magnitude, seasonality and quality of fine suspended sediments entering South San Francisco Bay from Coyote Creek and Guadalupe River. These watersheds will be compared to Zone 6, Line B, a small 2.15 km^2 storm sewershed near Fremont.

The data available to complete this analysis are those collected by USGS and its funding partners for Water Year (WY) 2000 to present. Data on sediment quality are derived from studies conducted by SFEI and its partners from WY 2003 – present. Water discharge during this period was generally below average. Annual suspended sediment loads varied in a single watershed by as much as 22x. On a unit area basis sediment supply from Zone 6 Line B far exceeded the supplies from both Coyote Creek and Guadalupe River, and delivered a greater portion of the total load than would be predicted by area or water discharge alone. Virtually all sediment transport occurred during the winter season in all three watersheds as is the norm in the Bay Area. In terms of sediment supply to restoration projects, the Coyote Creek gage is close to the Bay margin whereas maintenance sediment removal occurs downstream of both the Guadalupe River and Zone 6 Line B USGS gages. Mercury concentrations in suspended sediments are approximately 10x greater in Guadalupe River compared to Coyote Creek. It is reasonable to assume that sediment in Zone 6 line B is also low in mercury although SFEI presently has no data to prove this hypothesis.

Although we are lucky to have very good quality USGS water and suspended sediment data records for several of the South Bay watersheds, the data interpretation is made difficult by short records (2-4 WYs) collected during relatively dry conditions. Accurate estimates of fluvial sediment supply will only be obtained through the development of a sediment budget that takes into account decadal scale climatic variation and sediment removal by maintenance dredging for each watershed system. In contrast, sediment quality for each system could be estimated by several years of observation.

Challenges in estimating sediment supply rates from local watersheds to the South Bay

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Studies of sediment dynamics in San Francisco Bay have indicated that the South Bay depends on local watersheds as the source of sediment for maintaining intertidal habitats. Estimates of sediment yield from South Bay watersheds are therefore relevant to salt pond restoration. Examples of sediment supply rates in several Bay Area streams emphasizes the need to not only consider the natural characteristics of geology, and topography as sources of sediment, but to also consider the influences of historic drainage alterations, modern infrastructure, channel morphology, and floodplain connectivity to sediment storage and delivery to the Bay. Improving our understanding of sediment connectivity to floodplains and in-channel sediment storage is an essential component to estimating future sediment supplies to the Bay.

Landscape lowering rates for several local watersheds are given to demonstrate range and variability of sediment yields. The relative magnitude and geographic location of major sediment sources and storage components has changed over the last century and the influences of historic and modern land use impacts are demonstrated with example sediment budgets from Alameda, Sonoma, Crow, and Hollis Creeks. Future rates of sediment supply, storage, and delivery might be highly variable as some channels become depleted of sediment while others rapidly erode to compensate for increases in water and/or decreases in sediment. Additionally, the routing of sediment to the Bay through tidal channel reaches is poorly understood because we don't know if their rate of in-filling of their sloughs is now constant or still accelerated due to their initial loss of tidal prism. In some channels, most of the sediment that reaches the tidal reaches is trapped there, unless the channel is maintained. Dredging of these reaches increases their capacity to trap sediment and temporarily reduces their delivery of sediment to the Bay. In general, much of the sediment delivery to the Bay is probably associated with major storms and/or floods that generate sediment from landsliding or from instream channel adjustments of bed incision or bank erosion. Datasets that exclude such events can lead to gross underestimates of sediment supply.

The average annual yield of sediment reaching Niles Canyon of Alameda Creek is about 125,300 yd^{3}. Large reservoirs have withheld at least 194,000 yd^3/yr, much more than all the sediment delivered to Niles Canyon. Most of the sediment passing through Niles Canyon gets trapped in the flood control channel or removed by dredging. Delivery to the Bay is only about 50,000 yd^3 /yr. This sediment is enough to raise 1 mi^2 of intertidal habitat about 15 mm/yr. The average rate of sediment delivered by Sonoma Creek to its tidal reach is about 246,000 yd^3/yr. Only about 61,500 yd^3/yr reaches the Bay. This is enough to raise 1 mi^2 of intertidal habitat about 18 mm/yr. An estimated 64% of the San Lorenzo Creek watershed has been dammed and Crow Creek is its only remaining non-dammed large tributary. It has a short-term sediment supply rate of 46,032 yd^3/yr. Nearly all the small reservoirs to San Lorenzo Creek are nearly filled with sediment and their capacity to trap more is greatly diminished. San Lorenzo Creek Flood Control Channel, unlike Alameda Creek, is designed for critical flows and therefore delivers most of its sediment to the Bay. Conceptually, if all the Crow Creek sediment reached the Bay, it would raise 1 mi^2 of intertidal habitat about 14 mm/yr. Hollis Creek, another tributary to San Lorenzo Creek, provides evidence of the importance of extreme events. The December 2005 storm with a 2-5 yr RI rainfall supplied about 10,018 yd^3 of sediment to its filled reservoir. This single event supplied 2.3 times its annual average derived from a 50-year record. Analysis of recent and historical landsliding, indicates that three major storms (1958, 1982, and 2006) with 1-hr rainfall intensity exceeding 0.8 in/hr that followed at least 9 inches of seasonal rainfall, initiated abundant shallow landslides.

Trends in land development, flood control, and natural climatic triggers will surely influence future sediment supply rates to the Bay. Many severely modified watersheds have not yet experienced floods greater than a 50-yr RI. This suggests that the maximum influence of extreme events on sediment yields to the Bay are yet unknown. Given the continued modification of our watersheds, and the effects of modification on increased erosion rates and the ability of the watersheds to deliver the eroded sediment downstream, sediment supplies to the Bay from local watersheds will probably remain greater than they were under natural conditions, and are not likely to decrease below current conditions.

Sediment supply and demand

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The success of the South Bay Salt Pond Restoration Project depends on sufficient sediment supply to meet the sediment demand created by restoring tidal action to subsided ponds in a reasonable time. Pond elevations greater than mean tide level (MTL) are required for vegetation colonization. The quantity of sediment derived from the local watersheds is uncertain. The only comprehensive study of sediment loads was conducted in the late 1950s and early 1960s (Porterfield, 1980, USGS WRIR 80-64). The relations between streamflow and sediment loads determined by Porterfield have been the only means available to estimate present (2006) sediment supply from the watershed. Here we compare recently measured sediment loads with water year 1958-1962 measurements and with sediment loads calculated with the 1958-1962 relations. We also compare recent loads to pond volume below MTL.

Suspended sediment load was measured in the Guadalupe River in water years 1958-1962 and 2003-2005. During the 45-year interval between measurements sediment load decreased by a factor of four for high flows and a factor of eight for low flows. Porterfield used the 1958-1962 data to develop a power law relation between streamflow and sediment load. Applying the same relation to recent streamflow data resulted in a calculated sediment load that was 4.2 times greater than measured.

Porterfield used Guadalupe River streamflow, the relation between streamflow and sediment load, and an extrapolation factor to estimate sediment load from a 519 mi^2 area that includes Coyote Creek. We used the same method and applied an area correction factor to estimate sediment load in Coyote Creek (319 mi^2) to compare with recent measurements. The result overestimates sediment load in Coyote Creek from October 2003 to April 2004 by a factor of nine. Replacing the Guadalupe River sediment load calculated by Porterfield's method with the load measured in the Guadalupe River from October 2003 to April 2004 results in an overestimation of the Coyote Creek load by a factor of 1.8.

Sediment-supply data and relations from South Bay watersheds circa 1960 do not accurately estimate sediment supply in this decade so current data are needed. Urbanization of the watersheds has likely decreased erodible surface area. In addition, 1958-1962 data were collected near the peak of home construction and probably soil disruption (McKee, oral comm.).

Pond bathymetry and LIDAR data were used to determine that pond volume below MTL is 31 to 33 million m^3, over 99% within the Alviso ponds. The five most subsided ponds contain one-half of this volume. The measured sediment load from Guadalupe River and Coyote Creek in water year 2004, which had streamflow 93% and 80% of the mean annual flow, respectively, was about 15 million kg. This translates to a volume of 0.024 million m^3, assuming a typical bulk density of 624 kg/m^3. Thus, this annual watershed supply is three orders of magnitude less than the pond volume below MTL and about 30 million m^3 of additional sediment from the Bay is needed to successfully restore all of the Alviso ponds within a century.

What does the past tells us about whether there will be enough sediment to restore South San Francisco Bay salt ponds?

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Two key questions about salt pond restoration in South San Francisco Bay (South Bay) are: (1) Is there enough sediment in the system to restore the salt ponds to tidal marsh? , and, (2) Will restoration result in the loss of tidal flats? Analyses of bathymetric and topographic surveys of South San Francisco Bay made from 1858 to 2005 reveal the sediment dynamics of the bay and provide insight critical to answering these questions. The pattern and volumes of erosion and deposition in the bay indicate that sediment moves from north to south. Local tributaries alone do not supply a sufficient quantity of sediment to account for the observed deposition. Sediment is entering the system from the north (central SF Bay). In the region south of Dumbarton Bridge there has been an excess of sediment since 1858, including a period when subsidence from groundwater withdrawal in San Jose required additional sediment to maintain tidal flats. In contrast, the tidal flats and bay northeast of Dumbarton Bridge were erosional, in general, since 1858, but were less erosional or even depositional during periods when pulses of sediment from the north entered South Bay. One of the largest pulses of sediment to South Bay occurred from the 1930s to 1950s. Northwest of Dumbarton Bridge was also erosional in general; however, the timing and intensity of erosion do not always correspond with that in the east. A consequence of the north to south movement of sediment and the low-energy environment south of Dumbarton Bridge is that tidal flat area has been historically stable and even increased by 5 km^2 in the past 20 years. This is interesting in light of the fact that tidal marshes surrounding South Bay have decreased from more than 200 km^2 in 1858 to 35 km^2 in 1983 (Foxgrover et al, 2004). This bodes well for the likelihood of successful restoration of salt ponds in far South Bay. Despite the large sediment sink that will be created by opening the subsided ponds, historical trends indicate that restoration is not likely to result in a significant decrease in tidal flat area locally. The situation north of the Dumbarton Bridge is less clear, but historical trends indicate that the quantity of sediment available for elevating ponds to tidal marsh elevations is much less than in the southern South Bay. Further research is needed to determine the sediment transport pathways and processes and that considers the effect ofan accelerating rate of sea level rise, which will increase sediment demand in tidal flats and marshes. It is not known whether sediment availability will be a constraint on the restoration of salt ponds north of the Dumbarton Bridge.

Foxgrover, A.C., Higgins, S.A., Ingraca, M.K., Jaffe, B.E., and Smith, R.E., 2004, Deposition, erosion, and bathymetric change in South San Francisco Bay: 1858-1983: U.S. Geological Survey Open-File Report 2004-1192, 25 p. [URL: http://pubs.usgs.gov/of/2004/1192]

The interaction of an estuary with tidal marsh restoration sites: The Island Ponds and Coyote Creek

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In large-scale restoration of tidal marshes, the effect of restoration activity on the existing estuarine habitat is an important consideration, and is, to great extent, uncertain. The opening of new tidal habitat increases the tidal prism, which alters tidal stage and currents. The creation of these habitats also provides storage along the perimeter of the estuary, which could potentially alter the local salinity distribution due to tidal dispersion processes. Finally, the transport of suspended sediment, and potentially the estuarine bathymetry itself, will respond to both changes in the local tidal circulation and the accretion of sediments in the restored habitats.

In this talk, we discuss these processes, both generally and with specific application to the Island Pond restoration. The local analysis will be informed by some preliminary analysis of a recent set of observations collected along the axis of Coyote Creek from early March through early May. These observations provide a quantification of the important parameters in understanding the connection between the Island Pond sites and the adjoining estuarine habitat, lower Coyote Creek.

Physical Processes and Tidal Marsh Evolution: Cooley Landing and Warm Springs Marsh

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The 81 ha Warm Springs Restoration [aka Coyote Lagoon], implemented in 1986, and the 39 ha Cooley Landing Restoration implemented in 2000 represent the ‘bookends’ or range of opportunities and constraints likely to be encountered in deep subsided to shallow subsided salt pond restoration sites in South San Francisco Bay. At the time of breaching the Warm Springs Marsh had been excavated as a borrow pit approximately 5m below MTL. Key questions included: how quickly would estuarine sedimentation, marsh colonization and slough channel adjustment occur. Cross-section and vegetation surveys have shown rapid sedimentation of up to 6m in 13 years, raising mudflats to above colonization elevations, but spontaneous mudflat colonization has been slow with marsh vegetation mainly expanding laterally from the shoreline. Downstream Coyote Slough responded rapidly to the increase in tidal prism, deepening by 1.5m in the first year, and has continued to adjust over the next 15 years. At Cooley Landing, the abandoned salt pond had subsided by approximately 0.7m but the imprint of the original marshplain dendritic channel system was largely intact. The restoration project was designed to direct tidal flows away from linear artificial borrow ditches to recreate the natural tidal channel morphology. Monitoring of the evolution of this drainage system after restoration has shown that tidal flows are reoccupying the original slough system. Long term monitoring intended to inform improvements in future restoration planning and design was initiated 20 years ago at Warm Springs Marsh. This and other early monitoring efforts could be considered the start of an estuary wide adaptive management program now being systematized in the SBSP restoration program. Key uncertainties that these monitoring efforts have addressed are described in the Design Guidelines for Tidal Wetland Restoration [see www.wrmp.org/design]. Key conclusions from the monitoring described in this presentation are: 1. Rapid sedimentation will occur even in deeply subsided sites in the South Bay, but there may be a significant time lag for complete vegetation colonization to occur. 2. Large tidal channels downstream of restored sites will adjust quickly to increases in tidal prism. 3. it is possible to restore the original dendritic tidal channel system in shallow subsided sites where a topographic imprint remains, provided artificial and borrow ditches are blocked.

Sediment deposition in restored South Bay salt marshes: How much is enough?

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Sediment accumulation is a critical factor driving the development of restored salt marshes as they build elevation to a point suitable for vegetation establishment. This issue is particularly important for salt ponds and other areas that have experienced subsidence and may be anywhere from 20 to 200 cm below target elevations for vegetation. In addition, there are concerns that newly restored sites may create large-scale sediment sinks that may affect sediment dynamics and remove sediments from nearby habitats, e.g., existing mudflats and salt marshes. The particular questions of interest for our research include:

- What is the vertical rate of sediment accumulation within the ponds during the first year following breaching?
- What are the short-term, mass-based rates of accumulation, and how do they compare with measurements of suspended sediments (to be completed by Mark Stacey, UC Berkeley)?
- What are the vertical rates of sedimentation and erosion in nearby mudflats and salt marshes on Coyote Creek (near breaches) and Mud Slough (away from breaches)?

We are evaluating these questions at the Island Ponds, the first salt ponds to be restored as part of the South Bay Salt Pond Restoration Project. We are focusing on one pond, A21, and measuring sediment accumulation rates within the site at 37 stations set up across the marsh, using the sediment pin method (PVC pipes set approximately 3 meters into the sediment). The dense gypsum layer (up to 25 cm thick) and the lack of vegetation at the site preclude the use of other sediment methods. Pins will be monitored at 1 mo, 3 mo, 6 mo, and 1 year to evaluate vertical sediment accumulation rates. In addition, we anticipate that the gypsum layer will remain intact and can serve as a marker for measuring the depth of sediment accumulation with even greater spatial intensity. For short-term rates, we will be using a modification of the "filter paper method" (Reed 1989), with rubberized sampling sheets that are deployed over a two-week tidal period. Measurements in existing habitats will use sediment pins, as well as marker horizons (feldspar clay in vegetated areas and erosion cloth in unvegetated mudflats)

Our preliminary results indicate that there has been substantial sediment accumulation with Pond A21 in the six weeks since the pond was breached, with approximately 2 cm of sediment accumulating over this time period in many of the lower parts of the pond, and even greater accumulation in some locations. Rates at higher elevations are also variable but much lower. Mass-based measurements of accumulation reflect this same spatial variability across the pond. In the adjacent existing mudflats and marshes, the mudflat stations are highly dynamic with some indicating erosion and some deposition, while marsh stations indicate minimal deposition over this short time period. These preliminary results give a first indication of potential sediment dynamics within the restored ponds; however, longer-term results are necessary.

Water Quality in the salt ponds and effects of pond discharges on receiving waters

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The initial restoration actions of the South Bay Salt Pond Restoration Project commenced in summer 2004 with the implementation of the salinity reduction phase of the Initial Stewardship Plan (ISP). Under this plan, water control structures were constructed in several salt ponds, which regulated both the inflow of Bay waters to the ponds and the outflow of saline waters to the receiving waters of the Bay and adjacent sloughs. These structures created controlled circulation of Bay waters through several small salt pond systems in order to reduce the salt pond salinity. Discharges from the ponds to the Bay were regulated by the Regional Water Quality Control Board (RWQCB), and self-monitoring requirements of the U.S. Fish and Wildlife Service (USFWS; Alviso and Ravenswood pond systems) and California Department of Fish and Game (CDFG; Eden Landing pond system) were imposed according to initial pond salinity. From May through October, all discharge ponds were required to be monitored for salinity, pH, temperature, and dissolved oxygen (DO) on a continuous basis within the ponds and monthly in receiving waters. Ponds with salinity >44 ppt were required to undergo more frequent receiving water monitoring, including benthic invertebrate sampling prior to and at intervals following the initial discharge. USGS monitored discharge ponds A2W, A3W, A7, B2, and B10 during 2004, and additionally monitored A14, A16, B2C, and B8A when those ponds were discharged during 2005. Although elevated salinity was initially the primary concern for water quality, we found that salinity levels in discharge ponds dropped quickly and did not greatly alter the salinity levels in receiving waters. However, DO concentration in most ponds dropped below regulatory thresholds during summer months and required close monitoring throughout the summer and fall. Despite techniques used by USFWS to maintain elevated DO in the ponds, including the use of solar aerators and baffles to control locations of algal growth, there were periods of low DO which required intensive monitoring throughout both the 2004 and 2005 seasons. Receiving water data from 2004 and 2005 show depressed DO (<5 mg/L) that may not have been caused by salt pond discharges, suggesting that low DO may be normal in South Bay sloughs during summer. An understanding of baseline DO levels is necessary to determine the impact of salt pond discharges in South Bay sloughs. Additional monitoring in 2006 will focus on comparative monitoring with sloughs unaffected by salt pond discharges.

Surprising Trends of Phytoplankton Increase in South San Francisco Bay

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Since 1978 the U.S. Geological Survey has measured chlorophyll in San Francisco Bay as an index of phytoplankton biomass. Phytoplankton primary production fuels food webs in the Bay and is a key regulator of water quality. Phytoplankton dynamics in South Bay are characterized by a spring bloom followed by low chlorophyll the remainder of the year. This pattern changed in the late 1990's when we began to observe secondary blooms during autumn-winter and progressive increase in the annual minimum chlorophyll. These changes are ecologically significant, implying a near doubling of primary production over the past decade. Causes of this regime change have not been identified, but several independent hypotheses are supported by concurrent changes in the Bay, the coastal Pacific Ocean, and watersheds of the estuary: reduced abundances of suspension-feeding clams; anomalously strong coastal upwelling; reduced inputs of sediments from the Sacramento-San Joaquin Rivers; and reduced inputs of

toxic metals from wastewater treatment plants. Is phytoplankton increasing because of reduced clam grazing or heightened inputs of coastal phytoplankton or faster growth as Bay waters become clearer and less toxic? These hypotheses illustrate how water quality and biological communities of San Francisco Bay are strongly influenced by its connectivity to the Pacific, the Sacramento-San Joaquin watershed, and the local urban watershed. The South Bay Salt Pond Restoration Program will connect the Bay to salt ponds, establishing a new process of water quality and biological variability within the estuary. Results of early restoration actions have already documented within-Bay changes in dissolved oxygen and the appearance of harmful algae. Comprehensive monitoring and assessment are essential for fully understanding how restoration actions will continue to change water quality and living resources of South Bay.

Hydrodynamic connectivity between shallow & deep environments: A first-order control on phytoplankton blooms in South San Francisco Bay

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A joint numerical modeling and field study was conducted to estimate the relative importance of several processes potentially governing phytoplankton bloom development in South San Francisco Bay. Historically, this estuary has had two distinct sub-region types (shallow shoals and deep channel) and associated differences in local net rates of phytoplankton population growth and consumption. Field and modeling results suggest that lateral shoal-to-channel transport can result in phytoplankton biomass accumulation in the adjacent deep, unproductive channel. Processes in the shoals control the occurrence of a bloom system-wide; whereas, processes in the channel are likely to only modify system-wide bloom magnitude. Hydrodynamic connectivity between sub-regions provides remote control of locally observed algal biomass, allowing biomass to increase in environments which, if isolated, would not experience a bloom. As the geometry of SSFB changes, the general lesson of connectivity between biologically dissimilar sub-regions must be considered, as processes in one location may control phytoplankton biomass accumulation in another location.

South Bay trace contaminants: Recent findings

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Recent monitoring of cormorant eggs, small fish, sport fish, and sediment is shedding light on the degree of contamination of South Bay relative to other regions of San Francisco Bay, and providing essential context for interpreting the impact of the SBSPRP on regional water quality. In cormorant eggs, mercury concentrations were distinctly elevated in the South Bay, but PCBs, legacy pesticides, and PBDEs were comparable to other parts of San Francisco Bay. Selenium was elevated in one year, but not in another. Small fish mercury monitoring is being conducted as a RMP pilot study. A suite of species representing different depths and salinities is being sampled. Some of these species indicate elevated food web mercury in the South Bay, but the pattern is inconsistent among the species. Sport fish sampling found relatively high concentrations of mercury, PCBs, DDTs, and PBDEs in some species. Two white sturgeon samples from South Bay had the highest concentrations of PCBs, DDTs, and PBDEs observed across all species sampled. In contrast to the sharp contrasts among locations observed in the South Bay food web, concentrations of total mercury in South Bay sediment were not much different from other parts of the Bay, supporting the notion that processes affecting net mercury methylation are the primary control on spatial patterns in food web mercury.

Mercury in Birds of the San Francisco Bay-Delta: Trophic Pathways, Bioaccumulation and Ecotoxicological Risk to Avian Reproduction

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The San Francisco Bay estuary (SFBE) has a legacy of mercury (Hg) contamination from local mining operations and gold extraction. Wetland restoration efforts may remobilize Hg, potentially increasing waterbird exposure to methylmercury (MeHg). Avian reproduction is a sensitive endpoint to evaluate MeHg toxicity; however, assessing toxic risk is hampered by inadequate understanding of exposure among different foraging guilds and lack of field and laboratory integration. We quantified dietary exposure in three foraging guilds, examined Hg effects on adults and their reproduction, and determined interspecies variation in sensitivity with egg injection studies. Results indicated total mercury (THg) increased significantly from American Avocets, Surf Scoters, Forster's Terns, to Caspian Terns, and varied spatially and temporally. Breeding Forster's Tern males accumulated more THg than did females, implying females deposited Hg into their eggs. Hatching success ranged from 81-85% for avocets, 88% for stilts, and 78-83% for Forster's Terns; and recurve chicks accumulated THg rapidly. Hg concentration in eggs will be measured to determine effects on hatching success in the wild, including cross-seasonal work on Surf Scoters in the boreal forest. Thus far, our results highlight the importance of foraging area, diet, and life stage in determining Hg risks for avian species. They show the value of monitoring avian reproduction to assess the effects and risk of mercury to wildlife and indicate that restoration goals should include an understanding of potential mercury accumulation and reproductive effects based on avian foraging strategies.

Marsh plant associations of South San Francisco Bay: 2005 comparative study

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Large-scale plant community changes in the remaining marshes of South San Francisco Bay were first observed in the 1970's. Early studies conducted for the South Bay Dischargers Authority in 1984 confirmed those habitat changes. In 1989, as part of a monitoring program required by the San Francisco Bay Regional Water Quality Control Board, the City of San Jose commissioned a more detailed study of the marshes potentially affected by the freshwater discharge from the Water Pollution Control Plant (WPCP). Subsequent mapping studies were conducted in 1991, 1994, and annually thereafter. These studies documented changes in the distribution and aerial extent of salt, brackish and freshwater marsh. This study is the continuation of the WPCP monitoring program.

The 2005 plant association mapping was done on digital 1-meter Multispectral (4-bands) CIR & True Color IKONOS satellite imagery. All vegetation mapping was done by plant biologists in the field and spot-checked by senior biologists. Acreage calculations by plant associations, dominant species and habitat type maps and acreage tables were produced in Geographic Information Systems (GIS) software. Comparisons were made between the 2005 mapping and previous years' mapping.

The total marsh area mapped in 2005 was 1,761 acres for the Main Study Area and 280 acres for the Reference Site. The surface area of marsh habitat has increased by 343.5 acres between 1989 and 2005 within the Main Study Area. During the same period, 90.5 acres of new marsh has formed in the Reference Area.

From 1989 to 2005, a total of 128.6 acres of salt marsh habitat has converted to brackish marsh habitat in the Main Study Area, and 35.6 acres of salt marsh habitat converted to brackish marsh in the Reference Area. However, during the same time period, 34.3 acres of brackish marsh has converted to salt marsh habitat in the Main Study Area and 4.1 acres has converted from brackish marsh to salt marsh habitat in the Reference Area. Therefore, within the Main Study Area 94.3 acres of net conversion from salt marsh habitat to brackish marsh habitat has occurred since 1989. In the Reference Area, 31.5 acres of net conversion from salt marsh habitat to brackish marsh habitat has occurred since 1989.

The results of the vegetation mapping and associated assessment of edaphic characteristics provide a long-term dataset of trends in vegetation distribution, marsh development and conversion in the South Bay. These results can help track the changes to these habitats over time as restoration elements are implemented. For example, three former salt ponds were breached in 2006 as part of the Initial Stewardship Plan. The breaching of these ponds may result in changes to the vegetative habitats in the Main Study Area apart from any changes related to the WPCP discharges, and continued monitoring will inform where and how quickly scour and/or vegetation shifts can occur from restoration actions.

Fish species assemblages and water quality characteristics of salt ponds and sloughs in South San Francisco Bay

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In 2003, about 15,100 acres of commercial salt ponds in South San Francisco Bay were purchased by the State of California and the Federal Government for conversion to tidal wetlands. However, little information was available on fishery resources and environmental conditions in the salt ponds and in adjacent sloughs. This study was implemented to fill some of the data gaps. Specific objectives were to (i) document the fish species that use the salt ponds and sloughs, (ii) characterize the water quality and other environmental conditions, and (iii) determine if the composition of fish species assemblages was associated with environmental conditions. Twelve ponds and five sloughs in the Alviso and Eden Landing salt pond complexes were sampled at roughly seasonal intervals from March 2004 to June 2005. A total of 14,415 fish represented by 22 species and 16 families was captured with a combination of gill nets, seines (ponds only), and minnow traps. Topsmelt was most ubiquitous, occurring in all 17 sites. Longjaw mudsucker, northern anchovy, and yellowfin goby occurred in 16 sites, whereas rainwater killifish and Pacific staghorn sculpin occurred in 15 sites. All other species occurred in 7 or fewer sites. According to gill net catches, topsmelt was the most abundant species, followed by northern anchovy, leopard shark, and striped bass. However, according to seine catches, longjaw mudsucker, rainwater killifish, topsmelt, and yellowfin goby were most abundant. Longjaw mudsucker and rainwater killifish also dominated the minnow trap catches. Cluster analysis of presence-absence data for fish species was used to identify two major groups (clusters) of ponds and sloughs, where Cluster 1 was composed of nine

ponds (A2E, A10, A11, A12, B2, B4, B5, B6C, and B7) and Cluster 2 was composed of a mix of three ponds (A2W, A9 and B1) and five sloughs (Alameda Old Flood Control Channel, Coyote Hills Slough, Coyote Creek, Alviso Slough and Stevens Creek). Fish species present in Cluster 1 (topsmelt, Pacific herring, Pacific staghorn sculpin, northern anchovy, rainwater killifish, threespine stickleback, yellowfin goby, longjaw mudsucker, shimofuri goby, chameleon goby, starry flounder, and bay pipefish) were also found in Cluster 2. In addition, Cluster 2 contained jacksmelt, leopard shark, Sacramento sucker, American shad, threadfin shad, common carp, shiner perch, striped bass, bat ray, and longfin smelt. According to canonical discriminant analysis, four environmental variables (water temperature, dissolved oxygen, salinity, and tidal range) contributed towards separating the two clusters. These results suggest that fish species assemblages in restored salt ponds can be manipulated during the restoration process by creating certain environmental conditions.

Gull Predation on Shorebird and Tern Nests and Chicks in the South San Francisco Bay Salt Ponds

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We examined predation by California Gulls on the nests and chicks of American Avocets (*Recurvirostra americana*), Black-necked Stilts (*Himatopus mexicanus*), and Forster's Terns (*Sterna forsteri*) breeding in the South San Francisco Bay salt ponds during 2005. In the Alviso salt ponds (i.e., A1, A8, A16, and New Chicago Marsh), we monitored 352 Avocet, 98 Stilt, and 407 Tern nests. Overall nest success was 55% for Avocets, 48% for Stilts, and 88% for Terns. Within the same species, nest success was higher in salt ponds A1 (94% Terns) and A16 (94% Terns, 77% Avocets) then in A8 for Terns (73%) and Avocets (35%), indicating higher nest predation rates in A8. We also deployed 18 nests containing fake plasticine eggs in A8 and used tooth or beak marks to identify the type of nest predator; all 9 of the depredated nests had beak marks in the fake eggs indicating that the low nest success in A8 was primarily caused by gull predation, possibly due to the close proximity to the A6 gull colony (17,000 birds). To study chick survival, we radio-marked 74 Avocet chicks (in A8 and A16) and 33 Stilt chicks (in New Chicago Marsh) within 24 hours of hatching and tracked them daily with truck-mounted telemetry systems. Survival rates until 21 days after hatching were higher for Stilt chicks (32%) than for Avocet chicks (14%). For both species, the likelihood of mortality decreased with residual chick mass at hatching. However, Julian hatching date did not influence the likelihood of survival for either species. Survival rates of Avocet chicks also did not differ among salt ponds A8 and A16. Predation on Avocet chicks was mainly caused by avian predators (74%; primarily California Gulls), mammals (16%), snakes (5%), and found down animal burrows (5%). In contrast, no Stilt chicks were depredated by gulls; 43% of depredations were due to other avian predators, 29% by mammals, and 29% were found down animal burrows. Those Avocet chicks that survived quickly moved from exposed salt pond nesting islands (e.g., A16) into vegetated marshes (e.g., New Chicago Marsh) to find escape cover from predators, indicating that juxtaposition of salt pond and tidal marsh habitats is important for successful breeding. Our data indicate that California Gulls are the major predator of Avocet chicks, but not Stilt Chicks, and that gull predation on eggs reduced the nesting success of Avocets and Terns in A8. These results suggest that the expanding gull population can have a significant impact on the breeding success of ground-nesting birds in the South Bay salt ponds.

Waterbird monitoring at the Newark ponds

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The South Bay Salt Pond Restoration Plan will restore large tracts of much-needed tidal marsh and associated habitats to the south Bay. However, the Project Management Team is also dedicated to the preservation of viable habitat for the more than 80 species of waterbirds that utilize existing salt pond habitats. To plan and manage the restoration so that no net loss of birds results, the Team needs to know how birds are utilizing not only the restoration ponds (currently under study by USGS) but also the other 22 ponds (~2,800 hectares of south bay habitat) that remain in salt production.

Proponents of restoring all of the newly purchased to tidal marsh argue that these remaining salt ponds would provide adequate open water habitat for waterfowl and shorebirds. However, these areas have never been adequately surveyed to assess avian use. The San Francisco Bay Bird Observatory began monthly surveys of these Newark salt ponds in September 2005. Here we examine preliminary results of the first eight surveys to determine distributions of shorebirds and waterfowl, as well as more specialty species such as phalaropes and Eared Grebes. Birds were grouped together by foraging guilds, and results are summarized by area and by pond.

A team of two surveyers counted over 350,000 birds in approximately 16 weeks of surveys in eight months. Of the three areas counted, the Dumbarton ponds accounted for 60% of birds counted (212,406 including 161,256 shorebirds and 75% of all Eared Grebes counted) in only 19% of the the area of ponds counted. Mowry ponds accounted for 16% of birds (55,947 including 32,994 gulls) in 43% of the area, and in Coyote Hills 24% of birds were counted (85,157 predominantly dabbling ducks and shorebirds) in 38% of the area.

Of the 19,642 dabbling ducks counted, half of them were counted in pond N1A; of these 66% were foraging. Ten thousand diving ducks were counted, the majority of them on pond N4AA; only 10% of these were foraging. Of the 52,252 medium shorebirds counted, nearly half were counted on two ponds. One third of these were foraging on N1, but pond N3 appears to be used primarily for roosting as only 9% were foraging here. Small shorebirds accounted for 157,089 of all birds counted with ponds N1, N2, N3, and PP1 accounting for 132,000 of these. Small shorebirds used these ponds for foraging at rates ranging from 11-48%. Large numbers of gulls used ponds M6 and N3A (62,127) primarily for roosting. Fisheaters primarily used ponds N3A and N4AA (1935/4820), with approximately 50% of these birds foraging in these ponds. Ponds N1 and N3 appear to be important for Eared Grebes with over 11,000 counted on these two ponds; N3 was used more often for foraging. We counted only 124 phalaropes in all surveys with never more than 36 birds per pond; phalaropes present did utilize the ponds for foraging.

Future analysis will inlcude environmental conditions of the pond including pond area, salinity, water level, dissolved oxygen, and chlorophyll measurements. Collecting information on physical parameters will allow us to analyze how bird use and distribution is related to pond condition, and develop predictions for land managers on how bird use of salt ponds may change under differing water quality and depth management scenarios. Future use of these ponds by waterbirds will also depend in large part on management actions by Cargill Salt, Inc.

Waterbird Response to Trail Use around the San Francisco Bay

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We collected data on the response of foraging wetland birds to non-motorized trail use at three locations around San Francisco Bay from 1 July 1999 to 30 June 2000 and from 1 October 2000 to 30 September 2001. At Bothin Marsh in Mill Valley (Marin County), Redwood Shores in Redwood City (San Mateo County) and Shoreline at Mountain View in Mountain View (Santa Clara County), we set up 30.5 m^2 (100-$foot^2$) quadrats, marked by PVC posts, in tidal mudflat habitat adjacent to paired Trail and Control sites. Four times a month (twice on weekdays and twice on weekend days), we collected data on bird numbers, species, and behavior in the quadrats as well as on trail user numbers and behavior. On each observation day, data were collected for 4-hour periods at the same time at each paired Trail and Control site, beginning approximately1/2 hour to 1 and 1/2 hours after slack high tide.

Over the two years, at the three locations combined, 85% of birds recorded were shorebirds, 6% waterfowl, 1% large waterbirds, and 8% were others, including coots, gulls and terns. We found significant differences in human trail use between location (P>0.001), Trail and Control sites (P>0.001), seasons (P>0.001), and day of week (P>0.001), but not between years (P=0.106) (R^2=0.947, n=575). With respect to bird abundance, multivariate ANOVA showed significant differences among the three locations (P>0.001) and seasons (P>0.001), but not between years (P=0.824), Trail versus Control sites (P=0.196), or day of week (P=0.928). Nor was trail use a significant factor (P=0.172) (R^2=0.469, n=575). Location (P>0.001), season (P>0.001), and day of week (P=0.024) were significant factors in species richness. However, species richness was not significantly affected by year (P=0.107), Trail versus Control site (P=0.797), or human trail use (P=0.489) (R^2=0.464, n=575). Analysis by location did not show a consistent pattern of bird abundance or species richness in response to trail use at Trail versus Control sites. Specifically, we found that, at Shoreline, bird abundance and species richness were significantly greater at the Trail than Control site; at Redwood Shores the pattern was reversed and at Bothin there was no significant difference in bird numbers or diversity at Trail versus Control sites. In addition, there was no correlation between intensity of trail use and bird abundance or species richness at any Trail site for any season. A greater percentage of birds exhibited foraging behavior at the Trail sites compared to the Control sites at all three locations.

Overall, despite huge differences in trail use between Control and Trail sites and weekend versus weekdays, this study found no significant effects of trail user intensity on waterbird, specifically shorebird, numbers, species richness, or behavior. These results did not examine the effects of trail users on individual species; this pending analysis may reveal that some species are more sensitive than other to human presence on trails.

These results are applicable to the South Bay Salt Pond Restoration Project as they indicate that non-motorized trail use, on raised levees, tangential to tidal mudflat habitat does not have a significant overall effect on the numbers, species richness or behavior of foraging shorebirds. Research into the behavior of shorebirds, before a trail is in place and then after it is established, should also be undertaken to further investigate potential trail use effects. In addition, research on the sensitivity of other waterbird guilds, especially waterfowl, is needed. Many trails are being planned adjacent to foraging waterfowl habitat, but we have little data on the response of these species to trail use.

Predicting avian responses to landscape change in San Francisco Bay: Addressing and reducing multiple levels of uncertainty

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The acquisition and planned restoration of 6,000 ha of salt ponds in San Francisco Bay provides an opportunity to model the effects of large-scale habitat change on avian communities. Opening these ponds to tidal action will restore natural geomorphic processes and create valuable marsh habitat. However, there are trade-offs with the loss of salt ponds that support millions of migratory waterbirds. Thus, a successful restoration will retain enough intensively managed ponds, or equivalent shallow water habitat, to maintain current waterbird numbers, while maximizing the extent and quality of restored tidal marsh.

Using a combination of field-collected and remotely-sensed data, we generated a suite of linear models for focal avian species and groups. Multiple years of bird survey data were regressed on multi-scale, GIS-based marsh and pond habitat variables. LiDAR and boat-based sounding data were used to characterize pond bathymetry, while color-infrared aerial photos were used to quantify marsh channels and ponds. Using actual restoration alternatives generated by Phil Williams and Associates and HT Harvey, we developed site- and landscape-level predictions. Modeling results indicate a diversity of responses across species. Numbers of most waterbird species were predicted to increase immediately following restoration action, with the creation of new shallow open water habitats within breached ponds. At year 0, a maximum restoration scenario would result in more available habitat for most species. However, over a 50-year timeframe, as the restored ponds become vegetated, an intermediate restoration scenario containing intensively managed ponds, as well as large areas of new tidal marsh, would benefit most species.